OMAP-L137
C6000 DSP+ARM Processor

Technical Reference Manual

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About This Manual

This Technical Reference Manual (TRM) describes the System-on-Chip (SoC) and each peripheral in the device. The SoC consists of the following primary components:

- ARM subsystem and associated memories
- DSP subsystem and associated memories
- A set of I/O peripherals

Notational Conventions

This document uses the following conventions.

- Hexadecimal numbers are shown with the suffix h. For example, the following number is 40 hexadecimal (decimal 64): 40h.
- Registers in this document are shown in figures and described in tables.
  - Each register figure shows a rectangle divided into fields that represent the fields of the register. Each field is labeled with its bit name, its beginning and ending bit numbers above, and its read/write properties below. A legend explains the notation used for the properties.
  - Reserved bits in a register figure designate a bit that is used for future device expansion.

Related Documentation From Texas Instruments

Copies of these documents are available on the Internet at www.ti.com. *Tip:* Enter the literature number in the search box provided at www.ti.com.

The current documentation that describes related peripherals and other technical collateral, is available in the C6000 DSP product folder at: www.ti.com/c6000.

SPRUFK5— ***TMS320C674x DSP Megamodule Reference Guide.*** Describes the TMS320C674x digital signal processor (DSP) megamodule. Included is a discussion on the internal direct memory access (IDMA) controller, the interrupt controller, the power-down controller, memory protection, bandwidth management, and the memory and cache.

SPRUFE8— ***TMS320C674x DSP CPU and Instruction Set Reference Guide.*** Describes the CPU architecture, pipeline, instruction set, and interrupts for the TMS320C674x digital signal processors (DSPs). The C674x DSP is an enhancement of the C64x+ and C67x+ DSPs with added functionality and an expanded instruction set.

SPRUG82— ***TMS320C674x DSP Cache User's Guide.*** Explains the fundamentals of memory caches and describes how the two-level cache-based internal memory architecture in the TMS320C674x digital signal processor (DSP) can be efficiently used in DSP applications. Shows how to maintain coherence with external memory, how to use DMA to reduce memory latencies, and how to optimize your code to improve cache efficiency. The internal memory architecture in the C674x DSP is organized in a two-level hierarchy consisting of a dedicated program cache (L1P) and a dedicated data cache (L1D) on the first level. Accesses by the CPU to the these first level caches can complete without CPU pipeline stalls. If the data requested by the CPU is not contained in cache, it is fetched from the next lower memory level, L2 or external memory.

Overview

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1.1 Introduction

The OMAP-L137 Processor contains two primary CPU cores: an ARM RISC CPU for general-purpose processing and systems control; and a powerful DSP to efficiently handle communication and audio processing tasks. The OMAP-L137 Processor consists of the following primary components:

- ARM subsystem and associated memories
- DSP subsystem and associated memories
- A set of I/O peripherals
- A powerful DMA subsystem and SDRAM EMIF interface

1.2 Block Diagram

A block diagram for the OMAP-L137 Processor is shown in Figure 1-1.

1.3 DSP Subsystem

The DSP subsystem (DSPSS) includes TI's standard TMS320C674x megamodule and several blocks of internal memory (L1P, L1D, and L2). The *DSP Subsystem* chapter describes the DSPSS components.

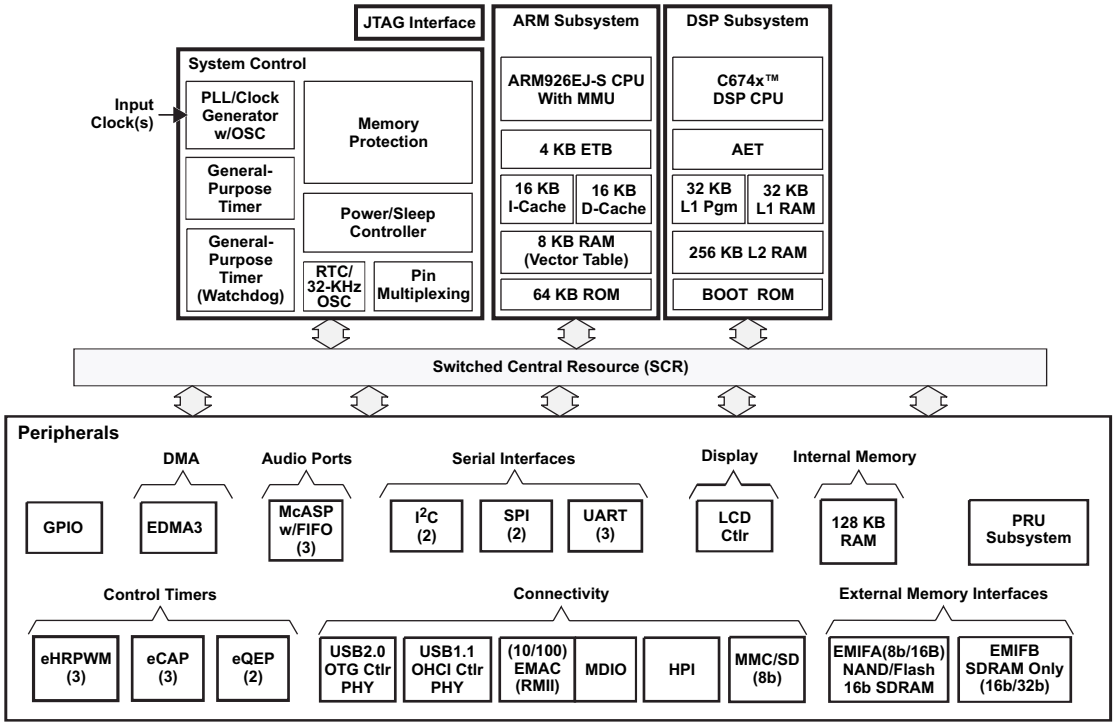
1.4 ARM Subsystem

The ARM926EJ-S™ 32-bit RISC CPU in the ARM subsystem (ARMSS) acts as the overall system controller. The ARM CPU performs general system control tasks, such as system initialization, configuration, power management, user interface, and user command implementation. The *ARM Subsystem* chapter describes the ARMSS components and system control functions that the ARM core performs.

1.5 DMA Subsystem

The DMA subsystem includes two instances of the enhanced DMA controller (EDMA3). For more information, see the *Enhanced Direct Memory Access (EDMA3) Controller* chapter.

Figure 1-1. OMAP-L137 Processor Block Diagram



Note: Not all peripherals are available at the same time due to multiplexing.

ARM Subsystem

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2.1 Introduction

This chapter describes the ARM subsystem and its associated memories. The ARM subsystem consists of the following components:

- ARM926EJ-S™ 32-bit RISC processor
- 16-kB Instruction cache
- 16-kB Data cache
- Memory management unit (MMU)
- Co-Processor 15 (CP15) to control MMU, cache, etc.
- Jazelle™ Java accelerator
- ARM Internal Memory
  - 8 kB RAM
  - 64 kB built-in ROM
- Embedded Trace Module and Embedded Trace Buffer (ETM/ETB)
- Features:
  - The main write buffer has a 16-word data buffer and a 4-address buffer
  - Support for 32-bit ARM/16-bit THUMB instruction sets
  - Fixed little-endian memory format
  - Enhanced DSP instructions

The ARM926EJ-S processor is a member of the ARM9 family of general-purpose microprocessors. The ARM926EJ-S processor targets multi-tasking applications where full memory management, high performance, low die size, and low power are all important.

The ARM926EJ-S processor supports the 32-bit ARM and the 16-bit THUMB instruction sets, enabling you to trade off between high performance and high code density. This includes features for efficient execution of Java byte codes and providing Java performance similar to Just in Time (JIT) Java interpreter without associated code overhead.

The ARM926EJ-S processor supports the ARM debug architecture and includes logic to assist in both hardware and software debugging. The ARM926EJ-S processor has a Harvard architecture and provides a complete high performance subsystem, including the following:

- An ARM926EJ-S integer core
- A memory management unit (MMU)
- Separate instruction and data Advanced Microcontroller Bus Architecture (AHBA) Advanced High Performance Bus (AHB) bus interfaces

NOTE: There is no TCM memory and interface on this device.

The ARM926EJ-S processor implements ARM architecture version 5TEJ.

The ARM926EJ-S core includes NEON signal processing extensions to enhance 16-bit fixed-point performance using a single-cycle 32 × 16 multiply-accumulate (MAC) unit. The ARM core also has 8 KB RAM (typically used for vector table) and 64 KB ROM (for boot images) associated with it. The RAM/ROM locations are not accessible by the DSP or any other master peripherals. Furthermore, the ARM has DMA and CFG bus master ports via the AHB interface.

2.2 Operating States/Modes

The ARM can operate in two states: ARM (32-bit) mode and THUMB (16-bit) mode. You can switch the ARM926EJ-S processor between ARM mode and THUMB mode using the BX instruction.

The ARM can operate in the following modes:

- User mode (USR): Non-privileged mode, usually for the execution of most application programs.
- Fast interrupt mode (FIQ): Fast interrupt processing
- Interrupt mode (IRQ): Normal interrupt processing
- Supervisor mode (SVC): Protected mode of execution for operating systems
- Abort mode (ABT): Mode of execution after a data abort or a pre-fetch abort
- System mode (SYS): Privileged mode of execution for operating systems
- Undefined mode (UND): Executing an undefined instruction causes the ARM to enter undefined mode.

You can only enter privileged modes (system or supervisor) from other privileged modes.

To enter supervisor mode from user mode, generate a software interrupt (SWI). An IRQ interrupt causes the processor to enter the IRQ mode. An FIQ interrupt causes the processor to enter the FIQ mode.

Different stacks must be set up for different modes. The stack pointer (SP) automatically changes to the SP of the mode that was entered.

2.3 Processor Status Registers

The processor status register (PSR) controls the enabling and disabling of interrupts and setting the mode of operation of the processor. The 8 least-significant bits PSR[7:0] are the control bits of the processor. PSR[27:8] are reserved bits and PSR[31:28] are status registers. The details of the control bits are:

- Bit 7 - I bit: Disable IRQ (I =1) or enable IRQ (I = 0)
- Bit 6 - F bit: Disable FIQ (F = 1) or enable FIQ (F = 0)
- Bit 5 - T bit: Controls whether the processor is in thumb mode (T = 1) or ARM mode (T = 0)
- Bits 4:0 Mode: Controls the mode of operation of the processor
  - PSR [4:0] = 10000 : User mode
  - PSR [4:0] = 10001 : FIQ mode
  - PSR [4:0] = 10010 : IRQ mode
  - PSR [4:0] = 10011 : Supervisor mode
  - PSR [4:0] = 10111 : Abort mode
  - PSR [4:0] = 11011 : Undefined mode
  - PSR [4:0] = 11111 : System mode

Status bits show the result of the most recent ALU operation. The details of status bits are:

- Bit 31 - N bit: Negative or less than
- Bit 30 - Z bit: Zero
- Bit 29 - C bit: Carry or borrow
- Bit 28 - V bit: Overflow or underflow

NOTE: See the Programmer's Model of the ARM926EJ-S Technical Reference Manual (TRM), downloadable from http://infocenter.arm.com/help/index.jsp for more detailed information.

2.4 Exceptions and Exception Vectors

Exceptions arise when the normal flow of the program must be temporarily halted. The exceptions that occur in an ARM system are given below:

- Reset exception: processor reset
- FIQ interrupt: fast interrupt
- IRQ interrupt: normal interrupt
- Abort exception: abort indicates that the current memory access could not be completed. The abort could be a pre-fetch abort or a data abort.
- SWI interrupt: use software interrupt to enter supervisor mode.
- Undefined exception: occurs when the processor executes an undefined instruction

The exceptions in the order of highest priority to lowest priority are: reset, data abort, FIQ, IRQ, pre-fetch abort, undefined instruction, and SWI. SWI and undefined instruction have the same priority. The ARM is configured with the VINITHI signal set high (VINITHI = 1), such that the vector table is located at address FFFF 0000h. This address maps to the beginning of the ARM local RAM (8 kB).

NOTE: The VINITHI signal is configurable by way of the register setting in CP15. However, it is not recommended to set VINITHI = 0, as the device has no physical memory in the 0000 0000h address region.

The default vector table is shown in Table 2-1.

Table 2-1. Exception Vector Table for ARM

Vector Offset Address	Exception	Mode on entry	I Bit State on Entry	F Bit State on Entry
0h	Reset	Supervisor	Set	Set
4h	Undefined instruction	Undefined	Set	Unchanged
8h	Software interrupt	Supervisor	Set	Unchanged
Ch	Pre-fetch abort	Abort	Set	Unchanged
10h	Data abort	Abort	Set	Unchanged
14h	Reserved	—	—	—
18h	IRQ	IRQ	Set	Unchanged
1Ch	FIQ	FIQ	Set	Set

2.5 The 16-BIS/32-BIS Concept

The key idea behind 16-BIS is that of a super-reduced instruction set. Essentially, the ARM926EJ processor has two instruction sets:

- ARM mode or 32-BIS: the standard 32-bit instruction set
- THUMB mode or 16-BIS: a 16-bit instruction set

The 16-bit instruction length (16-BIS) allows the 16-BIS to approach twice the density of standard 32-BIS code while retaining most of the 32-BIS's performance advantage over a traditional 16-bit processor using 16-bit registers. This is possible because 16-BIS code operates on the same 32-bit register set as 32-BIS code. 16-bit code can provide up to 65% of the code size of the 32-bit code and 160% of the performance of an equivalent 32-BIS processor connected to a 16-bit memory system.

2.6 16-BIS/32-BIS Advantages

16-bit instructions operate with the standard 32-bit register configuration, allowing excellent inter-operability between 32-BIS and 16-BIS states. Each 16-bit instruction has a corresponding 32-bit instruction with the same effect on the processor model. The major advantage of a 32-bit architecture over a 16-bit architecture is its ability to manipulate 32-bit integers with single instructions, and to address a large address space efficiently. When processing 32-bit data, a 16-bit architecture takes at least two instructions to perform the same task as a single 32-bit instruction. However, not all of the code in a program processes 32-bit data (for example, code that performs character string handling), and some instructions (like branches) do not process any data at all. If a 16-bit architecture only has 16-bit instructions, and a 32-bit architecture only has 32-bit instructions, then the 16-bit architecture has better code density overall, and has better than one half of the performance of the 32-bit architecture. Clearly, 32-bit performance comes at the cost of code density. The 16-bit instruction breaks this constraint by implementing a 16-bit instruction length on a 32-bit architecture, making the processing of 32-bit data efficient with compact instruction coding. This provides far better performance than a 16-bit architecture, with better code density than a 32-bit architecture. The 16-BIS also has a major advantage over other 32-bit architectures with 16-bit instructions. The advantage is the ability to switch back to full 32-bit code and execute at full speed. Thus, critical loops for applications such as fast interrupts and DSP algorithms can be coded using the full 32-BIS and linked with 16-BIS code. The overhead of switching from 16-bit code to 32-bit code is folded into sub-routine entry time. Various portions of a system can be optimized for speed or for code density by switching between 16-BIS and 32-BIS execution, as appropriate.

2.7 Co-Processor 15 (CP15)

The system control coprocessor (CP15) is used to configure and control instruction and data caches, Tightly-Coupled Memories (TCMs), Memory Management Units (MMUs), and many system functions. The CP15 registers are only accessible with MRC and MCR instructions by the ARM in a privileged mode like supervisor mode or system mode.

2.7.1 Addresses in an ARM926EJ-S System

Three different types of addresses exist in an ARM926EJ-S system. They are listed in Table 2-2.

Table 2-2. Different Address Types in ARM System

Domain	ARM9EJ-S	Caches and MMU	TCM and AMBA Bus
Address type	Virtual Address (VA)	Modified Virtual Address (MVA)	Physical Address (PA)

An example of the address manipulation that occurs when the ARM9EJ-S core requests an instruction is shown in Example 2-1.

Example 2-1. Address Manipulation

The VA of the instruction is issued by the ARM9EJ-S core.

The VA is translated to the MVA. The Instruction Cache (Icache) and Memory Management Unit (MMU) detect the MVA.

If the protection check carried out by the MMU on the MVA does not abort and the MVA tag is in the Icache, the instruction data is returned to the ARM9EJ-S core.

If the protection check carried out by the MMU on the MVA does not abort, and the MVA tag is not in the cache, then the MMU translates the MVA to produce the PA.

NOTE: See the Programmers Model of the ARM926EJ-S Technical Reference Manual (TRM), downloadable from http://infocenter.arm.com/help/index.jsp for more detailed information.

2.7.2 Memory Management Unit (MMU)

The ARM926EJ-S MMU provides virtual memory features required by operating systems such as SymbianOS, WindowsCE, and Linux. A single set of two level page tables stored in main memory controls the address translation, permission checks, and memory region attributes for both data and instruction accesses. The MMU uses a single unified Translation Lookaside Buffer (TLB) to cache the information held in the page tables.

The MMU features are as follows:

- Standard ARM architecture v4 and v5 MMU mapping sizes, domains, and access protection scheme.
- Mapping sizes are 1 MB (sections), 64 kB (large pages), 4 kB (small pages) and 1 kB (tiny pages)
- Access permissions for large pages and small pages can be specified separately for each quarter of the page (subpage permissions)
- Hardware page table walks
- Invalidate entire TLB, using CP15 register 8
- Invalidate TLB entry, selected by MVA, using CP15 register 8
- Lockdown of TLB entries, using CP15 register 10

NOTE: See the Memory Management Unit of the ARM926EJ-S Technical Reference Manual (TRM), downloadable from http://infocenter.arm.com/help/index.jsp for more detailed information.

2.7.3 Caches and Write Buffer

The ARM926EJ-S processor includes:

- An Instruction cache (Icache)
- A Data cache (Dcache)
- A write buffer

The size of the data cache is 16 kB, instruction cache is 16 kB, and write buffer is 17 bytes.

The caches have the following features:

- Virtual index, virtual tag, addressed using the Modified Virtual Address (MVA)
- Four-way set associative, with a cache line length of eight words per line (32 bytes per line), and two dirty bits in the Dcache
- Dcache supports write-through and write-back (or copy back) cache operation, selected by memory region using the C and B bits in the MMU translation tables
- Perform critical-word first cache refilling
- Cache lockdown registers enable control over which cache ways are used for allocation on a line fill, providing a mechanism for both lockdown and controlling cache pollution.
- Dcache stores the Physical Address TAG (PA TAG) corresponding to each Dcache entry in the TAGRAM for use during the cache line write-backs, in addition to the Virtual Address TAG stored in the TAG RAM. This means that the MMU is not involved in Dcache write-back operations, removing the possibility of TLB misses related to the write-back address.
- Cache maintenance operations to provide efficient invalidation of the following:
  - The entire Dcache or Icache
  - Regions of the Dcache or Icache
  - The entire Dcache
  - Regions of virtual memory
- They also provide operations for efficient cleaning and invalidation of the following:
  - The entire Dcache
  - Regions of the Dcache
  - Regions of virtual memory

The write buffer is used for all writes to a non-cachable bufferable region, write-through region, and write misses to a write-back region. A separate buffer is incorporated in the Dcache for holding write-back for cache line evictions or cleaning of dirty cache lines.

The main write buffer has a 16-word data buffer and a four-address buffer.

The Dcache write-back has eight data word entries and a single address entry.

The MCR drain write buffer enables both write buffers to be drained under software control.

The MCR wait for interrupt causes both write buffers to be drained and the ARM926EJ-S processor to be put into a low power state until an interrupt occurs.

NOTE: See the Caches and Write Buffer of the ARM926EJ-S Technical Reference Manual (TRM), downloadable from http://infocenter.arm.com/help/index.jsp for more detailed information.

DSP Subsystem

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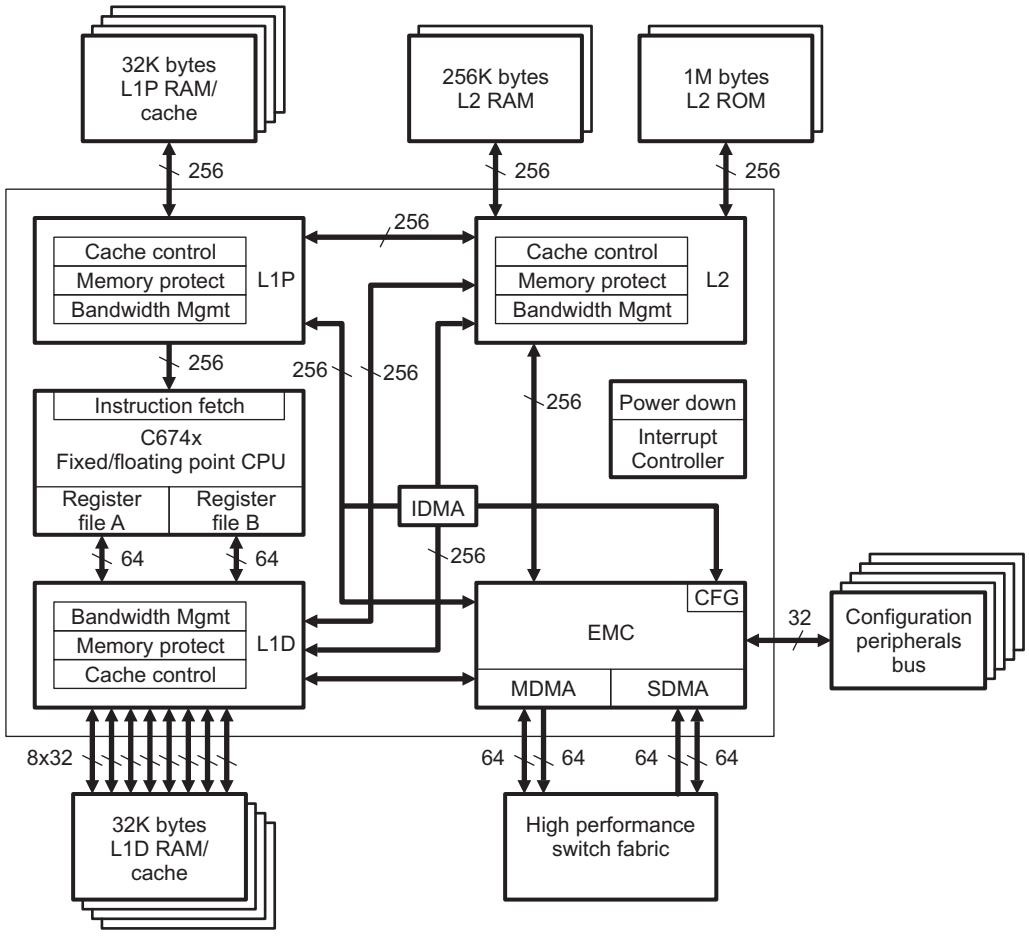
3.1 Introduction

The DSP subsystem (Figure 3-1) includes TI's standard TMS320C674x megamodule and several blocks of internal memory (L1P, L1D, and L2). This document provides an overview of the DSP subsystem and the following considerations associated with it:

- Memory mapping
- Interrupts
- Power management

For more information, see the *TMS320C674x DSP Megamodule Reference Guide* (SPRUFK5), the *TMS320C674x DSP CPU and Instruction Set Reference Guide* (SPRUFE8), and the *TMS320C674x DSP Cache User's Guide* (SPRUG82).

Figure 3-1. TMS320C674x Megamodule Block Diagram



3.2 TMS320C674x Megamodule

The C674x megamodule (Figure 3-1) consists of the following components:

- TMS320C674x CPU
- Internal memory controllers:
  - Level 1 program memory controller (PMC)
  - Level 1 data memory controller (DMC)
  - Level 2 unified memory controller (UMC)
  - Extended memory controller (EMC)
  - Internal direct memory access (IDMA) controller
- Internal peripherals:
  - Interrupt controller (INTC)
  - Power-down controller (PDC)
  - Bandwidth manager (BWM)
- Advanced event triggering (AET)

3.2.1 Internal Memory Controllers

The C674x megamodule implements a two-level internal cache-based memory architecture with external memory support. Level 1 memory (L1) is split into separate program memory (L1P memory) and data memory (L1D memory). L1 memory is accessible to the CPU without stalls. Level 2 memory (L2) can also be split into L2 RAM (normal addressable on-chip memory) and L2 cache for caching external memory locations. The internal direct memory access controller (IDMA) manages DMA among the L1P, L1D, and L2 memories.

For more information about each of these controllers, see the *TMS320C674x DSP Megamodule Reference Guide* (SPRUFK5).

3.2.2 Internal Peripherals

The C674x megamodule includes the following internal peripherals:

- DSP interrupt controller (INTC)
- DSP power-down controller (PDC)
- Bandwidth manager (BWM)
- Internal DMA (IDMA) controller

This section briefly describes the INTC, PDC, BWM, and IDMA controller. For more information on these internal peripherals, see the *TMS320C674x DSP Megamodule Reference Guide* (SPRUFK5).

3.2.2.1 Interrupt Controller (INTC)

The C674x megamodule includes an interrupt controller (INTC) to manage CPU interrupts. The INTC maps DSP device events to 12 CPU interrupts. All DSP device events are listed in Table 3-1. The INTC is fully described in the *TMS320C674x DSP Megamodule Reference Guide* (SPRUFK5).

The interrupt events listed in Table 3-1 are for the DSP interrupt controller (INTC) only. For the ARM interrupt controller (AINTC) event mappings, see the *ARM Interrupt Controller (AINTC)* chapter.

Table 3-1. DSP Interrupt Map

Event	Interrupt Name	Source
0	EVT0	C674x Interrupt Control 0
1	EVT1	C674x Interrupt Control 1
2	EVT2	C674x Interrupt Control 2
3	EVT3	C674x Interrupt Control 3

Table 3-1. DSP Interrupt Map (continued)

Event	Interrupt Name	Source
4	T64P0_TINT12	Timer64P0 - TINT12
5	SYSCFG_CHIPINT2	SYSCFG CHIPSIG Register
6	—	Reserved
7	EHRPWM0	HiResTimer/PWM0 Interrupt
8	TPCC0_INT1	TPCC0 Region 1 Interrupt
9	EMU-DTDMA	C674x-ECM
10	EHRPWM0TZ	HiResTimer/PWM0 Trip Zone Interrupt
11	EMU-RTDXRX	C674x-RTDX
12	EMU-RTDXTX	C674x-RTDX
13	IDMAINT0	C674x-EMC
14	IDMAINT1	C674x-EMC
15	MMCSD_INT0	MMCSD MMC/SD Interrupt
16	MMCSD_INT1	MMCSD SDIO Interrupt
17	—	Reserved
18	EHRPWM1	HiResTimer/PWM1 Interrupt
19	USB0_INT	USB0 (USB2.0) Interrupt
20	USB1_HCINT	USB1 (USB1.1) OHCI Host Controller Interrupt
21	USB1_R/WAKEUP	USB1 (USB1.1) Remote Wakeup Interrupt
22	—	Reserved
23	EHRPWM1TZ	HiResTimer/PWM1 Trip Zone Interrupt
24	EHRPWM2	HiResTimer/PWM2 Interrupt
25	EHRPWM2TZ	HiResTimer/PWM2 Trip Zone Interrupt
26	EMAC_C0RXTHRESH	EMAC - Core 0 Receive Threshold Interrupt
27	EMAC_C0RX	EMAC - Core 0 Receive Interrupt
28	EMAC_C0TX	EMAC - Core 0 Transmit Interrupt
29	EMAC_C0MISC	EMAC - Core 0 Miscellaneous Interrupt
30	EMAC_C1RXTHRESH	EMAC - Core 1 Receive Threshold Interrupt
31	EMAC_C1RX	EMAC - Core 1 Receive Interrupt
32	EMAC_C1TX	EMAC - Core 1 Transmit Interrupt
33	EMAC_C1MISC	EMAC - Core 1 Miscellaneous Interrupt
34	UHPI_DSPINT	HPI DSP Interrupt
35	—	Reserved
36	IIC0_INT	I2C0
37	SPI0_INT	SPI0
38	UART0_INT	UART0
39	—	Reserved
40	T64P1_TINT12	Timer64P1 Interrupt 12
41	GPIO_B1INT	GPIO Bank 1 Interrupt
42	IIC1_INT	I2C1
43	SPI1_INT	SPI1
44	—	Reserved
45	ECAP0	ECAP0
46	UART_INT1	UART1
47	ECAP1	ECAP1
48	T64P1_TINT34	Timer64P1 Interrupt 34
49	GPIO_B2INT	GPIO Bank 2 Interrupt
50	—	Reserved

Table 3-1. DSP Interrupt Map (continued)

Event	Interrupt Name	Source
51	ECAP2	ECAP2
52	GPIO_B3INT	GPIO Bank 3 Interrupt
53	EQEP1	EQEP1
54	GPIO_B4INT	GPIO Bank 4 Interrupt
55	EMIFA_INT	EMIFA
56	EDMA3_CC0_ERRINT	EDMA3 Channel Controller 0
57	EDMA3_TC0_ERRINT	EDMA3 Transfer Controller 0
58	EDMA3_TC1_ERRINT	EDMA3 Transfer Controller 1
59	GPIO_B5INT	GPIO Bank 5 Interrupt
60	EMIFB_INT	EMIFB Memory Error Interrupt
61	MCASP_INT	McASP0,1,2 Combined RX/TX Interrupts
62	GPIO_B6INT	GPIO Bank 6 Interrupt
63	RTC_IRQS	RTC Combined
64	T64P0_TINT34	Timer64P0 Interrupt 34
65	GPIO_B0INT	GPIO Bank 0 Interrupt
66	—	Reserved
67	SYSCFG_CHIPINT3	SYSCFG CHIPSIG Register
68	EQEP0	EQEP0
69	UART2_INT	UART2
70	PSC0_ALLINT	PSC0
71	PSC1_ALLINT	PSC1
72	GPIO_B7INT	GPIO Bank 7 Interrupt
73	LCDC_INT	LCD Controller
74	MPU_BOOTCFG_ERR	MPU Shared Interrupt
75-77	—	Reserved
78	T64P0_CMPINT0	Timer64P0 - Compare 0
79	T64P0_CMPINT1	Timer64P0 - Compare 1
80	T64P0_CMPINT2	Timer64P0 - Compare 2
81	T64P0_CMPINT3	Timer64P0 - Compare 3
82	T64P0_CMPINT4	Timer64P0 - Compare 4
83	T64P0_CMPINT5	Timer64P0 - Compare 5
84	T64P0_CMPINT6	Timer64P0 - Compare 6
85	T64P0_CMPINT7	Timer64P0 - Compare 7
86	T64P1_CMPINT0	Timer64P1 - Compare 0
87	T64P1_CMPINT1	Timer64P1 - Compare 1
88	T64P1_CMPINT2	Timer64P1 - Compare 2
89	T64P1_CMPINT3	Timer64P1 - Compare 3
90	T64P1_CMPINT4	Timer64P1 - Compare 4
91	T64P1_CMPINT5	Timer64P1 - Compare 5
92	T64P1_CMPINT6	Timer64P1 - Compare 6
93	T64P1_CMPINT7	Timer64P1 - Compare 7
94-95	—	Reserved
96	INTERR	C674x-Interrupt Control
97	EMC_IDMAERR	C674x-EMC
98-112	—	Reserved
113	PMC_ED	C674x-PMC
114-115	—	Reserved

Table 3-1. DSP Interrupt Map (continued)

Event	Interrupt Name	Source
116	UMC_ED1	C674x-UMC
117	UMC_ED2	C674x-UMC
118	PDC_INT	C674x-PDC
119	SYS_CMPA	C674x-SYS
120	PMC_CMPA	C674x-PMC
121	PMC_CMPA	C674x-PMC
122	DMC_CMPA	C674x-DMC
123	DMC_CMPA	C674x-DMC
124	UMC_CMPA	C674x-UMC
125	UMC_CMPA	C674x-UMC
126	EMC_CMPA	C674x-EMC
127	EMC_BUSERR	C674x-EMC

3.2.2.1.1 Interrupt Controller Registers

For more information on the DSP interrupt controller (INTC) registers, see the *TMS320C674x DSP Megamodule Reference Guide* (SPRUFK5).

3.2.2.1.2 NMI Interrupt

In addition to the interrupts listed in Table 3-1, the DSP also supports a special interrupt that behaves more like an exception, non-maskable interrupt (NMI). The NMI interrupt is controlled by two registers in the System Configuration Module, the chip signal register (CHIPSIG) and the chip signal clear register (CHIPSIG_CLR).

The NMI interrupt is asserted by writing a 1 to the CHIPSIG4 bit in CHIPSIG. The NMI interrupt is cleared by writing a 1 to the CHIPSIG4 bit in CHIPSIG_CLR. For more information on the System Configuration Module, CHIPSIG, and CHIPSIG_CLR, see the *System Configuration (SYSCFG) Module* chapter.

3.2.2.2 Power-Down Controller (PDC)

The C674x megamodule includes a power-down controller (PDC). The PDC can power-down all of the following components of the C674x megamodule and internal memories of the DSP subsystem:

- C674x CPU
- Level 1 program memory controller (PMC)
- Level 1 data memory controller (DMC)
- Level 2 unified memory controller (UMC)
- Extended memory controller (EMC)
- Internal Direct Memory Access controller (IDMA)
- L1P memory
- L1D memory
- L2 memory

This device supports the static power-down feature from the C674x megamodule. The *TMS320C674x DSP Megamodule Reference Guide* (SPRUFK5) describes the power-down control in more detail.

- Static power-down: The PDC initiates power-down (clock gating) of the entire C674x megamodule and all internal memories immediately upon command from software.

Static power-down (clock gating) affects all components of the C674x megamodule and all internal memories. Software can initiate static power-down by way of a register bit in the power-down controller command register (PDCCMD) of the PDC. For more information on the PDC, see the *TMS320C674x DSP Megamodule Reference Guide* (SPRUFK5).

3.2.2.3 Bandwidth Manager (BWM)

The bandwidth manager (BWM) provides a programmable interface for optimizing bandwidth among the requesters for resources, which include the following:

- EDMA3-initiated DMA transfers (and resulting coherency operations)
- DSP subsystem IDMA-initiated transfers (and resulting coherency operations)
- Programmable cache coherency operations
  - Block based coherency operations
  - Global coherency operations
- CPU direct-initiated transfers
  - Data access (load/store)
  - Program access

The resources include the following:

- L1P memory
- L1D memory
- L2 memory
- Resources outside of the C674x megamodule: external memory, on-chip peripherals, registers

Since any given requestor could potentially block a resource for extended periods of time, the bandwidth manager is implemented to assure fairness for all requesters.

The bandwidth manager implements a weighted-priority-driven bandwidth allocation. Each requestor (EDMA, IDMA, CPU, etc.) is assigned a priority level on a per-transfer basis. The programmable priority level has a single meaning throughout the system. There are a total of nine priority levels, where priority zero is the highest priority and priority eight is the lowest priority. When requests for a single resource contend, access is granted to the highest-priority requestor. When the contention occurs for multiple successive cycles, a contention counter assures that the lower-priority requestor gets access to the resource every 1 out of *n* arbitration cycles, where *n* is programmable. A priority level of -1 represents a transfer whose priority has been increased due to expiration of the contention counter or a transfer that is fixed as the highest-priority transfer to a given resource.

3.2.2.4 Internal DMA (IDMA) Controller

The IDMA controller performs fast block transfers between any two memory locations local to the C674x megamodule. Local memory locations are defined as those in Level 1 program (L1P), Level 1 data (L1D), and Level 2 (L2) memories, or in the external peripheral configuration (CFG) memory. The IDMA cannot transfer data to or from the internal DSP memory-mapped register space. The IDMA is fully described in the *TMS320C674x DSP Megamodule Reference Guide* (SPRUFK5).

3.3 Memory Map

Refer to your device-specific data manual for memory-map information.

3.3.1 DSP Internal Memory

See the *System Memory* chapter for a description of the DSP internal memory.

3.3.2 External Memory

See the *System Interconnect* chapter and the *System Memory* chapter for a description of the additional system memory and peripherals that the DSP has access to.

3.4 Advanced Event Triggering (AET)

The C674x megamodule supports advanced event triggering (AET). This capability can be used to debug complex problems as well as understand performance characteristics of user applications. AET provides the following capabilities:

- Hardware Program Breakpoints: specify addresses or address ranges that can generate events such as halting the processor or triggering the trace capture.
- Data Watchpoints: specify data variable addresses, address ranges, or data values that can generate events such as halting the processor or triggering the trace capture.
- Counters: count the occurrence of an event or cycles for performance monitoring.
- State Sequencing: allows combinations of hardware program breakpoints and data watchpoints to precisely generate events for complex sequences.

System Interconnect

Topic **Page**

4.1 Introduction

The DSP, the ARM, the EDMA3 transfer controllers, and the device peripherals are interconnected through a switch fabric architecture (see Section 4.2). The switch fabric is composed of multiple switched central resources (SCRs) and multiple bridges. The SCRs establish low-latency connectivity between master peripherals and slave peripherals.

Additionally, the SCRs provide priority-based arbitration and facilitate concurrent data movement between master and slave peripherals. Through SCR, the DSP can send data to the EMIF without affecting a data transfer between a device peripheral and internal shared memory. Bridges are mainly used to perform bus-width conversion as well as bus operating frequency conversion.

The DSP, the ARM, the EDMA3 transfer controllers, and the various device peripherals can be classified into two categories: master peripherals and slave peripherals.

Master peripherals are typically capable of initiating read and write transfers in the system and do not rely on the EDMA3 or on a CPU to perform transfers to and from them. The system master peripherals include the DSP, the ARM, the EDMA3 transfer controllers, EMAC, HPI, LCDC, and USB. Not all master peripherals may connect to all slave peripherals. The supported connections are designated by an X in Table 4-1.

Table 4-1. OMAP-L137 Processor System Interconnect Matrix

Masters		Slaves							
Master	Default Priority	ARM ROM, AINTC	ARM RAM	DSP SDMA	EMIFA	EMIFB	128 kB RAM	EDMA3TC Group [1]	Peripheral Group [2]
EDMA3CC0	0							X	
EDMA3TC0	0			X	X	X	X	X	X
EDMA3TC1	0			X	X	X	X	X	X
PRU0	0		X	X	X	X	X	X	X
PRU1	0			X	X	X	X	X	X
ARM I	2	X	X	X	X	X	X		
ARM D	2	X	X	X	X	X	X	X	X
DSP CFG	2							X	X
DSP MDMA	2				X	X	X		
EMAC	4			X	X	X	X		
USB2.0	4			X	X	X	X		
USB1.1	4			X	X	X	X		
LCDC	5					X			
HPI	6			X		X	X		X [3]

(1) EDMA3TC group: EDMA3TC0, EDMA3TC1

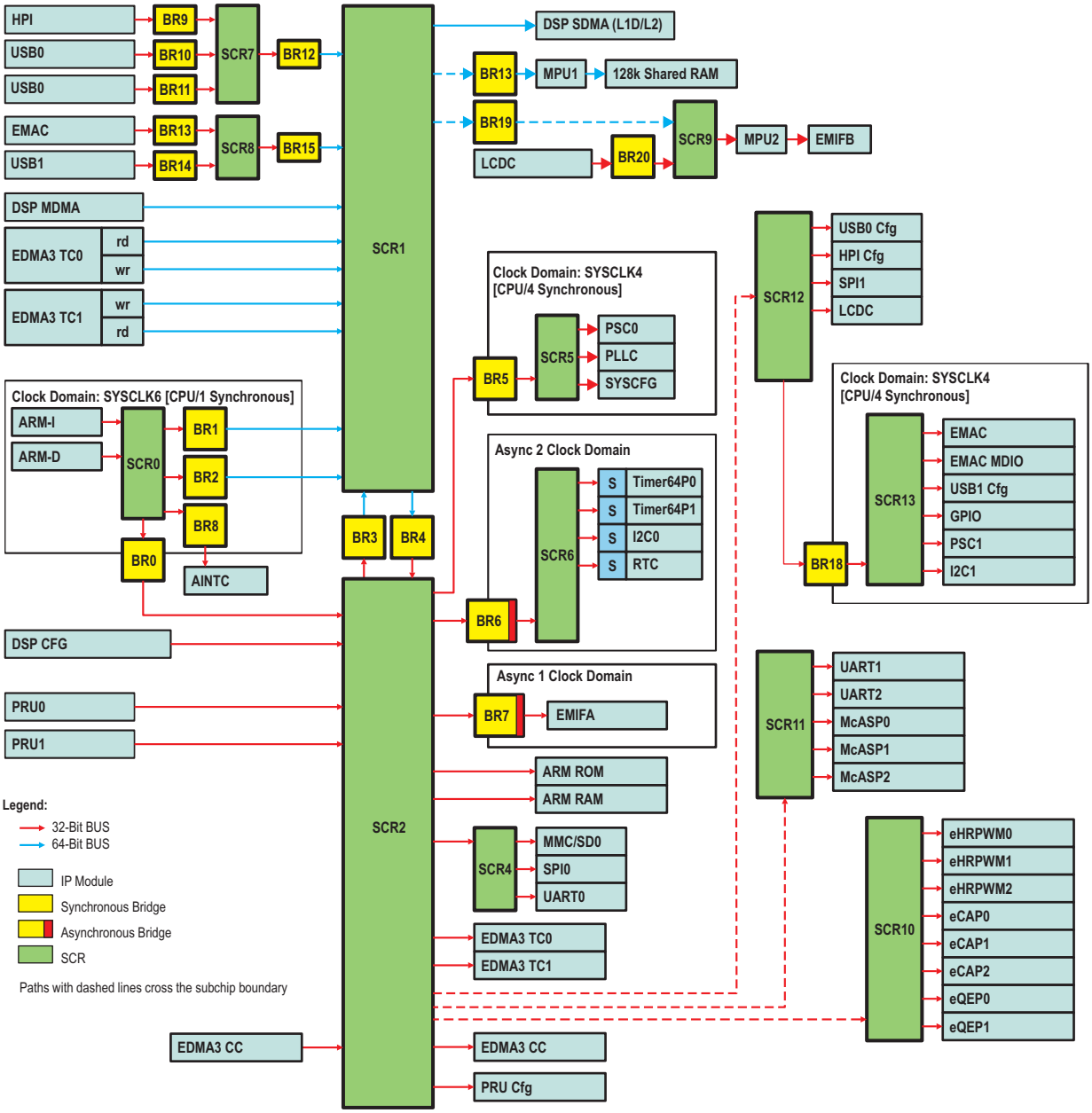
(2) Peripheral group: SYSCFG, EMAC, eCAP0, eCAP1, eCAP2, eHRPWM0, eHRPWM1, eHRPWM2, GPIO, I2C0, I2C1, LCDC, McASP0, McASP1, McASP2, MDIO, MMC/SD, PLLC, PRU RAM0, PRU RAM1, PRU Config, PSC0, PSC1, RTC, SPI0, SPI1, TIMER64P0, TIMER64P1, EDMA3CC0, UART0, UART1, UART2, HPI, USB0 (USB2.0), USB1 (USB1.1).

(3) The HPI does not have access to all registers in the SYSCFG module because it operates with the User Privilege Level.

4.2 System Interconnect Block Diagram

Figure 4-1 shows a system interconnect block diagram.

Figure 4-1. System Interconnect Block Diagram



System Memory

Topic **Page**

5.1 Introduction

This device has multiple on-chip/off-chip memories and several external device interfaces associated with its two processors and various subsystems. To help simplify software development, a unified memory-map is used wherever possible to maintain a consistent view of device resources across all masters (CPU and master peripherals).

For details on the memory addresses, actual memory supported and accessibility by various bus masters, see the detailed memory-map information in the device-specific data manual.

5.2 ARM Memories

The configuration for the ARM internal memory is:

- 8 kB ARM local RAM
- 64 kB ARM local ROM
- 16 kB Instruction Cache and 16 kB Data cache

The ARM RAM/ROM are only accessible by ARM.

5.3 DSP Memories

The DSP internal memories are accessible by the ARM and other master peripherals (as dictated by the connectivity matrix) via the system interconnect through the DSP SDMA port. The accesses by the DSP to its internal memory are internal to the DSP subsystem and do not go out on the system interconnect.

The DSP internal memory consists of L1P, L1D, and L2. The DSP internal memory configuration is:

- L1P memory includes 32 kB of RAM. The DSP program memory controller (PMC) allows you to configure part or all of the L1P RAM as normal program RAM or as cache. You can configure cache sizes of 0 kB, 4 kB, 8 kB, 16 kB, or 32 kB of the 32 kB of RAM. The default configuration is 32 kB cache.
- L1D memory includes 32 kB of RAM. The DSP data memory controller (DMC) allows you to configure part of the L1D RAM as normal data RAM or as cache. You can configure cache sizes of 0 kB, 4 kB, 8 kB, 16 kB, or 32 kB of the 32 kB of RAM. The default configuration is 32 kB cache.
- L2 memory includes 256 kB of RAM. The DSP unified memory controller (UMC) allows you to configure part or all of the L2 RAM as normal RAM or as cache. You can configure cache sizes of 0 kB, 4 kB, 8 kB, 16 kB, 32 kB, 64 kB, 128 kB, or 256 kB of the 256 kB of RAM. The default configuration is 256 kB normal RAM.
- L2 memory also includes 1024 kB of ROM.

5.4 Shared RAM

This device also offers an on-chip 128-kB shared RAM, apart from the ARM and the DSP internal memories. This shared RAM is accessible by the ARM and the DSP, and also is accessible by several master peripherals.

5.5 External Memories

This device has two external memory interfaces that provide multiple external memory options accessible by the CPU and master peripherals:

- EMIFA:
  - 8/16-bit wide asynchronous EMIF module that supports asynchronous devices such as ASRAM, NAND Flash, and NOR Flash (up to 4 devices)
  - 8/16-bit wide NAND Flash with 4-bit ECC (up to 4 devices)
  - 16-bit SDRAM with 128-MB address space
- EMIFB: 32/16-bit SDRAM with up to 256-MB SDRAM address space

5.6 Internal Peripherals

The following peripherals are internal to the DSP subsystem and are only accessible to the DSP:

- DSP interrupt controller (INTC)
- DSP power down controller (PDC)
- Bandwidth manager (BWM)
- Internal DMA (IDMA)

For more information on these internal peripherals, see the *TMS320C674x DSP Megamodule Reference Guide* (SPRUFK5).

The peripheral only accessible by the ARM is the ARM interrupt controller (AINTC). For more information on the AINTC, see the *ARM Interrupt Controller (AINTC)* chapter.

5.7 Peripherals

The ARM and the DSP have access to all peripherals on the device. This also includes system modules like the PLL controller (PLLC), the power and sleep controller (PSC), and the system configuration module (SYSCFG). See the device-specific data manual for the complete list of peripherals supported on your device.

Memory Protection Unit (MPU)

Topic **Page**

6.1 Introduction

This device supports two memory protection units (MPU1 and MPU2). MPU1 supports the 128 kB shared RAM and MPU2 supports the EMIFB.

6.1.1 Purpose of the MPU

The memory protection unit (MPU) is provided to manage access to memory. The MPU allows you to define multiple ranges and limit access to system masters based on their privilege ID. The MPU can record a detected fault, or invalid access, and notify the system through an interrupt.

6.1.2 Features

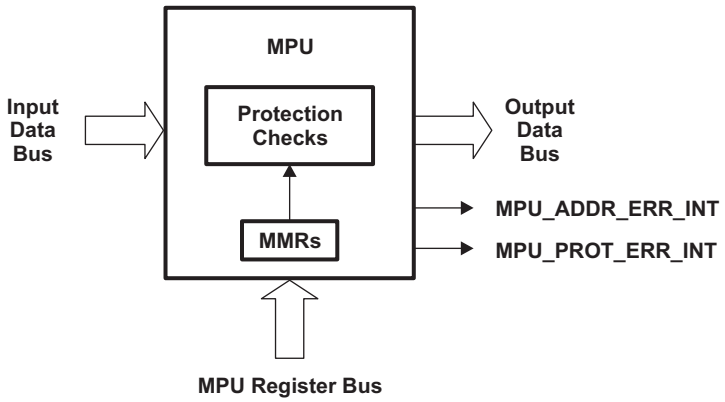
The MPU supports the following features:

- Supports multiple programmable address ranges
- Supports 0 or 1 fixed range
- Supports read, write, and execute access privileges
- Supports privilege ID associations with ranges
- Generates an interrupt when there is a protection violation, and saves violating transfer parameters
- Supports L1/L2 cache accesses
- Supports protection of its own registers

6.1.3 Block Diagram

Figure 6-1 shows a block diagram of the MPU. An access to a protected memory must pass through the MPU. During an access, the MPU checks the memory address on the input data bus against fixed and programmable ranges. If allowed, the transfer is passed unmodified to the output data bus. If the transfer fails the protection check then the MPU does not pass the transfer to the output bus but rather services the transfer internally back to the input bus (to prevent a hang) returning the fault status to the requestor as well as generating an interrupt about the fault. The MPU generates two interrupts: an address error interrupt (MPU_ADDR_ERR_INT) and a protection interrupt (MPU_PROT_ERR_INT).

Figure 6-1. MPU Block Diagram



6.1.4 MPU Default Configuration

Two MPUs are supported on the device, one for the 128 kB shared RAM and one for the EMIFB. Table 6-1 shows the memory regions protected by each MPU. Table 6-2 shows the configuration of each MPU.

Table 6-1. MPU Memory Regions

		Memory Region	
Unit	**Memory Protection**	**Start Address**	**End Address**
MPU1	128 kB Shared RAM	8000 0000h	8001 FFFFh
MPU2	EMIFB	C000 0000h	DFFF FFFFh

Table 6-2. MPU Default Configuration

Setting	**MPU1**	**MPU2**
Default permission	Assume allowed	Assume allowed
Number of allowed IDs supported	12	12
Number of fixed ranges supported	1	0
Number of programmable ranges supported	6	12
Compare width	1 kB granularity	64 kB granularity

6.2 Architecture

6.2.1 Privilege Levels

The privilege level of a memory access determines what level of permissions the originator of the memory access might have. Two privilege levels are supported: supervisor and user.

Supervisor level is generally granted access to peripheral registers and the memory protection configuration. User level is generally confined to the memory spaces that the OS specifically designates for its use.

ARM and DSP CPU instruction and data accesses have a privilege level associated with them. The privilege level is inherited from the code running on the CPU. See the *TMS320C674x DSP CPU and Instruction Set Reference Guide* (SPRUFE8) and the ARM926EJ-S Technical Reference Manual (TRM), downloadable from http://infocenter.arm.com/help/index.jsp for more details on privilege levels of the DSP and ARM CPU.

Although master peripherals like the EMAC do not execute code, they still have a privilege level associated with them. Unlike the ARM and DSP CPU , the privilege level of this peripheral is fixed.

Table 6-3 shows the privilege ID of the CPU and every mastering peripheral. Table 6-3 also shows the privilege level (supervisor vs. user) and access type (instruction read vs. data/DMA read or write) of each master on the device. In some cases, a particular setting depends on software being executed at the time of the access or the configuration of the master peripheral.

Table 6-3. Device Master Settings

Master	Privilege ID	Privilege Level	Access Type
EDMA3CC	Inherited	Inherited	DMA
EDMA3TC0 and TC1	Inherited	Inherited	DMA
ARM (instruction access)	0	Software dependant	Instruction
ARM (data access)	0	Software dependant	Data
DSP	1	Software dependant	Software dependant
PRU0/PRU1	2	Supervisor	DMA
HPI	3	User	DMA
EMAC	4	Supervisor	Data/DMA
USB1.1	5	Supervisor	DMA
USB2.0	6	Supervisor	DMA
LCD Controller	7	Supervisor	DMA

6.2.2 Memory Protection Ranges

NOTE: In some cases the amount of physical memory in actual use may be less than the maximum amount of memory supported by the device. For example, the device may support a total of 512 Mbytes of SDRAM memory, but your design may only populate 128 Mbytes. In such cases, the “unpopulated” memory range must be protected in order to prevent unintended/disallowed “aliased” access to protected memory. One of the programmable address ranges could be used to detect accesses to this “unpopulated” memory.

The MPU divides its assigned memory into address ranges. Each MPU can support one fixed address range and multiple programmable address ranges. The fixed address range is configured to an exact address. The programmable address range allows software to program the start and end addresses.

Each address range has the following set of registers:

- Range start and end address registers (MPSAR and MPEAR): Specifies the starting and ending address of the address range.
- Memory protection page attribute register (MPPA): Use to program the permission settings of the address range.

It is allowed to configure ranges such that they overlap each other. In this case, all the overlapped ranges must allow the access, otherwise the access is not allowed. The final permissions given to the access are the lowest of each type of permission from any hit range.

Addresses not covered by a range are either allowed or disallowed based on the configuration of the MPU. The MPU can be configured for “assumed allowed” or “assumed disallowed” mode as dictated by the ASSUME_ALLOWED bit in the configuration register (CONFIG).

6.2.3 Permission Structures

The MPU defines a per-range permission structure with three permission fields in a 32-bit permission entry. Figure 6-2 shows the structure of a permission entry.

Figure 6-2. Permission Fields

31									22	21	20	19	18	17	16
Reserved										Allowed IDs					
										AID11	AID10	AID9	AID8	AID7	AID6
15	14	13	12	11	10	9	8		6	5	4	3	2	1	0
Allowed IDs							Reserved			Access Types					
AID5	AID4	AID3	AID2	AID1	AID0	AIX				SR	SW	SX	UR	UW	UX

6.2.3.1 Requestor-ID Based Access Controls

Each master on the device has an N-bit code associated with it that identifies it for privilege purposes. This privilege ID accompanies all memory accesses made on behalf of that master. That is, when a master triggers a memory access command, the privilege ID will be carried alongside the command.

Each memory protection range has an allowed ID (AID) field associated with it that indicates which requestors may access the given address range. The MPU maps the privilege IDs of all the possible requestors to bits in the allowed IDs field in the memory protection page attribute registers (MPPA).

- AID0 through AID11 are used to specify the allowed privilege IDs.
- An additional allowed ID bit, AIDX, captures access made by all privilege IDs not covered by AID0 through AID11.

When set to 1, the AID bit grants access to the corresponding ID. When cleared to 0, the AID bit denies access to the corresponding requestor.

6.2.3.2 Request-Type Based Permissions

The memory protection model defines three fundamental functional access types: read, write, and execute. Read and write refer to data accesses -- accesses originating via the load/store units on the CPU or via a master peripheral. Execute refers to accesses associated with an instruction fetch.

The memory protection model allows controlling read, write, and execute permissions independently for both user and supervisor mode. This results in six permission bits, listed in Table 6-4. For each bit, a 1 permits the access type and a 0 denies access. For example, UX = 1 means that User Mode may execute from the given page. The memory protection unit allows you to specify all six of these bits separately; 64 different encodings are permitted altogether, although programs might not use all of them.

Table 6-4. Request Type Access Controls

Bit	Field	Description
5	SR	Supervisor may read
4	SW	Supervisor may write
3	SX	Supervisor may execute
2	UR	User may read
1	UW	User may write
0	UX	User may execute

6.2.4 Protection Check

During a memory access, the MPU checks if the address range of the input transfer overlaps one of the address ranges. When the input transfer address is within a range the transfer parameters are checked against the address range permissions.

The MPU first checks the transfer's privilege ID against the AID settings. If the AID bit is 0, then the range will not be checked; if the AID bit is 1, then the transfer parameters are checked against the memory protection page attribute register (MPPA) values to detect an allowed access.

For non-debug accesses, the read, write, and execute permissions are also checked. There is a set of permissions for supervisor mode and a set for user mode. For supervisor mode accesses, the SR, SW, and SX bits are checked. For user mode accesses, the UR, UW, and UX bits are checked.

If the transfer address range does not match any address range then the transfer is either allowed or disallowed based on the configuration of the MPU. The MPU can be configured for "assumed allowed" or "assumed disallowed" mode as dictated by the ASSUME_ALLOWED bit in the configuration register (CONFIG).

In the case that a transfer spans multiple address ranges, all the overlapped ranges must allow the access, otherwise the access is not allowed. The final permissions given to the access are the lowest of each type of permission from any hit range. Therefore, if a transfer matches 2 ranges, one that is RW and one that is RX, then the final permission is just R.

The MPU has a special mechanism for handling DSP L1/L2 cache controller read accesses, see Section 6.2.5 for more details.

6.2.5 DSP L1/L2 Cache Controller Accesses

A memory read access that originates from the DSP L1/L2 cache is treated differently to allow memory protection to be enforced by the DSP level. This is because a subsequent memory access that hits in the cache does not pass through the MPU. Instead the memory access is serviced directly by the L1/L2 memory controllers.

During a cache memory read, the permission settings stored in the memory protection page attribute registers (MPPA) are passed to the L1/L2 memory controllers along with the read data. The permissions settings returned by the MPU are taken from MPPA that covers the address range of the original request—only the SR, SW, SX, UR, UW, and UX bits are passed. If the request address is covered by multiple address ranges, then the returned value is the logical-AND of all MPPA permissions. If the transfer address range is not covered by an address range then the transfer is either allowed or disallowed based on the configuration of the MPU.

6.2.6 MPU Register Protection

Access to the range start and end address registers (MPSAR and MPEAR) and memory protection page attribute registers (MPPA) is also protected. All non-debug writes must be by a supervisor entity. A protection fault can occur from a register write with invalid permissions and this triggers an interrupt just like a memory access.

Faults are not recorded (nor interrupts generated) for debug accesses.

6.2.7 Invalid Accesses and Exceptions

When a transfer fails the protection check, the MPU does not pass the transfer to the output bus. The MPU instead services the transfer locally to prevent a hang and returns a protection error to the requestor. The behavior of the MPU depends on whether the access was a read or a write:

- For a read: The MPU returns 0s, a permission value is 0 (no access allowed), a protection error status.
- For a write: The MPU receives all the write data and returns a protection error status.

The MPU captures system faults due to addressing or protection violations in its registers. The MPU can store the fault information for only one fault, so the first detected fault is recorded into the fault registers and an interrupt is generated. Software must use the fault clear register (FLTCLR) to clear the fault status so that another fault can be recorded. The MPU will not record another fault nor generate another interrupt until the existing fault has been cleared. Also, additional faults will be ignored. Faults are not recorded (no interrupts generated) for debug accesses.

6.2.8 Reset Considerations

After reset, the memory protection page attribute registers (MPPA) default to 0. This disables all protection features.

6.2.9 Interrupt Support

6.2.9.1 Interrupt Events and Requests

The MPU generates two interrupts: an address error interrupt (MPU_ADDR_ERR_INT) and a protection interrupt (MPU_PROT_ERR_INT). The MPU_ADDR_ERR_INT is generated when there is an addressing violation due to an access to a non-existent location in the MPU register space. The MPU_PROT_ERR_INT interrupt is generated when there is a protection violation of either in the defined ranges or to the MPU registers.

The transfer parameters that caused the violation are saved in the MPU registers.

6.2.9.2 Interrupt Multiplexing

The interrupts from both MPUs are combined with the boot configuration module into a single interrupt called MPU_BOOTCFG_ERR. The combined interrupt is routed to the ARM and DSP interrupt controllers. Table 6-5 shows the interrupt sources that are combined to make MPU_BOOTCFG_ERR.

Table 6-5. MPU_BOOTCFG_ERR Interrupt Sources

Interrupt	Source
MPU1_ADDR_ERR_INT	MPU1 address error interrupt
MPU1_PROT_ERR_INT	MPU1 protection interrupt
MPU2_ADDR_ERR_INT	MPU2 address error interrupt
MPU2_PROT_ERR_INT	MPU2 protection interrupt
BOOTCFG_ADDR_ERR	Boot configuration address error
BOOTCFG_PROT_ERR	Boot configuration protection error

6.2.10 Emulation Considerations

Memory and MPU registers are not protected against emulation accesses.

6.3 MPU Registers

There are two MPUs on the device. Each MPU contains a set of memory-mapped registers.

Table 6-6 lists the memory-mapped registers for the MPU1. Table 6-7 lists the memory-mapped registers for the MPU2.

Table 6-6. Memory Protection Unit 1 (MPU1) Registers

Address	Acronym	Register Description	Section
01E1 4000h	REVID	Revision identification register	Section 6.3.1
01E1 4004h	CONFIG	Configuration register	Section 6.3.2
01E1 4010h	IRAWSTAT	Interrupt raw status/set register	Section 6.3.3
01E1 4014h	IENSTAT	Interrupt enable status/clear register	Section 6.3.4
01E1 4018h	IENSET	Interrupt enable set register	Section 6.3.5
01E1 401Ch	IENCLR	Interrupt enable clear register	Section 6.3.6
01E1 4200h	PROG1_MPSAR	Programmable range 1 start address register	Section 6.3.10.1
01E1 4204h	PROG1_MPEAR	Programmable range 1 end address register	Section 6.3.11.1
01E1 4208h	PROG1_MPPA	Programmable range 1 memory protection page attributes register	Section 6.3.12
01E1 4210h	PROG2_MPSAR	Programmable range 2 start address register	Section 6.3.10.1
01E1 4214h	PROG2_MPEAR	Programmable range 2 end address register	Section 6.3.11.1
01E1 4218h	PROG2_MPPA	Programmable range 2 memory protection page attributes register	Section 6.3.12
01E1 4220h	PROG3_MPSAR	Programmable range 3 start address register	Section 6.3.10.1
01E1 4224h	PROG3_MPEAR	Programmable range 3 end address register	Section 6.3.11.1
01E1 4228h	PROG3_MPPA	Programmable range 3 memory protection page attributes register	Section 6.3.12
01E1 4230h	PROG4_MPSAR	Programmable range 4 start address register	Section 6.3.10.1
01E1 4234h	PROG4_MPEAR	Programmable range 4 end address register	Section 6.3.11.1
01E1 4238h	PROG4_MPPA	Programmable range 4 memory protection page attributes register	Section 6.3.12
01E1 4240h	PROG5_MPSAR	Programmable range 5 start address register	Section 6.3.10.1
01E1 4244h	PROG5_MPEAR	Programmable range 5 end address register	Section 6.3.11.1
01E1 4248h	PROG5_MPPA	Programmable range 5 memory protection page attributes register	Section 6.3.12
01E1 4250h	PROG6_MPSAR	Programmable range 6 start address register	Section 6.3.10.1
01E1 4254h	PROG6_MPEAR	Programmable range 6 end address register	Section 6.3.11.1
01E1 4258h	PROG6_MPPA	Programmable range 6 memory protection page attributes register	Section 6.3.12
01E1 4300h	FLTADDRR	Fault address register	Section 6.3.13
01E1 4304h	FLTSTAT	Fault status register	Section 6.3.14
01E1 4308h	FLTCLR	Fault clear register	Section 6.3.15

Table 6-7. Memory Protection Unit 2 (MPU2) Registers

Address	Acronym	Register Description	Section
01E1 5000h	REVID	Revision identification register	Section 6.3.1
01E1 5004h	CONFIG	Configuration register	Section 6.3.2
01E1 5010h	IRAWSTAT	Interrupt raw status/set register	Section 6.3.3
01E1 5014h	IENSTAT	Interrupt enable status/clear register	Section 6.3.4
01E1 5018h	IENSET	Interrupt enable set register	Section 6.3.5
01E1 501Ch	IENCLR	Interrupt enable clear register	Section 6.3.6
01E1 5100h	FXD_MPSAR	Fixed range start address register	Section 6.3.7
01E1 5104h	FXD_MPEAR	Fixed range end address register	Section 6.3.8
01E1 5108h	FXD_MPPA	Fixed range memory protection page attributes register	Section 6.3.9

Table 6-7. Memory Protection Unit 2 (MPU2) Registers (continued)

Address	Acronym	Register Description	Section
01E1 5200h	PROG1_MPSAR	Programmable range 1 start address register	Section 6.3.10.2
01E1 5204h	PROG1_MPEAR	Programmable range 1 end address register	Section 6.3.11.2
01E1 5208h	PROG1_MPPA	Programmable range 1 memory protection page attributes register	Section 6.3.12
01E1 5210h	PROG2_MPSAR	Programmable range 2 start address register	Section 6.3.10.2
01E1 5214h	PROG2_MPEAR	Programmable range 2 end address register	Section 6.3.11.2
01E1 5218h	PROG2_MPPA	Programmable range 2 memory protection page attributes register	Section 6.3.12
01E1 5220h	PROG3_MPSAR	Programmable range 3 start address register	Section 6.3.10.2
01E1 5224h	PROG3_MPEAR	Programmable range 3 end address register	Section 6.3.11.2
01E1 5228h	PROG3_MPPA	Programmable range 3 memory protection page attributes register	Section 6.3.12
01E1 5230h	PROG4_MPSAR	Programmable range 4 start address register	Section 6.3.10.2
01E1 5234h	PROG4_MPEAR	Programmable range 4 end address register	Section 6.3.11.2
01E1 5238h	PROG4_MPPA	Programmable range 4 memory protection page attributes register	Section 6.3.12
01E1 5240h	PROG5_MPSAR	Programmable range 5 start address register	Section 6.3.10.2
01E1 5244h	PROG5_MPEAR	Programmable range 5 end address register	Section 6.3.11.2
01E1 5248h	PROG5_MPPA	Programmable range 5 memory protection page attributes register	Section 6.3.12
01E1 5250h	PROG6_MPSAR	Programmable range 6 start address register	Section 6.3.10.2
01E1 5254h	PROG6_MPEAR	Programmable range 6 end address register	Section 6.3.11.2
01E1 5258h	PROG6_MPPA	Programmable range 6 memory protection page attributes register	Section 6.3.12
01E1 5260h	PROG7_MPSAR	Programmable range 7 start address register	Section 6.3.10.2
01E1 5274h	PROG7_MPEAR	Programmable range 7 end address register	Section 6.3.11.2
01E1 5268h	PROG7_MPPA	Programmable range 7 memory protection page attributes register	Section 6.3.12
01E1 5270h	PROG8_MPSAR	Programmable range 8 start address register	Section 6.3.10.2
01E1 5274h	PROG8_MPEAR	Programmable range 8 end address register	Section 6.3.11.2
01E1 5278h	PROG8_MPPA	Programmable range 8 memory protection page attributes register	Section 6.3.12
01E1 5280h	PROG9_MPSAR	Programmable range 9 start address register	Section 6.3.10.2
01E1 5284h	PROG9_MPEAR	Programmable range 9 end address register	Section 6.3.11.2
01E1 5288h	PROG9_MPPA	Programmable range 9 memory protection page attributes register	Section 6.3.12
01E1 5290h	PROG10_MPSAR	Programmable range 10 start address register	Section 6.3.10.2
01E1 5294h	PROG10_MPEAR	Programmable range 10 end address register	Section 6.3.11.2
01E1 5298h	PROG10_MPPA	Programmable range 10 memory protection page attributes register	Section 6.3.12
01E1 52A0h	PROG11_MPSAR	Programmable range 11 start address register	Section 6.3.10.2
01E1 52A4h	PROG11_MPEAR	Programmable range 11 end address register	Section 6.3.11.2
01E1 52A8h	PROG11_MPPA	Programmable range 11 memory protection page attributes register	Section 6.3.12
01E1 52B0h	PROG12_MPSAR	Programmable range 12 start address register	Section 6.3.10.2
01E1 52B4h	PROG12_MPEAR	Programmable range 12 end address register	Section 6.3.11.2
01E1 52B8h	PROG12_MPPA	Programmable range 12 memory protection page attributes register	Section 6.3.12
01E1 5300h	FLTADDRR	Fault address register	Section 6.3.13
01E1 5304h	FLTSTAT	Fault status register	Section 6.3.14
01E1 5308h	FLTCLR	Fault clear register	Section 6.3.15

6.3.1 Revision Identification Register (REVID)

The revision ID register (REVID) contains the MPU revision. The REVID is shown in Figure 6-3 and described in Table 6-8.

Figure 6-3. Revision ID Register (REVID)

31	0
REV	
R-4E81 0101h	

LEGEND: R = Read only; -*n* = value after reset

Table 6-8. Revision ID Register (REVID) Field Descriptions

Bit	Field	Value	Description
31-0	REV	4E81 0101h	Revision ID of the MPU.

6.3.2 Configuration Register (CONFIG)

The configuration register (CONFIG) contains the configuration value of the MPU. The CONFIG is shown in Figure 6-4 and described in Table 6-9.

NOTE: Although the NUM_AIDS bit defaults to 12 (Ch), not all AIDs may be supported on your device. Unsupported AIDs should be cleared to 0 in the memory page protection attributes registers (MPPA). See Table 6-3 for a list of AIDs supported on your device.

Figure 6-4. Configuration Register (CONFIG)

31	24	23	20	19	16
ADDR_WIDTH		NUM_FIXED		NUM_PROG	
R-0[1] or 6h[2]		R-0[1] or 1[2]		R-6h[1] or Ch[2]	

15	12	11	1	0
NUM_AIDS		Reserved		ASSUME_ALLOWED
R-Ch		R-0		R-1

LEGEND: R = Read only; -*n* = value after reset

(1) For MPU1.
(2) For MPU2.

Table 6-9. Configuration Register (CONFIG) Field Descriptions

Bit	Field	Value	Description
31-24	ADDR_WIDTH	0-FFh	Address alignment (2^n kByte alignment) for range checking.
23-20	NUM_FIXED	0-Fh	Number of fixed address ranges.
19-16	NUM_PROG	0-Fh	Number of programmable address ranges.
15-12	NUM_AIDS	0-Fh	Number of supported AIDs.
11-1	Reserved	0	Reserved
0	ASSUME_ALLOWED		Assume allowed. When an address is not covered by any MPU protection range, this bit determines whether the transfer is assumed to be allowed or not allowed.
		0	Assume is disallowed.
		1	Assume is allowed.

6.3.3 Interrupt Raw Status/Set Register (IRAWSTAT)

Reading the interrupt raw status/set register (IRAWSTAT) returns the status of all interrupts. Software can write to IRAWSTAT to manually set an interrupt; however, an interrupt is generated only if the interrupt is enabled in the interrupt enable set register (IENSET). Writes of 0 have no effect. The IRAWSTAT is shown in Figure 6-5 and described in Table 6-10.

Figure 6-5. Interrupt Raw Status/Set Register (IRAWSTAT)

31	16
Reserved	
R-0	

15	2	1	0
Reserved		ADDRERR	PROTERR
R-0		R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 6-10. Interrupt Raw Status/Set Register (IRAWSTAT) Field Descriptions

Bit	Field	Value	Description
31-2	Reserved	0	Reserved
1	ADDRERR		Address violation error. Reading this bit reflects the status of the interrupt. Writing 1 sets the status; writing 0 has no effect.
		0	Interrupt is not set.
		1	Interrupt is set.
0	PROTERR		Protection violation error. Reading this bit reflects the status of the interrupt. Writing 1 sets the status; writing 0 has no effect.
		0	Interrupt is not set.
		1	Interrupt is set.

6.3.4 Interrupt Enable Status/Clear Register (IENSTAT)

Reading the interrupt enable status/clear register (IENSTAT) returns the status of only those interrupts that are enabled in the interrupt enable set register (IENSET). Software can write to IENSTAT to clear an interrupt; the interrupt is cleared from both IENSTAT and the interrupt raw status/set register (IRAWSTAT). Writes of 0 have no effect. The IENSTAT is shown in Figure 6-6 and described in Table 6-11.

Figure 6-6. Interrupt Enable Status/Clear Register (IENSTAT)

31	16
Reserved	
R-0	

15	2	1	0
Reserved		ADDRERR	PROTERR
R-0		R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

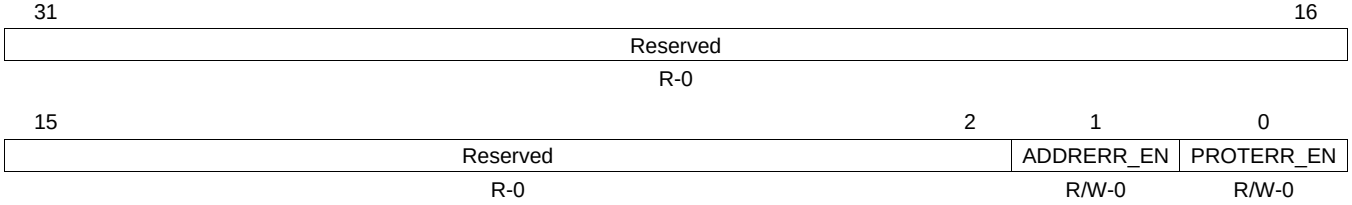
Table 6-11. Interrupt Enable Status/Clear Register (IENSTAT) Field Descriptions

Bit	Field	Value	Description
31-2	Reserved	0	Reserved
1	ADDRERR		Address violation error. If the interrupt is enabled, reading this bit reflects the status of the interrupt. If the interrupt is disabled, reading this bit returns 0. Writing 1 sets the status; writing 0 has no effect.
		0	Interrupt is not set.
		1	Interrupt is set.
0	PROTERR		Protection violation error. If the interrupt is enabled, reading this bit reflects the status of the interrupt. If the interrupt is disabled, reading this bit returns 0. Writing 1 sets the status; writing 0 has no effect.
		0	Interrupt is not set.
		1	Interrupt is set.

6.3.5 Interrupt Enable Set Register (IENSET)

Reading the interrupt enable set register (IENSET) returns the interrupts that are enabled. Software can write to IENSET to enable an interrupt. Writes of 0 have no effect. The IENSET is shown in Figure 6-7 and described in Table 6-12.

Figure 6-7. Interrupt Enable Set Register (IENSET)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

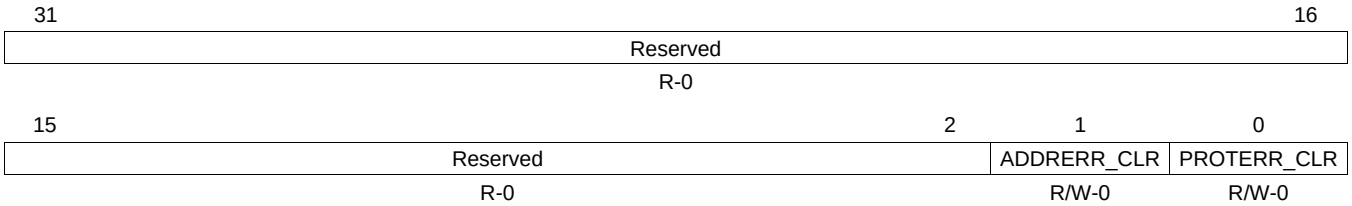
Table 6-12. Interrupt Enable Set Register (IENSET) Field Descriptions

Bit	Field	Value	Description
31-2	Reserved	0	Reserved
1	ADDRERR_EN		Address violation error enable.
		0	Writing 0 has no effect.
		1	Interrupt is enabled.
0	PROTERR_EN		Protection violation error enable.
		0	Writing 0 has no effect.
		1	Interrupt is enabled.

6.3.6 Interrupt Enable Clear Register (IENCLR)

Reading the interrupt enable clear register (IENCLR) returns the interrupts that are enabled. Software can write to IENCLR to clear/disable an interrupt. Writes of 0 have no effect. The IENCLR is shown in Figure 6-8 and described in Table 6-13.

Figure 6-8. Interrupt Enable Clear Register (IENCLR)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

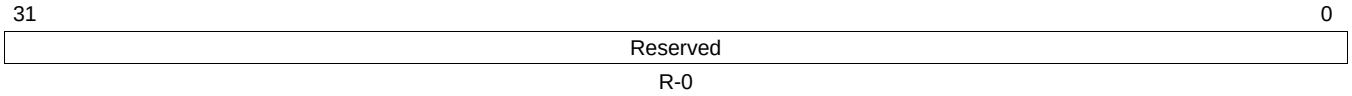
Table 6-13. Interrupt Enable Clear Register (IENCLR) Field Descriptions

Bit	Field	Value	Description
31-2	Reserved	0	Reserved
1	ADDRERR_CLR		Address violation error disable.
		0	Writing 0 has no effect.
		1	Interrupt is cleared/disabled.
0	PROTERR_CLR		Protection violation error disable.
		0	Writing 0 has no effect.
		1	Interrupt is cleared/disabled.

6.3.7 Fixed Range Start Address Register (FXD_MPSAR)

The fixed range start address register (FXD_MPSAR) holds the start address for the fixed range. The fixed address range manages access to the EMIFB control registers (B000 0000h–B000 7FFFh). However, these addresses are *not* indicated in FXD_MPSAR and the fixed range end address register (FXD_MPEAR), which instead read as 0. The FXD_MPSAR is shown in Figure 6-9.

Figure 6-9. Fixed Range Start Address Register (FXD_MPSAR)

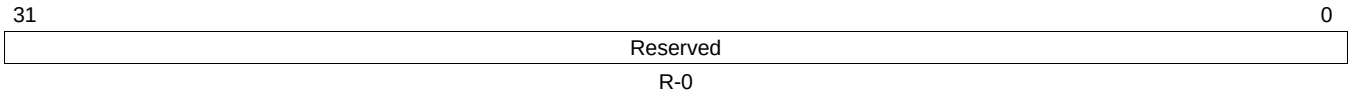


LEGEND: R = Read only; -*n* = value after reset

6.3.8 Fixed Range End Address Register (FXD_MPEAR)

The fixed range end address register (FXD_MPEAR) holds the end address for the fixed range. The fixed address range manages access to the EMIFB control registers (B000 0000h–B000 7FFFh). However, these addresses are *not* indicated in FXD_MPEAR and the fixed range start address register (FXD_MPSAR), which instead read as 0. The FXD_MPEAR is shown in Figure 6-10.

Figure 6-10. Fixed Range End Address Register (FXD_MPEAR)



LEGEND: R = Read only; -*n* = value after reset

6.3.9 Fixed Range Memory Protection Page Attributes Register (FXD_MPPA)

The fixed range memory protection page attributes register (FXD_MPPA) holds the permissions for the fixed region. This register is writeable by a supervisor entity only. The FXD_MPPA is shown in Figure 6-11 and described in Table 6-14.

Figure 6-11. Fixed Range Memory Protection Page Attributes Register (FXD_MPPA)

31										26	25						22	21	20	19	18	17	16
Reserved											Reserved							AID11	AID10	AID9	AID8	AID7	AID6
R-0											R-Fh							R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0								
AID5	AID4	AID3	AID2	AID1	AID0	AIDX	Rsvd	Rsvd	Rsvd	SR	SW	SX	UR	UW	UX								
R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R-0	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1								

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 6-14. Fixed Range Memory Protection Page Attributes Register (FXD_MPPA) Field Descriptions

Bit	Field	Value	Description
31-26	Reserved	0	Reserved
25-22	Reserved	Fh	Reserved
21-10	AID*n*		Controls access from ID = *n*.
		0	Access is denied.
		1	Access is granted.
9	AIDX		Controls access from ID > 11.
		0	Access is denied.
		1	Access is granted.
8	Reserved	0	Reserved
7	Reserved	1	Reserved. This bit must be written as 1.
6	Reserved	1	Reserved. This bit must be written as 1.
5	SR		Supervisor Read permission.
		0	Access is denied.
		1	Access is allowed.
4	SW		Supervisor Write permission.
		0	Access is denied.
		1	Access is allowed.
3	SX		Supervisor Execute permission.
		0	Access is denied.
		1	Access is allowed.
2	UR		User Read permission.
		0	Access is denied.
		1	Access is allowed.
1	UW		User Write permission.
		0	Access is denied.
		1	Access is allowed.
0	UX		User Execute permission.
		0	Access is denied.
		1	Access is allowed.

6.3.10 Programmable Range *n* Start Address Registers (PROG*n*_MPSAR)

NOTE: In some cases the amount of physical memory in actual use may be less than the maximum amount of memory supported by the device. For example, the device may support a total of 512 Mbytes of SDRAM memory, but your design may only populate 128 Mbytes. In such cases, the unpopulated memory range must be protected in order to prevent unintended/disallowed aliased access to protected memory, especially memory. One of the programmable address ranges could be used to detect accesses to this unpopulated memory.

The programmable range *n* start address register (PROG*n*_MPSAR) holds the start address for the range *n*. The PROG*n*_MPSAR is writeable by a supervisor entity only.

The start address must be aligned on a page boundary. The size of the page depends on the MPU: the page size for MPU1 is 1 kBbyte; the page size for MPU2 is 64 kBytes. The size of the page determines the width of the address field in PROG*n*_MPSAR and the programmable range *n* end address register (PROG*n*_MPEAR). For example, to protect a 64-kB page starting at byte address 8001 0000h, write 8001 0000h to PROG*n*_MPSAR and 8001 FFFFh to PROG*n*_MPEAR.

6.3.10.1 MPU1 Programmable Range *n* Start Address Register (PROG1_MPSAR-PROG6_MPSAR)

The PROG*n*_MPSAR for MPU1 is shown in Figure 6-12 and described in Table 6-15.

Figure 6-12. MPU1 Programmable Range *n* Start Address Register (PROG*n*_MPSAR)

31	10	9	0
START_ADDR		Reserved	
R/W-20 0000h		R-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 6-15. MPU1 Programmable Range *n* Start Address Register (PROG*n*_MPSAR) Field Descriptions

Bit	Field	Value	Description
31-10	START_ADDR	20 0000h–20 007Fh	Start address for range N.
9-0	Reserved	0	Reserved

6.3.10.2 MPU2 Programmable Range *n* Start Address Register (PROG1_MPSAR-PROG12_MPSAR)

The PROG*n*_MPSAR for MPU2 is shown in Figure 6-13 and described in Table 6-16.

Figure 6-13. MPU2 Programmable Range *n* Start Address Register (PROG*n*_MPSAR)

31	16	15	0
START_ADDR		Reserved	
R/W-C000h		R-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 6-16. MPU2 Programmable Range *n* Start Address Register (PROG*n*_MPSAR) Field Descriptions

Bit	Field	Value	Description
31-16	START_ADDR	C000h–DFFFh	Start address for range N.
15-0	Reserved	0	Reserved

6.3.11 Programmable Range *n* End Address Registers (PROG*n*_MPEAR)

The programmable range *n* end address register (PROG*n*_MPEAR) holds the end address for the range *n*. This register is writeable by a supervisor entity only.

The end address must be aligned on a page boundary. The size of the page depends on the MPU: the page size for MPU1 is 1 kByte; the page size for MPU2 is 64 kBytes. The size of the page determines the width of the address field in the programmable range *n* start address register (PROG*n*_MPSAR) and PROG*n*_MPEAR. For example, to protect a 64-kB page starting at byte address 8001 0000h, write 8001 0000h to PROG*n*_MPSAR and 8001 FFFFh to PROG*n*_MPEAR.

6.3.11.1 MPU1 Programmable Range *n* End Address Register (PROG1_MPEAR-PROG6_MPEAR)

The PROG*n*_MPEAR for MPU1 is shown in Figure 6-14 and described in Table 6-17.

Figure 6-14. MPU1 Programmable Range *n* End Address Register (PROG*n*_MPEAR)

31	10	9	0
END_ADDR		Reserved	
R/W-20 007Fh		R-3FFh	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 6-17. MPU1 Programmable Range *n* End Address Register (PROG*n*_MPEAR) Field Descriptions

Bit	Field	Value	Description
31-10	END_ADDR	20 0000h–20 007Fh	End address for range N.
9-0	Reserved	3FFh	Reserved

6.3.11.2 MPU2 Programmable Range *n* End Address Register (PROG1_MPEAR-PROG12_MPEAR)

The PROG*n*_MPEAR for MPU2 is shown in Figure 6-15 and described in Table 6-18.

Figure 6-15. MPU2 Programmable Range *n* End Address Register (PROG*n*_MPEAR)

31	16	15	0
END_ADDR		Reserved	
R/W-DFFFh		R-FFFFh	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 6-18. MPU2 Programmable Range *n* End Address Register (PROG*n*_MPEAR) Field Descriptions

Bit	Field	Value	Description
31-16	END_ADDR	C000h–DFFFh	Start address for range N.
15-0	Reserved	FFFFh	Reserved

6.3.12 Programmable Range *n* Memory Protection Page Attributes Register (PROG*n*_MPPA)

The programmable range *n* memory protection page attributes register (PROG*n*_MPPA) holds the permissions for the region *n*. This register is writeable only by a supervisor entity. The PROG*n*_MPPA is shown in Figure 6-16 and described in Table 6-19.

Figure 6-16. Programmable Range Memory Protection Page Attributes Register (PROG*n*_MPPA)

31										26	25						22	21	20	19	18	17	16
Reserved											Reserved							AID11	AID10	AID9	AID8	AID7	AID6
R-0											R-Fh							R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0								
AID5	AID4	AID3	AID2	AID1	AID0	AIDX	Rsvd	Rsvd	Rsvd	SR	SW	SX	UR	UW	UX								
R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R-0	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1								

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 6-19. Programmable Range Memory Protection Page Attributes Register (PROG*n*_MPPA) Field Descriptions

Bit	Field	Value	Description
31-26	Reserved	0	Reserved
25-22	Reserved	Fh	Reserved
21-10	AID*n*		Controls access from ID = *n*.
		0	Access is denied.
		1	Access is granted.
9	AIDX		Controls access from ID > 11.
		0	Access is denied.
		1	Access is granted.
8	Reserved	0	Reserved
7	Reserved	1	Reserved. This bit must be written as 1.
6	Reserved	1	Reserved. This bit must be written as 1.
5	SR		Supervisor Read permission.
		0	Access is denied.
		1	Access is allowed.
4	SW		Supervisor Write permission.
		0	Access is denied.
		1	Access is allowed.
3	SX		Supervisor Execute permission.
		0	Access is denied.
		1	Access is allowed.
2	UR		User Read permission.
		0	Access is denied.
		1	Access is allowed.
1	UW		User Write permission.
		0	Access is denied.
		1	Access is allowed.
0	UX		User Execute permission.
		0	Access is denied.
		1	Access is allowed.

6.3.13 Fault Address Register (FLTADDRR)

The fault address register (FLTADDRR) holds the address of the first protection fault transfer. The FLTADDRR is shown in Figure 6-17 and described in Table 6-20.

Figure 6-17. Fault Address Register (FLTADDRR)

31	0
FLTADDR	
R-0	

LEGEND: R = Read only; -*n* = value after reset

Table 6-20. Fault Address Register (FLTADDRR) Field Descriptions

Bit	Field	Value	Description
31-0	FLTADDR	0-FFFF FFFFh	Memory address of fault.

6.3.14 Fault Status Register (FLTSTAT)

The fault status register (FLTSTAT) holds the status and attributes of the first protection fault transfer. The FLTSTAT is shown in Figure 6-18 and described in Table 6-21.

Figure 6-18. Fault Status Register (FLTSTAT)

31	24	23	16
Reserved		MSTID	
R-0		R-0	

15	13	12	9	8	6	5	0
Reserved		PRIVID		Reserved		TYPE	
R-0		R-0		R-0		R-0	

LEGEND: R = Read only; -*n* = value after reset

Table 6-21. Fault Status Register (FLTSTAT) Field Descriptions

Bit	Field	Value	Description
31-24	Reserved	0	Reserved
23-16	MSTID	0-FFh	Master ID of fault transfer.
15-13	Reserved	0	Reserved
12-9	PRIVID	0-Fh	Privilege ID of fault transfer.
8-6	Reserved	0	Reserved
5-0	TYPE	0-3Fh	Fault type. The TYPE bit field is cleared when a 1 is written to the CLEAR bit in the fault clear register (FLTCLR).
		0	No fault.
		1h	User execute fault.
		2h	User write fault.
		3h	Reserved
		4h	User read fault.
		5h-7h	Reserved
		8h	Supervisor execute fault.
		9h-Fh	Reserved
		10h	Supervisor write fault.
		11h	Reserved
		12h	Relaxed cache write back fault.
		13h-1Fh	Reserved
		20h	Supervisor read fault.
		21h-3Eh	Reserved
		3Fh	Relaxed cache line fill fault.

6.3.15 Fault Clear Register (FLTCLR)

The fault clear register (FLTCLR) allows software to clear the current fault so that another can be captured in the fault status register (FLTSTAT) as well as produce an interrupt. Only the TYPE bit field in FLTSTAT is cleared when a 1 is written to the CLEAR bit. The FLTCLR is shown in Figure 6-19 and described in Table 6-22.

Figure 6-19. Fault Clear Register (FLTCLR)

31	16
Reserved	
R-0	

15	1	0
Reserved		CLEAR
R-0		W-0

LEGEND: R = Read only; W = Write only; -*n* = value after reset

Table 6-22. Fault Clear Register (FLTCLR) Field Descriptions

Bit	Field	Value	Description
31-1	Reserved	0	Reserved
0	CLEAR		Command to clear the current fault. Writing 0 has no effect.
		0	No effect.
		1	Clear the current fault.

Device Clocking

Topic **Page**

7.1 Overview

This device requires two primary reference clocks:

- One reference clock is required for the phase-locked loop controller (PLLC)
- One reference clock is required for the real-time clock (RTC) module.

These reference clocks may be sourced from either a crystal input or by an external oscillator. For detailed specifications on clock frequency and voltage requirements, see the device-specific data manual.

In addition to the reference clocks required for the PLLC and RTC module, some peripherals, such as the USB, may also require an input reference clock to be supplied. All possible input clocks are described in Table 7-1. The CPU and the majority of the device peripherals operate at fixed ratios of the primary system/CPU clock frequency, as listed in Table 7-2. However, there are three system clock domains that do not require a fixed ratio to the CPU clock frequency, these are SYSCLK3, SYSCLK5, and SYSCLK7. Figure 7-1 shows the clocking architecture.

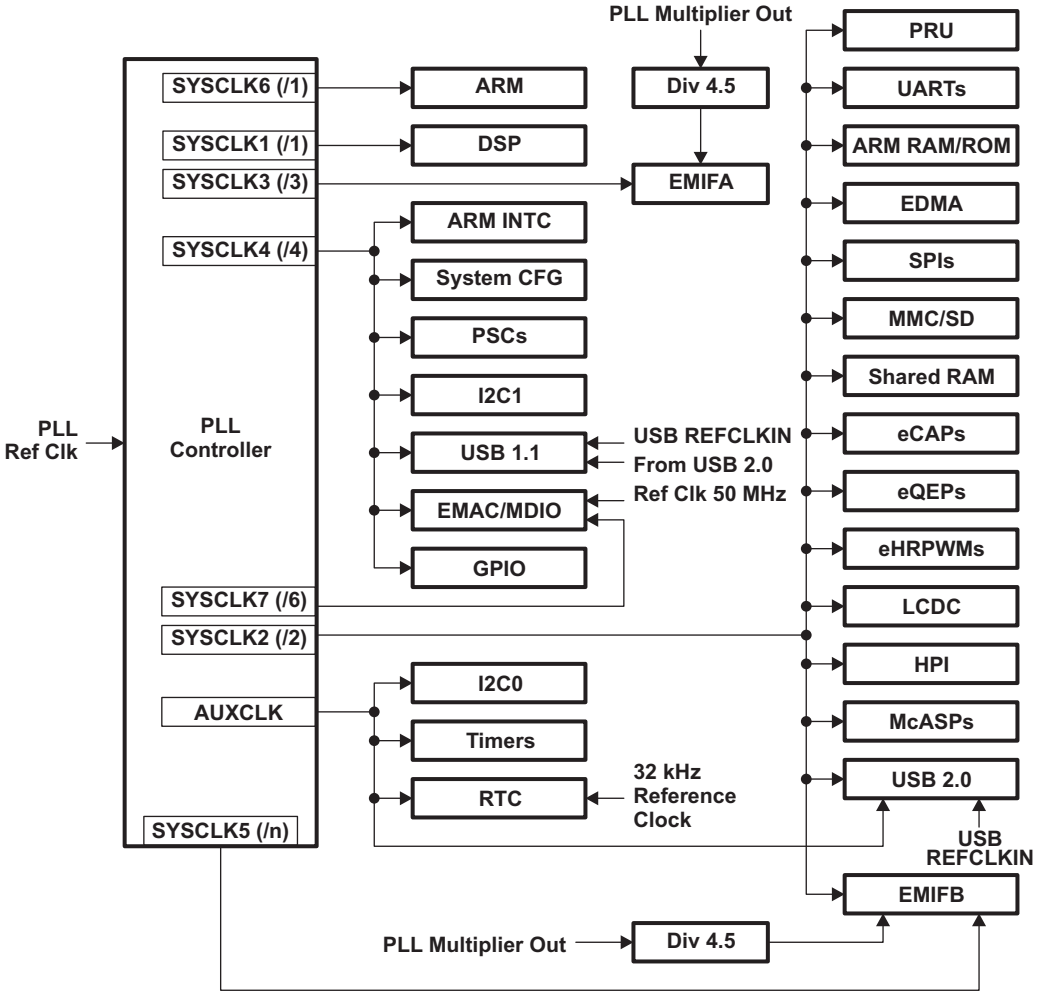
Table 7-1. Device Clock Inputs

Peripheral	Input Clock Signal Name
Oscillator/PLL	OSCIN
RTC	RTC_XI
JTAG	TCK, RTCK
EMAC	RMII_MHZ_50_CLK
USB2.0 and USB1.1	USB_REFCLKIN
McASPs	ACLKRn, AHCLKRn, ACLKXn, AHCLKXn
I2Cs	I2Cn_SCL
SPIs	SPIn_CLK
Timer0	TM64P0_IN12

Table 7-2. System Clock Domains

CPU/Device Peripherals	System Clock Domain	Fixed Ratio to CPU Clock Required?	Default Ratio to CPU Clock
DSP	SYSCLK1	Yes	1:1
PRU, UARTs, EDMA, SPIs, MMC/SD, Shared RAM, eCAPs, eQEPs, eHRPWMs, LCDC, HPI, McASPs, USB2.0, ARM RAM/ROM, EMIFB	SYSCLK2	Yes	1:2
EMIFA	SYSCLK3	No	1:3
ARM INTC, SYSCFG, PSCs, I2C1, USB1.1, EMAC/MDIO, GPIO	SYSCLK4	Yes	1:4
EMIFB I/O Clock	SYSCLK5	No	1:3
ARM	SYSCLK6	Yes	1:1
EMAC	SYSCLK7	No	1:6
I2C0, Timers, McASP serial clock , RTC, USB2.0	AUXCLK	Not Applicable	PLL Bypass Clock

Figure 7-1. Overall Clocking Diagram



7.2 Frequency Flexibility

There are two clocking modes:

- PLL Bypass that can serve as a power savings mode
- PLL Active where the PLL is enabled and multiplies the input clock up to the desired operating frequency

When the PLL is in Bypass mode, the reference clock supplied on OSCIN serves as the clock source from which all of the system clocks (SYSCLK1-SYSCLK7) are derived. This means, when the PLL is in Bypass mode, the reference clock supplied on OSCIN passes directly to the system of PLLDIV blocks that creates each of the system clocks. When the PLL operates in Active mode, the PLL is enabled and the PLL multiplier setting is used to multiply the input clock frequency supplied on the OSCIN pin up to the desired frequency. It is this multiplied frequency that all system clocks are derived from in PLL Active mode.

The output of the PLL multiplier passes through a post divider (POSTDIV) block and then is applied to the system of PLLDIV blocks that creates each of the system clock domains (SYSCLK1-SYSCLK7). Each SYSCLK has a PLLDIV block associated with it. See the *Phase-Locked Loop Controller (PLLC)* chapter for more details on the PLL.

The combination of the PLL multiplier, POSTDIV, and PLLDIV blocks provides flexibility in the frequencies that the system clock domains support. This flexibility does have limitations, as follows:

- OSCIN input frequency is limited to a supported range.
- The output of the PLL Multiplier must be within the range specified in the device-specific data manual.
- The output of each PLLDIV block must be less than or equal to the maximum device frequency specified in the device-specific data manual.

NOTE: The above limitations are provided here as an example and are used to illustrate the recommended configuration of the PLL controller. These limitations may vary based on core voltage and between devices. See the device-specific data manual for more details.

Table 7-3 shows examples of possible PLL multiplier settings, along with the available PLL post-divider modes. The PLL post-divider modes are defined by the value programmed in the RATIO field of the PLL post-divider control register (POSTDIV). For Div1, Div2, Div3, and Div4 modes, the RATIO field would be programmed to 0, 1, 2, and 3, respectively. The Div1, Div2, Div3, and Div4 modes are shown here as an example. Additional post-divider modes are supported and are documented in the *Phase-Locked Loop Controller (PLLC)* chapter.

NOTE: PLL power consumption increases as the output frequency of the PLL multiplier increases. To decrease PLL power consumption, the lowest PLL multiplier (PLLM) setting should be chosen that achieves the desired frequency. For example, if 200 MHz is the desired CPU operating frequency and the OSCIN frequency is 25 MHz; lower power consumption is achieved by choosing a PLLM setting of ×16 and a post-divider (POSTDIV) setting of /2 instead of a PLLM setting of ×24 and a POSTDIV setting of /3, even though both of these modes would result in a CPU frequency of 200 MHz.

Table 7-3. Example PLL Frequencies

OSCIN Frequency	PLL Multiplier	Multiplier Frequency (MHz)	Div1	Div2	Div3	Div4
20	30	600	600	300	200	150
24	25	600	600	300	200	150
25	24	600	600	300	200	150
30	20	600	600	300	200	150
20	25	500	500	250	167	125
24	20	480	480	240	160	120
25	18	450	450	225	150	112.5
30	14	420	420	210	140	105
25	16	400	400	200	133	100

7.3 Peripheral Clocking

7.3.1 USB Clocking

Figure 7-2 displays the clock connections for the USB2.0 module. The USB2.0 subsystem requires a reference clock for its internal PLL. This reference clock can be sourced from either the USB_REFCLKIN pin or from the AUXCLK of the system PLL. The reference clock input to the USB2.0 subsystem is selected by programming the USB0PHYCLKMUX bit in the chip configuration 2 register (CFGCHIP2) of the System Configuration Module. The USB_REFCLKIN source should be selected when it is not possible (such as when specific audio rates are required) to operate the device at one of the allowed input frequencies to the USB2.0 subsystem. The USB2.0 subsystem peripheral bus clock is sourced from SYSCLK2.

The USB1.1 subsystem requires both a 48 MHz (CLK48) and a 12 MHz (CLK12) clock input. The 12 MHz clock is derived from the 48 MHz clock. The 48 MHz clock required by the USB1.1 subsystem can be sourced from either the USB_REFCLKIN or from the 48 MHz clock provided by the USB2.0 PHY. The CLK48 source is selected by programming the USB1PHYCLKMUX bit in CFGCHIP2 of the System Configuration Module. The USB1.1 subsystem peripheral bus clock is sourced from SYSCLK4. See Table 7-4.

NOTE: If the USB1.1 subsystem is used and the 48 MHz clock input is sourced from the USB2.0 PHY, then the USB2.0 must be configured to always generate the 48 MHz clock. The USB0PHY_PLLON bit in CFGCHIP2 controls the USB2.0 PHY, allowing or preventing it from stopping the 48 MHz clock during USB SUSPEND. When the USB0PHY_PLLON bit is set to 1, the USB2.0 PHY is prevented from stopping the 48 MHz clock during USB SUSPEND; when the USB0PHY_PLLON bit is cleared to 0, the USB2.0 PHY is allowed to stop the 48 MHz clock during USB SUSPEND.

Figure 7-2. USB Clocking Diagram

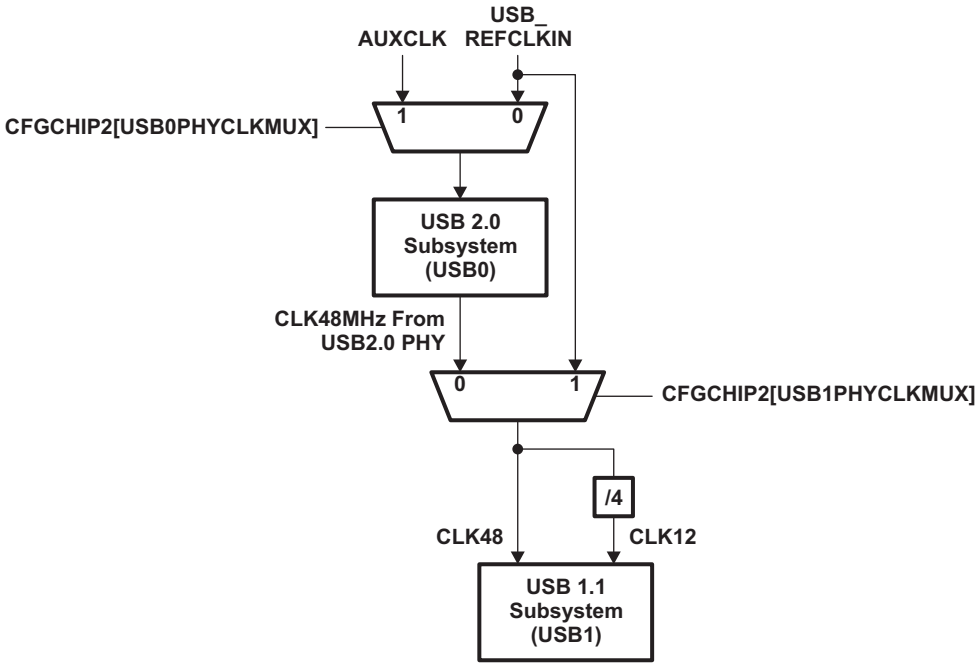


Table 7-4. USB Clock Multiplexing Options

CFGCHIP2. USB0PHYCLKMUX bit	CFGCHIP2. USB1PHYCLKMUX bit	USB2.0 Clock Source	USB1.1 Clock Source	Additional Conditions
0	0	USB_REFCLKIN	CLK48MHZ output from USB2.0 PHY	USB_REFCLKIN must be 12, 24, 48, 19.2, 38.4, 13, 26, 20, or 40 MHz. The PLL inside the USB2.0 PHY can be configured to accept any of these input clock frequencies.
0	1	USB_REFCLKIN	USB_REFCLKIN	USB_REFCLKIN must be 48 MHz. The PLL inside the USB2.0 PHY can be configured to accept this input clock frequency.
1	0	PLL0_AUXCLK	CLK48MHZ output from USB2.0 PHY	PLL0_AUXCLK must be 12, 24, 48, 19.2, 38.4, 13, 26, 20, or 40 MHz. The PLL inside the USB2.0 PHY can be configured to accept any of these input clock frequencies.
1	1	PLL0_AUXCLK	USB_REFCLKIN	PLL0_AUXCLK must be 12, 24, 48, 19.2, 38.4, 13, 26, 20, or 40 MHz. The PLL inside the USB2.0 PHY can be configured to accept any of these input clock frequencies. USB_REFCLKIN must be 48 MHz.

7.3.2 EMIFB Clocking

The EMIFB requires two input clocks to source VCLK and MCLK (see Figure 7-3):

- VCLK is sourced from SYSCLK2 that clocks the peripheral bus interface of EMIFB
- MCLK, which sets the clock rate for the I/O clock (EMB_CLK), is sourced from either SYSCLK5 or DIV4P5. The EMB_CLKSRC bit in the chip configuration 3 register (CFGCHIP3) of the System Configuration Module controls whether SYSCLK5 or DIV4P5 is selected as the clock source for MCLK.

Selecting the appropriate clock source for MCLK is determined by the desired clock rate of the memory clock, EMB_CLK. Table 7-5 shows example PLL register settings and the resulting DIV4P5 and SYSCLK5 frequencies based on the OSCIN reference clock frequency of 25 MHz. From these example configurations, the following observations can be made:

- To achieve the maximum frequency (133 MHz) supported by EMIFB and the typical CPU frequency of 300 MHz, the output of the PLL multiplier should be set to be 600 MHz and the EMB_CLK source should be set to DIV4P5.
- The frequency of the DIV4P5 clock is fixed at the output frequency of the PLL multiplier block divided by 4.5.
- The PLLDIV5 block that sets the divider ratio for SYSCLK5 can be changed to achieve various clock frequencies.
- For certain PLL multiplier and PLL post-divider control register (POSTDIV) settings, a higher clock frequency can be achieved by selecting SYSCLK5 as the clock source for MCLK.

As shown in Figure 7-3, the EMIFB output clock, EMB_CLK, can be sourced from either the output of the EMIFB LPSC (CLK1 in Figure 7-3) or directly from the output of the clock multiplexer selecting either DIV4P5 or SYSCLK5 (CLK2 in Figure 7-3). The PINMUX0_15_12 bits in the pin multiplexing control 0 register (PINMUX0) of the SCM control this clock selection.

The purpose in providing two clock sources for EMB_CLK is to support the ability to generate a free running clock that could be used by an FPGA or for some other purpose. The difference between CLK1 and CLK2 is that if LPSC #6 is configured to clock gate the EMIFB, then CLK1 will also be clock gated, but CLK2 will not be clock gated. Therefore, if EMIFB is being used to interface to an SDRAM memory, it is best practice to choose CLK1 as the source for EMB_CLK. This will allow the maximum power savings when the LPSC is used to clock gate the EMIFB clock. If EMIFB is not in use and the EMB_CLK is used in the application as a free running clock, then CLK2 should be used as the source for EMB_CLK. This will allow clock gating of the majority of the logic in EMIFB via the LPSC while still providing a clock on the EMB_CLK.

NOTE: EMB_CLK is only an output clock. EMIFB does not support an externally provided input clock.

Figure 7-3. EMIFB Clocking Diagram

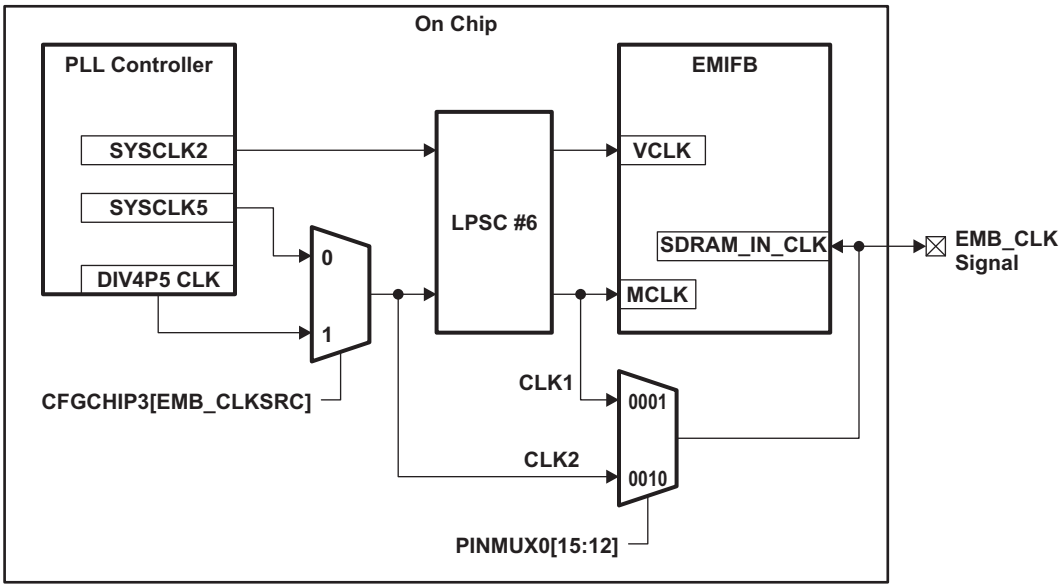


Table 7-5. EMIFB MCLK Frequencies

OSCIN Frequency	PLL Multiplier Register Setting	Multiplier Frequency (MHz)	Post Divider Mode [(1)]	POSTDIV Output Frequency	DIV4P5	PLLDIV5 Register Setting	SYSCLK5
25	24	600	Div2	300 MHz	133 MHz	2	100 MHz
			Div3	200 MHz	133 MHz	2	66.6 MHz
						1	100 MHz
			Div4	150 MHz	133 MHz	1	75 MHz
25	18	450	Div2	225 MHz	100 MHz	2	75 MHz
						1	112.5 MHz
			Div3	150 MHz	100 MHz	1	75 MHz
			Div4	112.5 MHz	100 MHz	1	56.3 MHz
						0	112.5 MHz
25	16	400	Div2	200 MHz	89 MHz	2	66.6 MHz
						1	100 MHz
			Div3	133 MHz	89 MHz	0	133 MHz
			Div4	100 MHz	89 MHz	0	133 MHz

(1) See Section 7.2 for an explanation of POSTDIV divider modes.

7.3.3 EMIFA Clocking

EMIFA requires a single input clock source. The EMIFA clock can be sourced from either SYSCLK3 or DIV4P5 (see Figure 7-4). The EMA_CLKSRC bit in the chip configuration 3 register (CFGCHIP3) of the System Configuration Module controls whether SYSCLK3 or DIV4P5 is selected as the clock source for EMIFA.

Selecting the appropriate clock source for EMIFA is determined by the desired clock rate. Table 7-6 shows example PLL register settings and the resulting DIV4P5 and SYSCLK3 frequencies based on the OSCIN reference clock frequency of 25 MHz. From these example configurations, the following observations can be made:

- To achieve a typical frequency of 100 MHz supported by EMIFA and the typical CPU frequency of 300 MHz, the output of the PLL multiplier should be set to 600 MHz and the EMA_CLK source should be set to SYSCLK3 with the PLLDIV3 register set to 3.
- The frequency of the DIV4P5 clock is fixed at the output frequency of the PLL multiplier block divided by 4.5.
- The PLLDIV3 block that sets the divider ratio for SYSCLK3 can be changed to achieve various clock frequencies.

Figure 7-4. EMIFA Clocking Diagram

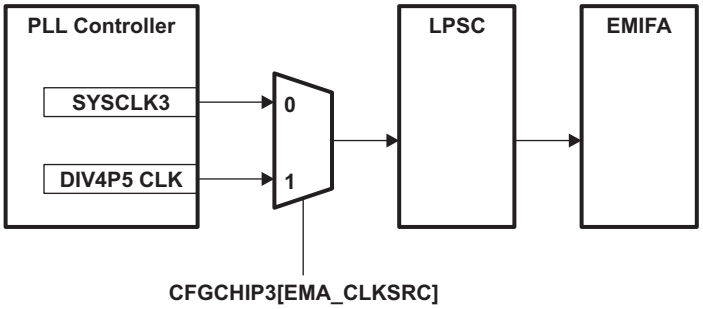


Table 7-6. EMIFA Frequencies

OSCIN Frequency	PLL Multiplier Register Setting	Multiplier Frequency (MHz)	Post Divider Mode [1]	POSTDIV Output Frequency	DIV4P5	PLLDIV3 Register Setting	SYSCLK3
25	24	600	Div2	300 MHz	133 MHz	2	100 MHz
			Div3	200 MHz	133 MHz	2	66.6 MHz
						1	100 MHz
			Div4	150 MHz	133 MHz	1	75 MHz
25	18	450	Div2	225 MHz	100 MHz	3	56.3 MHz
						2	75 MHz
			Div3	150 MHz	100 MHz	1	75 MHz
			Div4	112.5 MHz	100 MHz	1	56.3 MHz
						0	112.5 MHz
25	16	400	Div2	200 MHz	89 MHz	2	66.6 MHz
						1	100 MHz
			Div3	133 MHz	89 MHz	1	66.5 MHz
			Div4	100 MHz	89 MHz	0	100 MHz

[1] See Section 7.2 for explanation of POSTDIV divider modes.

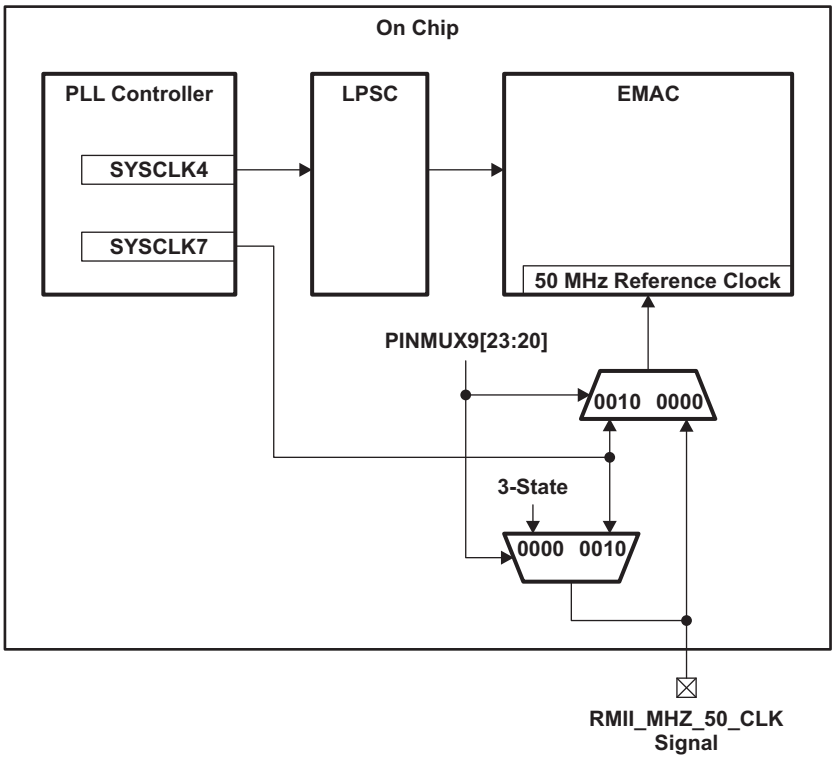
7.3.4 EMAC Clocking

The EMAC module sources its peripheral bus interface reference clock from SYSCLK4 that is at a fixed ratio of the CPU clock. The external clock requirement for EMAC varies with the interface used. When the MII interface is active, the MII_TXCLK and MII_RXCLK signals must be provided from an external source. When the RMII interface is active, the RMII 50 MHz reference clock is sourced either from an external clock on the RMII_MHZ_50_CLK pin or from SYSCLK7 (as shown in Figure 7-5). The PINMUX9_23_20 bits in the pin multiplexing control 9 register (PINMUX9) of the System Configuration Module control this clock selection:

- PINMUX9_23_20 = 0: enables sourcing of the 50 MHz reference clock from an external source on the RMII_MHZ_50_CLK pin.
- PINMUX9_23_20 = 2h: enables sourcing of the 50 MHz reference clock from SYSCLK7. Also, SYSCLK7 is driven out on the RMII_MHZ_50_CLK pin.

Table 7-7 shows example PLL register settings and the resulting SYSCLK7 frequencies based on the OSCIN reference clock frequency of 25 MHz.

Figure 7-5. EMAC Clocking Diagram



NOTE: The SYSCLK7 output clock does not meet the RMII reference clock specification of 50 MHz +/-50 ppm.

Table 7-7. EMAC Reference Clock Frequencies

OSCIN Frequency	PLL Multiplier Register Setting	Multiplier Frequency (MHz)	Post Divider Mode [1]	POSTDIV Output Frequency	PLLDIV7 Register Setting	SYSCLK7
25	24	600	Div2	300 MHz	5	50 MHz
			Div3	200 MHz	3	50 MHz
			Div4	150 MHz	2	50 MHz
25	18	450	Div2	225 MHz		Not Applicable[2]
			Div3	150 MHz	2	50 MHz
			Div4	112.5 MHz		Not Applicable[2]

(1) See Section 7.2 for explanation of POSTDIV divider modes.
(2) Certain PLL configurations do not support a 50 MHz clock on SYSCLK7.

7.3.5 I/O Domains

The I/O domains refer to the frequencies of the peripherals that communicate through device pins. In many cases, there are frequency requirements for a peripheral pin interface that are set by an outside standard and must be met. It is not necessarily possible to obtain these frequencies from the on-chip clock generation circuitry, so the frequencies must be obtained from external sources and are asynchronous to the CPU frequency by definition.

Peripherals can be divided into 4 groups, depending upon their clock requirements, as shown in Table 7-8.

Table 7-8. Peripherals

Peripheral Group	Peripheral Group Definition	Peripherals Contained within Group	Source of Peripheral Clock
RTC	Operates off of a dedicated 32 kHz crystal oscillator.	RTC	—
Fixed-Frequency Peripherals	As the name suggests, fixed-frequency peripherals have a fixed-frequency. They are fed the AUXCLK directly from the oscillator input.	Timers	—
		I2C0	—
Synchronous Peripherals	Synchronous peripherals have their frequencies derived from the CPU clock frequency. The peripheral system clock frequency changes accordingly, if the PLL1 frequency changes. Most synchronous peripherals have internal dividers so they can generate their required clock frequencies.	eCAP	—
		eQEP	—
		eHRPWM	—
		MMC/SD	—
		UARTs	—
		GPIO	—
		HPI	—
		LCDC	—
Asynchronous Peripherals	Asynchronous peripherals are not required to operate at a fixed ratio of the CPU clock.	EMIFA	DIV4P5 or SYSCLK3
		EMIFB	DIV4P4 or SYSCLK5
Synchronous/Asynchronous Peripherals	Synchronous/asynchronous peripherals can be run with either internally generated synchronous clocks, or externally generated asynchronous clocks.	McASPs	AUXCLK or Peripheral Serial Clocks
		SPIs	SYSCLK2 or Peripheral Serial Clock
		I2C1	SYSCLK4 or Peripheral Serial Clock
		USB	USB_REF_CLK or AUXCLK
		EMAC	SYSCLK7 or RMII_MHZ_50_CLK

Phase-Locked Loop Controller (PLLC)

Topic **Page**

8.1 Introduction

This device has one phase-locked loop (PLL) controller, PLL0, that provides a clock to different parts of the system. PLL0 provides clocks (through various dividers) to most of the components of the device.

The PLL0 provides the following:

- Glitch-Free Transitions (on changing clock settings)
- Domain Clocks Alignment
- Clock Gating
- PLL power-down

The various clock outputs given by the controller are as follows:

- Domain Clocks: SYSCLK [1:n]
- Auxiliary Clock from reference clock source: AUXCLK

Various dividers that can be used are as follows:

- Pre-PLL Divider: PREDIV
- Post-PLL Divider: POSTDIV
- SYSCLK Divider: D1, …, Dn

Various other controls supported are as follows:

- PLL Multiplier Control: PLLM
- Software programmable PLL Bypass: PLLEN

8.2 PLL0 Control

PLL0 supplies the primary system clock. Software controls the PLL0 operation through the system PLL controller 0 (PLLC0) registers. Figure 8-1 shows the PLL0 in the device.

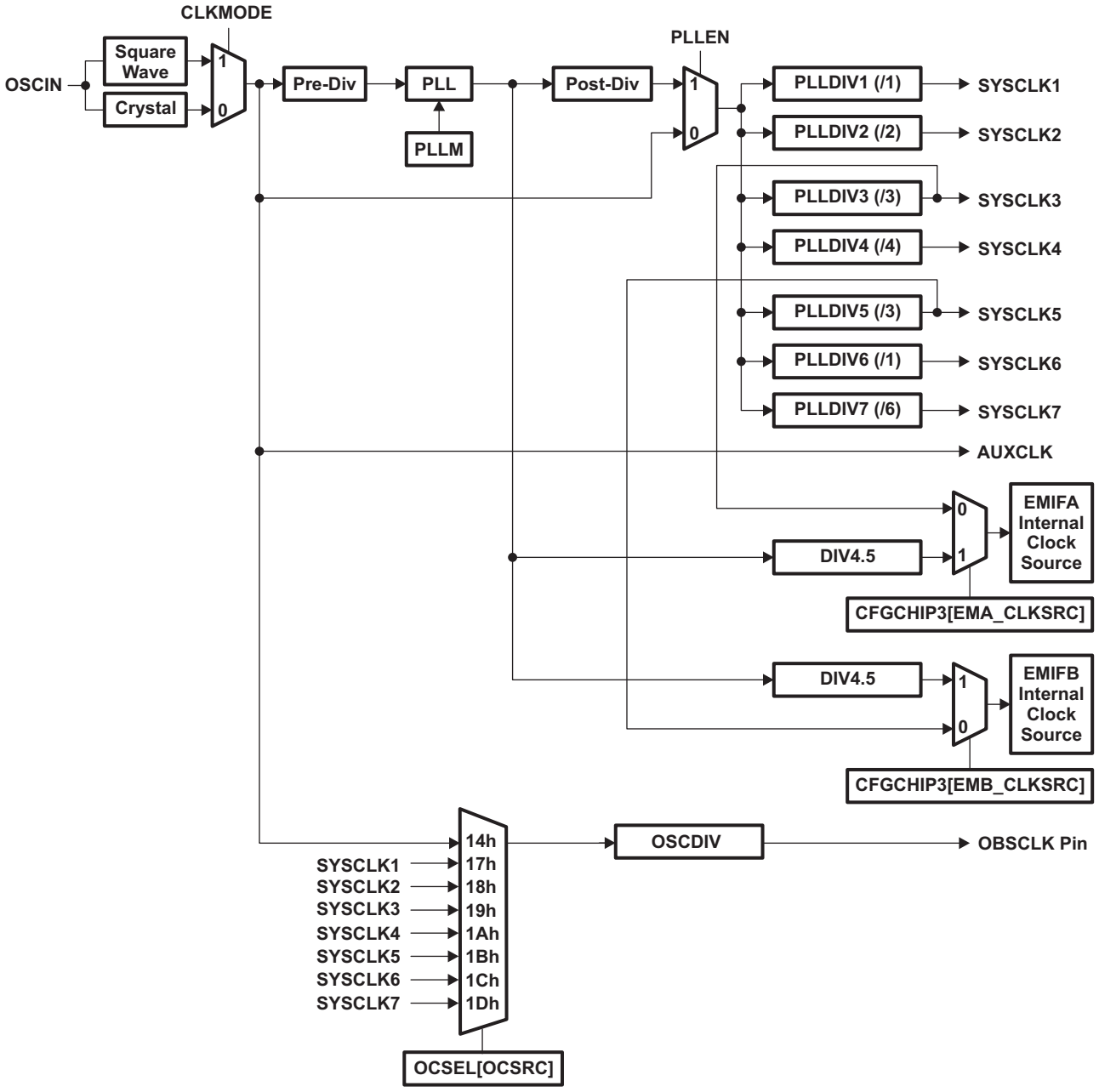
AUXCLK is the clock provided to the fixed clock domain.

The PLL0 multiplier is controlled by the PLLM bits in the PLL multiplier control register (PLLM) and is set to a default value of 0000 0013h at power-up, resulting in a PLL multiplier of 20×. The PLL0 output clock may be divided-down for slower device operation using the PLLC0 post-divider. This divider defaults to a /2 value, but may be modified by software (RATIO bit in POSTDIV) to achieve lower power device operation. These default settings yield a 300-MHz PLL output clock when using a 30-MHz clock source. The PLL0 multiplier may be modified by software.

At power-up, PLL0 is powered-down/disabled and must be powered-up by software through the PLLPWRDN bit in the PLL control register (PLLCTL). The system operates in bypass mode by default and the system clock (OSCIN) is provided directly from an input reference clock (square wave or internal oscillator) selected by the CLKMODE bit in PLLCTL. Once the PLL is powered-up and locked, software can switch the device to PLL mode operation (set the PLLEN bit in PLLCTL to 1).

Registers used in PLLC0 are listed in Section 8.4.

Figure 8-1. PLL0 Structure



8.2.1 Device Clock Generation

PLL0 is controlled by PLL controller 0. The PLLC0 manages the clock ratios, alignment, and gating for the system clocks to the chip. The PLLC is responsible for controlling all modes of the PLL through software, in terms of pre-division of the clock inputs, multiply factor within the PLL, and post-division for each of the chip-level clocks from the PLL output. The PLLC also controls reset propagation through the chip, clock alignment, and test points.

PLLC0 generates several clocks from the PLL0 output clock for use by the various processors and modules. These are summarized in Table 8-1. The output clock divider values SYSCLK1 to SYSCLK*n* are fixed. This maintains the clock ratios between the various device components no matter what reference clock (PLL or bypass) or PLL frequency is used.

Table 8-1. System PLLC0 Output Clocks

Output Clock	Used by	Default Ratio (relative to SYSCLK1)	Notes
SYSCLK1	DSP	/1	Fixed Ratio
SYSCLK2	ARM RAM/ROM, EDMA, DSP ports, EMIFB (bus ports), eCAPs, eHRPWMs, eQEPs, Shared RAM, LCDC, McASPs, SPIs, MMC/SD, HPI, USB2.0, UARTs, PRU	/2	Fixed Ratio
SYSCLK3	EMIFA	/3	No Required Ratio
SYSCLK4	System configuration (SYSCFG), AINTC, PLLC0, PSCs, EMAC/MDIO, GPIO, I2C1, USB1.1	/4	Fixed Ratio
SYSCLK5	EMIFB	/3	No Required Ratio
SYSCLK6	ARM	/1	Fixed Ratio
SYSCLK7	RMII clock to EMAC	/6	No Required Ratio
AUXCLK	McASP serial clock, Timers, I2C0, RTC, USB2.0	PLL Bypass Clock	Not Applicable
OBSCLK	Observation clock (OBSCLK) source	Pin configurable	Not Applicable

- The divide values in PLL controller 0 for SYSCLK1/SYSCLK6, SYSCLK2, and SYSCLK4 are not fixed so that you can change the divide values for power saving reasons. But you are responsible to assure that the divide ratios between these clock domains must be fixed to 1:2:4.
- PLL controller supports post-divider value n = 4.5. When 4.5 divide values are used, the duty cycle of the resulting clock will not be 50%. In this case, the duty cycle will be 44.4%. For EMIF clock generation, see the next note.
- The DIV4P5 (/4.5) hardware clock divider is provided to generate 133 MHz from the 600 MHz PLL clock for use as clocks to the EMIFs. See Figure 8-1.

8.2.2 Steps for Changing PLL0 Domain Frequency

Refer to the appropriate subsection on how to program the PLL0/Core Domain clocks:

- If the PLL is powered down (PLLPWRDN bit in PLLCTL is set to 1), follow the full PLL initialization procedure in Section 8.2.2.1 to initialize the PLL.
- If the PLL is not powered down (PLLPWRDN bit in PLLCTL is cleared to 0), follow the sequence in Section 8.2.2.2 to change the PLL multiplier.
- If the PLL is already running at a desired multiplier and you only want to change the SYSCLK dividers, follow the sequence in Section 8.2.2.3.

Note that the PLL is powered down after a Power-on Reset (POR). The PLL is not powered down after a Warm Reset (RESET), but the PLLEN bit in PLLCTL is cleared to 0 (bypass mode) and the PLLDIVx registers are reset to default values.

8.2.2.1 Initializing PLL Mode from PLL Power Down

If the PLL is powered down (PLLPWRDN bit in PLLCTL is set to 1), perform the following procedure to initialize the PLL:

1. Clear the PLLEN bit in PLLCTL to 0 (select PLL Bypass mode) and reset the PLL by clearing PLLRST bit in PLLCTL. Wait for 4 OSCIN cycles to ensure PLLC switches to bypass mode properly.
2. Select the clock mode by programming the CLKMODE bit in PLLCTL.
   (a) Clear the PLLENSRC bit in PLLCTL to 0 to allow PLLCTL.PLLEN to take effect.
   (b) PLLCTL.EXTCLKSRC should be left to 0.
3. Clear the PLLRST bit in PLLCTL to 0 (reset PLL).
4. Clear the PLLPWRDN bit in PLLCTL to 0 to bring the PLL out of power-down mode.
5. Program the required multiplier value in PLLM. If desired to scale all the SYSCLK frequencies of a given PLLC, program the POSTDIV ratio.
6. If necessary, program PLLDIVn registers to change the SYSCLK0 to SYSCLKn divide values:
   (a) Check for GOSTAT bit in PLLSTAT to clear to 0 to indicate that no GO operation is currently in progress.
   (b) Program the RATIO field in PLLDIVx with the desired divide factors.
   (c) Set the GOSET bit in PLLCMD to 1 to initiate a new divider transition.
   (d) Wait for the GOSTAT bit in PLLSTAT to clear to 0 (completion of phase alignment).
7. Set the PLLRST bit in PLLCTL to 1 to bring the PLL out of reset.
8. Wait for PLL to lock. See the device-specific data manual for PLL lock time.
9. Set the PLLEN bit in PLLCTL to 1 to remove the PLL from bypass mode.

8.2.2.2 Changing PLL Multiplier

If the PLL is not powered down (PLLPWRDN bit in PLLCTL is cleared to 0), perform the following procedure to change PLL0 multiplier.

1. Before changing the PLL frequency, switch to PLL bypass mode:
   (a) Clear the PLLENSRC bit in PLLCTL to 0 to allow PLLCTL.PLLEN to take effect.
   (b) Clear the PLLEN bit in PLLCTL to 0 (select PLL bypass mode).
   (c) Wait for 4 OSCIN cycles to ensure PLLC switches to bypass mode properly.
2. Clear the PLLRST bit in PLLCTL to 0 (reset PLL).
3. Program the required multiplier value in PLLM. If desired to scale all the SYSCLK frequencies of a given PLLC, program the POSTDIV ratio.
4. If necessary, program PLLDIVn registers to change the SYSCLKn divide values:
   (a) Program the RATIO field in PLLDIVn with the desired divide factors.
   (b) Set the GOSET bit in PLLCMD to 1 to initiate a new divider transition.
   (c) Wait for the GOSTAT bit in PLLSTAT to clear to 0 (completion of phase alignment).
5. Set the PLLRST bit in PLLCTL to 1 to bring the PLL out of reset.
6. Wait for PLL to lock. See the device-specific data manual for PLL lock time.
7. Set the PLLEN bit in PLLCTL to 1 to remove the PLL from bypass mode.

8.2.2.3 Changing SYSCLK Dividers

This section discusses the software sequence to change the SYSCLK dividers. The SYSCLK divider change sequence is also referred to as GO operation, as it involves hitting the GO bit (GOSET bit in PLLCMD) to initiate the divider change.

1. Check for the GOSTAT bit in PLLSTAT to clear to 0 to indicate that no GO operation is currently in progress.
2. Program the RATIO field in PLLDIVn with the desired divide factors.
3. Set the GOSET bit in PLLCMD to 1 to initiate a new divider transition.
4. Wait for the GOSTAT bit in PLLSTAT to clear to 0 (completion of divider change).

8.3 Locking/Unlocking PLL Register Access

A lock mechanism is present on the device that can prevent inadvertent reconfiguration of the PLLC registers. This primarily provides protection for the watchdog timer that runs on the AUXCLK output of PLL0. The PLL has a bit that is capable of disabling AUXCLK and therefore capable of stopping the watchdog timer.

To prevent this, when the PLL_MASTER_LOCK bit of the chip configuration 0 register (CFGCHIP0) in the System Configuration Module is set, writes to any PLLC registers are locked. The PLL_MASTER_LOCK bit is protected as type "Priv" and it is also protected by the Kick0 and Kick1 registers in the System Configuration Module. The master writing to the Kick0/Kick1/CFGCHIP0 registers needs to have appropriate privilege, and write the correct key values to the Kick0 and Kick 1 registers before writing to the PLLC registers. See the *System Configuration (SYSCFG) Module* chapter for information on privilege type and the Kick0 and Kick1 registers.

To modify the PLLC registers, use the following sequence:

1. Write the correct key values to Kick0 and Kick1 registers.
2. Clear the PLL_MASTER_LOCK bit in CFGCHIP0.
3. Configure the desired PLLC register values.
4. Write an incorrect key value to the Kick registers.

NOTE: The PLL_MASTER_LOCK bit in CFGCHIP0 defaults to unlocked after reset, so the above procedure is only required after the PLL_MASTER_LOCK bit has been locked (set to 1).

8.4 PLLC Registers

Table 8-2 lists the memory-mapped registers for the PLLC.

Table 8-2. PLL Controller (PLLC) Registers

Address	Acronym	Register Description	Section
01C1 1000h	REVID	Revision Identification Register	Section 8.4.1
01C1 10E4h	RSTYPE	Reset Type Status Register	Section 8.4.2
01C1 1100h	PLLCTL	PLL Control Register	Section 8.4.3
01C1 1104h	OCSEL	OBSCLK Select Register	Section 8.4.4
01C1 1110h	PLLM	PLL Multiplier Control Register	Section 8.4.5
01C1 1114h	PREDIV	PLL Pre-Divider Control Register	Section 8.4.6
01C1 1118h	PLLDIV1	PLL Controller Divider 1 Register	Section 8.4.7
01C1 111Ch	PLLDIV2	PLL Controller Divider 2 Register	Section 8.4.8
01C1 1120h	PLLDIV3	PLL Controller Divider 3 Register	Section 8.4.9
01C1 1124h	OSCDIV	Oscillator Divider 1 Register (OBSCLK)	Section 8.4.14
01C1 1128h	POSTDIV	PLL Post-Divider Control Register	Section 8.4.15
01C1 1138h	PLLCMD	PLL Controller Command Register	Section 8.4.16
01C1 113Ch	PLLSTAT	PLL Controller Status Register	Section 8.4.17
01C1 1140h	ALNCTL	PLL Controller Clock Align Control Register	Section 8.4.18
01C1 1144h	DCHANGE	PLLDIV Ratio Change Status Register	Section 8.4.19
01C1 1148h	CKEN	Clock Enable Control Register	Section 8.4.20
01C1 114Ch	CKSTAT	Clock Status Register	Section 8.4.21
01C1 1150h	SYSTAT	SYSCLK Status Register	Section 8.4.22
01C1 1160h	PLLDIV4	PLL Controller Divider 4 Register	Section 8.4.10
01C1 1164h	PLLDIV5	PLL Controller Divider 5 Register	Section 8.4.11
01C1 1168h	PLLDIV6	PLL Controller Divider 6 Register	Section 8.4.12
01C1 116Ch	PLLDIV7	PLL Controller Divider 7 Register	Section 8.4.13
01C1 11F0h	EMUCNT0	Emulation Performance Counter 0 Register	Section 8.4.23
01C1 11F4h	EMUCNT1	Emulation Performance Counter 1 Register	Section 8.4.24

8.4.1 Revision Identification Register (REVID)

The revision identification register (REVID) is shown in Figure 8-2 and described in Table 8-3.

Figure 8-2. Revision Identification Register (REVID)

31	0
REV	
R-4481 3C00h	

LEGEND: R = Read only; -*n* = value after reset

Table 8-3. Revision Identification Register (REVID) Field Descriptions

Bit	Field	Value	Description
31-0	REV	4481 3C00h	Peripheral revision ID.

8.4.2 Reset Type Status Register (RSTYPE)

The reset type status register (RSTYPE) is shown in Figure 8-3 and described in Table 8-4. RSTYPE latches the cause of the last reset. If multiple reset sources are asserted simultaneously, RSTYPE records the reset source that deasserts last. If multiple reset sources are asserted and deasserted simultaneously, RSTYPE latches the highest priority reset source.

Figure 8-3. Reset Type Status Register (RSTYPE)

31	16
Reserved	
R-0	

15	3	2	1	0
Reserved		PLLSWRST	XWRST	POR
R-0		R-0	R-0	R-0

LEGEND: R = Read only; -*n* = value after reset

Table 8-4. Reset Type Status Register (RSTYPE) Field Descriptions

Bit	Field	Value	Description
31-3	Reserved	0	Reserved
2	PLLSWRST		PLL software reset.
		0	PLL soft reset was not the last reset to occur.
		1	PLL soft was the last reset to occur.
1	XWRST		External warm reset.
		0	External warm reset was not the last reset to occur.
		1	External warm reset was the last reset to occur.
0	POR		Power on reset.
		0	Power On Reset (POR) was not the last reset to occur.
		1	Power On Reset (POR) was the last reset to occur.

8.4.3 PLL Control Register (PLLCTL)

The PLL control register (PLLCTL) is shown in Figure 8-4 and described in Table 8-5.

Figure 8-4. PLL Control Register (PLLCTL)

31	16
Reserved	
R-0	

15	9	8	7	6	5	4	3	2	1	0
Reserved		CLKMODE	Reserved		PLLENSRC	Reserved	PLLRST	Rsvd	PLLPWRDN	PLLEN
R-0		R/W-0	R-1		R/W-1	R/W-1	R/W-0	R-0	R/W-1	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 8-5. PLL Control Register (PLLCTL) Field Descriptions

Bit	Field	Value	Description
31-9	Reserved	0	Reserved
8	CLKMODE		Reference Clock Selection
		0	Internal oscillator (crystal)
		1	Square wave
7-6	Reserved	1	Reserved
5	PLLENSRC	0	This bit must be cleared before PLLEN will have any effect.
4	Reserved	1	Reserved. Write the default value when modifying this register.
3	PLLRST		Asserts RESET to PLL if supported.
		0	PLL reset is asserted
		1	PLL reset is not asserted
2	Reserved	0	Reserved
1	PLLPWRDN		PLL power-down.
		0	PLL operation
		1	PLL power-down
0	PLLEN		PLL mode enables.
		0	Bypass mode
		1	PLL mode, not bypassed

8.4.4 OBSCLK Select Register (OCSEL)

The OBSCLK select register (OCSEL) controls which clock is output on the OBSCLK pin so that it may be used for test and debug purposes (in addition to its normal function of being a direct input clock divider). The OCSEL is shown in Figure 8-5 and described in Table 8-6.

Figure 8-5. OBSCLK Select Register (OCSEL)

31	16
Reserved	
R-0	

15	5	4	0
Reserved		OCSRC	
R-0		R/W-14h	

LEGEND: R/W = Read/Write; R = Read only; *-n* = value after reset

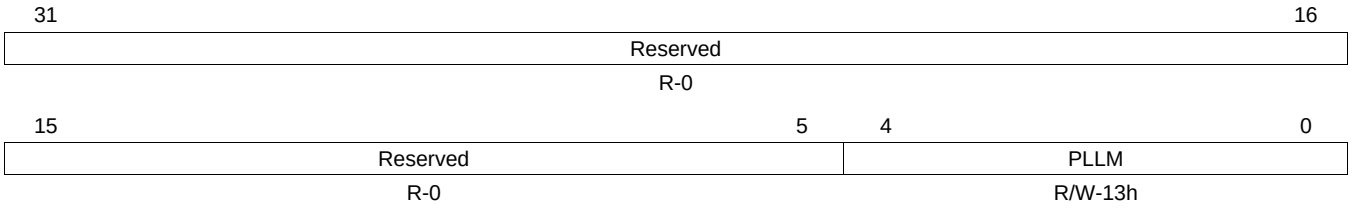
Table 8-6. OBSCLK Select Register (OCSEL) Field Descriptions

Bit	Field	Value	Description
31-5	Reserved	0	Reserved
4-0	OCSRC	0-1Fh	OBSCLK source. Output on OBSCLK pin.
		0-13h	Reserved
		14h	OSCIN
		15h-16h	Reserved
		17h	PLLC0 SYSCLK1
		18h	PLLC0 SYSCLK2
		19h	PLLC0 SYSCLK3
		1Ah	PLLC0 SYSCLK4
		1Bh	PLLC0 SYSCLK5
		1Ch	PLLC0 SYSCLK6
		1Dh	PLLC0 SYSCLK7
		1Eh	Reserved
		1Fh	Disabled

8.4.5 PLL Multiplier Control Register (PLLM)

The PLL multiplier control register (PLLM) is shown in Figure 8-6 and described in Table 8-7.

Figure 8-6. PLL Multiplier Control Register (PLLM)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

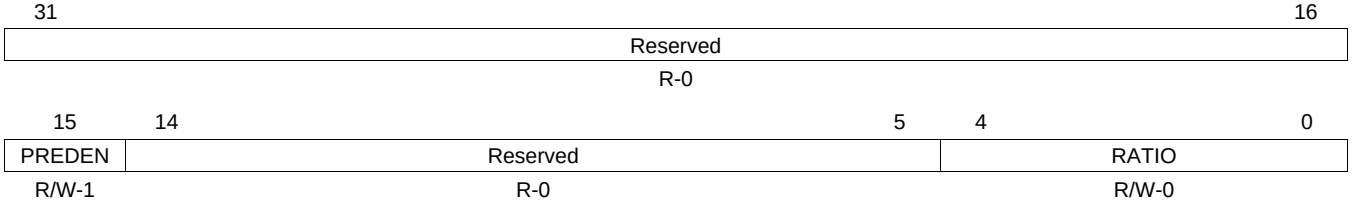
Table 8-7. PLL Multiplier Control Register (PLLM) Field Descriptions

Bit	Field	Value	Description
31-5	Reserved	0	Reserved
4-0	PLLM	0-1Fh	PLL Multiplier Select. Multiplier Value = PLLM + 1. The valid range of multiplier values for a given OSCIN is defined by the minimum and maximum frequency limits on the PLL VCO frequency. See the device-specific data manual for PLL VCO frequency specification limits.

8.4.6 PLL Pre-Divider Control Register (PREDIV)

The PLL pre-divider control register (PREDIV) is shown in Figure 8-7 and described in Table 8-8.

Figure 8-7. PLL Pre-Divider Control Register (PREDIV)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 8-8. PLL Pre-Divider Control Register (PREDIV) Field Descriptions

Bit	Field	Value	Description
31-14	Reserved	0	Reserved
15	PREDEN		Pre_Divider enable.
		0	Disable
		1	Enable
14-5	Reserved	0	Reserved
4-0	RATIO	0-1Fh	Divider ratio. Divider Value = RATIO + 1. RATIO defaults to 0 (PLL pre-divide by 1).

8.4.7 PLL Controller Divider 1 Register (PLLDIV1)

The PLL controller divider 1 register (PLLDIV1) is shown in Figure 8-8 and described in Table 8-9. Divider 1 controls the divider for SYSCLK1.

Figure 8-8. PLL Controller Divider 1 Register (PLLDIV1)

31	16
Reserved	
R-0	

15	14	5	4	0
D1EN	Reserved		RATIO	
R/W-1	R-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 8-9. PLL Controller Divider 1 Register (PLLDIV1) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	Reserved
15	D1EN		Divider Enable.
		0	Disable
		1	Enable
14-5	Reserved	0	Reserved
4-0	RATIO	0-1Fh	Divider ratio. Divider Value = RATIO + 1. RATIO defaults to 0 (PLL divide by 1).

8.4.8 PLL Controller Divider 2 Register (PLLDIV2)

The PLL controller divider 2 register (PLLDIV2) is shown in Figure 8-9 and described in Table 8-10. Divider 2 controls the divider for SYSCLK2.

Figure 8-9. PLL Controller Divider 2 Register (PLLDIV2)

31	16
Reserved	
R-0	

15	14	5	4	0
D2EN	Reserved		RATIO	
R/W-1	R-0		R/W-1	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 8-10. PLL Controller Divider 2 Register (PLLDIV2) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	Reserved
15	D2EN		Divider Enable.
		0	Disable
		1	Enable
14-5	Reserved	0	Reserved
4-0	RATIO	0-1Fh	Divider ratio. Divider Value = RATIO + 1. RATIO defaults to 1 (PLL divide by 2).

8.4.9 PLL Controller Divider 3 Register (PLLDIV3)

The PLL controller divider 3 register (PLLDIV3) is shown in Figure 8-10 and described in Table 8-11. Divider 3 controls the divider for SYSCLK3.

Figure 8-10. PLL Controller Divider 3 Register (PLLDIV3)

31	16
Reserved	
R-0	

15	14	5	4	0
D3EN	Reserved		RATIO	
R/W-1	R-0		R/W-2h	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 8-11. PLL Controller Divider 3 Register (PLLDIV3) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	Reserved
15	D3EN		Divider Enable.
		0	Disable
		1	Enable
14-5	Reserved	0	Reserved
4-0	RATIO	0-1Fh	Divider ratio. Divider Value = RATIO + 1. RATIO defaults to 2h (PLL divide by 3).

8.4.10 PLL Controller Divider 4 Register (PLLDIV4)

The PLL controller divider 4 register (PLLDIV4) is shown inFigure 8-11 and described in Table 8-12. Divider 4 controls the divider for SYSCLK4.

Figure 8-11. PLL Controller Divider 4 Register (PLLDIV4)

31	16
Reserved	
R-0	

15	14	5	4	0
D4EN	Reserved		RATIO	
R/W-1	R-0		R/W-3h	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 8-12. PLL Controller Divider 4 Register (PLLDIV4) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	Reserved
15	D4EN		Divider Enable.
		0	Disable
		1	Enable
14-5	Reserved	0	Reserved
4-0	RATIO	0-1Fh	Divider ratio. Divider Value = RATIO + 1. RATIO defaults 3 (PLL divide by 4).

8.4.11 PLL Controller Divider 5 Register (PLLDIV5)

The PLL controller divider 5 register (PLLDIV5) is shown in Figure 8-12 and described in Table 8-13. Divider 5 controls the divider for SYSCLK5.

Figure 8-12. PLL Controller Divider 5 Register (PLLDIV5)

31	16
Reserved	
R-0	

15	14	5	4	0
D5EN	Reserved		RATIO	
R/W-1	R-0		R/W-2h	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 8-13. PLL Controller Divider 5 Register (PLLDIV5) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	Reserved
15	D5EN		Divider Enable.
		0	Disable
		1	Enable
14-5	Reserved	0	Reserved
4-0	RATIO	0-1Fh	Divider ratio. Divider Value = RATIO + 1. RATIO defaults 2 (PLL divide by 3).

8.4.12 PLL Controller Divider 6 Register (PLLDIV6)

The PLL controller divider 6 register (PLLDIV6) is shown in Figure 8-13 and described in Table 8-14. Divider 6 controls the divider for SYSCLK6.

Figure 8-13. PLL Controller Divider 6 Register (PLLDIV6)

31	16
Reserved	
R-0	

15	14	5	4	0
D6EN	Reserved		RATIO	
R/W-1	R-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 8-14. PLL Controller Divider 6 Register (PLLDIV6) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	Reserved
15	D6EN		Divider Enable.
		0	Disable
		1	Enable
14-5	Reserved	0	Reserved
4-0	RATIO	0-1Fh	Divider ratio. Divider Value = RATIO + 1. RATIO defaults to 0 (PLL divide by 1).

8.4.13 PLL Controller Divider 7 Register (PLLDIV7)

The PLL controller divider 7 register (PLLDIV7) is shown in Figure 8-14 and described in Table 8-15. Divider 7 controls the divider for SYSCLK7.

Figure 8-14. PLL Controller Divider 7 Register (PLLDIV7)

31	16
Reserved	
R-0	

15	14	5	4	0
D7EN	Reserved		RATIO	
R/W-1	R-0		R/W-5h	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 8-15. PLL Controller Divider 7 Register (PLLDIV7) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	Reserved
15	D7EN		Divider Enable.
		0	Disable
		1	Enable
14-5	Reserved	0	Reserved
4-0	RATIO	0-1Fh	Divider ratio. Divider Value = RATIO + 1. RATIO defaults to 5 (PLL divide by 6).

8.4.14 Oscillator Divider 1 Register (OSCDIV)

The oscillator divider 1 register (OSCDIV) controls the divider for OBSCLK, dividing down the clock selected as the OBSCLK source from the OBSCLK select register (OCSEL). The OBSCLK is connected to the OBSCLK pin. The OSCDIV is shown in Figure 8-15 and described in Table 8-16.

Figure 8-15. Oscillator Divider 1 Register (OSCDIV)

31	16
Reserved	
R-0	

15	14	5	4	0
OD1EN	Reserved		RATIO	
R/W-1	R-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

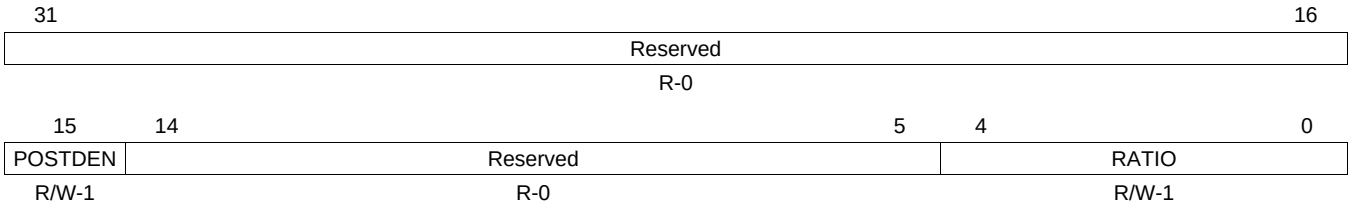
Table 8-16. Oscillator Divider 1 Register (OSCDIV) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	Reserved
15	OD1EN		Oscillator divider 1 enable.
		0	Oscillator divider 1 is disabled.
		1	Oscillator divider 1 is enabled. For OBSCLK to toggle, both the OD1EN bit and the OBSEN bit in the clock enable control register (CKEN) must be set to 1.
14-5	Reserved	0	Reserved
4-0	RATIO	0-1Fh	Divider ratio. Divider value = RATIO + 1. For example, RATIO = 0 means divide by 1.

8.4.15 PLL Post-Divider Control Register (POSTDIV)

The PLL post-divider control register (POSTDIV) is shown in Figure 8-16 and described in Table 8-17.

Figure 8-16. PLL Post-Divider Control Register (POSTDIV)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

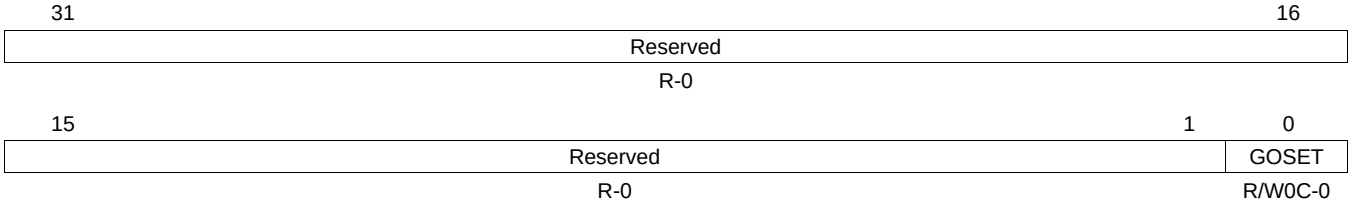
Table 8-17. PLL Post-Divider Control Register (POSTDIV) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	Reserved
15	POSTDEN		Post_Divider enable.
		0	Disable
		1	Enable
14-5	Reserved	0	Reserved
4-0	RATIO	0-1Fh	Divider ratio. Divider Value = RATIO + 1. RATIO defaults to 1 (PLL post-divide by 2).

8.4.16 PLL Controller Command Register (PLLCMD)

The PLL controller command register (PLLCMD) is shown in Figure 8-17 and described in Table 8-18. contains command bits for various operations. Writes of 1 initiate command; writes of 0 clear the bit, but have no effect.

Figure 8-17. PLL Controller Command Register (PLLCMD)



LEGEND: R/W = Read/Write; R = Read only; W0C = Write 0 to clear bit; -*n* = value after reset

Table 8-18. PLL Controller Command Register (PLLCMD) Field Descriptions

Bit	Field	Value	Description
31-1	Reserved	0	Reserved
0	GOSET		GO bit for SYSCLKx phase alignment.
		0	Clear bit (no effect)
		1	Phase alignment

8.4.17 PLL Controller Status Register (PLLSTAT)

The PLL controller status register (PLLSTAT) is shown in Figure 8-18 and described in Table 8-19.

Figure 8-18. PLL Controller Status Register (PLLSTAT)

31	16
Reserved	
R-0	

15	3	2	1	0
Reserved		STABLE	Reserved	GOSTAT
R-0		R-0	R-0	R-0

LEGEND: R = Read only; -*n* = value after reset

Table 8-19. PLL Controller Status Register (PLLSTAT) Field Descriptions

Bit	Field	Value	Description
31-3	Reserved	0	Reserved
2	STABLE		OSC counter done, oscillator assumed to be stable. By the time the device comes out of reset, this bit should become 1.
		0	No
		1	Yes
1	Reserved	0	Reserved
0	GOSTAT		Status of GO operation. If 1, indicates GO operation is in progress.
		0	GO operation is not in progress.
		1	GO operation is in progress.

8.4.18 PLL Controller Clock Align Control Register (ALNCTL)

The PLL controller clock align control register (ALNCTL) is shown in Figure 8-19 and described in Table 8-20. Indicates which SYSCLKs need to be aligned for proper device operation.

Figure 8-19. PLL Controller Clock Align Control Register (ALNCTL)

31	16
Reserved	
R-0	

15	7	6	5	4	3	2	1	0
Reserved		ALN7	ALN6	ALN5	ALN4	ALN3	ALN2	ALN1
R-0		R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 8-20. PLL Controller Clock Align Control Register (ALNCTL) Field Descriptions

Bit	Field	Value	Description
31-7	Reserved	0	Reserved
6	ALN7		SYSCLK7 needs to be aligned to others selected in this register.
		0	No
		1	Yes
5	ALN6		SYSCLK6 needs to be aligned to others selected in this register.
		0	No
		1	Yes
4	ALN5		SYSCLK5 needs to be aligned to others selected in this register.
		0	No
		1	Yes
3	ALN4		SYSCLK4 needs to be aligned to others selected in this register.
		0	No
		1	Yes
2	ALN3		SYSCLK3 needs to be aligned to others selected in this register.
		0	No
		1	Yes
1	ALN2		SYSCLK2 needs to be aligned to others selected in this register.
		0	No
		1	Yes
0	ALN1		SYSCLK1 needs to be aligned to others selected in this register.
		0	No
		1	Yes

8.4.19 PLLDIV Ratio Change Status Register (DCHANGE)

The PLLDIV ratio change status register (DCHANGE) is shown in Figure 8-20 and described in Table 8-21. Indicates if SYSCLK divide ratio has been modified.

Figure 8-20. PLLDIV Ratio Change Status Register (DCHANGE)

31	16
Reserved	
R-0	

15	7	6	5	4	3	2	1	0
Reserved		SYS7	SYS6	SYS5	SYS4	SYS3	SYS2	SYS1
R-0		R-0	R-0	R-0	R-0	R-0	R-0	R-0

LEGEND: R = Read only; -*n* = value after reset

Table 8-21. PLLDIV Ratio Change Status Register (DCHANGE) Field Descriptions

Bit	Field	Value	Description
31-7	Reserved	0	Reserved
6	SYS7		SYSCLK7 divide ratio is modified.
		0	Ratio is not modified.
		1	Ratio is modified.
5	SYS6		SYSCLK6 divide ratio is modified.
		0	Ratio is not modified.
		1	Ratio is modified.
4	SYS5		SYSCLK5 divide ratio is modified.
		0	Ratio is not modified.
		1	Ratio is modified.
3	SYS4		SYSCLK4 divide ratio is modified.
		0	Ratio is not modified.
		1	Ratio is modified.
2	SYS3		SYSCLK3 divide ratio is modified.
		0	Ratio is not modified.
		1	Ratio is modified.
1	SYS2		SYSCLK2 divide ratio is modified.
		0	Ratio is not modified.
		1	Ratio is modified.
0	SYS1		SYSCLK1 divide ratio is modified.
		0	Ratio is not modified.
		1	Ratio is modified.

8.4.20 Clock Enable Control Register (CKEN)

The clock enable control register (CKEN) is shown in Figure 8-21 and described in Table 8-22. Clock enable control for miscellaneous output clocks.

Figure 8-21. Clock Enable Control Register (CKEN)

31	16
Reserved	
R-0	

15	2	1	0
Reserved		OBSEN	AUXEN
R-0		R/W-1	R/W-1

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 8-22. Clock Enable Control Register (CKEN) Field Descriptions

Bit	Field	Value	Description
31-2	Reserved	0	Reserved
1	OBSEN		OBSCLK enable. Actual OBSCLK status is shown in the clock status register (CKSTAT).
		0	OBSCLK is disabled.
		1	OBSCLK is enabled. For OBSCLK to toggle, both the OBSEN bit and the OD1EN bit in the oscillator divider 1 register (OSCDIV) must be set to 1.
0	AUXEN		AUXCLK enable. Actual AUXCLK status is shown in the clock status register (CKSTAT).
		0	AUXCLK is disabled.
		1	AUXCLK is enabled.

8.4.21 Clock Status Register (CKSTAT)

The clock status register (CKSTAT) is shown in Figure 8-22 and described in Table 8-23. Clock status for all clocks, except SYSCLK*n*.

Figure 8-22. Clock Status Register (CKSTAT)

31	16
Reserved	
R-0	

15	1	0
Reserved	OBSON	AUXEN
R-0	R-1	R-1

LEGEND: R = Read only; -*n* = value after reset

Table 8-23. Clock Status Register (CKSTAT) Field Descriptions

Bit	Field	Value	Description
31-2	Reserved	0	Reserved
1	OBSON		OBSCLK on status. OBSCLK is controlled in the oscillator divider 1 register (OSCDIV) and by the OBSEN bit in the clock enable control register (CKEN).
		0	OBSCLK is off.
		1	OBSCLK is on.
0	AUXEN		AUXCLK on status. AUXCLK is controlled by the AUXEN bit in the clock enable control register (CKEN).
		0	AUXCLK is off.
		1	AUXCLK is on.

8.4.22 SYSCLK Status Register (SYSTAT)

The SYSCLK status register (SYSTAT) is shown in Figure 8-23 and described in Table 8-24. Indicates SYSCLK on/off status. Actual default is determined by actual clock on/off status, which depends on the D*n*EN bit in PLLDIV*n* default.

Figure 8-23. SYSCLK Status Register (SYSTAT)

31							8
Reserved							
R-0							
7	6	5	4	3	2	1	0
Reserved	SYS7ON	SYS6ON	SYS5ON	SYS4ON	SYS3ON	SYS2ON	SYS1ON
R-0	R-1	R-1	R-1	R-1	R-1	R-1	R-1

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 8-24. SYSCLK Status Register (SYSTAT) Field Descriptions

Bit	Field	Value	Description
31-7	Reserved	0	Reserved
6	SYS7ON		SYSCLK7 on status
		0	Off
		1	On
5	SYS6ON		SYSCLK6 on status
		0	Off
		1	On
4	SYS5ON		SYSCLK5 on status
		0	Off
		1	On
3	SYS4ON		SYSCLK4 on status
		0	Off
		1	On
2	SYS3ON		SYSCLK3 on status
		0	Off
		1	On
1	SYS2ON		SYSCLK2 on status
		0	Off
		1	On
0	SYS1ON		SYSCLK1 on status
		0	Off
		1	On

8.4.23 Emulation Performance Counter 0 Register (EMUCNT0)

The emulation performance counter 0 register (EMUCNT0) is shown in Figure 8-24 and described in Table 8-25. EMUCNT0 is for emulation performance profiling. It counts in a divide-by-4 of the system clock. To start the counter, a write must be made to EMUCNT0. This register is not writable, but only used to start the register. After the register is started, it can not be stopped except for power on reset. When EMUCNT0 is read, it snapshots EMUCNT0 and EMUCNT1. The snapshot version is what is read. It is important to read the EMUCNT0 followed by EMUCNT1 or else the snapshot version may not get updated correctly.

Figure 8-24. Emulation Performance Counter 0 Register (EMUCNT0)

31	0
COUNT	
R-0	

LEGEND: R = Read only; -*n* = value after reset

Table 8-25. Emulation Performance Counter 0 Register (EMUCNT0) Field Descriptions

Bit	Field	Value	Description
31-0	COUNT	0-FFFF FFFFh	Counter value for lower 64-bits.

8.4.24 Emulation Performance Counter 1 Register (EMUCNT1)

The emulation performance counter 1 register (EMUCNT1) is shown in Figure 8-25 and described in Table 8-26. EMUCNT1 is for emulation performance profiling. To start the counter, a write must be made to EMUCNT0. This register is not writable, but only used to start the register. After the register is started, it can not be stopped except for power on reset. When EMUCNT0 is read, it snapshots EMUCNT0 and EMUCNT1. The snapshot version is what is read. It is important to read the EMUCNT0 followed by EMUCNT1 or else the snapshot version may not get updated correctly.

Figure 8-25. Emulation Performance Counter 1 Register (EMUCNT1)

31	0
COUNT	
R-0	

LEGEND: R = Read only; -*n* = value after reset

Table 8-26. Emulation Performance Counter 1 Register (EMUCNT1) Field Descriptions

Bit	Field	Value	Description
31-0	COUNT	0-FFFF FFFFh	Counter value for upper 64-bits.

Power and Sleep Controller (PSC)

Topic **Page**

9.1 Introduction

The Power and Sleep Controllers (PSC) are responsible for managing transitions of system power on/off, clock on/off, resets (device level and module level). It is used primarily to provide granular power control for on chip modules (peripherals and CPU). A PSC module consists of a Global PSC (GPSC) and a set of Local PSCs (LPSCs). The GPSC contains memory mapped registers, PSC interrupts, a state machine for each peripheral/module it controls. An LPSC is associated with every module that is controlled by the PSC and provides clock and reset control. Many of the operations of the PSC are transparent to user (software), such as power on and reset control. However, the PSC module(s) also provide you with interface to control several important power, clock and reset operations. The module level power, clock and reset operations managed and controlled by the PSC are the focus of this chapter.

The PSC includes the following features:

- Manages chip power-on/off
- Provides a software interface to:
  - Control module clock enable/disable
  - Control module reset
  - Control CPU local reset
- Manages on-chip RAM sleep modes (for DSP memories and L3 RAM)
- Supports IcePick emulation features: power, clock and reset

9.2 Power Domain and Module Topology

This device includes two PSC modules. Each PSC module consists of an Always On power domain and an additional pseudo/internal power domain that manages the sleep modes for the RAMs present in the DSP subsystem and the L3 RAM , respectively.

Each PSC module controls clock states for several on the on chip modules, controllers and interconnect components. Table 9-1 and Table 9-2 lists the set of peripherals/modules that are controlled by the PSC, the power domain they are associated with, the LPSC assignment and the default (power-on reset) module states. See the device-specific data manual for the peripherals available on a given device. The module states and terminology are defined in Section 9.2.2.

Even though there are 2 PSC modules with 2 power domains each on the device, both PSC modules and all the power domains are powered by the CVDD pins of the device. All power domains are on when the chip is powered on. There is no provision to remove power externally for the non Always On domains, that is, the pseudo/internal power domains.

There are a few modules/peripherals on the device that do not have a LPSC assigned to them. These modules do not have their module reset/clocks controlled by the PSC module. The decision to assign an LPSC to a module on a device is primarily based on whether or not disabling the clocks to a module will result in significant power savings. This typically depends on the size and the frequency of operation of the module.

Table 9-1. PSC0 Default Module Configuration

LPSC Number	Module Name	Power Domain	Default Module State	Auto Sleep/Wake Only
0	EDMA3 Channel Controller	AlwaysON (PD0)	SwRstDisable	—
1	EDMA3 Transfer Controller 0	AlwaysON (PD0)	SwRstDisable	—
2	EDMA3 Transfer Controller 1	AlwaysON (PD0)	SwRstDisable	—
3	EMIFA (BR7)	AlwaysON (PD0)	SwRstDisable	—
4	SPI0	AlwaysON (PD0)	SwRstDisable	—
5	MMC/SD0	AlwaysON (PD0)	SwRstDisable	—
6	ARM Interrupt Controller	AlwaysON (PD0)	Enable	—
7	ARM RAM/ROM	AlwaysON (PD0)	Enable	Yes
8	Not Used	—	—	—
9	UART0	AlwaysON (PD0)	SwRstDisable	—

Table 9-1. PSC0 Default Module Configuration (continued)

LPSC Number	Module Name	Power Domain	Default Module State	Auto Sleep/Wake Only
10	SCR0 (BR0, BR1, BR2, BR8)	AlwaysON (PD0)	Enable	Yes
11	SCR1 (BR4)	AlwaysON (PD0)	Enable	Yes
12	SCR2 (BR3, BR5, BR6)	AlwaysON (PD0)	Enable	Yes
13	PRU	AlwaysON (PD0)	SwRstDisable	—
14	ARM	AlwaysON (PD0)	SwRstDisable	—
15	DSP	PD_DSP (PD1)	Enable	—

Table 9-2. PSC1 Default Module Configuration

LPSC Number	Module Name	Power Domain	Default Module State	Auto Sleep/Wake Only
0	Not Used	—	—	—
1	USB0 (USB2.0)	AlwaysON (PD0)	SwRstDisable	—
2	USB1 (USB1.1)	AlwaysON (PD0)	SwRstDisable	—
3	GPIO	AlwaysON (PD0)	SwRstDisable	—
4	HPI	AlwaysON (PD0)	SwRstDisable	—
5	EMAC	AlwaysON (PD0)	SwRstDisable	—
6	EMIFB (BR20)	AlwaysON (PD0)	SwRstDisable	—
7	McASP0 (+ McASP0 FIFO)	AlwaysON (PD0)	SwRstDisable	—
8	McASP1 (+ McASP1 FIFO)	AlwaysON (PD0)	SwRstDisable	—
9	McASP2 (+ McASP2 FIFO)	AlwaysON (PD0)	SwRstDisable	—
10	SPI1	AlwaysON (PD0)	SwRstDisable	—
11	I2C1	AlwaysON (PD0)	SwRstDisable	—
12	UART1	AlwaysON (PD0)	SwRstDisable	—
13	UART2	AlwaysON (PD0)	SwRstDisable	—
14-15	Not Used	—	—	—
16	LCDC	AlwaysON (PD0)	SwRstDisable	—
17	eHRPWM0/1/2	AlwaysON (PD0)	SwRstDisable	—
18-19	Not Used	—	—	—
20	eCAP0/1/2	AlwaysON (PD0)	SwRstDisable	—
21	eQEP0/1	AlwaysON (PD0)	SwRstDisable	—
22-23	Not Used	—	—	—
24	SCR8 (BR15)	AlwaysON (PD0)	Enable	Yes
25	SCR7 (BR12)	AlwaysON (PD0)	Enable	Yes
26	SCR12 (BR18)	AlwaysON (PD0)	Enable	Yes
27-30	Not Used	—	—	—
31	Shared RAM (BR13)	PD_SHRAM	Enable	Yes

9.2.1 Power Domain States

A power domain can only be in one of the two states: ON or OFF, defined as follows:

- ON: power to the domain is on
- OFF: power to the domain is off

In this device, for both PSC0 and PSC1, the Always ON domain (or PD0 power domain), is always in the ON state when the chip is powered-on. This domain is not programmable to OFF state (See details on PDCTL register).

Additionally, for both PSC0 and PSC1, the PD1 power domains, the internal/pseudo power domain can either be in the ON state or OFF state. Furthermore, for these power domains the transition from ON to OFF state is further qualified by the PSC0/1.PDCTL1.PDMODE settings. The PDCTL1.PDMODE settings determines the various sleep mode for the on-chip RAM associated with module in the PD1 domain.

- On PSC0 PD1/PD_DSP Domain: Controls the sleep state for DSP L1 and L2 Memories
- On PSC1 PD1/PD_SHRAM Domain: Controls the sleep state for the 128 kB Shared RAM

NOTE: Currently programming the PD1 power domain state to OFF is not supported. You should leave both the PDCTL1.NEXT and PDCTL1.PDMODE values at default/power on reset values.

Both PD0 and PD1 power domains in PSC0 and PSC1 are powered by the CVDD pins of the device. There is no capability to individually remove voltage/power from the DSP or Shared RAM power domains.

9.2.2 Module States

The PSC defines several possible states for a module. This various states are essentially a combination of the module reset asserted or de-asserted and module clock on/enabled or off/disabled. The various module states are defined in Table 9-3.

The key difference between the Auto Sleep and Auto Wake states is that once the module is configured in Auto Sleep mode, it will transition back to the clock disabled state (automatically sleep) after servicing the internal read/write access request where as in Auto Wake mode, on receiving the first internal read/write access request, the module will permanently transition from the clock disabled to clock enabled state (automatically wake).

When the module state is programmed to Disable, SwRstDisable, Auto Sleep or Auto Wake modes, where in the module clocks are off/disabled, an external event or I/O request cannot enable the clocks. For the module to appropriately respond to such external request, it would need to be reconfigured to the Enable state.

9.2.2.1 Auto Sleep/Wake Only Configurations and Limitation

NOTE: Currently no modules should be configured in Auto Sleep or Auto Wake modes. If the module clocks need to gated/disabled for power savings, you should program the module state to Disable. For Auto Sleep/Auto Wake Only modules, disabling the clock is not supported and they should be kept in their default “Enable” state.

Table 9-1 and Table 9-2 each have a column to indicate whether or not the LPSC configuration for a module is Auto Sleep/Wake Only. Modules that have a “Yes” marked for the Auto Sleep/Wake Only column can be programmed in software to be in Enable, Auto Sleep and Auto Wake states only; that is, if the software tries to program these modules to Disable, SyncReset, or SwRstDisable state the power sleep controller ignores these transition requests and transitions the module state to Enable.

Table 9-3. Module States

Module State	Module Reset	Module Clock	Module State Definition
Enable	De-asserted	On	A module in the enable state has its module reset de-asserted and it has its clock on. This is the normal operational state for a given module
Disable	De-asserted	Off	A module in the disabled state has its module reset de-asserted and it has its module clock off. This state is typically used for disabling a module clock to save power. This device is designed in full static CMOS, so when you stop a module clock, it retains the module's state. When the clock is restarted, the module resumes operating from the stopping point.
SyncReset	Asserted	On	A module state in the SyncReset state has its module reset asserted and it has its clock on. Generally, software is not expected to initiate this state
SwRstDisable	Asserted	Off	A module in the SwResetDisable state has its module reset asserted and it has its clock disabled. After initial power-on, several modules come up in the SwRstDisable state. Generally, software is not expected to initiate this state
Auto Sleep	De-asserted	Off	A module in the Auto Sleep state also has its module reset de-asserted and its module clock disabled, similar to the Disable state. However this is a special state, once a module is configured in this state by software, it can "automatically" transition to "Enable" state whenever there is an internal read/write request made to it, and after servicing the request it will "automatically" transition into the sleep state (with module reset re de-asserted and module clock disabled), without any software intervention. The transition from sleep to enabled and back to sleep state has some cycle latency associated with it. It is not envisioned to use this mode when peripherals are fully operational and moving data. See Section 9.2.2.1 for additional considerations, constraints, limitations around this mode.
Auto Wake	De-asserted	Off	A module in the Auto Wake state also has its module reset de-asserted and its module clock disabled, similar to the Disable state. However this is a special state, once a module is configured in this state by software, it will "automatically" transition to "Enable" state whenever there is an internal read/write request made to it, and will remain in the "Enabled" state from then on (with module reset re de-asserted and module clock on), without any software intervention. The transition from sleep to enabled state has some cycle latency associated with it. It is not envisioned to use this mode when peripherals are fully operational and moving data. See Section 9.2.2.1 for additional considerations, constraints, limitations around this mode.

9.2.2.2 Local Reset

In addition to module reset, some modules can be reset using a special local reset that is also a part of the PSC module control for resets. The modules that support the local reset are:

- DSP: When the DSP local reset is asserted the DSP internal memories (L1P, L1D and L2) are still accessible. The local reset only resets the DSP CPU core, not the rest of DSP subsystem, as the DSP module reset would. Local Reset is useful in cases where the DSP is in enable or disable state; since when module is in SyncReset or SwRstDisable state the module reset is asserted, and the module reset takes precedence over the local reset.
- ARM: When the ARM local reset is asserted the entire ARM processor is reset , including cache etc. This does not include the ARM RAM/ROM or ARM interrupt controller module as these exist outside the ARM core. The local reset for ARM additionally ensures that any outstanding requests are completed before ARM is reset, therefore for scenarios where it is needed to just reset the ARM locally but not change the state of clocks, user can use ARM local reset feature.

The procedures for asserting and de-asserting the local reset are as follows (where *n* corresponds to the module that supports local reset):

1. Clear the LRST bit in the module control register (MDCTL*n*) to 0 to assert the module's local reset.
2. Set the LRST bit in the module control register (MDCTL*n*) to 1 to de-assert module's local reset.

If the CPU is in the enable state, it immediately executes program instructions after reset is de-asserted.

9.3 Executing State Transitions

This section describes how to execute the state transitions modules.

9.3.1 Power Domain State Transitions

This device consists of 2 types of domain (in each PSC controller): the Always On Domain(s) and the pseudo/RAM power domain(s). The Always On power domains are always in the ON state when the chip is powered on. You are not allowed to change the power domain state to OFF.

The pseudo/RAM power domains allow internally powering down the state of the RAMs associated with these domains (L1/L2 for PD_DSP in PSC0 and Shared RAM for PD_SHRAM in PSC1) so that these RAMs can run in lower power sleep modes via the power sleep controller.

NOTE: Currently powering down the RAMs via the pseudo/RAM power domain is not supported; therefore, these domains and the RAM should be left in their default power on state.

As mentioned in Section 9.2, the pseudo/RAM power domains are powered down internally, and in this context powering down does not imply removing the core voltage from pins externally.

9.3.2 Module State Transitions

This section describes the procedure for transitioning the module state (clock and reset control). Note that some peripherals have special programming requirements and additional recommended steps you must take before you can invoke the PSC module state transition. See the individual peripheral user guides for more details. For example, the external memory controller requires that you first place the SDRAM memory in self-refresh mode before you invoke the PSC module state transitions, if you want to maintain the memory contents.

The following procedure is directly applicable for all modules that are controlled via the PSC (shown in Table 9-1 and Table 9-2), except for the core(s). To transition the DSP or ARM module state, there are additional system considerations and constraints that you should be aware of. These system considerations and the procedure for transitioning the DSP or ARM module state are described in details in the *Power Management* chapter.

NOTE: In the following procedure, x is 0 for modules in PD0 (Power Domain 0 or Always On domain) and x is 1 for modules in PD1 (Power Domain 1) . See Table 9-1 and Table 9-2 for power domain associations.

The procedure for module state transitions is:

1. Wait for the GOSTAT[x] bit in PTSTAT to clear to 0. You must wait for any previously initiated transitions to finish before initiating a new transition.
2. Set the NEXT bit in MDCTL*n* to SwRstDisable (0), SyncReset (1), Disable (2h), Enable (3h), Auto Sleep (4h) or Auto Wake (5h).

   NOTE: You may set transitions in multiple NEXT bits in MDCTL*n* in this step. Transitions do not actually take place until you set the GO[x] bit in PTCMD in a later step.

3. Set the GO[x] bit in PTCMD to 1 to initiate the transition(s).
4. Wait for the GOSTAT[x] bit in PTSTAT to clear to 0. The modules are safely in the new states only after the GOSTAT[x] bit in PTSTAT is cleared to 0.

9.4 IcePick Emulation Support in the PSC

The PSC supports IcePick commands that allow IcePick emulation tools to have some control over the state of power domains and modules. This IcePick support only applies to the following modules:

- DSP [MDCTL15]
- ARM [MDCTL14]

In particular, Table 9-4 shows IcePick emulation commands recognized by the PSC.

Table 9-4. IcePick Emulation Commands

Power On and Enable Features	Power On and Enable Descriptions	Reset Features	Reset Descriptions
Inhibit Sleep	Allows emulation to prevent software from transitioning the module out of the enable state.	Assert Reset	Allows emulation to assert the module's local reset.
Force Power	Allows emulation to force the power domain into an on state. Not applicable as AlwaysOn power domain is always on.	Wait Reset	Allows emulation to keep local reset asserted for an extended period of time after software initiates local reset de-assert.
Force Active	Allows emulation to force the module into the enable state.	Block Reset	Allows emulation to block software initiated local and module resets.

NOTE: When emulation tools remove the above commands, the PSC immediately executes a state transition based on the current values in the NEXT bit in PDCTL0 and the NEXT bit in MDCTL*n*, as set by software.

9.5 PSC Interrupts

The PSC has an interrupt that is tied to the core interrupt controller. This interrupt is named PSCINT in the interrupt map. The PSC interrupt is generated when certain IcePick emulation events occur.

9.5.1 Interrupt Events

The PSC interrupt is generated when any of the following events occur:

- Power Domain Emulation Event (applies to pseudo/RAM power domain only)
- Module State Emulation event
- Module Local Reset Emulation event

These interrupt events are summarized in Table 9-5 and described in more detail in this section.

Table 9-5. PSC Interrupt Events

Interrupt Enable Bits		
Control Register	**Enable Bit**	**Interrupt Condition**
PDCTL*n*	EMUIHBIE	Interrupt occurs when the emulation alters the power domain state
MDCTL*n*	EMUIHBIE	Interrupt occurs when the emulation alters the module state
MDCTL*n*	EMURSTIE	Interrupt occurs when the emulation tries to alter the module's local reset

The PSC interrupt events only apply when IcePick emulation alters the state of the module from the user-programmed state in the NEXT bit in the MDCTL/PDCTL registers. IcePick support only applies to the modules listed in Section 9.4; therefore, the PSC interrupt conditions only apply to those modules listed.

9.5.1.1 Power Domain Emulation Events

A power domain emulation event occurs when emulation alters the state of a power domain (does not apply to the Always On domain). Status is reflected in the EMUIHB bit in PDSTAT*n*. In particular, a power domain emulation event occurs under the following conditions:

- When inhibit sleep is asserted by emulation and software attempts to transition the module out of the on state
- When force power is asserted by emulation and power domain is not already in the on state
- When force active is asserted by emulation and power domain is not already in the on state

NOTE: Putting the pseudo/RAM power domain associated with DSP (PD_DSP) to off state is currently **not** supported.

9.5.1.2 Module State Emulation Events

A module state emulation event occurs when emulation alters the state of a module. Status is reflected in the EMUIHB bit in the module status register (MDSTAT*n*). In particular, a module state emulation event occurs under the following conditions:

- When inhibit sleep is asserted by emulation and software attempts to transition the module out of the enable state
- When force active is asserted by emulation and module is not already in the enable state

9.5.1.3 Local Reset Emulation Events

A local reset emulation event occurs when emulation alters the local reset of a module. Status is reflected in the EMURST bit in the module status register (MDSTAT*n*). In particular, a module local reset emulation event occurs under the following conditions:

- When assert reset is asserted by emulation although software de-asserted the local reset
- When wait reset is asserted by emulation
- When block reset is asserted by emulation and software attempts to change the state of local reset

9.5.2 Interrupt Registers

The PSC interrupt enable bits are: the EMUIHBIE bit in PDCTL1 (PSC0), the EMUIHBIE and the EMURSTIE bits in MDCTL*n* (where n is the modules that have IcePick emulation support, as specified in Section 9.4).

NOTE: To interrupt the CPU, the power sleep controller interrupt (PSC0_ALLINT and PSC1_ALLINT) must also be enabled appropriately in the ARM interrupt controller. For details on the ARM interrupt controller, see the *ARM Interrupt Controller (AINTC)* chapter.

The PSC interrupt status bits are:

- For DSP:
  - The M[15] bit in the module error pending register 0 (MERRPR0) in PSC0 module.
  - The EMUIHB and the EMURST bits in the module status register for DSP (MDSTAT15).
  - The P[1] bit in the power error pending register (PERRPR) for the pseudo/RAM power domain associated with DSP memories.
- For ARM:
  - The M[14] bit in the module error pending register 0 (MERRPR0) in PSC0 module.
  - The EMUIHB and the EMURST bits in the module status register for ARM (MDSTAT14).

The status bit in MERRPR0 and PERRPR registers is read by software to determine which module or power domain has generated an emulation interrupt and then software can read the corresponding status bits in MDSTAT register or the PDSTATn (PDCTL1 for pseudo/RAM power domain in PSC0) to determine which event caused the interrupt.

The PSC interrupt can be cleared by writing to bit corresponding to the module number in the module error clear register (MERRCR0), or the bit corresponding to the power domain number in the power error clear register (PERRCR) in PSC0 module.

The PSC interrupt evaluation bit is the ALLEV bit in the INTEVAL register. When set, this bit forces the PSC interrupt logic to re-evaluate event status. If any events are still active (if any status bits are set) when the ALLEV bit in the INTEVAL is set to 1, the PSC interrupt is re-asserted to the interrupt controller. Set the ALLEV bit in the INTEVAL before exiting your PSC interrupt service routine to ensure that you do not miss any PSC interrupts.

See Section 9.6 for a description of the PSC registers.

9.5.3 Interrupt Handling

Handle the PSC interrupts as described in the following procedure:

First, enable the interrupt:

1. Set the EMUIHBIE bit in PDCTL*n*, the EMUIHBIE and the EMURSTIE bits in MDCTL*n* to enable the interrupt events that you want.

NOTE: The PSC interrupt is sent to the device interrupt controller when at least one enabled event becomes active.

2. Enable the power sleep controller interrupt (PSC*n*_ALLINT) in the device interrupt controller. To interrupt the CPU, PSC*n*_ALLINT must be enabled in the device interrupt controller. See the *ARM Interrupt Controller (AINTC)* chapter for more information on interrupts.

The CPU enters the interrupt service routine (ISR) when it receives the interrupt.

1. Read the P[n] bit in PERRPR, and/or the M[n] bit in MERRPR0, the M[n] bit in MERRPR1, to determine the source of the interrupt(s).
2. For each active event that you want to service:
   (a) Read the event status bits in PDSTAT*n* and MDSTAT*n*, depending on the status bits read in the previous step to determine the event that caused the interrupt.
   (b) Service the interrupt as required by your application.
   (c) Write the M[n] bit in MERRCR*n* and the P[n] bit in PERRCR to clear corresponding status.
   (d) Set the ALLEV bit in INTEVAL. Setting this bit reasserts the PSC interrupt to the device interrupt controller, if there are still any active interrupt events.

9.6 PSC Registers

Table 9-6 lists the memory-mapped registers for the PSC0 and Table 9-7 lists the memory-mapped registers for the PSC1.

Table 9-6. Power and Sleep Controller 0 (PSC0) Registers

Address	Acronym	Register Description	Section
01C1 0000h	REVID	Revision Identification Register	Section 9.6.1
01C1 0018h	INTEVAL	Interrupt Evaluation Register	Section 9.6.2
01C1 0040h	MERRPR0	Module Error Pending Register 0 (module 0-15)	Section 9.6.3
01C1 0050h	MERRCR0	Module Error Clear Register 0 (module 0-15)	Section 9.6.5
01C1 0060h	PERRPR	Power Error Pending Register	Section 9.6.7
01C1 0068h	PERRCR	Power Error Clear Register	Section 9.6.8
01C1 0120h	PTCMD	Power Domain Transition Command Register	Section 9.6.9
01C1 0128h	PTSTAT	Power Domain Transition Status Register	Section 9.6.10
01C1 0200h	PDSTAT0	Power Domain 0 Status Register	Section 9.6.11
01C1 0204h	PDSTAT1	Power Domain 1 Status Register	Section 9.6.12
01C1 0300h	PDCTL0	Power Domain 0 Control Register	Section 9.6.13
01C1 0304h	PDCTL1	Power Domain 1 Control Register	Section 9.6.14
01C1 0400h	PDCFG0	Power Domain 0 Configuration Register	Section 9.6.15
01C1 0404h	PDCFG1	Power Domain 1 Configuration Register	Section 9.6.16
01C1 0800h-01C1 083Ch	MDSTAT0-MDSTAT15	Module Status *n* Register (modules 0-15)	Section 9.6.17
01C1 0A00h-01C1 0A3Ch	MDCTL0-MDCTL15	Module Control *n* Register (modules 0-15)	Section 9.6.18

Table 9-7. Power and Sleep Controller 1 (PSC1) Registers

Address	Acronym	Register Description	Section
01E2 7000h	REVID	Revision Identification Register	Section 9.6.1
01E2 7018h	INTEVAL	Interrupt Evaluation Register	Section 9.6.2
01E2 7040h	MERRPR0	Module Error Pending Register 0 (module 0-31)	Section 9.6.4
01E2 7050h	MERRCR0	Module Error Clear Register 0 (module 0-31)	Section 9.6.6
01E2 7060h	PERRPR	Power Error Pending Register	Section 9.6.7
01E2 7068h	PERRCR	Power Error Clear Register	Section 9.6.8
01E2 7120h	PTCMD	Power Domain Transition Command Register	Section 9.6.9
01E2 7128h	PTSTAT	Power Domain Transition Status Register	Section 9.6.10
01E2 7200h	PDSTAT0	Power Domain 0 Status Register	Section 9.6.11
01E2 7204h	PDSTAT1	Power Domain 1 Status Register	Section 9.6.12
01E2 7300h	PDCTL0	Power Domain 0 Control Register	Section 9.6.13
01E2 7304h	PDCTL1	Power Domain 1 Control Register	Section 9.6.14
01E2 7400h	PDCFG0	Power Domain 0 Configuration Register	Section 9.6.15
01E2 7404h	PDCFG1	Power Domain 1 Configuration Register	Section 9.6.16
01E2 7800h-01E2 787Ch	MDSTAT0-MDSTAT31	Module Status *n* Register (modules 0-31)	Section 9.6.17
01E2 7A00h-01E2 7A7Ch	MDCTL0-MDCTL31	Module Control *n* Register (modules 0-31)	Section 9.6.19

9.6.1 Revision Identification Register (REVID)

The revision identification register (REVID) is shown in Figure 9-1 and described in Table 9-8.

Figure 9-1. Revision Identification Register (REVID)

31	0
REV	
R-4482 3A00h	

LEGEND: R = Read only; -*n* = value after reset

Table 9-8. Revision Identification Register (REVID) Field Descriptions

Bit	Field	Value	Description
31-0	REV	4482 3A00h	Peripheral revision ID.

9.6.2 Interrupt Evaluation Register (INTEVAL)

The interrupt evaluation register (INTEVAL) is shown in Figure 9-2 and described in Table 9-9.

Figure 9-2. Interrupt Evaluation Register (INTEVAL)

31	16
Reserved	
R-0	

15	1	0
Reserved		ALLEV
R-0		W-0

LEGEND: R = Read only; W= Write only; -*n* = value after reset

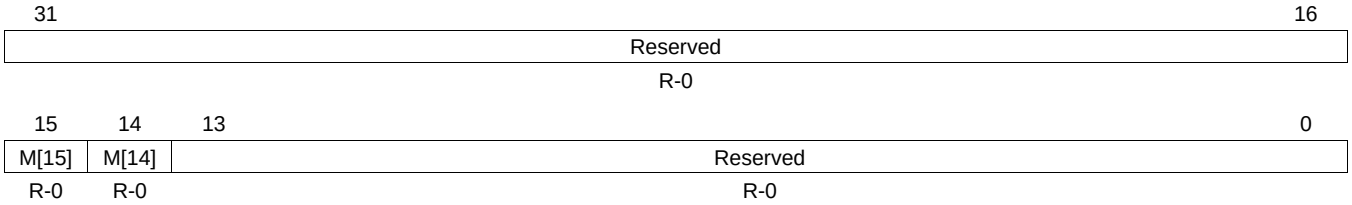
Table 9-9. Interrupt Evaluation Register (INTEVAL) Field Descriptions

Bit	Field	Value	Description
31-1	Reserved	0	Reserved
0	ALLEV		Evaluate PSC interrupt (PSC*n*_ALLINT).
		0	A write of 0 has no effect.
		1	A write of 1 re-evaluates the interrupt condition.

9.6.3 PSC0 Module Error Pending Register 0 (modules 0-15) (MERRPR0)

The PSC0 module error pending register 0 (MERRPR0) is shown in Figure 9-3 and described in Table 9-10.

Figure 9-3. PSC0 Module Error Pending Register 0 (MERRPR0)



LEGEND: R = Read only; -*n* = value after reset

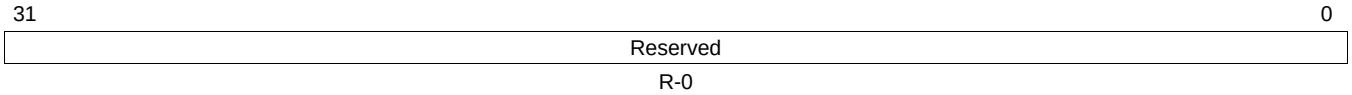
Table 9-10. PSC0 Module Error Pending Register 0 (MERRPR0) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	Reserved
15	M[15]		Module interrupt status bit for module 15 (DSP).
		0	Module 15 does not have an error condition.
		1	Module 15 has an error condition. See the module status 15 register (MDSTAT15) for the error condition.
14	M[14]		Module interrupt status bit for module 14 (ARM).
		0	Module 14 does not have an error condition.
		1	Module 14 has an error condition. See the module status 14 register (MDSTAT14) for the error condition.
13-0	Reserved	0	Reserved

9.6.4 PSC1 Module Error Pending Register 0 (modules 0-31) (MERRPR0)

The PSC1 module error pending register 0 (MERRPR0) is shown in Figure 9-4.

Figure 9-4. PSC1 Module Error Pending Register 0 (MERRPR0)

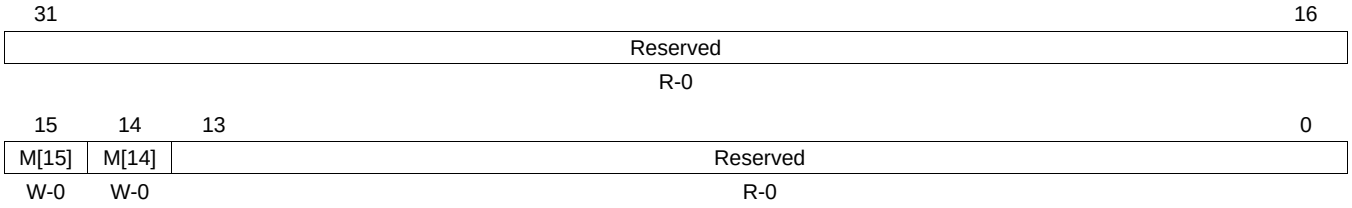


LEGEND: R = Read only; -*n* = value after reset

9.6.5 PSC0 Module Error Clear Register 0 (modules 0-15) (MERRCR0)

The PSC0 module error clear register 0 (MERRCR0) is shown in Figure 9-5 and described in Table 9-11.

Figure 9-5. PSC0 Module Error Clear Register 0 (MERRCR0)



LEGEND: R = Read only; W = Write only; -*n* = value after reset

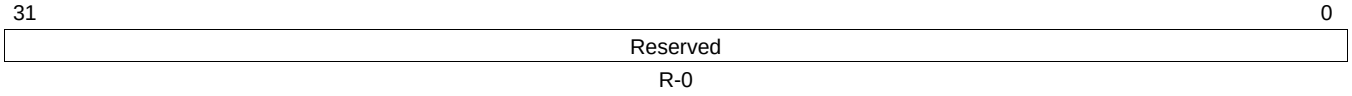
Table 9-11. PSC0 Module Error Clear Register 0 (MERRCR0) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	Reserved
15	M[15]		Clears the interrupt status bit (M[15]) set in the PSC0 module error pending register 0 (MERRPR0) and the interrupt status bits set in the module status 15 register (MDSTAT15).
		0	A write of 0 has no effect.
		1	A write of 1 clears the M[15] bit in MERRPR0 and the EMUIHB and EMURST bits in MDSTAT15.
14	M[14]		Clears the interrupt status bit (M[14]) set in the PSC0 module error pending register 0 (MERRPR0) and the interrupt status bits set in the module status 14 register (MDSTAT14).
		0	A write of 0 has no effect.
		1	A write of 1 clears the M[14] bit in MERRPR0 and the EMUIHB and EMURST bits in MDSTAT14.
13-0	Reserved	0	Reserved

9.6.6 PSC1 Module Error Clear Register 0 (modules 0-31) (MERRCR0)

The PSC1 module error clear register 0 (MERRCR0) is shown in Figure 9-6.

Figure 9-6. PSC1 Module Error Clear Register 0 (MERRCR0)



LEGEND: R = Read only; -*n* = value after reset

9.6.7 Power Error Pending Register (PERRPR)

The power error pending register (PERRPR) is shown in Figure 9-7 and described in Table 9-12.

Figure 9-7. Power Error Pending Register (PERRPR)

31	16
Reserved	
R-0	

15	2	1	0
Reserved		P[1]	Rsvd
R-0		R-0	R-0

LEGEND: R = Read only; -*n* = value after reset

Table 9-12. Power Error Pending Register (PERRPR) Field Descriptions

Bit	Field	Value	Description
31-2	Reserved	0	Reserved
1	P[1]		RAM/Pseudo (PD1) power domain interrupt status.
		0	RAM/Pseudo power domain does not have an error condition.
		1	RAM/Pseudo power domain has an error condition. See the power domain 1 status register (PDSTAT1) for the error condition.
0	Reserved	0	Reserved

9.6.8 Power Error Clear Register (PERRCR)

The power error clear register (PERRCR) is shown in Figure 9-8 and described in Table 9-13.

Figure 9-8. Power Error Clear Register (PERRCR)

31	16
Reserved	
R-0	

15	2	1	0
Reserved		P[1]	Rsvd
R-0		W-0	R-0

LEGEND: R = Read only; W = Write only; -*n* = value after reset

Table 9-13. Power Error Clear Register (PERRCR) Field Descriptions

Bit	Field	Value	Description
31-2	Reserved	0	Reserved
1	P[1]		Clears the interrupt status bit (P) set in the power error pending register (PERRPR) and the interrupt status bits set in the power domain 1 status register (PDSTAT1).
		0	A write of 0 has no effect.
		1	A write of 1 clears the P bit in PERRPR and the interrupt status bits in PDSTAT1.
0	Reserved	0	Reserved

9.6.9 Power Domain Transition Command Register (PTCMD)

The power domain transition command register (PTCMD) is shown in Figure 9-9 and described in Table 9-14.

Figure 9-9. Power Domain Transition Command Register (PTCMD)

31	16
Reserved	
R-0	

15	2	1	0
Reserved		GO[1]	GO[0]
R-0		W-0	W-0

LEGEND: R = Read only; W = Write only; -*n* = value after reset

Table 9-14. Power Domain Transition Command Register (PTCMD) Field Descriptions

Bit	Field	Value	Description
31-2	Reserved	0	Reserved
1	GO[1]		RAM/Pseudo (PD1) power domain GO transition command.
		0	A write of 0 has no effect.
		1	A write of 1 causes the PSC to evaluate all the NEXT fields relevant to this power domain (including PDCTL.NEXT for this domain, and MDCTL.NEXT for all the modules residing on this domain). If any of the NEXT fields are not matching the corresponding current state (PDSTAT.STATE, MDSTAT.STATE), the PSC will transition those respective domain/modules to the new NEXT state.
0	GO[0]		Always ON (PD0) power domain GO transition command.
		0	A write of 0 has no effect.
		1	A write of 1 causes the PSC to evaluate all the NEXT fields relevant to this power domain (including MDCTL.NEXT for all the modules residing on this domain). If any of the NEXT fields are not matching the corresponding current state (MDSTAT.STATE), the PSC will transition those respective domain/modules to the new NEXT state.

9.6.10 Power Domain Transition Status Register (PTSTAT)

The power domain transition status register (PTSTAT) is shown in Figure 9-10 and described in Table 9-15 .

Figure 9-10. Power Domain Transition Status Register (PTSTAT)

31	16
Reserved	
R-0	

15	2	1	0
Reserved		GOSTAT[1]	GOSTAT[0]
R-0		R-0	R-0

LEGEND: R = Read only; -*n* = value after reset

Table 9-15. Power Domain Transition Status Register (PTSTAT) Field Descriptions

Bit	Field	Value	Description
31-2	Reserved	0	Reserved
1	GOSTAT[1]		RAM/Pseudo (PD1) power domain transition status.
		0	No transition in progress.
		1	RAM/Pseudo power domain is transitioning (that is, either the power domain is transitioning or modules in this power domain are transitioning).
0	GOSTAT[0]		Always ON (PD0) power domain transition status.
		0	No transition in progress.
		1	Modules in Always ON power domain are transitioning. Always On power domain is transitioning.

9.6.11 Power Domain 0 Status Register (PDSTAT0)

The power domain 0 status register (PDSTAT0) is shown in Figure 9-11 and described in Table 9-16.

Figure 9-11. Power Domain 0 Status Register (PDSTAT0)

31	16
Reserved	
R-0	

15	12	11	10	9	8	7	5	4	0
Reserved		EMUIHB	Rsvd	PORDONE	POR	Reserved		STATE	
R-0		R-0	R-0	R-0	R-0	R-0		R-0	

LEGEND: R = Read only; -*n* = value after reset

Table 9-16. Power Domain 0 Status Register (PDSTAT0) Field Descriptions

Bit	Field	Value	Description
31-12	Reserved	0	Reserved
11	EMUIHB		Emulation alters domain state.
		0	Interrupt is not active. No emulation altering user-desired power domain states.
		1	Interrupt is active. Emulation alters user-desired power domain state.
10	Reserved	0	Reserved
9	PORDONE		Power_On_Reset (POR) Done status
		0	Power domain POR is not done.
		1	Power domain POR is done.
8	POR		Power Domain Power_On_Reset (POR) status. This bit reflects the POR status for this power domain including all modules in the domain.
		0	Power domain POR is asserted.
		1	Power domain POR is de-asserted.
7-5	Reserved	0	Reserved
4-0	STATE	0-1Fh	Power Domain Status.
		0	Power domain is in the off state.
		1h	Power domain is in the on state.
		2h-Fh	Reserved
		10h-1Ah	Power domain is in transition.
		1Bh-1Fh	Reserved

9.6.12 Power Domain 1 Status Register (PDSTAT1)

The power domain 1 status register (PDSTAT1) is shown in Figure 9-12 and described in Table 9-17.

Figure 9-12. Power Domain 1 Status Register (PDSTAT1)

31	16
Reserved	
R-0	

15	12	11	10	9	8	7	5	4	0
Reserved		EMUIHB	Rsvd	PORDONE	POR	Reserved		STATE	
R-0		R-0	R-0	R-0	R-0	R-0		R-0	

LEGEND: R = Read only; -*n* = value after reset

Table 9-17. Power Domain 1 Status Register (PDSTAT1) Field Descriptions

Bit	Field	Value	Description
31-12	Reserved	0	Reserved
11	EMUIHB		Emulation alters domain state.
		0	Interrupt is not active. No emulation altering user-desired power domain states.
		1	Interrupt is active. Emulation alters user-desired power domain state.
10	Reserved	0	Reserved
9	PORDONE		Power_On_Reset (POR) Done status
		0	Power domain POR is not done.
		1	Power domain POR is done.
8	POR		Power Domain Power_On_Reset (POR) status. This bit reflects the POR status for this power domain including all modules in the domain.
		0	Power domain POR is asserted.
		1	Power domain POR is de-asserted.
7-5	Reserved	0	Reserved
4-0	STATE	0-1Fh	Power Domain Status.
		0	Power domain is in the off state.
		1h	Power domain is in the on state.
		2h-Fh	Reserved
		10h-1Ah	Power domain is in transition.
		1Bh-1Fh	Reserved

9.6.13 Power Domain 0 Control Register (PDCTL0)

The power domain 0 control register (PDCTL0) is shown in Figure 9-13 and described in Table 9-18.

Figure 9-13. Power Domain 0 Control Register (PDCTL0)

31	24	23	16
Reserved		WAKECNT	
R-0		R/W-1Fh	

15	12	11	10	9	8	7	1	0
PDMODE		Reserved		EMUIHBIE	Rsvd	Reserved		NEXT
R-Fh		R-0		R/W-0	R-1	R-0		R/W-1

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 9-18. Power Domain 0 Control Register (PDCTL0) Field Descriptions

Bit	Field	Value	Description
31-24	Reserved	0	Reserved
23-16	WAKECNT	0-FFh	RAM wake count delay value. Not recommended to change the default value (1Fh). Bits 23-30: GOOD2ACCESS wake delay. Bits 19-16: ON2GOOD wake delay.
15-12	PDMODE	0-Fh	Power down mode.
		0-Eh	Reserved
		Fh	Core on, RAM array on, RAM periphery on.
11-10	Reserved	0	Reserved
9	EMUIHBIE		Emulation alters power domain state interrupt enable.
		0	Disable interrupt.
		1	Enable interrupt.
8	Reserved	1	Reserved
7-1	Reserved	0	Reserved
0	NEXT		Power domain next state. For Always ON power domain this bit is read/write, but writes have no effect since internally this power domain always remains in the on state.
		0	Power domain off.
		1	Power domain on.

9.6.14 Power Domain 1 Control Register (PDCTL1)

The power domain 1 control register (PDCTL1) is shown in Figure 9-14 and described in Table 9-19.

Figure 9-14. Power Domain 1 Control Register (PDCTL1)

31	24	23	16
Reserved		WAKECNT	
R-0		R/W-1Fh	

15	12	11	10	9	8	7	1	0
PDMODE		Reserved		EMUIHBIE	Rsvd	Reserved		NEXT
R-Fh		R-0		R/W-0	R-1	R-0		R/W-1

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 9-19. Power Domain 1 Control Register (PDCTL1) Field Descriptions

Bit	Field	Value	Description
31-24	Reserved	0	Reserved
23-16	WAKECNT	0-FFh	RAM wake count delay value. Not recommended to change the default value (1Fh). Bits 23-30: GOOD2ACCESS wake delay. Bits 19-16: ON2GOOD wake delay.
15-12	PDMODE	0-Fh	Power down mode.
		0	Core off, RAM array off, RAM periphery off.
		1h	Core off, RAM array retention, RAM periphery off (deep sleep).
		2h-3h	Reserved
		4h	Core retention, RAM array off, RAM periphery off.
		5h	Core retention, RAM array retention, RAM periphery off (deep sleep).
		6h-7h	Reserved
		8h	Core on, RAM array off, RAM periphery off.
		9h	Core on, RAM array retention, RAM periphery off (deep sleep).
		Ah	Core on, RAM array retention, RAM periphery off (light sleep).
		Bh	Core on, RAM array retention, RAM periphery on.
		Ch-Eh	Reserved
		Fh	Core on, RAM array on, RAM periphery on.
11-10	Reserved	0	Reserved
9	EMUIHBIE		Emulation alters power domain state interrupt enable.
		0	Disable interrupt.
		1	Enable interrupt.
8	Reserved	1	Reserved
7-1	Reserved	0	Reserved
0	NEXT		User-desired power domain next state.
		0	Power domain off.
		1	Power domain on.

9.6.15 Power Domain 0 Configuration Register (PDCFG0)

The power domain 0 configuration register (PDCFG0) is shown in Figure 9-15 and described in Table 9-20.

Figure 9-15. Power Domain 0 Configuration Register (PDCFG0)

31	16
Reserved	
R-0	

15	4	3	2	1	0
Reserved		PD_LOCK	ICEPICK	RAM_PSM	ALWAYSON
R-0		R-1	R-1	R-0	R-1

LEGEND: R = Read only; -*n* = value after reset

Table 9-20. Power Domain 0 Configuration Register (PDCFG0) Field Descriptions

Bit	Field	Value	Description
31-4	Reserved	0	Reserved
3	PD_LOCK		PDCTL.NEXT lock. For Always ON power domain this bit is a don't care.
		0	PDCTL.NEXT bit is locked and cannot be changed in software.
		1	PDCTL.NEXT bit is not locked.
2	ICEPICK		IcePick support.
		0	Not present
		1	Present
1	RAM_PSM		RAM power domain.
		0	Not a RAM power domain.
		1	RAM power domain.
0	ALWAYSON		Always ON power domain.
		0	Not an Always ON power domain.
		1	Always ON power domain.

9.6.16 Power Domain 1 Configuration Register (PDCFG1)

The power domain 1 configuration register (PDCFG1) is shown in Figure 9-16 and described in Table 9-21.

Figure 9-16. Power Domain 1 Configuration Register (PDCFG1)

31	16
Reserved	
R-0	

15	4	3	2	1	0
Reserved		PD_LOCK	ICEPICK	RAM_PSM	ALWAYSON
R-0		R-1	R-1	R-0	R-1

LEGEND: R = Read only; -*n* = value after reset

Table 9-21. Power Domain 1 Configuration Register (PDCFG1) Field Descriptions

Bit	Field	Value	Description
31-4	Reserved	0	Reserved
3	PD_LOCK		PDCTL.NEXT lock. For Always ON power domain this bit is a don't care.
		0	PDCTL.NEXT bit is locked and cannot be changed in software.
		1	PDCTL.NEXT bit is not locked.
2	ICEPICK		IcePick support.
		0	Not present
		1	Present
1	RAM_PSM		RAM power domain.
		0	Not a RAM power domain.
		1	RAM power domain.
0	ALWAYSON		Always ON power domain.
		0	Not an Always ON power domain.
		1	Always ON power domain.

9.6.17 Module Status *n* Register (MDSTAT*n*)

The module status *n* register (MDSTAT*n*) is shown in Figure 9-17 and described in Table 9-22.

Figure 9-17. Module Status *n* Register (MDSTAT*n*)

31	18	17	16
Reserved		EMUIHB	EMURST
R-0		R-0	R-0

15	13	12	11	10	9	8	7	6	5	0
Reserved		MCKOUT	Rsvd	MRST	LRSTDONE	LRST	Reserved		STATE	
R-0		R-0	R-1	R-0	R-1	R-1	R-0		R-0	

LEGEND: R = Read only; -*n* = value after reset

Table 9-22. Module Status *n* Register (MDSTAT*n*) Field Descriptions

Bit	Field	Value	Description
31-18	Reserved	0	Reserved
17	EMUIHB		Emulation alters module state. This bit applies to ARM module (module 14) and DSP module (module 15). This field is 0 for all other modules.
		0	No emulation altering user-desired module state programmed in the NEXT bit in the module control 14 register (MDCTL14) and the module control 15 register (MDCTL15).
		1	Emulation altered user-desired state programmed in the NEXT bit in MDCTL14 and MDCTL15. If you desire to generate a PSCINT upon this event, you must set the EMUIHBIE bit in MDCTL14 and MDCTL15.
16	EMURST		Emulation alters module reset. This bit applies to ARM module (module 14) and DSP module (module 15). This field is 0 for all other modules.
		0	No emulation altering user-desired module reset state.
		1	Emulation altered user-desired module reset state. If you desire to generate a PSCINT upon this event, you must set the EMURSTIE bit in the module control 14 register (MDCTL14) and the module control 15 register (MDCTL15).
15-13	Reserved	0	Reserved
12	MCKOUT		Module clock output status. Shows status of module clock.
		0	Module clock is off.
		1	Module clock is on.
11	Reserved	1	Reserved
10	MRST		Module reset status. Reflects actual state of module reset.
		0	Module reset is asserted.
		1	Module reset is de-asserted.
9	LRSTDONE		Local reset done. Software is responsible for checking if local reset is done before accessing this module. This bit applies to ARM module (module 14) and DSP module (module 15). This field is 1 for all other modules.
		0	Local reset is not done.
		1	Local reset is done.
8	LRST		Module local reset status. This bit applies to ARM module (module 14) and DSP module (module 15).
		0	Local reset is asserted.
		1	Local reset is de-asserted.
7-6	Reserved	0	Reserved
5-0	STATE	0-3Fh	Module state status: indicates current module status.
		0	SwRstDisable state
		1h	SyncReset state
		2h	Disable state
		3h	Enable state
		4h-3Fh	Indicates transition

9.6.18 PSC0 Module Control *n* Register (modules 0-15) (MDCTL*n*)

The PSC0 module control *n* register (MDCTL*n*) is shown in Figure 9-18 and described in Table 9-23.

Figure 9-18. PSC0 Module Control *n* Register (MDCTL*n*)

31	30	16
FORCE	Reserved	
R/W-0	R-0	

15	11	10	9	8	7	3	2	0
Reserved		EMUIHBIE	EMURSTIE	LRST	Reserved		NEXT	
R-0		R/W-0	R/W-0	R/W-0	R-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 9-23. PSC0 Module Control *n* Register (MDCTL*n*) Field Descriptions

Bit	Field	Value	Description
31	FORCE		Force enable. This bit forces the module state programmed in the NEXT bit in the module control 14 register (MDCTL14) and the module control 15 register (MDCTL15), ignoring and bypassing all the clock stop request handshakes managed by the PSC to change the state of the clocks to the module.
			Note: It is **not** recommended to use the FORCE bit to disable the module clock, unless specified.
		0	Force is disabled.
		1	Force is enabled.
30-11	Reserved	0	Reserved
10	EMUIHBIE		Interrupt enable for emulation alters module state. This bit applies to ARM module (module 14) and DSP module (module 15).
		0	Disable interrupt.
		1	Enable interrupt.
9	EMURSTIE		Interrupt enable for emulation alters reset. This bit applies to ARM module (module 14) and DSP module (module 15).
		0	Disable interrupt.
		1	Enable interrupt.
8	LRST		Module local reset control. This bit applies to ARM module (module 14) and DSP module (module 15).
		0	Assert local reset
		1	De-assert local reset
7-3	Reserved	0	Reserved
2-0	NEXT	0-3h	Module next state.
		0	SwRstDisable state
		1h	SyncReset state
		2h	Disable state
		3h	Enable state

9.6.19 PSC1 Module Control *n* Register (modules 0-31) (MDCTL*n*)

The PSC1 module control *n* register (MDCTL*n*) is shown in Figure 9-19 and described in Table 9-24.

Figure 9-19. PSC1 Module Control *n* Register (MDCTL*n*)

31	30	16
FORCE	Reserved	
R/W-0	R-0	

15	3	2	0
Reserved		NEXT	
R-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 9-24. PSC1 Module Control *n* Register (MDCTL*n*) Field Descriptions

Bit	Field	Value	Description
31	FORCE		Force enable. This bit forces the module state programmed in the NEXT bit in the module control 14 register (MDCTL14) and the module control 15 register (MDCTL15), ignoring and bypassing all the clock stop request handshakes managed by the PSC to change the state of the clocks to the module. Note: It is **not** recommended to use the FORCE bit to disable the module clock, unless specified.
		0	Force is disabled.
		1	Force is enabled.
30-3	Reserved	0	Reserved
2-0	NEXT	0-3h	Module next state.
		0	SwRstDisable state
		1h	SyncReset state
		2h	Disable state
		3h	Enable state

Power Management

Topic **Page**

10.1 Introduction

Power management is an important aspect for most embedded applications. For several applications and target markets, there may be a specific power budget and requirements to minimize power consumption for both power supply sizing and battery life considerations. Additionally, lower power consumption results in more optimal and efficient designs from cost, design, and energy perspectives. This device has several means of managing the power consumption. This chapter discusses the various power management features.

10.2 Power Consumption Overview

Power consumed by semiconductor devices has two components: dynamic and static. This can be shown as:

$Ptotal = P_{dynamic} + P_{static}$

The dynamic power is the power consumed to perform work when the device is in active modes (clocks applied, busses, and I/O switching), that is, analog circuits changing states. The dynamic power is defined by:

$P_{dynamic} = Capacitance \times Voltage^2 \times Frequency$

From the above formula, the dynamic power scales with the clock frequency (device/module frequency for core operations and switching frequency for I/O). Dynamic power can be reduced by controlling the clocks in such a way as to either operate at a clock setting just high enough to complete the required operation in the required timeline or to run at a clock setting until the work is complete and then drastically reduce the clock frequency or cut off the clocks until additional work must be performed.

In the formula, the dynamic power varies with the voltage squared, so the voltage of operations has significant impact on overall power consumption and, thus, on the battery life. Dynamic power can be reduced by scaling the operating voltage, when the performance requirements are not that high and the device can be operated at a corresponding lower frequency.

The capacitance is the capacitance of the switching nodes, or the load capacitances on the switching I/O pins.

The static power, as the name suggests, is independent of the switching frequency of the logic. It can be shown as:

$P_{static} = f_{(leakage\ current)}$

It is essentially a function of the “leakage”, or the power consumed by the logic when it is not switching or is not performing any work. Leakage current is dependent mostly on the manufacturing process used, the size of the die, etc. Leakage current is unavoidable while power is applied and scales roughly with the operating junction temperatures. Leakage power can only be avoided by removing power completely from a device or subsystem. The static power consumption plays a significant role in the Standby Modes (when the application is not running and in a dormant state) and plays an important role in the battery life for portable applications, etc.

10.3 PSC and PLLC Overview

The power and sleep controller (PSC) module plays an important role in managing the enabling/disabling of the clocks to the core and various peripheral modules. The PSC provides a granular support to turn on/off clocks on a module by module basis. Similarly, the PLL controller (PLLC) plays an important role in device and module clock generation, and manages the frequency scaling operations for the device. Together, both of these modules play a significant role in managing the clocks from a power management feature standpoint. For detailed information on the PSC, see the *Power and Sleep Controller (PSC)* chapter. For detailed information on the PLLC, see the *Device Clocking* chapter and the *Phase-Locked Loop Controller (PLLC)* chapter.

10.4 Features

This device has several means of managing power consumption, as detailed in the subsequent sections. This device uses the state-of-the-art 65 nm process, which provides a good balance on power and performance, providing high-performance transistors with relatively less leakage current and, thereby, low standby-power consumption modes.

There are several features in design as well as user driven software control to reduce dynamic power consumption. The design features (not under user control) include a power optimized clock tree design to reduce overall clock tree power consumption and automatic clock gating in several modules when the logic in the modules is not active.

The on-chip power and sleep controller (PSC) module provides granular software controlled module level clock gating, which reduces both clock tree and module power by basically disabling the clocks when the modules are not being used. Clock management also allows you to slow down the clocks, to reduce the dynamic power.

Table 10-1 describes the power management features.

Table 10-1. Power Management Features

Power Management	Description	Features
	Clock Management	
PLL power-down	The PLL can be powered-down and run in bypass modes when not in use.	Reduces the dynamic power consumption of the core.
Module clock ON/OFF	Module clocks can be turned on/off without requiring reconfiguring the registers.	Reduces the dynamic/switching power consumption of the core and I/O (if any free running I/O clocks).
Core/module clock frequency scaling	The device can be run at a lower frequency using the PLLM/PLL dividers. Many modules have internal clock dividers to scale module/IO frequency.	Reduces the dynamic/switching power consumption of core and I/O.
	Core Sleep Management	
ARM subsystem sleep modes	The ARM CPU can be put in sleep mode. Additionally, the ARM subsystem clock can be completely gated when not in use.	Reduces the dynamic power.
DSP subsystem sleep mode	The DSP CPU can be put in sleep (IDLE) mode. Additionally, the DSP subsystem clock can be completely gated when not in use.	Reduces the dynamic power.
	Voltage Management	
RTC-only mode	Allows removing power from all core and I/O supply and just have the real-time clock (RTC) running.	Reduces the dynamic and static power for standby modes that require only the RTC to be functional.
	Peripheral I/O Power Management	
USB Phy power-down	The USB2.0 Phy can be powered-down.	Minimizes USB2.0 I/O power consumption when not in use.

10.5 Clock Management

10.5.1 Module Clock ON/OFF

The module clock on/off feature allows software to disable clocks to module individually, in order to reduce the module's dynamic/switching power consumption down to zero. This device is designed in full static CMOS; thus, when a module clock stops, the module's state is preserved and retained. When the clock is restarted, the module resumes operating from the stopping point.

NOTE: Stopping clocks to a module only affects dynamic power consumption, it does not affect static power consumption of the module or the device.

The power and sleep controller (PSC) module controls module clock gating. If a module's clock(s) is stopped while being accessed, the access may not occur, and it can potentially result in unexpected behavior. The PSC provides some protection against such erroneous conditions by monitoring the internal bus activity to ensure there are no accesses to the module from the internal bus, before allowing module's internal clock to be gated. However, it is still recommended that software must ensure that all of the transactions to the module are finished prior to disabling the clocks.

The procedure to turn module clocks on/off using the PSC is described in the *Power and Sleep Controller (PSC)* chapter.

Furthermore, special consideration must be given to DSP/ARM clock on/off. The procedure to turn the core clock on/off is further described in Section 10.7.4.

Additionally some peripherals implement additional power saving features by automatically shutting of clock to components within the module , when the logic is not active. This is transparent to you, but reduces overall dynamic power consumption when modules are not active.

10.5.2 Module Clock Frequency Scaling

Module clock frequency is scalable by programming the PLL multiply and divide parameters. Additionally, some modules might also have internal clock dividers. Reducing the clock frequency reduces the dynamic/switching power consumption, which scales linearly with frequency.

The *Device Clocking* chapter details the clocking structure of the device. The *Phase-Locked Loop Controller (PLLC)* chapter describes how to program the PLL0 and PLL1 frequency and the frequency constraints.

10.5.3 PLL Bypass and Power Down

You can bypass the PLL in the device. Bypassing the PLL sends the PLL reference clock (OSCIN) instead of the PLL VCO output (PLLOUT) to the system clocks of the PLLC. The PLL OSCIN is typically, at most, up to 50 MHz. You can use this mode to reduce the core and module clock frequencies to very low maintenance levels without using the PLL during periods of very low system activity, this again can lower the overall dynamic/switching power consumption, which is linearly proportional to the frequency. Furthermore, you can also power-down the PLL when bypassing it to minimize the overall power consumed by the PLL module.

The *Device Clocking* chapter and the *Phase-Locked Loop Controller (PLLC)* chapter describe PLL bypass and PLL power down.

10.6 ARM Sleep Mode Management

10.6.1 ARM Wait-For-Interrupt Sleep Mode

The ARM module can be put into a low-power state using a special sleep mode called wait-for-interrupt (WFI). When the wait-for-interrupt mode is enabled, all internal clocks within the ARM9 module are shut off, the core is completely inactive and only resumes operation after receiving an interrupt. This is a feature for dynamic power management of the ARM processor itself, it does not impact the static power.

NOTE: To enable the WFI mode, the ARM needs to be in supervisor mode.

You can enable the WFI mode via the CP15 register #7 using the following instruction:

- MCR p15, #0, <Rd>, c7, c0, #4

Once the ARM module transitions into the WFI mode, it will remain in this state until an interrupt request (IRQ/FIQ) occurs.

The following sequence exemplifies how to enter the WFI mode:

- Enable any interrupt (for example, an external interrupt) that you plan to use as the wake-up interrupt to exit from the WFI mode.
- Enable the WFI mode using the following CP15 instruction:
  - MCR p15, #0, r3, c7, c0, #4

The following sequence describes the procedure to wake-up from the WFI mode:

- To wake-up from the WFI mode, trigger any enabled interrupt (for example, an external interrupt).
- The ARM's PC jumps to the IRQ/FIQ vector and you must handle the interrupt in an interrupt service routine (ISR).

Exit the ISR and continue normal program execution starting from the instruction immediately following the instruction that enabled the WFI mode.

NOTE: The ARM interrupt controller (AINTC) and the module sourcing the wake-up interrupt (for example, GPIO or watchdog timer) must not be disabled, or the device will never wake up.

For more information on this sleep mode, see the ARM926EJ-S Technical Reference Manual (TRM), downloadable from http://infocenter.arm.com/help/index.jsp.

10.6.2 ARM Subsystem Clock OFF

The software must be structured such that no peripheral is allowed to access the ARM resources before disabling the clocks to the ARM subsystem. The ARM must check for the completion of all its master peripheral initiated requests (that is, CFG and DMA port operations, etc.). The DSP must check for the completion of all transactions initiated by it and the peripherals controls by it to the ARM resources.

ARM module clock off sequence:

1. The DSP stops all masters from accessing the ARM and ARM memory.
2. The DSP polls all masters for write-completion status (or wait *n* number of cycles, if the transfer completion status is not implemented).
3. The ARM must have the ARM Clock Stop Request interrupt (ARMCLKSTOPREQ, ARM interrupt # 90) enabled and the associated interrupt service routine (ISR) set up before the DSP initiates the following ARM clock shutdown procedure.
   (a) Initiate the ARM clock off sequence by issuing the ARM clock stop command (PSC DISABLE Command) to the ARM subsystem by writing a 2h to the NEXT bit field in the ARM local power sleep controller (LPSC) module control register (PSC0.MDCTL14).
   (b) Write a 1 to the GO[0] bit (ARM subsystem is part of the PD_ALWAYSON domain) in the power domain transition command register (PSC0.PTCMD) to start the state transition sequence for the ARM module. This generates the ARMCLKSTOPREQ interrupt to the ARM.
   (c) Check (poll for 0) the GOSTAT[0] bit in the power domain transition status register (PSC0.PTSTAT) for power transition sequence completion. The GOSTAT[0] bit transitions to 0 when the ARM executes the wait-for-interrupt instruction from inside its interrupt service routine (ISR).
   (d) Check (poll for 2h) the STATE bit field in the ARM LPSC module status register (PSC0.MDSTAT14) indicating the ARM clock stop sequence completion (STATE: Disable).

The following sequence should be executed by the ARM within the ARM clock stop request interrupt ISR:

1. Check for completion of all ARM master requests (the ARM polls transfer completion statuses of all Master peripherals).
2. Enable the interrupt to be used as “wake-up” interrupt (for example, one of the CHIPSIG interrupts controlled by the chip signal register (CHIPSIG) in the system configuration (SYSCFG) module—CHIPSIG[0], CHIPSIG[1], etc.) that will be used to wake-up the ARM during the ARM clock-on sequence.
3. Execute the wait-for-interrupt (WFI) ARM instruction.

10.6.3 ARM Subsystem Clock ON

The ARM module defaults to the SwRstDisable state; therefore, the DSP side software is responsible for enabling the clock and releasing the reset to the ARM at power-on reset. If the DSP has put the ARM in the clock off/Disable state, the following clock on sequence is applicable only when it is required to wake-up the ARM. Perform the following sequence for the DSP to enable clocks to the ARM:

1. Wait for the GOSTAT[0] bit in the power domain transition status register (PSC0.PTSTAT) to clear to 0. You must wait for the power domain to finish any previously initiated transitions before initiating a new transition.
2. Write a 3h to the NEXT bit in the ARM local power sleep controller (LPSC) module control register (PSC0.MDCTL14) to prepare the ARM module for an enable transition.
3. Write a 1 to the GO[0] bit (ARM subsystem is part of the PD_ALWAYSON domain) in the power domain transition command register (PSC0.PTCMD) to start the state transition sequence for the ARM module.
4. Check (poll for 0) the GOSTAT[0] bit in PSC0.PTSTAT for power transition sequence completion. The domain is only safely in the new state after the GOSTAT[0] bit is cleared to 0.
5. Wait for the STATE bit field in the ARM LPSC module status register (PSC0.MDSTAT14) to change to 3h. The module is only safely in the new state after the STATE bit field changes to reflect the new state.

NOTE: This only applies if you are transitioning from the Disable state. If previously in the Disable state, a wake-up interrupt must be triggered in order to wake the ARM (to exit the wait-for-interrupt mode). This example assumes that the ARM enabled this interrupt before entering its wait-for-interrupt sleep mode state.

For the DSP to wake the ARM if transitioning from the Disable state, trigger an ARM interrupt that has previously been configured as a wake-up interrupt.

10.7 DSP Sleep Mode Management

10.7.1 DSP Sleep Modes

The C674x megamodule has an internal power down controller (PDC) module that provides additional power management features in addition to clock management control provided by the device-level power and sleep controller (PSC) module. For information on the PDC module, see the *TMS320C674x DSP Megamodule Reference Guide* (SPRUFK5).

10.7.2 C674x DSP CPU Sleep Mode

The DSP CPU can be put in a low-power state by executing the IDLE instruction. For information on the IDLE instruction, see the *TMS320C674x DSP CPU and Instruction Set Reference Guide* (SPRUFE8).

10.7.3 C674x Megamodule Sleep Mode

The IDLE instruction is used as part of the procedure for shutting down the entire C674x megamodule, by the power-down controller (PDC) module. In shutting down the entire C674x megamodule, the PDC can internally clock gate off the following components of the megamodule and internal memories of the DSP subsystem:

- C674x CPU
- Level 1 Program Memory Controller (PMC)
- Level 1 Data Memory Controller (DMC)
- Level 2 Unified Memory Controller (UMC)
- Extended Memory Controller (EMC)
- L1P Memory
- L1D Memory
- L2 Memory

Putting the entire C674x megamodule into the low-power sleep mode is typically more useful and saves a lot more power, as compared to just executing the IDLE instruction to put only the CPU in idle mode.

For information on putting the C674x megamodule in the low-power mode using the PDC, see the *TMS320C674x DSP Megamodule Reference Guide* (SPRUFK5).

10.7.4 C674x Megamodule Clock ON/OFF

The C674x megamodule can clock gate its own components to save power. Additional power saving can be achieved by stopping the clock sourced (PLL output) to the C674x megamodule by programming the power and sleep controller (PSC) module to place the megamodule in the Disable state. The DSP cannot perform this programming task on its own, because the DSP will not be able to complete the PSC programming sequence if its clock source is gated in the middle of the process.

If additional power saving is desired (more then just power savings obtained by using the power down controller), then you can choose to disable the clock to the DSP using the PSC. The ARM is responsible for programming the PSC to disable the clock going to the C674x megamodule at the root level (stopping SYSCLK1 at the PLL output). By clock gating the megamodule at the root, this enables saving additional clock tree power (for the path from the PLL to the megamodule boundary). The ARM is also responsible for programming the PSC to enable the C674x megamodule.

10.7.4.1 C674x Megamodule Clock OFF

The software must be structured such that no peripheral is allowed to access the DSP resources before disabling the DSP clocks. The DSP must check for the completion of all its master peripheral initiated requests (that is, IDMA, MDMA, EDMA, cache operations, etc.). The ARM must check for the completion of all transactions initiated by it and the peripherals controls by it to the DSP resources.

1. The ARM stops all masters from accessing the DSP and DSP memory.
2. The ARM polls all masters for write-completion status (or wait *n* number of cycles, if the transfer completion status is not implemented).
3. The DSP must have the power-down controller interrupt PDC_INT (DSP interrupt #118) enabled and the PDC interrupt service routine (ISR) set up before the ARM initiates the following DSP clock shutdown procedure.
   (a) Initiate the DSP clock off sequence by issuing the DSP clock stop command (PSC DISABLE Command) to the DSP subsystem by writing a 2h to the NEXT bit field in the DSP local power sleep controller (LPSC) module control register (PSC0.MDCTL15).
   (b) Write a 1 to the GO[1] bit (DSP subsystem is part of the PD_DSP domain) in the power domain transition command register (PSC0.PTCMD) to start the state transition sequence for the DSP module. This generates the PDC_INT interrupt to the DSP.
   (c) Check (poll for 0) the GOSTAT[1] bit in the power domain transition status register (PSC0.PTSTAT) for power transition sequence completion. The GOSTAT[1] bit transitions to 0 when the DSP executes the IDLE instruction from inside its interrupt service routine (ISR).
   (d) Check (poll for 2h) the STATE bit field in the DSP LPSC module status register (PSC0.MDSTAT15) indicating the DSP clock stop sequence completion (STATE: Disable).

The following sequence should be executed by the DSP within the PDC interrupt ISR:

1. Check for completion of all DSP master requests (the DSP polls transfer completion statuses of all Master peripherals).
2. Enable the interrupt to be used as “wake-up” interrupt (for example, one of the CHIPSIG interrupts controlled by the chip signal register (CHIPSIG) in the system configuration (SYSCFG) module—CHIPSIG[2], CHIPSIG[3], or CHIPSIG[4]/NMI interrupt) that will be used to wake-up the DSP during the DSP clock-on sequence.

NOTE: The power-down command register (PDCCMD) in the power-down controller (PDC) can only be written while the DSP is in Supervisor mode.

3. Write a 0001 5555h to PDCCMD.
4. Execute the IDLE instruction.

10.7.4.2 C674x Megamodule Clock ON

The C674x megamodule defaults to the Enable state; therefore, the DSP subsystem clock is on, and the following sequence is typically not needed. This clock on sequence is only required to wake-up the DSP, if the ARM put the DSP in a clock off state. Perform the following sequence for the ARM to enable clocks to the DSP:

1. Wait for the GOSTAT[1] bit in the power domain transition status register (PSC0.PTSTAT) to clear to 0. You must wait for the power domain to finish any previously initiated transitions before initiating a new transition.
2. Write a 3h to the NEXT bit field in the DSP local power sleep controller (LPSC) module control register (PSC0.MDCTL15) to prepare the DSP module for an enable transition.
3. Write a 1 to the GO[1] bit (DSP subsystem is part of the PD_DSP domain) in the power domain transition command register (PSC0.PTCMD) to start the state transition sequence for the DSP module.
4. Check (poll for 0) the GOSTAT[1] bit in PSC0.PTSTAT for power transition sequence completion. The domain is only safely in the new state after the GOSTAT[1] bit is cleared to 0.
5. Wait for the STATE bit field in the DSP LPSC module status register (PSC0.MDSTAT15) to change to 3h. The module is only safely in the new state after the STATE bit field changes to reflect the new state.

NOTE: This only applies if you are transitioning from the Disable state. If previously in the Disable state, a wake-up interrupt must be triggered in order to wake the DSP. This example assumes that the DSP enabled this interrupt before entering its IDLE state. See the *DSP Subsystem* chapter for more information on DSP interrupts.

For the ARM to wake the DSP if transitioning from the Disable state, trigger a DSP interrupt that has previously been configured as a wake-up interrupt.

10.8 RTC-Only Mode

NOTE: To put the device in RTC-only mode, there is no software control sequence. You can put the device in the RTC-only mode by removing the power supply from all core and I/O logic, except for the RTC core logic supply (RTC_CVDD).

When the rest of device is powered off, there is no up mechanism from the RTC logic to wake-up the rest of the chip or signal the external power supply on when to reapply the power. If the device is put in the RTC-only mode, then external control/decision making logic would be required to reapply power to the device.

In real-time clock (RTC)-only mode, the RTC is powered on and the rest of the device can be completely powered off (core and I/O voltage removed). In this mode, the RTC is fully functional and keeps track of date, hours, minutes, and seconds. In this mode, the overall power consumption would be significantly lower, as voltage from the rest of the core and I/O logic can be completely removed, eliminating most of the active and static power of the device, except for what is consumed by the RTC module, running at 32 kHz.

10.9 Additional Peripheral Power Management Considerations

This section lists additional power management features and considerations that might be part of other chip-level or peripheral logic, apart from the features supported by the core, PLL controller (PLLC), and power and sleep controller (PSC).

10.9.1 USB PHY Power Down Control

The USB modules can be clock gated using the PSC; however, this does not power down/clock gate the PHY logic. You can put the USB2.0 PHY and OTG module in the lowest power state, when not in use, by writing to the USB0PHYPWDN and the USB0OTGPWRDN bits in the chip configuration 2 register (CFGCHIP2) of the system configuration (SYSCFG) module.

NOTE: If the USB1.1 subsystem is used and the 48 MHz clock input is sourced from the USB2.0 PHY, then the USB2.0 PHY should not be powered down.

10.9.2 EMIFB Memory Clock Gating

As discussed in the *Device Clocking* chapter, the EMIFB output clock (EMB_CLK) can be sourced from either the output of the EMIFB LPSC (CLK1) or directly from the output of the clock multiplexer (CLK2). If the EMB_CLK is not intended to be used as a free-running clock and the EMIFB is being used as an SDRAM interface, it is recommended to use CLK1 as the source, as it allows maximal power savings (clock gating both VCLK/MCLK and EMB_CLK signal) via the PSC.

System Configuration (SYSCFG) Module

Topic **Page**

11.1 Introduction

The system configuration (SYSCFG) module is a system-level module containing status and top level control logic required by the device. The system configuration module consists of a set of memory-mapped status and control registers, accessible by the CPU, supporting all of the following system features, and miscellaneous functions and operations.

- Device Identification
- Device Configuration
  - Pin multiplexing control
  - Device Boot Configuration Status
- Master Priority Control
  - Controls the system priority for all master peripherals (including EDMA3TC)
- Emulation Control
  - Emulation suspend control for peripherals that support the feature
- Special Peripheral Status and Control
  - Locking of PLL control settings
  - Default burst size configuration for EDMA3 transfer controllers
  - Event source selection for the eCAP peripheral input capture
  - McASP AMUTEIN selection and clearing of AMUTE
  - USB PHY Control
  - Clock source selection for EMIFA and EMIFB
  - HPI Control
- ARM-DSP Integration
  - On-chip inter-processor interrupts and status for signaling between ARM and DSP

The system configuration module controls several global operations of the device; therefore, the module supports protection against erroneous and illegal accesses to the registers in its memory-map. The protection mechanisms that are present in the module are:

- A special key sequence that needs to be written into a set of registers in the system configuration module, to allow write ability to the rest of registers in the system configuration module.
- Several registers in the module are only accessible when the CPU requesting read/write access is in privileged mode.

11.2 Protection

Table 11-1 provides the list of registers in the SYSCFG module; it also indicates whether a particular register can be accessed only when the CPU is in privileged mode. See Section 11.5 for a description of these registers.

Table 11-1. System Configuration (SYSCFG) Module Register Access

Offset	Acronym	Register Description	Access
0h	REVID	Revision Identification Register	—
8h-14h	DIEIDR0-DIEIDR3	Die Identification 0-3 Registers	—
18h	DEVIDR0	Device Identification Register 0	—
20h	BOOTCFG	Boot Configuration Register	Privileged mode
24h	CHIPREVID	Silicon Revision Identification Register	Privileged mode
38h	KICK0R	Kick 0 Register	Privileged mode
3Ch	KICK1R	Kick 1 Register	Privileged mode
40h	HOST0CFG	Host 0 Configuration Register	—
44h	HOST1CFG	Host 1 Configuration Register	—
E0h	IRAWSTAT	Interrupt Raw Status/Set Register	Privileged mode
E4h	IENSTAT	Interrupt Enable Status/Clear Register	Privileged mode
E8h	IENSET	Interrupt Enable Register	Privileged mode
ECh	IENCLR	Interrupt Enable Clear Register	Privileged mode
F0h	EOI	End of Interrupt Register	Privileged mode
F4h	FLTADDRR	Fault Address Register	Privileged mode
F8h	FLTSTAT	Fault Status Register	—
110h-118h	MSTPRI0-MSTPRI2	Master Priority 0-2 Registers	Privileged mode
120h-16Ch	PINMUX0-PINMUX19	Pin Multiplexing Control 0-19 Registers	Privileged mode
170h	SUSPSRC	Suspend Source Register	Privileged mode
174h	CHIPSIG	Chip Signal Register	—
178h	CHIPSIG_CLR	Chip Signal Clear Register	—
17Ch-18Ch	CFGCHIP0-CFGCHIP4	Chip Configuration 0-4 Registers	Privileged mode

11.2.1 Requirements to Access SYSCFG Registers

As mentioned previously, the SYSCFG module controls several global operations of the device; therefore, it has protection mechanism that prevents spurious and illegal accesses to the registers in its memory map. The protection mechanism enables accesses to these registers only if certain conditions are met. The protection mechanisms that are present in the module are described in the following sections.

11.2.1.1 Privilege Mode Protection

The CPU supports two privilege levels: Supervisor and User. Several registers in the SYSCFG memory-map can only be accessed when the accessing host (CPU or master peripheral) is operating in privileged mode, that is, in Supervisor mode. The registers that can only be accessed in privileged mode are listed in Section 11.5. See the *TMS320C674x DSP CPU and Instruction Set Reference Guide* (SPRUFE8) and the ARM926EJ-S Technical Reference Manual (TRM), downloadable from http://infocenter.arm.com/help/index.jsp for details on privilege levels.

11.2.1.2 Kicker Mechanism Protection

NOTE: The Kick 0 and Kick 1 registers can only be accessed in privileged mode (the host needs to be in Supervisor mode). Any number of accesses may be performed to the SYSCFG module, while the module is unlocked.

The SYSCFG module remains unlocked after the unlock sequence, until locked again. Locking the module is accomplished by writing any value other then the key values to either KICK0 or KICK1.

To access any registers in the SYSCFG module, it is required to follow a special sequence of writes to the Kick registers (Kick0 and Kick1) with correct key values. Writing the correct key value to the kick registers unlocks the registers in the SYSCFG memory-map. In order to access the SYSCFG registers, the following unlock sequence needs to be executed in software:

1. Write the key value of 83E7 0B13h to Kick 0 register.
2. Write the key value of 95A4 F1E0h to Kick 1 register.

After steps 1 and 2, the SYSCFG module registers are accessible and can be configured as per the application requirements.

11.3 Master Priority Control

The on-chip peripherals/modules are essentially divided into two broad categories, masters and slaves. The master peripherals are typically capable of initiating their own read/write data access requests, this includes the ARM, DSP, EDMA3 transfer controllers, and peripherals that do not rely on the CPU or EDMA3 for initiating the data transfer to/from them. In order to determine allowed connection between masters and slave, each master request source must have a unique master ID (mstid) associated with it. The master ID is shown in Table 11-2. See the device-specific data manual to determine the masters present on your device.

Each switched central resource (SCR) performs prioritization based on priority level of the master that sends the read/write requests. For all peripherals/ports classified as masters on the device, the priority is programmed in the master priority registers (MSTPRI0-3) in the SYSCFG modules. The default priority levels for each bus master is shown in Table 11-3. Application software is expected to modify these values to obtain the desired performance.

Table 11-2. Master IDs

Master ID	Peripheral
0	ARM - Instruction
1	ARM - Data
2	DSP MDMA
3	DSP CFG
4-7	Reserved
8	PRU0
9	PRU1
10	TPCC0
11-15	Reserved
16	TPTC0 - read
17	TPTC0 - write
18	TPTC1 - read
19	TPTC1 - write
20-33	Reserved
34	USB2.0 CFG
35	USB2.0 DMA
36	Reserved
37	HPI
38-63	Reserved
64	EMAC
65	USB1.1
66-95	Reserved
96	LCDC
97-255	Reserved

Table 11-3. Default Master Priority

Master	Default Priority [1]	Master Priority Register
PRU0	0	MSTPRI1
PRU1	0	MSTPRI1
EDMA3TC0[2]	0	MSTPRI1
EDMA3TC1	0	MSTPRI1
ARM - Instruction	2	MSTPRI0
ARM - Data	2	MSTPRI0
DSP MDMA[3]	2	MSTPRI0
DSP CFG[4]	2	MSTPRI0
EMAC	4	MSTPRI2
USB2.0 CFG	4	MSTPRI2
USB2.0 DMA	4	MSTPRI2
USB1.1	4	MSTPRI2
LCDC [5]	5	MSTPRI2
HPI	6	MSTPRI2

(1) The default priority settings might not be optimal for all applications. The master priority should be changed from default based on application specific requirement, in order to get optimal performance and prioritization for masters moving data that is real time sensitive.
(2) The priority for EDMA3TC0 and EDMA3TC1 is configurable through fields in MSTPRI1, not the EDMA3CC QUEPRI register.
(3) The priority for DSP MDMA and DSP CFG is controlled by fields in MSTPRI0 and not DSP.MDMAARBE.PRI (DSP Bandwidth manager module).
(4) The priority for DSP MDMA and DSP CFG is controlled by fields in MSTPRI0 and not DSP.MDMAARBE.PRI (DSP Bandwidth manager module).
(5) LCDC traffic is typically real-time sensitive, therefore, the default priority of 5, which is lower as compared to the default priority of several masters, is not recommended. You should reconfigure LCDC priority to the highest or equal to other high-priority masters in an application to ensure that throughput/latency requirements for LCDC are met.

11.4 Interrupt Support

11.4.1 Interrupt Events and Requests

The SYSCFG module generates two interrupts: an address error interrupt (BOOTCFG_ADDR_ERR) and a protection interrupt (BOOTCFG_PROT_ERR). The BOOTCFG_ADDR_ERR is generated when there is an addressing violation due to an access to a non-existent location in the SYSCFG register space. The BOOTCFG_PROT_ERR interrupt is generated when there is a protection violation of either in the defined ranges or to the SYSCFG registers. It is required to write a value of 0 to the end of interrupt register (EOI) after the software has processed the SYSCFG interrupt, this acts as an acknowledgement of completion of the SYSCFG interrupt so that the module can reliably generate subsequent interrupts.

The transfer parameters that caused the violation are saved in the fault address register (FLTADDRR) and the fault status register (FLTSTAT).

11.4.2 Interrupt Multiplexing

The interrupts from the SYSCFG module are combined with the interrupts from the MPU module into a single interrupt called MPU_BOOTCFG_ERR. The combined interrupt is routed to the ARM and DSP interrupt controllers.

11.4.3 ARM-DSP Communication Interrupts

The SYSCFG module also has a set of registers, the chip signal register (CHIPSIG) and the chip signal clear register (CHIPSIG_CLR), to facilitate interprocessor communication. This is generally used to allow the ARM and the DSP to coordinate. For example, the ARM may interrupt the DSP when it is ready to have the DSP process some data buffer in shared memory. A typical sequence, often referred to as ARM-DSP communication, is as follows:

1. ARM writes command in shared memory.
2. ARM interrupts DSP.
3. DSP responds to interrupt and reads command in shared memory.
4. DSP executes a task based on the command.
5. DSP interrupts ARM upon completion of the task.

Either of the processors can set specific bits in this SYSCFG register, which in turn can interrupt the other processor, if the interrupts have been appropriately enabled in the processor's interrupt controller.

11.5 SYSCFG Registers

Table 11-4 lists the memory-mapped registers for the system configuration module (SYSCFG).

Table 11-4. System Configuration Module (SYSCFG) Registers

Address	Acronym	Register Description	Section
01C1 4000h	REVID	Revision Identification Register	Section 11.5.1
01C1 4008h	DIEIDR0[(1)]	Die Identification Register 0	—
01C1 400Ch	DIEIDR1[(1)]	Die Identification Register 1	—
01C1 4010h	DIEIDR2[(1)]	Die Identification Register 2	—
01C1 4014h	DIEIDR3[(1)]	Die Identification Register 3	—
01C1 4018h	DEVIDR0	Device Identification Register 0	Section 11.5.2
01C1 4020h	BOOTCFG	Boot Configuration Register	Section 11.5.3
01C1 4024h	CHIPREVID	Silicon Revision Identification Register	Section 11.5.4
01C1 4038h	KICK0R	Kick 0 Register	Section 11.5.5.1
01C1 403Ch	KICK1R	Kick 1 Register	Section 11.5.5.2
01C1 4040h	HOST0CFG	Host 0 Configuration Register	Section 11.5.6
01C1 4044h	HOST1CFG	Host 1 Configuration Register	Section 11.5.7
01C1 40E0h	IRAWSTAT	Interrupt Raw Status/Set Register	Section 11.5.8.1
01C1 40E4h	IENSTAT	Interrupt Enable Status/Clear Register	Section 11.5.8.2
01C1 40E8h	IENSET	Interrupt Enable Register	Section 11.5.8.3
01C1 40ECh	IENCLR	Interrupt Enable Clear Register	Section 11.5.8.4
01C1 40F0h	EOI	End of Interrupt Register	Section 11.5.8.5
01C1 40F4h	FLTADDRR	Fault Address Register	Section 11.5.9.1
01C1 40F8h	FLTSTAT	Fault Status Register	Section 11.5.9.2
01C1 4110h	MSTPRI0	Master Priority 0 Register	Section 11.5.10.1
01C1 4114h	MSTPRI1	Master Priority 1 Register	Section 11.5.10.2
01C1 4118h	MSTPRI2	Master Priority 2 Register	Section 11.5.10.3
01C1 4120h	PINMUX0	Pin Multiplexing Control 0 Register	Section 11.5.11.1
01C1 4124h	PINMUX1	Pin Multiplexing Control 1 Register	Section 11.5.11.2
01C1 4128h	PINMUX2	Pin Multiplexing Control 2 Register	Section 11.5.11.3
01C1 412Ch	PINMUX3	Pin Multiplexing Control 3 Register	Section 11.5.11.4
01C1 4130h	PINMUX4	Pin Multiplexing Control 4 Register	Section 11.5.11.5
01C1 4134h	PINMUX5	Pin Multiplexing Control 5 Register	Section 11.5.11.6

(1) This register is for internal-use only.

Table 11-4. System Configuration Module (SYSCFG) Registers (continued)

Address	Acronym	Register Description	Section
01C1 4138h	PINMUX6	Pin Multiplexing Control 6 Register	Section 11.5.11.7
01C1 413Ch	PINMUX7	Pin Multiplexing Control 7 Register	Section 11.5.11.8
01C1 4140h	PINMUX8	Pin Multiplexing Control 8 Register	Section 11.5.11.9
01C1 4144h	PINMUX9	Pin Multiplexing Control 9 Register	Section 11.5.11.10
01C1 4148h	PINMUX10	Pin Multiplexing Control 10 Register	Section 11.5.11.11
01C1 414Ch	PINMUX11	Pin Multiplexing Control 11 Register	Section 11.5.11.12
01C1 4150h	PINMUX12	Pin Multiplexing Control 12 Register	Section 11.5.11.13
01C1 4154h	PINMUX13	Pin Multiplexing Control 13 Register	Section 11.5.11.14
01C1 4158h	PINMUX14	Pin Multiplexing Control 14 Register	Section 11.5.11.15
01C1 415Ch	PINMUX15	Pin Multiplexing Control 15 Register	Section 11.5.11.16
01C1 4160h	PINMUX16	Pin Multiplexing Control 16 Register	Section 11.5.11.17
01C1 4164h	PINMUX17	Pin Multiplexing Control 17 Register	Section 11.5.11.18
01C1 4168h	PINMUX18	Pin Multiplexing Control 18 Register	Section 11.5.11.19
01C1 416Ch	PINMUX19	Pin Multiplexing Control 19 Register	Section 11.5.11.20
01C1 4170h	SUSPSRC	Suspend Source Register	Section 11.5.12
01C1 4174h	CHIPSIG	Chip Signal Register	Section 11.5.13
01C1 4178h	CHIPSIG_CLR	Chip Signal Clear Register	Section 11.5.14
01C1 417Ch	CFGCHIP0	Chip Configuration 0 Register	Section 11.5.15
01C1 4180h	CFGCHIP1	Chip Configuration 1 Register	Section 11.5.16
01C1 4184h	CFGCHIP2	Chip Configuration 2 Register	Section 11.5.17
01C1 4188h	CFGCHIP3	Chip Configuration 3 Register	Section 11.5.18
01C1 418Ch	CFGCHIP4	Chip Configuration 4 Register	Section 11.5.19

11.5.1 Revision Identification Register (REVID)

The revision identification register (REVID) provides the revision information for the SYSCFG module. The REVID is shown in Figure 11-1 and described in Table 11-5.

Figure 11-1. Revision Identification Register (REVID)

31	0
REV	
R-4E84 0102h	

LEGEND: R = Read only; -*n* = value after reset

Table 11-5. Revision Identification Register (REVID) Field Descriptions

Bit	Field	Value	Description
31-0	REV	4E84 0102h	**Revision ID.** Revision information for the SYSCFG module.

11.5.2 Device Identification Register 0 (DEVIDR0)

The device identification register 0 (DEVIDR0) contains a software readable version of the JTAG ID device. Software can use this register to determine the version of the device on which it is executing. The DEVIDR0 is shown in Figure 11-2 and described in Table 11-6.

Figure 11-2. Device Identification Register 0 (DEVIDR0)

31	0
DEVID0	
R-0B7D F02Fh	

LEGEND: R = Read only; -*n* = value after reset

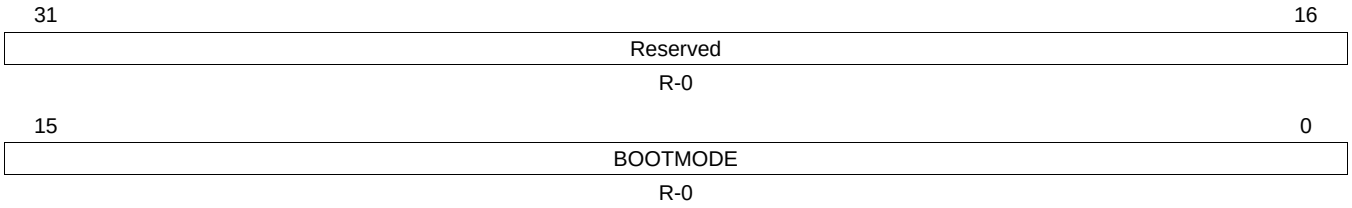
Table 11-6. Device Identification Register 0 (DEVIDR0) Field Descriptions

Bit	Field	Value	Description
31-0	DEVID0	R-0B7D F02Fh	Device identification.

11.5.3 Boot Configuration Register (BOOTCFG)

The device boot and configuration settings are latched at device reset, and captured in the boot configuration register (BOOTCFG). See the device-specific data manual and the *Boot Considerations* chapter for details on boot and configuration settings. The BOOTCFG is shown in Figure 11-3 and described in Table 11-7.

Figure 11-3. Boot Configuration Register (BOOTCFG)



LEGEND: R = Read only; -*n* = value after reset

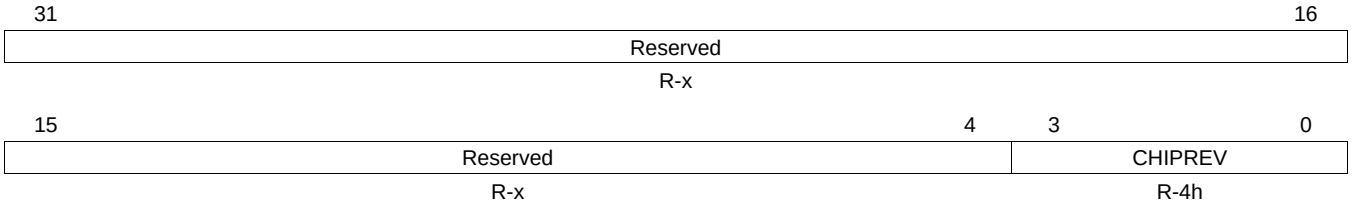
Table 11-7. Boot Configuration Register (BOOTCFG) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	Reserved
15-0	BOOTMODE	0-FFFFh	**Boot Mode.** This reflects the state of the boot mode pins.

11.5.4 Silicon Revision Identification Register (CHIPREVID)

The silicon revision identification register (CHIPREVID) provides software-readable silicon revision information for the device. The CHIPREVID is shown in Figure 11-4 and described in Table 11-8.

Figure 11-4. Silicon Revision Identification Register (CHIPREVID)



LEGEND: R = Read only; -*n* = value after reset; x = value is indeterminate after reset

Table 11-8. Silicon Revision Identification Register (CHIPREVID) Field Descriptions

Bit	Field	Value	Description
31-4	Reserved	0	Reserved
3-0	CHIPREV		**Identifies silicon revision of device.**
		0-3h	Older silicon revision
		4h	Silicon revision 3.0

11.5.5 Kick Registers (KICK0R-KICK1R)

The SYSCFG module has a protection mechanism to prevent any spurious writes from changing any of the modules memory-mapped registers. At power-on reset, none of the SYSCFG module registers are writeable (they are readable). To allow writing to the registers in the module, it is required to “unlock” the registers by writing to two memory-mapped registers in the SYSCFG module, Kick0 and Kick1, with exact data values. Once these values are written, then all the registers in the SYSCFG module that are writeable can be written to. See Section 11.2.1.2 for the exact key values and sequence of steps. Writing any other data value to either of these kick registers will cause the memory mapped registers to be “locked” again and block out any write accesses to registers in the SYSCFG module.

11.5.5.1 Kick 0 Register (KICK0R)

The KICK0R is shown in Figure 11-5 and described in Table 11-9.

Figure 11-5. Kick 0 Register (KICK0R)

31	0
KICK1	
R/W-0	

LEGEND: R/W = Read/Write; *-n* = value after reset

Table 11-9. Kick 0 Register (KICK0R) Field Descriptions

Bit	Field	Value	Description
31-0	KICK0	0-FFFF FFFFh	**KICK0R allows writing to unlock the kick0 data.** The written data must be 83E7 0B13h to unlock this register. It must be written before writing to the kick1 register. Writing any other value will lock the other MMRs.

11.5.5.2 Kick 1 Register (KICK1R)

The KICK1R is shown in Figure 11-6 and described in Table 11-10.

Figure 11-6. Kick 1 Register (KICK1R)

31	0
KICK0	
R/W-0	

LEGEND: R/W = Read/Write; *-n* = value after reset

Table 11-10. Kick 1 Register (KICK1R) Field Descriptions

Bit	Field	Value	Description
31-0	KICK1	0-FFFF FFFFh	**KICK1R allows writing to unlock the kick1 data and the kicker mechanism to write to other MMRs.** The written data must be 95A4 F1E0h to unlock this register. KICK0R must be written before writing to the kick1 register. Writing any other value will lock the other MMRs.

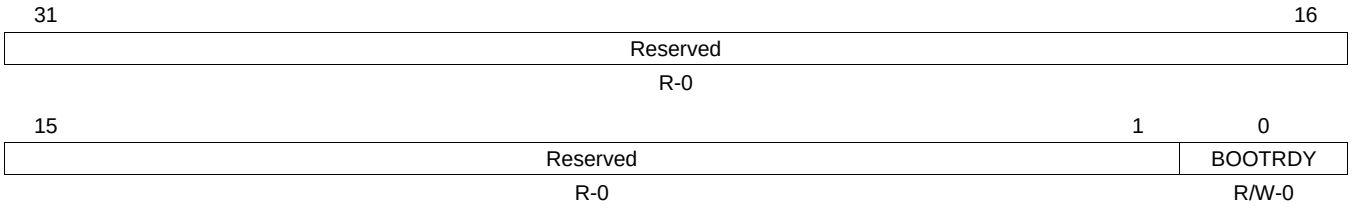
11.5.6 Host 0 Configuration Register (HOST0CFG)

On this device, the ARM subsystem is initially held in reset. The ARM subsystem is released from reset when 1 is written to the BOOTRDY bit in the host 0 configuration register (HOST0CFG). The boot address for ARM is fixed and cannot be changed by software.

The HOST0CFG is shown in Figure 11-7 and described in Table 11-11.

NOTE: In addition to writing to HOST0CFG, the ARM subsystem must be enabled via the power and sleep controller (PSC) module. By default, the ARM subsystem is in a SwRstDisable state (see the *Power and Sleep Controller (PSC)* chapter for additional details).

Figure 11-7. Host 0 Configuration Register (HOST0CFG)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

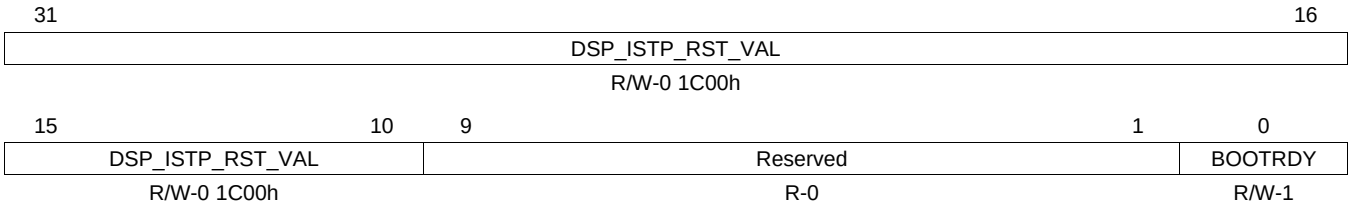
Table 11-11. Host 0 Configuration Register (HOST0CFG) Field Descriptions

Bit	Field	Value	Description
31-1	Reserved	0	Reserved
0	BOOTRDY		**ARM boot ready bit allowing ARM to boot.**
		0	ARM held in reset mode.
		1	ARM released from wait in reset mode.

11.5.7 Host 1 Configuration Register (HOST1CFG)

The host 1 configuration register (HOST1CFG) provides information on the DSP boot address value at power-on reset. The boot address defaults to 0070 0000h (DSP ROM) on power-up. The address field is read/writeable after reset and can be modified to allow execution from an alternate location after a module level or local reset on the DSP. The HOST1CFG is shown in Figure 11-8 and described in Table 11-12.

Figure 11-8. Host 1 Configuration Register (HOST1CFG)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 11-12. Host 1 Configuration Register (HOST1CFG) Field Descriptions

Bit	Field	Value	Description
31-10	DSP_ISTP_RST_VAL	0-3F FFFFh	**DSP boot address vector.**
9-1	Reserved	0	Reserved
0	BOOTRDY		**DSP boot ready bit allowing DSP to boot.**
		0	DSP held in reset mode.
		1	DSP released from wait in reset mode.

11.5.8 Interrupt Registers

The interrupt registers are a set of registers that provide control for the address and protection violation error interrupt generated by the SYSCFG module when there is an address or protection violation to the module's memory-mapped register address space. This includes enable control, interrupt set and clear control, and end of interrupt (EOI) control.

11.5.8.1 Interrupt Raw Status/Set Register (IRAWSTAT)

The interrupt raw status/set register (IRAWSTAT) shows the interrupt status before enabling the interrupt and allows setting of the interrupt status. The IRAWSTAT is shown in Figure 11-9 and described in Table 11-13.

Figure 11-9. Interrupt Raw Status/Set Register (IRAWSTAT)

31	16
Reserved	
R-0	

15	2	1	0
Reserved		ADDRERR	PROTERR
R-0		R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 11-13. Interrupt Raw Status/Set Register (IRAWSTAT) Field Descriptions

Bit	Field	Value	Description
31-2	Reserved	0	Reserved. Always read 0.
1	ADDRERR		**Addressing violation error.** Reading this bit field reflects the raw status of the interrupt before enabling.
		0	Indicates the interrupt is not set. Writing 0 has no effect.
		1	Indicates the interrupt is set. Writing 1 sets the status.
0	PROTERR		**Protection violation error.** Reading this bit field reflects the raw status of the interrupt before enabling.
		0	Indicates the interrupt is not set. Writing 0 has no effect.
		1	Indicates the interrupt is set. Writing 1 sets the status.

11.5.8.2 Interrupt Enable Status/Clear Register (IENSTAT)

The interrupt enable status/clear register (IENSTAT) shows the status of enabled interrupt and allows clearing of the interrupt status. The IENSTAT is shown in Figure 11-10 and described in Table 11-14.

Figure 11-10. Interrupt Enable Status/Clear Register (IENSTAT)

31	16
Reserved	
R-0	

15	2	1	0
Reserved		ADDRERR	PROTERR
R-0		R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 11-14. Interrupt Enable Status/Clear Register (IENSTAT) Field Descriptions

Bit	Field	Value	Description
31-2	Reserved	0	Reserved. Always read 0.
1	ADDRERR		**Addressing violation error.** Reading this bit field reflects the interrupt enabled status.
		0	Indicates the interrupt is not set. Writing 0 has no effect.
		1	Indicates the interrupt is set. Writing 1 clears the status.
0	PROTERR		**Protection violation error.** Reading this bit field reflects the interrupt enabled status.
		0	Indicates the interrupt is not set. Writing 0 has no effect.
		1	Indicates the interrupt is set. Writing 1 clears the status.

11.5.8.3 Interrupt Enable Register (IENSET)

The interrupt enable register (IENSET) allows setting/enabling the interrupt for address and/or protection violation condition. It also shows the value of the register (whether or not interrupt is enabled). The IENSET is shown in Figure 11-11 and described in Table 11-15.

Figure 11-11. Interrupt Enable Register (IENSET)

31			16
Reserved			
R-0			

15	2	1	0
Reserved		ADDRERR_EN	PROTERR_EN
R-0		R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 11-15. Interrupt Enable Register (IENSET) Field Descriptions

Bit	Field	Value	Description
31-2	Reserved	0	Reserved. Always read 0.
1	ADDRERR_EN		**Addressing violation error.**
		0	Writing a 0 has not effect.
		1	Writing a 1 enables this interrupt.
0	PROTERR_EN		**Protection violation error.**
		0	Writing a 0 has not effect.
		1	Writing a 1 enables this interrupt.

11.5.8.4 Interrupt Enable Clear Register (IENCLR)

The interrupt enable clear register (IENCLR) allows clearing/disable the interrupt for address and/or protection violation condition. It also shows the value of the interrupt enable register (IENSET). The IENCLR is shown in Figure 11-12 and described in Table 11-16.

Figure 11-12. Interrupt Enable Clear Register (IENCLR)

31			16
Reserved			
R-0			

15	2	1	0
Reserved		ADDRERR_CLR	PROTERR_CLR
R-0		R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 11-16. Interrupt Enable Clear Register (IENCLR) Field Descriptions

Bit	Field	Value	Description
31-2	Reserved	0	Reserved. Always read 0.
1	ADDRERR_CLR		**Addressing violation error.**
		0	Writing a 0 has not effect.
		1	Writing a 1 clears/disables this interrupt.
0	PROTERR_CLR		**Protection violation error.**
		0	Writing a 0 has not effect.
		1	Writing a 1 clears/disables this interrupt.

11.5.8.5 End of Interrupt Register (EOI)

The end of interrupt register (EOI) is used in software to indicate completion of the interrupt servicing of the SYSCFG interrupt (for address/protection violation). It is required to write a value of 0 to the EOI register after the software has processed the SYSCFG interrupt, this acts as an acknowledgement of completion of the SYSCFG interrupt so that the module can reliably generate the subsequent interrupts. The EOI is shown in Figure 11-13 and described in Table 11-17.

Figure 11-13. End of Interrupt Register (EOI)

31	16
Reserved	
R-0	

15	8	7	0
Reserved		EOIVECT	
R-0		W-0	

LEGEND: R = Read only; W = Write only; -*n* = value after reset

Table 11-17. End of Interrupt Register (EOI) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved. Always read 0.
7-0	EOIVECT	0-FFh	**EOI vector value.** Write the interrupt distribution value of the chip.

11.5.9 Fault Registers

The fault registers are a group of registers responsible for capturing the details on the faulty (address/protection violation errors) accesses, such as address and type of error.

11.5.9.1 Fault Address Register (FLTADDRR)

The fault address register (FLTADDRR) captures the address of the first transfer that causes the address or memory violation error. The FLTADDRR is shown in Figure 11-14 and described in Table 11-18.

Figure 11-14. Fault Address Register (FLTADDRR)

31	0
FLTADDR	
R-0	

LEGEND: R = Read only; -*n* = value after reset

Table 11-18. Fault Address Register (FLTADDRR) Field Descriptions

Bit	Field	Value	Description
31-0	FLTADDR	0-FFFF FFFFh	**Fault address for the first fault transfer.**

11.5.9.2 Fault Status Register (FLTSTAT)

The fault status register (FLTSTAT) holds/captures additional attributes and status of the first erroneous transaction. This includes things like the master id for the master that caused the address/memory violation error, details on whether it is a user or supervisor level read/write or execute fault. The FLTSTAT is shown in Figure 11-15 and described in Table 11-19.

Figure 11-15. Fault Status Register (FLTSTAT)

31	24	23	16
ID		MSTID	
R-0		R-0	

15	13	12	9	8	6	5	0
Reserved		PRIVID		Reserved		TYPE	
R-0		R-0		R-0		R-0	

LEGEND: R = Read only; -*n* = value after reset

Table 11-19. Fault Status Register (FLTSTAT) Field Descriptions

Bit	Field	Value	Description
31-24	ID	0-FFh	**Transfer ID of the first fault transfer.**
23-16	MSTID	0-FFh	**Master ID of the first fault transfer.**
15-13	Reserved	0	Reserved. Always read 0
12-9	PRIVID	0-Fh	**Privilege ID of the first fault transfer.**
8-6	Reserved	0	Reserved. Always read 0
5-0	TYPE		**Fault type of first fault transfer.**
		0	No transfer fault
		1h	User execute fault
		2h	User write fault
		3h	*Reserved*
		4h	User read fault
		5h-7h	*Reserved*
		8h	Supervisor execute fault
		9h-Fh	*Reserved*
		10h	Supervisor write fault
		11h-1Fh	*Reserved*
		20h	Supervisor read fault
		21h-3Fh	*Reserved*

11.5.10 Master Priority Registers (MSTPRI0-MSTPRI2)

11.5.10.1 Master Priority 0 Register (MSTPRI0)

The master priority 0 register (MSTPRI0) is shown in Figure 11-16 and described in Table 11-20.

Figure 11-16. Master Priority 0 Register (MSTPRI0)

31	30 28	27	26 24	23	22 20	19	18 16
Rsvd	Reserved	Rsvd	Reserved	Rsvd	Reserved	Rsvd	Reserved
R/W-0	R/W-4h	R/W-0	R/W-4h	R/W-0	R/W-4h	R/W-0	R/W-4h

15	14 12	11	10 8	7	6 4	3	2 0
Rsvd	DSP_CFG	Rsvd	DSP_MDMA	Rsvd	ARM_D	Rsvd	ARM_I
R/W-0	R/W-2h	R-0	R/W-2h	R-0	R/W-2h	R-0	R/W-2h

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 11-20. Master Priority 0 Register (MSTPRI0) Field Descriptions

Bit	Field	Value	Description
31	Reserved	0	Reserved. Write the default value when modifying this register.
30-28	Reserved	4h	Reserved. Write the default value when modifying this register.
27	Reserved	0	Reserved. Write the default value when modifying this register.
26-24	Reserved	4h	Reserved. Write the default value when modifying this register.
23	Reserved	0	Reserved. Write the default value when modifying this register.
22-20	Reserved	4h	Reserved. Write the default value when modifying this register.
19	Reserved	0	Reserved. Write the default value when modifying this register.
18-16	Reserved	4h	Reserved. Write the default value when modifying this register.
15	Reserved	0	Reserved. Write the default value when modifying this register.
14-12	DSP_CFG	0-7h	**DSP CFG port priority.** Bit = 0 = priority 0 (highest); bit = 7h = priority 7 (lowest).
11	Reserved	0	Reserved. Always read as 0.
10-8	DSP_MDMA	0-7h	**DSP DMA port priority.** Bit = 0 = priority 0 (highest); bit = 7h = priority 7 (lowest).
7	Reserved	0	Reserved. Always read as 0.
6-4	ARM_D	0-7h	**ARM CFG port priority.** Bit = 0 = priority 0 (highest); bit = 7h = priority 7 (lowest).
3	Reserved	0	Reserved. Always read as 0.
2-0	ARM_I	0-7h	**ARM DMA port priority.** Bit = 0 = priority 0 (highest); bit = 7h = priority 7 (lowest).

11.5.10.2 Master Priority 1 Register (MSTPRI1)

The master priority 1 register (MSTPRI1) is shown in Figure 11-17 and described in Table 11-21.

Figure 11-17. Master Priority 1 Register (MSTPRI1)

31	30 28	27	26 24	23	22 20	19	18 16
Rsvd	Reserved	Rsvd	Reserved	Rsvd	Reserved	Rsvd	Reserved
R/W-0	R/W-4h	R/W-0	R/W-4h	R/W-0	R/W-4h	R/W-0	R/W-4h

15	14 12	11	10 8	7	6 4	3	2 0
Rsvd	EDMATC1	Rsvd	EDMATC0	Rsvd	PRU1	Rsvd	PRU0
R/W-0	R/W-0	R-0	R/W-0	R-0	R/W-0	R-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 11-21. Master Priority 1 Register (MSTPRI1) Field Descriptions

Bit	Field	Value	Description
31	Reserved	0	Reserved. Write the default value when modifying this register.
30-28	Reserved	4h	Reserved. Write the default value when modifying this register.
27	Reserved	0	Reserved. Write the default value when modifying this register.
26-24	Reserved	4h	Reserved. Write the default value when modifying this register.
23	Reserved	0	Reserved. Write the default value when modifying this register.
22-20	Reserved	4h	Reserved. Write the default value when modifying this register.
19	Reserved	0	Reserved. Write the default value when modifying this register.
18-16	Reserved	4h	Reserved. Write the default value when modifying this register.
15	Reserved	0	Reserved. Write the default value when modifying this register.
14-12	EDMATC1	0-7h	**EDMA3TC1 priority.** Bit = 0 = priority 0 (highest); bit = 7h = priority 7 (lowest).
11	Reserved	0	Reserved. Always read as 0.
10-8	EDMATC0	0-7h	**EDMA3TC0 priority.** Bit = 0 = priority 0 (highest); bit = 7h = priority 7 (lowest).
7	Reserved	0	Reserved. Always read as 0.
6-4	PRU1	0-7h	**PRU1 priority.** Bit = 0 = priority 0 (highest); bit = 7h = priority 7 (lowest).
3	Reserved	0	Reserved. Always read as 0.
2-0	PRU0	0-7h	**PRU0 priority.** Bit = 0 = priority 0 (highest); bit = 7h = priority 7 (lowest).

11.5.10.3 Master Priority 2 Register (MSTPRI2)

The master priority 2 register (MSTPRI2) is shown in Figure 11-18 and described in Table 11-22.

Figure 11-18. Master Priority 2 Register (MSTPRI2)

31	30 28	27	26 24	23	22 20	19	18 16
Rsvd	LCDC	Rsvd	USB1	Rsvd	UHPI	Rsvd	Reserved
R/W-0	R/W-5h	R/W-0	R/W-4h	R/W-0	R/W-6h	R/W-0	R/W-0

15	14 12	11	10 8	7	6 4	3	2 0
Rsvd	USB0CDMA	Rsvd	USB0CFG	Rsvd	Reserved	Rsvd	EMAC
R/W-0	R/W-4h	R/W-0	R/W-4h	R/W-0	R/W-0	R/W-0	R/W-4h

LEGEND: R/W = Read/Write; *-n* = value after reset

Table 11-22. Master Priority 2 Register (MSTPRI2) Field Descriptions

Bit	Field	Value	Description
31	Reserved	0	Reserved. Write the default value when modifying this register.
30-28	LCDC	0-7h	**LCDC priority.** Bit = 0 = priority 0 (highest); bit = 7h = priority 7 (lowest).
27	Reserved	0	Reserved. Write the default value when modifying this register.
26-24	USB1	0-7h	**USB1 (USB1.1) priority.** Bit = 0 = priority 0 (highest); bit = 7h = priority 7 (lowest).
23	Reserved	0	Reserved. Write the default value when modifying this register.
22-20	UHPI	0-7h	**HPI priority.** Bit = 0 = priority 0 (highest); bit = 7h = priority 7 (lowest).
19	Reserved	0	Reserved. Write the default value when modifying this register.
18-16	Reserved	0	Reserved. Write the default value when modifying this register.
15	Reserved	0	Reserved. Write the default value when modifying this register.
14-12	USB0CDMA	0-7h	**USB0 (USB2.0) CDMA priority.** Bit = 0 = priority 0 (highest); bit = 7h = priority 7 (lowest).
11	Reserved	0	Reserved. Write the default value when modifying this register.
10-8	USB0CFG	0-7h	**USB0 (USB2.0) CFG priority.** Bit = 0 = priority 0 (highest); bit = 7h = priority 7 (lowest).
7	Reserved	0	Reserved. Write the default value when modifying this register.
6-4	Reserved	0	Reserved. Write the default value when modifying this register.
3	Reserved	0	Reserved. Write the default value when modifying this register.
2-0	EMAC	0-7h	**EMAC priority.** Bit = 0 = priority 0 (highest); bit = 7h = priority 7 (lowest).

11.5.11 Pin Multiplexing Control Registers (PINMUX0-PINMUX19)

Extensive use of pin multiplexing is used to accommodate the large number of peripheral functions in the smallest possible package. On the device, pin multiplexing can be controlled on a pin by pin basis. This is done by the pin multiplexing registers (PINMUX0-PINMUX19). Each pin that is multiplexed with several different functions has a corresponding 4-bit field in PINMUX*n*. Pin multiplexing selects which of several peripheral pin functions control the pins IO buffer output data and output enable values only. Note that the input from each pin is always routed to all of the peripherals that share the pin; the PINMUX registers have no effect on input from a pin. Hardware does not attempt to ensure that the proper pin multiplexing is selected for the peripherals or that interface mode is being used. Detailed information about the pin multiplexing and control is covered in the device-specific data manual. Access to the pin multiplexing utility is available in *OMAP-L137, TMS320C6747/6745/6743 Pin Multiplexing Utility Application Report* (SPRAB06).

11.5.11.1 Pin Multiplexing Control 0 Register (PINMUX0)

Figure 11-19. Pin Multiplexing Control 0 Register (PINMUX0)

31 28	27 24	23 20	19 16
PINMUX0_31_28	PINMUX0_27_24	PINMUX0_23_20	PINMUX0_19_16
R/W-0	R/W-0	R/W-0	R/W-0
15 12	**11 8**	**7 4**	**3 0**
PINMUX0_15_12	PINMUX0_11_8	PINMUX0_7_4	PINMUX0_3_0
R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; -*n* = value after reset

Table 11-23. Pin Multiplexing Control 0 Register (PINMUX0) Field Descriptions

Bit	Field	ZKB Ball	Value	Description
31-28	PINMUX0_31_28	K15		**$\overline{\text{EMB\_WE}}$ Control**
			0	Pin is 3-stated.
			1h	Selects Function $\overline{\text{EMB\_WE}}$
			2h-Fh	*Reserved*
27-24	PINMUX0_27_24	A8		**$\overline{\text{EMB\_RAS}}$ Control**
			0	Pin is 3-stated.
			1h	Selects Function $\overline{\text{EMB\_RAS}}$
			2h-Fh	*Reserved*
23-20	PINMUX0_23_20	L13		**$\overline{\text{EMB\_CAS}}$ Control**
			0	Pin is 3-stated.
			1h	Selects Function $\overline{\text{EMB\_CAS}}$
			2h-Fh	*Reserved*
19-16	PINMUX0_19_16	D9		**$\overline{\text{EMB\_CS[0]}}$ Control**
			0	Pin is 3-stated.
			1h	Selects Function $\overline{\text{EMB\_CS[0]}}$
			2h-Fh	*Reserved*
15-12	PINMUX0_15_12	C14		**EMB_CLK Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_CLK from EMIFB LPSC (CLK1)
			2h	Selects Function EMB_CLK from PLL DIV4P5 or SYSCLK5 (CLK2)
			3h-Fh	*Reserved*

Table 11-23. Pin Multiplexing Control 0 Register (PINMUX0) Field Descriptions (continued)

Bit	Field	ZKB Ball	Value	Description
11-8	PINMUX0_11_8	C13		**EMB_SDCKE Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_SDCKE
			2h-Fh	*Reserved*
7-4	PINMUX0_7_4	J5		**GP7[15]/EMU[0] Control**
			0	Pin is 3-stated.
			1h	Selects Function GP7[15]
			2h-7h	*Reserved*
			8h	Selects Function EMU[0]
			9h-Fh	*Reserved*
3-0	PINMUX0_3_0	K1		**GP7[14]/RTCK Control**
			0	Selects Function RTCK
			1h	Selects Function GP7[14]
			2h-7h	*Reserved*
			8h	Selects Function RTCK
			9h-Fh	*Reserved*

11.5.11.2 Pin Multiplexing Control 1 Register (PINMUX1)

Figure 11-20. Pin Multiplexing Control 1 Register (PINMUX1)

31 28	27 24	23 20	19 16
PINMUX1_31_28	PINMUX1_27_24	PINMUX1_23_20	PINMUX1_19_16
R/W-0	R/W-0	R/W-0	R/W-0
15 12	**11 8**	**7 4**	**3 0**
PINMUX1_15_12	PINMUX1_11_8	PINMUX1_7_4	PINMUX1_3_0
R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; *-n* = value after reset

Table 11-24. Pin Multiplexing Control 1 Register (PINMUX1) Field Descriptions

Bit	Field	ZKB Ball	Value	Description
31-28	PINMUX1_31_28	C11		**EMB_A[5]/GP7[7] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_A[5]
			2h-7h	*Reserved*
			8h	Selects Function GP7[7]
			9h-Fh	*Reserved*
27-24	PINMUX1_27_24	D11		**EMB_A[4]/GP7[6] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_A[4]
			2h-7h	*Reserved*
			8h	Selects Function GP7[6]
			9h-Fh	*Reserved*
23-20	PINMUX1_23_20	A10		**EMB_A[3]/GP7[5] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_A[3]
			2h-7h	*Reserved*
			8h	Selects Function GP7[5]
			9h-Fh	*Reserved*
19-16	PINMUX1_19_16	B10		**EMB_A[2]/GP7[4] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_A[2]
			2h-7h	*Reserved*
			8h	Selects Function GP7[4]
			9h-Fh	*Reserved*
15-12	PINMUX1_15_12	C10		**EMB_A[1]/GP7[3] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_A[1]
			2h-7h	*Reserved*
			8h	Selects Function GP7[3]
			9h-Fh	*Reserved*

Table 11-24. Pin Multiplexing Control 1 Register (PINMUX1) Field Descriptions (continued)

Bit	Field	ZKB Ball	Value	Description
11-8	PINMUX1_11_8	D10		**EMB_A[0]/GP7[2] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_A[0]
			2h-7h	*Reserved*
			8h	Selects Function GP7[2]
			9h-Fh	*Reserved*
7-4	PINMUX1_7_4	C9		**EMB_BA[0]/GP7[1] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_BA[0]
			2h-7h	*Reserved*
			8h	Selects Function GP7[1]
			9h-Fh	*Reserved*
3-0	PINMUX1_3_0	B9		**EMB_BA[1]/GP7[0] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_BA[1]
			2h-7h	*Reserved*
			8h	Selects Function GP7[0]
			9h-Fh	*Reserved*

11.5.11.3 Pin Multiplexing Control 2 Register (PINMUX2)

Figure 11-21. Pin Multiplexing Control 2 Register (PINMUX2)

31 28	27 24	23 20	19 16
PINMUX2_31_28	PINMUX2_27_24	PINMUX2_23_20	PINMUX2_19_16
R/W-0	R/W-0	R/W-0	R/W-0
15 12	**11 8**	**7 4**	**3 0**
PINMUX2_15_12	PINMUX2_11_8	PINMUX2_7_4	PINMUX2_3_0
R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; -*n* = value after reset

Table 11-25. Pin Multiplexing Control 2 Register (PINMUX2) Field Descriptions

Bit	Field	ZKB Ball	Value	Description
31-28	PINMUX2_31_28	G14		**EMB_D[31] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_D[31]
			2h-Fh	*Reserved*
27-24	PINMUX2_27_24	B15		**EMB_A[12]/GP3[13] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_A[12]
			2h-7h	*Reserved*
			8h	Selects Function GP3[13]
			9h-Fh	*Reserved*
23-20	PINMUX2_23_20	B12		**EMB_A[11]/GP7[13] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_A[11]
			2h-7h	*Reserved*
			8h	Selects Function GP7[13]
			9h-Fh	*Reserved*
19-16	PINMUX2_19_16	A9		**EMB_A[10]/GP7[12] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_A[10]
			2h-7h	*Reserved*
			8h	Selects Function GP7[12]
			9h-Fh	*Reserved*
15-12	PINMUX2_15_12	C12		**EMB_A[9]/GP7[11] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_A[9]
			2h-7h	*Reserved*
			8h	Selects Function GP7[11]
			9h-Fh	*Reserved*
11-8	PINMUX2_11_8	D12		**EMB_A[8]/GP7[10] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_A[8]
			2h-7h	*Reserved*
			8h	Selects Function GP7[10]
			9h-Fh	*Reserved*

Table 11-25. Pin Multiplexing Control 2 Register (PINMUX2) Field Descriptions (continued)

Bit	Field	ZKB Ball	Value	Description
7-4	PINMUX2_7_4	A11		**EMB_A[7]/GP7[9] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_A[7]
			2h-7h	*Reserved*
			8h	Selects Function GP7[9]
			9h-Fh	*Reserved*
3-0	PINMUX2_3_0	B11		**EMB_A[6]/GP7[8] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_A[6]
			2h-7h	*Reserved*
			8h	Selects Function GP7[8]
			9h-Fh	*Reserved*

11.5.11.4 Pin Multiplexing Control 3 Register (PINMUX3)

Figure 11-22. Pin Multiplexing Control 3 Register (PINMUX3)

31 28	27 24	23 20	19 16
PINMUX3_31_28	PINMUX3_27_24	PINMUX3_23_20	PINMUX3_19_16
R/W-0	R/W-0	R/W-0	R/W-0
15 12	**11 8**	**7 4**	**3 0**
PINMUX3_15_12	PINMUX3_11_8	PINMUX3_7_4	PINMUX3_3_0
R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; *-n* = value after reset

Table 11-26. Pin Multiplexing Control 3 Register (PINMUX3) Field Descriptions

Bit	Field	ZKB Ball	Value	Description
31-28	PINMUX3_31_28	L15		**EMB_D[23] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_D[23]
			2h-Fh	*Reserved*
27-24	PINMUX3_27_24	A13		**EMB_D[24] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_D[24]
			2h-Fh	*Reserved*
23-20	PINMUX3_23_20	B14		**EMB_D[25] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_D[25]
			2h-Fh	*Reserved*
19-16	PINMUX3_19_16	A14		**EMB_D[26] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_D[26]
			2h-Fh	*Reserved*
15-12	PINMUX3_15_12	E14		**EMB_D[27] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_D[27]
			2h-Fh	*Reserved*
11-8	PINMUX3_11_8	E15		**EMB_D[28] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_D[28]
			2h-Fh	*Reserved*
7-4	PINMUX3_7_4	F14		**EMB_D[29] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_D[29]
			2h-Fh	*Reserved*
3-0	PINMUX3_3_0	F15		**EMB_D[30] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_D[30]
			2h-Fh	*Reserved*

11.5.11.5 Pin Multiplexing Control 4 Register (PINMUX4)

Figure 11-23. Pin Multiplexing Control 4 Register (PINMUX4)

31 28	27 24	23 20	19 16
PINMUX4_31_28	PINMUX4_27_24	PINMUX4_23_20	PINMUX4_19_16
R/W-0	R/W-0	R/W-0	R/W-0
15 12	**11 8**	**7 4**	**3 0**
PINMUX4_15_12	PINMUX4_11_8	PINMUX4_7_4	PINMUX4_3_0
R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; *-n* = value after reset

Table 11-27. Pin Multiplexing Control 4 Register (PINMUX4) Field Descriptions

Bit	Field	ZKB Ball	Value	Description
31-28	PINMUX4_31_28	A12		**$\overline{\text{EMB\_WE\_DQM[3]}}$ Control**
			0	Pin is 3-stated.
			1h	Selects Function $\overline{\text{EMB\_WE\_DQM[3]}}$
			2h-Fh	*Reserved*
27-24	PINMUX4_27_24	G15		**EMB_D[16] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_D[16]
			2h-Fh	*Reserved*
23-20	PINMUX4_23_20	H14		**EMB_D[17] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_D[17]
			2h-Fh	*Reserved*
19-16	PINMUX4_19_16	H15		**EMB_D[18] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_D[18]
			2h-Fh	*Reserved*
15-12	PINMUX4_15_12	J14		**EMB_D[19] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_D[19]
			2h-Fh	*Reserved*
11-8	PINMUX4_11_8	K13		**EMB_D[20] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_D[20]
			2h-Fh	*Reserved*
7-4	PINMUX4_7_4	K16		**EMB_D[21] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_D[21]
			2h-Fh	*Reserved*
3-0	PINMUX4_3_0	L14		**EMB_D[22] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_D[22]
			2h-Fh	*Reserved*

11.5.11.6 Pin Multiplexing Control 5 Register (PINMUX5)

Figure 11-24. Pin Multiplexing Control 5 Register (PINMUX5)

31 28	27 24	23 20	19 16
PINMUX5_31_28	PINMUX5_27_24	PINMUX5_23_20	PINMUX5_19_16
R/W-0	R/W-0	R/W-0	R/W-0
15 12	**11 8**	**7 4**	**3 0**
PINMUX5_15_12	PINMUX5_11_8	PINMUX5_7_4	PINMUX5_3_0
R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; *-n* = value after reset

Table 11-28. Pin Multiplexing Control 5 Register (PINMUX5) Field Descriptions

Bit	Field	ZKB Ball	Value	Description
31-28	PINMUX5_31_28	J15		**EMB_D[6]/GP6[6] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_D[6]
			2h-7h	*Reserved*
			8h	Selects Function GP6[6]
			9h-Fh	*Reserved*
27-24	PINMUX5_27_24	J13		**EMB_D[5]/GP6[5] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_D[5]
			2h-7h	*Reserved*
			8h	Selects Function GP6[5]
			9h-Fh	*Reserved*
23-20	PINMUX5_23_20	H16		**EMB_D[4]/GP6[4] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_D[4]
			2h-7h	*Reserved*
			8h	Selects Function GP6[4]
			9h-Fh	*Reserved*
19-16	PINMUX5_19_16	H13		**EMB_D[3]/GP6[3] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_D[3]
			2h-7h	*Reserved*
			8h	Selects Function GP6[3]
			9h-Fh	*Reserved*
15-12	PINMUX5_15_12	G16		**EMB_D[2]/GP6[2] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_D[2]
			2h-7h	*Reserved*
			8h	Selects Function GP6[2]
			9h-Fh	*Reserved*

Table 11-28. Pin Multiplexing Control 5 Register (PINMUX5) Field Descriptions (continued)

Bit	Field	ZKB Ball	Value	Description
11-8	PINMUX5_11_8	G13		**EMB_D[1]/GP6[1] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_D[1]
			2h-7h	*Reserved*
			8h	Selects Function GP6[1]
			9h-Fh	*Reserved*
7-4	PINMUX5_7_4	F16		**EMB_D[0]/GP6[0] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_D[0]
			2h-7h	*Reserved*
			8h	Selects Function GP6[0]
			9h-Fh	*Reserved*
3-0	PINMUX5_3_0	B13		**$\overline{\text{EMB\_WE\_DQM[2]}}$ Control**
			0	Pin is 3-stated.
			1h	Selects Function $\overline{\text{EMB\_WE\_DQM[2]}}$
			2h-Fh	*Reserved*

11.5.11.7 Pin Multiplexing Control 6 Register (PINMUX6)

Figure 11-25. Pin Multiplexing Control 6 Register (PINMUX6)

31 28	27 24	23 20	19 16
PINMUX6_31_28	PINMUX6_27_24	PINMUX6_23_20	PINMUX6_19_16
R/W-0	R/W-0	R/W-0	R/W-0
15 12	**11 8**	**7 4**	**3 0**
PINMUX6_15_12	PINMUX6_11_8	PINMUX6_7_4	PINMUX6_3_0
R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; *-n* = value after reset

Table 11-29. Pin Multiplexing Control 6 Register (PINMUX6) Field Descriptions

Bit	Field	ZKB Ball	Value	Description
31-28	PINMUX6_31_28	E16		**EMB_D[14]/GP6[14] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_D[14]
			2h-7h	*Reserved*
			8h	Selects Function GP6[14]
			9h-Fh	*Reserved*
27-24	PINMUX6_27_24	E13		**EMB_D[13]/GP6[13] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_D[13]
			2h-7h	*Reserved*
			8h	Selects Function GP6[13]
			9h-Fh	*Reserved*
23-20	PINMUX6_23_20	D16		**EMB_D[12]/GP6[12] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_D[12]
			2h-7h	*Reserved*
			8h	Selects Function GP6[12]
			9h-Fh	*Reserved*
19-16	PINMUX6_19_16	D15		**EMB_D[11]/GP6[11] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_D[11]
			2h-7h	*Reserved*
			8h	Selects Function GP6[11]
			9h-Fh	*Reserved*
15-12	PINMUX6_15_12	D14		**EMB_D[10]/GP6[10] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_D[10]
			2h-7h	*Reserved*
			8h	Selects Function GP6[10]
			9h-Fh	*Reserved*

Table 11-29. Pin Multiplexing Control 6 Register (PINMUX6) Field Descriptions (continued)

Bit	Field	ZKB Ball	Value	Description
11-8	PINMUX6_11_8	D13		**EMB_D[9]/GP6[9] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_D[9]
			2h-7h	*Reserved*
			8h	Selects Function GP6[9]
			9h-Fh	*Reserved*
7-4	PINMUX6_7_4	C16		**EMB_D[8]/GP6[8] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_D[8]
			2h-7h	*Reserved*
			8h	Selects Function GP6[8]
			9h-Fh	*Reserved*
3-0	PINMUX6_3_0	J16		**EMB_D[7]/GP6[7] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_D[7]
			2h-7h	*Reserved*
			8h	Selects Function GP6[7]
			9h-Fh	*Reserved*

11.5.11.8 Pin Multiplexing Control 7 Register (PINMUX7)

Figure 11-26. Pin Multiplexing Control 7 Register (PINMUX7)

31 28	27 24	23 20	19 16
PINMUX7_31_28	PINMUX7_27_24	PINMUX7_23_20	PINMUX7_19_16
R/W-0	R/W-0	R/W-0	R/W-0
15 12	**11 8**	**7 4**	**3 0**
PINMUX7_15_12	PINMUX7_11_8	PINMUX7_7_4	PINMUX7_3_0
R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; *-n* = value after reset

Table 11-30. Pin Multiplexing Control 7 Register (PINMUX7) Field Descriptions

Bit	Field	ZKB Ball	Value	Description
31-28	PINMUX7_31_28	N4		**$\overline{\text{SPI0\_SCS[0]}}$/$\overline{\text{UART0\_RTS}}$/EQEP0B/GP5[4]/BOOT[4] Control**
			0	Pin is 3-stated.
			1h	Selects Function $\overline{\text{SPI0\_SCS[0]}}$
			2h	Selects Function $\overline{\text{UART0\_RTS}}$
			3h	*Reserved*
			4h	Selects Function EQEP0B
			5h-7h	*Reserved*
			8h	Selects Function GP5[4]
			9h-Fh	*Reserved*
27-24	PINMUX7_27_24	R5		**$\overline{\text{SPI0\_ENA}}$/$\overline{\text{UART0\_CTS}}$/EQEP0A/GP5[3]/BOOT[3] Control**
			0	Pin is 3-stated.
			1h	Selects Function $\overline{\text{SPI0\_ENA}}$
			2h	Selects Function $\overline{\text{UART0\_CTS}}$
			3h	*Reserved*
			4h	Selects Function EQEP0A
			5h-7h	*Reserved*
			8h	Selects Function GP5[3]
			9h-Fh	*Reserved*
23-20	PINMUX7_23_20	T5		**SPI0_CLK/EQEP1I/GP5[2]/BOOT[2] Control**
			0	Pin is 3-stated.
			1h	Selects Function SPI0_CLK
			2h	Selects Function EQEP1I
			3h-7h	*Reserved*
			8h	Selects Function GP5[2]
			9h-Fh	*Reserved*
19-16	PINMUX7_19_16	P6		**SPI0_SIMO[0]/EQEP0S/GP5[1]/BOOT[1] Control**
			0	Pin is 3-stated.
			1h	Selects Function SPI0_SIMO[0]
			2h	Selects Function EQEP0S
			3h-7h	*Reserved*
			8h	Selects Function GP5[1]
			9h-Fh	*Reserved*

Table 11-30. Pin Multiplexing Control 7 Register (PINMUX7) Field Descriptions (continued)

Bit	Field	ZKB Ball	Value	Description
15-12	PINMUX7_15_12	R6		**SPI0_SOMI[0]/EQEP0I/GP5[0]/BOOT[0] Control**
			0	Pin is 3-stated.
			1h	Selects Function SPI0_SOMI[0]
			2h	Selects Function EQEP0I
			3h-7h	*Reserved*
			8h	Selects Function GP5[0]
			9h-Fh	*Reserved*
11-8	PINMUX7_11_8	K14		**$\overline{\text{EMB\_WE\_DQM[0]}}$/GP5[15] Control**
			0	Pin is 3-stated.
			1h	Selects Function $\overline{\text{EMB\_WE\_DQM[0]}}$
			2h-7h	*Reserved*
			8h	Selects Function GP5[15]
			9h-Fh	*Reserved*
7-4	PINMUX7_7_4	C15		**$\overline{\text{EMB\_WE\_DQM[1]}}$/GP5[14] Control**
			0	Pin is 3-stated.
			1h	Selects Function $\overline{\text{EMB\_WE\_DQM[1]}}$
			2h-7h	*Reserved*
			8h	Selects Function GP5[14]
			9h-Fh	*Reserved*
3-0	PINMUX7_3_0	F13		**EMB_D[15]/GP6[15] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMB_D[15]
			2h-7h	*Reserved*
			8h	Selects Function GP6[15]
			9h-Fh	*Reserved*

11.5.11.9 Pin Multiplexing Control 8 Register (PINMUX8)

Figure 11-27. Pin Multiplexing Control 8 Register (PINMUX8)

31 28	27 24	23 20	19 16
PINMUX8_31_28	PINMUX8_27_24	PINMUX8_23_20	PINMUX8_19_16
R/W-0	R/W-0	R/W-0	R/W-0
15 12	**11 8**	**7 4**	**3 0**
PINMUX8_15_12	PINMUX8_11_8	PINMUX8_7_4	PINMUX8_3_0
R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; *-n* = value after reset

Table 11-31. Pin Multiplexing Control 8 Register (PINMUX8) Field Descriptions

Bit	Field	ZKB Ball	Value	Description
31-28	PINMUX8_31_28	R4		**$\overline{\text{SPI1\_ENA}}$/UART2_RXD/GP5[12] Control**
			0	Pin is 3-stated.
			1h	Selects Function $\overline{\text{SPI1\_ENA}}$
			2h	Selects Function UART2_RXD
			3h-7h	*Reserved*
			8h	Selects Function GP5[12]
			9h-Fh	*Reserved*
27-24	PINMUX8_27_24	T4		**AXR1[11]/GP5[11] Control**
			0	Pin is 3-stated.
			1h	Selects Function AXR1[11]
			2h-7h	*Reserved*
			8h	Selects Function GP5[11]
			9h-Fh	*Reserved*
23-20	PINMUX8_23_20	N3		**AXR1[10]/GP5[10] Control**
			0	Pin is 3-stated.
			1h	Selects Function AXR1[10]
			2h-7h	*Reserved*
			8h	Selects Function GP5[10]
			9h-Fh	*Reserved*
19-16	PINMUX8_19_16	P3		**UART0_TXD/I2C0_SCL/TM64P0_OUT12/GP5[9]/BOOT[9] Control**
			0	Pin is 3-stated.
			1h	Selects Function UART0_TXD
			2h	Selects Function I2C0_SCL
			3h	*Reserved*
			4h	Selects Function TM64P0_OUT12
			5h-7h	*Reserved*
			8h	Selects Function GP5[9]
			9h-Fh	*Reserved*

Table 11-31. Pin Multiplexing Control 8 Register (PINMUX8) Field Descriptions (continued)

Bit	Field	ZKB Ball	Value	Description
15-12	PINMUX8_15_12	R3		**UART0_RXD/I2C0_SDA/TM64P0_IN12/GP5[8]/BOOT[8] Control**
			0	Pin is 3-stated.
			1h	Selects Function UART0_RXD
			2h	Selects Function I2C0_SDA
			3h	*Reserved*
			4h	Selects Function TM64P0_IN12
			5h-7h	*Reserved*
			8h	Selects Function GP5[8]
			9h-Fh	*Reserved*
11-8	PINMUX8_11_8	T6		**SPI1_CLK/EQEP1S/GP5[7]/BOOT[7] Control**
			0	Pin is 3-stated.
			1h	Selects Function SPI1_CLK
			2h	Selects Function EQEP1S
			3h-7h	*Reserved*
			8h	Selects Function GP5[7]
			9h-Fh	*Reserved*
7-4	PINMUX8_7_4	N5		**SPI1_SIMO[0]/I2C1_SDA/GP5[6]/BOOT[6] Control**
			0	Pin is 3-stated.
			1h	Selects Function SPI1_SIMO[0]
			2h	Selects Function I2C1_SDA
			3h-7h	*Reserved*
			8h	Selects Function GP5[6]
			9h-Fh	*Reserved*
3-0	PINMUX8_3_0	P5		**SPI1_SOMI[0]/I2C1_SCL/GP5[5]/BOOT[5] Control**
			0	Pin is 3-stated.
			1h	Selects Function SPI1_SOMI[0]
			2h	Selects Function I2C1_SCL
			3h-7h	*Reserved*
			8h	Selects Function GP5[5]
			9h-Fh	*Reserved*

11.5.11.10 Pin Multiplexing Control 9 Register (PINMUX9)

Figure 11-28. Pin Multiplexing Control 9 Register (PINMUX9)

31 28	27 24	23 20	19 16
PINMUX9_31_28	PINMUX9_27_24	PINMUX9_23_20	PINMUX9_19_16
R/W-0	R/W-0	R/W-0	R/W-0
15 12	**11 8**	**7 4**	**3 0**
PINMUX9_15_12	PINMUX9_11_8	PINMUX9_7_4	PINMUX9_3_0
R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; *-n* = value after reset

Table 11-32. Pin Multiplexing Control 9 Register (PINMUX9) Field Descriptions

Bit	Field	ZKB Ball	Value	Description
31-28	PINMUX9_31_28	C4		**AFSR0/GP3[12] Control**
			0	Pin is 3-stated.
			1h	Selects Function AFSR0
			2h-7h	*Reserved*
			8h	Selects Function GP3[12]
			9h-Fh	*Reserved*
27-24	PINMUX9_27_24	B4		**ACLKR0/ECAP1/APWM1/GP2[15] Control**
			0	Pin is 3-stated.
			1h	Selects Function ACLKR0
			2h	Selects Function ECAP1/APWM1
			3h-7h	*Reserved*
			8h	Selects Function GP2[15]
			9h-Fh	*Reserved*
23-20	PINMUX9_23_20	A4		**AHCLKR0/RMII_MHZ_50_CLK/GP2[14]/BOOT[11] Control**
			0	Pin is 3-stated. Enables sourcing of the EMAC 50 MHz reference clock from an external source on the RMII_MHZ_50_CLK pin.
			1h	Selects Function AHCLKR0
			2h	Selects Function RMII_MHZ_50_CLK. Enables sourcing of the EMAC 50 MHz reference clock from PLL SYSCLK7. Also, SYSCLK7 is driven out on the RMII_MHZ_50_CLK pin.
			3h-7h	*Reserved*
			8h	Selects Function GP2[14]
			9h-Fh	*Reserved*
19-16	PINMUX9_19_16	D5		**AFSX0/GP2[13]/BOOT[10] Control**
			0	Pin is 3-stated.
			1h	Selects Function AFSX0
			2h-7h	*Reserved*
			8h	Selects Function GP2[13]
			9h-Fh	*Reserved*
15-12	PINMUX9_15_12	C5		**ACLKX0/ECAP0/APWM0/GP2[12] Control**
			0	Pin is 3-stated.
			1h	Selects Function ACLKX0
			2h	Selects Function ECAP0/APWM0
			3h-7h	*Reserved*
			8h	Selects Function GP2[12]
			9h-Fh	*Reserved*

Table 11-32. Pin Multiplexing Control 9 Register (PINMUX9) Field Descriptions (continued)

Bit	Field	ZKB Ball	Value	Description
11-8	PINMUX9_11_8	B5		**AHCLKX0/AHCLKX2/USB_REFCLKIN/GP2[11] Control**
			0	Pin is 3-stated.
			1h	Selects Function AHCLKX0
			2h	Selects Function AHCLKX2
			3h	*Reserved*
			4h	Selects Function USB_REFCLKIN
			5h-7h	*Reserved*
			8h	Selects Function GP2[11]
			9h-Fh	*Reserved*
7-4	PINMUX9_7_4	E4		**USB0_DRVVBUS/GP4[15] Control**
			0	Pin is 3-stated.
			1h	Selects Function USB0_DRVVBUS
			2h-7h	*Reserved*
			8h	Selects Function GP4[15]
			9h-Fh	*Reserved*
3-0	PINMUX9_3_0	P4		**$\overline{\text{SPI1\_SCS[0]}}$/UART2_TXD/GP5[13] Control**
			0	Pin is 3-stated.
			1h	Selects Function $\overline{\text{SPI1\_SCS[0]}}$
			2h	Selects Function UART2_TXD
			3h-7h	*Reserved*
			8h	Selects Function GP5[13]
			9h-Fh	*Reserved*

11.5.11.11 Pin Multiplexing Control 10 Register (PINMUX10)

Figure 11-29. Pin Multiplexing Control 10 Register (PINMUX10)

31–28	27–24	23–20	19–16
PINMUX10_31_28	PINMUX10_27_24	PINMUX10_23_20	PINMUX10_19_16
R/W-0	R/W-0	R/W-0	R/W-0
15–12	**11–8**	**7–4**	**3–0**
PINMUX10_15_12	PINMUX10_11_8	PINMUX10_7_4	PINMUX10_3_0
R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; *-n* = value after reset

Table 11-33. Pin Multiplexing Control 10 Register (PINMUX10) Field Descriptions

Bit	Field	ZKB Ball	Value	Description
31-28	PINMUX10_31_28	D7		**AXR0[6]/RMII_RXER[0]/ACLKR2/GP3[6] Control**
			0	Pin is 3-stated.
			1h	Selects Function AXR0[6]
			2h	Selects Function RMII_RXER[0]
			3h	*Reserved*
			4h	Selects Function ACLKR2
			5h-7h	*Reserved*
			8h	Selects Function GP3[6]
			9h-Fh	*Reserved*
27-24	PINMUX10_27_24	C7		**AXR0[5]/RMII_RXD[1]/AFSX2/GP3[5] Control**
			0	Pin is 3-stated.
			1h	Selects Function AXR0[5]
			2h	Selects Function RMII_RXD[1]
			3h	*Reserved*
			4h	Selects Function AFSX2
			5h-7h	*Reserved*
			8h	Selects Function GP3[5]
			9h-Fh	*Reserved*
23-20	PINMUX10_23_20	B7		**AXR0[4]/RMII_RXD[0]/AXR2[1]/GP3[4] Control**
			0	Pin is 3-stated.
			1h	Selects Function AXR0[4]
			2h	Selects Function RMII_RXD[0]
			3h	*Reserved*
			4h	Selects Function AXR2[1]
			5h-7h	*Reserved*
			8h	Selects Function GP3[4]
			9h-Fh	*Reserved*

Table 11-33. Pin Multiplexing Control 10 Register (PINMUX10) Field Descriptions (continued)

Bit	Field	ZKB Ball	Value	Description
19-16	PINMUX10_19_16	A7		**AXR0[3]/RMII_CRS_DV/AXR2[2]/GP3[3] Control**
			0	Pin is 3-stated.
			1h	Selects Function AXR0[3]
			2h	Selects Function RMII_CRS_DV
			3h	*Reserved*
			4h	Selects Function AXR2[2]
			5h-7h	*Reserved*
			8h	Selects Function GP3[3]
			9h-Fh	*Reserved*
15-12	PINMUX10_15_12	D8		**AXR0[2]/RMII_TXEN/AXR2[3]/GP3[2] Control**
			0	Pin is 3-stated.
			1h	Selects Function AXR0[2]
			2h	Selects Function RMII_TXEN
			3h	*Reserved*
			4h	Selects Function AXR2[3]
			5h-7h	*Reserved*
			8h	Selects Function GP3[2]
			9h-Fh	*Reserved*
11-8	PINMUX10_11_8	C8		**AXR0[1]/RMII_TXD[1]/ACLKX2/GP3[1] Control**
			0	Pin is 3-stated.
			1h	Selects Function AXR0[1]
			2h	Selects Function RMII_TXD[1]
			3h	*Reserved*
			4h	Selects Function ACLKX2
			5h-7h	*Reserved*
			8h	Selects Function GP3[1]
			9h-Fh	*Reserved*
7-4	PINMUX10_7_4	B8		**AXR0[0]/RMII_TXD[0]/AFSR2/GP3[0] Control**
			0	Pin is 3-stated.
			1h	Selects Function AXR0[0]
			2h	Selects Function RMII_TXD[0]
			3h	*Reserved*
			4h	Selects Function AFSR2
			5h-7h	*Reserved*
			8h	Selects Function GP3[0]
			9h-Fh	*Reserved*
3-0	PINMUX10_3_0	L4		**AMUTE0/$\overline{\text{RESETOUT}}$ Control**
			0	Selects Function $\overline{\text{RESETOUT}}$
			1h	Selects Function AMUTE0
			2h-7h	*Reserved*
			8h	Selects Function $\overline{\text{RESETOUT}}$
			9h-Fh	*Reserved*

11.5.11.12 Pin Multiplexing Control 11 Register (PINMUX11)

Figure 11-30. Pin Multiplexing Control 11 Register (PINMUX11)

31 28	27 24	23 20	19 16
PINMUX11_31_28	PINMUX11_27_24	PINMUX11_23_20	PINMUX11_19_16
R/W-0	R/W-0	R/W-0	R/W-0
15 12	**11 8**	**7 4**	**3 0**
PINMUX11_15_12	PINMUX11_11_8	PINMUX11_7_4	PINMUX11_3_0
R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; *-n* = value after reset

Table 11-34. Pin Multiplexing Control 11 Register (PINMUX11) Field Descriptions

Bit	Field	ZKB Ball	Value	Description
31-28	PINMUX11_31_28	K4		**AFSX1/EPWMSYNCI/EPWMSYNC0/GP4[10] Control**
			0	Pin is 3-stated.
			1h	Selects Function AFSX1
			2h	Selects Function EPWMSYNCI
			3h	*Reserved*
			4h	Selects Function EPWMSYNC0
			5h-7h	*Reserved*
			8h	Selects Function GP4[10]
			9h-Fh	*Reserved*
27-24	PINMUX11_27_24	K3		**ACLKX1/EPWM0A/GP3[15] Control**
			0	Pin is 3-stated.
			1h	Selects Function ACLKX1
			2h	Selects Function EPWM0A
			3h-7h	*Reserved*
			8h	Selects Function GP3[15]
			9h-Fh	*Reserved*
23-20	PINMUX11_23_20	K2		**AHCLKX1/EPWM0B/GP3[14] Control**
			0	Pin is 3-stated.
			1h	Selects Function AHCLKX1
			2h	Selects Function EPWM0B
			3h-7h	*Reserved*
			8h	Selects Function GP3[14]
			9h-Fh	*Reserved*
19-16	PINMUX11_19_16	A5		**AXR0[11]/AXR2[0]/GP3[11] Control**
			0	Pin is 3-stated.
			1h	Selects Function AXR0[11]
			2h-3h	*Reserved*
			4h	Selects Function AXR2[0]
			5h-7h	*Reserved*
			8h	Selects Function GP3[11]
			9h-Fh	*Reserved*

Table 11-34. Pin Multiplexing Control 11 Register (PINMUX11) Field Descriptions (continued)

Bit	Field	ZKB Ball	Value	Description
15-12	PINMUX11_15_12	D6		**UART1_TXD/AXR0[10]/GP3[10] Control**
			0	Pin is 3-stated.
			1h	Selects Function UART1_TXD
			2h	Selects Function AXR0[10]
			3h-7h	*Reserved*
			8h	Selects Function GP3[10]
			9h-Fh	*Reserved*
11-8	PINMUX11_11_8	C6		**UART1_RXD/AXR0[9]/GP3[9] Control**
			0	Pin is 3-stated.
			1h	Selects Function UART1_RXD
			2h	Selects Function AXR0[9]
			3h-7h	*Reserved*
			8h	Selects Function GP3[9]
			9h-Fh	*Reserved*
7-4	PINMUX11_7_4	B6		**AXR0[8]/MDIO_D/GP3[8] Control**
			0	Pin is 3-stated.
			1h	Selects Function AXR0[8]
			2h	Selects Function MDIO_D
			3h-7h	*Reserved*
			8h	Selects Function GP3[8]
			9h-Fh	*Reserved*
3-0	PINMUX11_3_0	A6		**AXR0[7]/MDIO_CLK/GP3[7] Control**
			0	Pin is 3-stated.
			1h	Selects Function AXR0[7]
			2h	Selects Function MDIO_CLK
			3h-7h	*Reserved*
			8h	Selects Function GP3[7]
			9h-Fh	*Reserved*

11.5.11.13 Pin Multiplexing Control 12 Register (PINMUX12)

Figure 11-31. Pin Multiplexing Control 12 Register (PINMUX12)

31 28	27 24	23 20	19 16
PINMUX12_31_28	PINMUX12_27_24	PINMUX12_23_20	PINMUX12_19_16
R/W-0	R/W-0	R/W-0	R/W-0
15 12	**11 8**	**7 4**	**3 0**
PINMUX12_15_12	PINMUX12_11_8	PINMUX12_7_4	PINMUX12_3_0
R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; *-n* = value after reset

Table 11-35. Pin Multiplexing Control 12 Register (PINMUX12) Field Descriptions

Bit	Field	ZKB Ball	Value	Description
31-28	PINMUX12_31_28	P1		**AXR1[3]/EQEP1A/GP4[3] Control**
			0	Pin is 3-stated.
			1h	Selects Function AXR1[3]
			2h	Selects Function EQEP1A
			3h-7h	*Reserved*
			8h	Selects Function GP4[3]
			9h-Fh	*Reserved*
27-24	PINMUX12_27_24	P2		**AXR1[2]/GP4[2] Control**
			0	Pin is 3-stated.
			1h	Selects Function AXR1[2]
			2h-7h	*Reserved*
			8h	Selects Function GP4[2]
			9h-Fh	*Reserved*
23-20	PINMUX12_23_20	R2		**AXR1[1]/GP4[1] Control**
			0	Pin is 3-stated.
			1h	Selects Function AXR1[1]
			2h-7h	*Reserved*
			8h	Selects Function GP4[1]
			9h-Fh	*Reserved*
19-16	PINMUX12_19_16	T3		**AXR1[0]/GP4[0] Control**
			0	Pin is 3-stated.
			1h	Selects Function AXR1[0]
			2h-7h	*Reserved*
			8h	Selects Function GP4[0]
			9h-Fh	*Reserved*
15-12	PINMUX12_15_12	D4		**AMUTE1/EHRPWMTZ/GP4[14] Control**
			0	Pin is 3-stated.
			1h	Selects Function AMUTE1
			2h	Selects Function EHRPWMTZ
			3h-7h	*Reserved*
			8h	Selects Function GP4[14]
			9h-Fh	*Reserved*

Table 11-35. Pin Multiplexing Control 12 Register (PINMUX12) Field Descriptions (continued)

Bit	Field	ZKB Ball	Value	Description
11-8	PINMUX12_11_8	L3		**AFSR1/GP4[13] Control**
			0	Pin is 3-stated.
			1h	Selects Function AFSR1
			2h-7h	*Reserved*
			8h	Selects Function GP4[13]
			9h-Fh	*Reserved*
7-4	PINMUX12_7_4	L2		**ACLKR1/ECAP2/APWM2/GP4[12] Control**
			0	Pin is 3-stated.
			1h	Selects Function ACLKR1
			2h	Selects Function ECAP2/APWM2
			3h-7h	*Reserved*
			8h	Selects Function GP4[12]
			9h-Fh	*Reserved*
3-0	PINMUX12_3_0	L1		**AHCLKR1/GP4[11] Control**
			0	Pin is 3-stated.
			1h	Selects Function AHCLKR1
			2h-7h	*Reserved*
			8h	Selects Function GP4[11]
			9h-Fh	*Reserved*

11.5.11.14 Pin Multiplexing Control 13 Register (PINMUX13)

Figure 11-32. Pin Multiplexing Control 13 Register (PINMUX13)

31 28	27 24	23 20	19 16
PINMUX13_31_28	PINMUX13_27_24	PINMUX13_23_20	PINMUX13_19_16
R/W-0	R/W-0	R/W-0	R/W-0
15 12	**11 8**	**7 4**	**3 0**
PINMUX13_15_12	PINMUX13_11_8	PINMUX13_7_4	PINMUX13_3_0
R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; *-n* = value after reset

Table 11-36. Pin Multiplexing Control 13 Register (PINMUX13) Field Descriptions

Bit	Field	ZKB Ball	Value	Description
31-28	PINMUX13_31_28	R15		**EMA_D[1]/MMCSD_DAT[1]/UHPI_HD[1]/GP0[1] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMA_D[1]
			2h	Selects Function MMCSD_DAT[1]
			3h	*Reserved*
			4h	Selects Function UHPI_HD[1]
			5h-7h	*Reserved*
			8h	Selects Function GP0[1]
			9h-Fh	*Reserved*
27-24	PINMUX13_27_24	T13		**EMA_D[0]/MMCSD_DAT[0]/UHPI_HD[0]/GP0[0]/BOOT[12] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMA_D[0]
			2h	Selects Function MMCSD_DAT[0]
			3h	*Reserved*
			4h	Selects Function UHPI_HD[0]
			5h-7h	*Reserved*
			8h	Selects Function GP0[0]
			9h-Fh	*Reserved*
23-20	PINMUX13_23_20	M1		**AXR1[9]/GP4[9] Control**
			0	Pin is 3-stated.
			1h	Selects Function AXR1[9]
			2h-7h	*Reserved*
			8h	Selects Function GP4[9]
			9h-Fh	*Reserved*
19-16	PINMUX13_19_16	M2		**AXR1[8]/EPWM1A/GP4[8] Control**
			0	Pin is 3-stated.
			1h	Selects Function AXR1[8]
			2h	Selects Function EPWM1A
			3h-7h	*Reserved*
			8h	Selects Function GP4[8]
			9h-Fh	*Reserved*

Table 11-36. Pin Multiplexing Control 13 Register (PINMUX13) Field Descriptions (continued)

Bit	Field	ZKB Ball	Value	Description
15-12	PINMUX13_15_12	M3		**AXR1[7]/EPWM1B/GP4[7] Control**
			0	Pin is 3-stated.
			1h	Selects Function AXR1[7]
			2h	Selects Function EPWM1B
			3h-7h	*Reserved*
			8h	Selects Function GP4[7]
			9h-Fh	*Reserved*
11-8	PINMUX13_11_8	M4		**AXR1[6]/EPWM2A/GP4[6] Control**
			0	Pin is 3-stated.
			1h	Selects Function AXR1[6]
			2h	Selects Function EPWM2A
			3h-7h	*Reserved*
			8h	Selects Function GP4[6]
			9h-Fh	*Reserved*
7-4	PINMUX13_7_4	N1		**AXR1[5]/EPWM2B/GP4[5] Control**
			0	Pin is 3-stated.
			1h	Selects Function AXR1[5]
			2h	Selects Function EPWM2B
			3h-7h	*Reserved*
			8h	Selects Function GP4[5]
			9h-Fh	*Reserved*
3-0	PINMUX13_3_0	N2		**AXR1[4]/EQEP1B/GP4[4] Control**
			0	Pin is 3-stated.
			1h	Selects Function AXR1[4]
			2h	Selects Function EQEP1B
			3h-7h	*Reserved*
			8h	Selects Function GP4[4]
			9h-Fh	*Reserved*

11.5.11.15 Pin Multiplexing Control 14 Register (PINMUX14)

Figure 11-33. Pin Multiplexing Control 14 Register (PINMUX14)

31–28	27–24	23–20	19–16
PINMUX14_31_28	PINMUX14_27_24	PINMUX14_23_20	PINMUX14_19_16
R/W-0	R/W-0	R/W-0	R/W-0
15–12	**11–8**	**7–4**	**3–0**
PINMUX14_15_12	PINMUX14_11_8	PINMUX14_7_4	PINMUX14_3_0
R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; *-n* = value after reset

Table 11-37. Pin Multiplexing Control 14 Register (PINMUX14) Field Descriptions

Bit	Field	ZKB Ball	Value	Description
31-28	PINMUX14_31_28	T14		**EMA_D[9]/UHPI_HD[9]/LCD_D[9]/GP0[9] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMA_D[9]
			2h	Selects Function UHPI_HD[9]
			3h	*Reserved*
			4h	Selects Function LCD_D[9]
			5h-7h	*Reserved*
			8h	Selects Function GP0[9]
			9h-Fh	*Reserved*
27-24	PINMUX14_27_24	N12		**EMA_D[8]/UHPI_HD[8]/LCD_D[8]/GP0[8] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMA_D[8]
			2h	Selects Function UHPI_HD[8]
			3h	*Reserved*
			4h	Selects Function LCD_D[8]
			5h-7h	*Reserved*
			8h	Selects Function GP0[8]
			9h-Fh	*Reserved*
23-20	PINMUX14_23_20	M15		**EMA_D[7]/MMCSD_DAT[7]/UHPI_HD[7]/GP0[7]/BOOT[13] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMA_D[7]
			2h	Selects Function MMCSD_DAT[7]
			3h	*Reserved*
			4h	Selects Function UHPI_HD[7]
			5h-7h	*Reserved*
			8h	Selects Function GP0[7]
			9h-Fh	*Reserved*

Table 11-37. Pin Multiplexing Control 14 Register (PINMUX14) Field Descriptions (continued)

Bit	Field	ZKB Ball	Value	Description
19-16	PINMUX14_19_16	N13		**EMA_D[6]/MMCSD_DAT[6]/UHPI_HD[6]/GP0[6] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMA_D[6]
			2h	Selects Function MMCSD_DAT[6]
			3h	*Reserved*
			4h	Selects Function UHPI_HD[6]
			5h-7h	*Reserved*
			8h	Selects Function GP0[6]
			9h-Fh	*Reserved*
15-12	PINMUX14_15_12	N15		**EMA_D[5]/MMCSD_DAT[5]/UHPI_HD[5]/GP0[5] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMA_D[5]
			2h	Selects Function MMCSD_DAT[5]
			3h	*Reserved*
			4h	Selects Function UHPI_HD[5]
			5h-7h	*Reserved*
			8h	Selects Function GP0[5]
			9h-Fh	*Reserved*
11-8	PINMUX14_11_8	P13		**EMA_D[4]/MMCSD_DAT[4]/UHPI_HD[4]/GP0[4] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMA_D[4]
			2h	Selects Function MMCSD_DAT[4]
			3h	*Reserved*
			4h	Selects Function UHPI_HD[4]
			5h-7h	*Reserved*
			8h	Selects Function GP0[4]
			9h-Fh	*Reserved*
7-4	PINMUX14_7_4	P15		**EMA_D[3]/MMCSD_DAT[3]/UHPI_HD[3]/GP0[3] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMA_D[3]
			2h	Selects Function MMCSD_DAT[3]
			3h	*Reserved*
			4h	Selects Function UHPI_HD[3]
			5h-7h	*Reserved*
			8h	Selects Function GP0[3]
			9h-Fh	*Reserved*
3-0	PINMUX14_3_0	R13		**EMA_D[2]/MMCSD_DAT[2]/UHPI_HD[2]/GP0[2] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMA_D[2]
			2h	Selects Function MMCSD_DAT[2]
			3h	*Reserved*
			4h	Selects Function UHPI_HD[2]
			5h-7h	*Reserved*
			8h	Selects Function GP0[2]
			9h-Fh	*Reserved*

11.5.11.16 Pin Multiplexing Control 15 Register (PINMUX15)

Figure 11-34. Pin Multiplexing Control 15 Register (PINMUX15)

31 28	27 24	23 20	19 16
PINMUX15_31_28	PINMUX15_27_24	PINMUX15_23_20	PINMUX15_19_16
R/W-0	R/W-0	R/W-0	R/W-0
15 12	**11 8**	**7 4**	**3 0**
PINMUX15_15_12	PINMUX15_11_8	PINMUX15_7_4	PINMUX15_3_0
R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; *-n* = value after reset

Table 11-38. Pin Multiplexing Control 15 Register (PINMUX15) Field Descriptions

Bit	Field	ZKB Ball	Value	Description
31-28	PINMUX15_31_28	R9		**EMA_A[1]/MMCSD_CLK/UHPI_HCNTL0/GP1[1] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMA_A[1]
			2h	Selects Function MMCSD_CLK
			3h	*Reserved*
			4h	Selects Function UHPI_HCNTL0
			5h-7h	*Reserved*
			8h	Selects Function GP1[1]
			9h-Fh	*Reserved*
27-24	PINMUX15_27_24	T9		**EMA_A[0]/LCD_D[7]/GP1[0] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMA_A[0]
			2h	Selects Function LCD_D[7]
			3h-7h	*Reserved*
			8h	Selects Function GP1[0]
			9h-Fh	*Reserved*
23-20	PINMUX15_23_20	M16		**EMA_D[15]/UHPI_HD[15]/LCD_D[15]/GP0[15] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMA_D[15]
			2h	Selects Function UHPI_HD[15]
			3h	*Reserved*
			4h	Selects Function LCD_D[15]
			5h-7h	*Reserved*
			8h	Selects Function GP0[15]
			9h-Fh	*Reserved*

Table 11-38. Pin Multiplexing Control 15 Register (PINMUX15) Field Descriptions (continued)

Bit	Field	ZKB Ball	Value	Description
19-16	PINMUX15_19_16	N14		**EMA_D[14]/UHPI_HD[14]/LCD_D[14]/GP0[14] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMA_D[14]
			2h	Selects Function UHPI_HD[14]
			3h	*Reserved*
			4h	Selects Function LCD_D[14]
			5h-7h	*Reserved*
			8h	Selects Function GP0[14]
			9h-Fh	*Reserved*
15-12	PINMUX15_15_12	N16		**EMA_D[13]/UHPI_HD[13]/LCD_D[13]/GP0[13] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMA_D[13]
			2h	Selects Function UHPI_HD[13]
			3h	*Reserved*
			4h	Selects Function LCD_D[13]
			5h-7h	*Reserved*
			8h	Selects Function GP0[13]
			9h-Fh	*Reserved*
11-8	PINMUX15_11_8	P14		**EMA_D[12]/UHPI_HD[12]/LCD_D[12]/GP0[12] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMA_D[12]
			2h	Selects Function UHPI_HD[12]
			3h	*Reserved*
			4h	Selects Function LCD_D[12]
			5h-7h	*Reserved*
			8h	Selects Function GP0[12]
			9h-Fh	*Reserved*
7-4	PINMUX15_7_4	P16		**EMA_D[11]/UHPI_HD[11]/LCD_D[11]/GP0[11] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMA_D[11]
			2h	Selects Function UHPI_HD[11]
			3h	*Reserved*
			4h	Selects Function LCD_D[11]
			5h-7h	*Reserved*
			8h	Selects Function GP0[11]
			9h-Fh	*Reserved*
3-0	PINMUX15_3_0	R14		**EMA_D[10]/UHPI_HD[10]/LCD_D[10]/GP0[10] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMA_D[10]
			2h	Selects Function UHPI_HD[10]
			3h	*Reserved*
			4h	Selects Function LCD_D[10]
			5h-7h	*Reserved*
			8h	Selects Function GP0[10]
			9h-Fh	*Reserved*

11.5.11.17 Pin Multiplexing Control 16 Register (PINMUX16)

Figure 11-35. Pin Multiplexing Control 16 Register (PINMUX16)

31 28	27 24	23 20	19 16
PINMUX16_31_28	PINMUX16_27_24	PINMUX16_23_20	PINMUX16_19_16
R/W-0	R/W-0	R/W-0	R/W-0
15 12	**11 8**	**7 4**	**3 0**
PINMUX16_15_12	PINMUX16_11_8	PINMUX16_7_4	PINMUX16_3_0
R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; *-n* = value after reset

Table 11-39. Pin Multiplexing Control 16 Register (PINMUX16) Field Descriptions

Bit	Field	ZKB Ball	Value	Description
31-28	PINMUX16_31_28	R11		**EMA_A[9]/LCD_HSYNC/GP1[9] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMA_A[9]
			2h	Selects Function LCD_HSYNC
			3h-7h	*Reserved*
			8h	Selects Function GP1[9]
			9h-Fh	*Reserved*
27-24	PINMUX16_27_24	T11		**EMA_A[8]/LCD_PCLK/GP1[8] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMA_A[8]
			2h	Selects Function LCD_PCLK
			3h-7h	*Reserved*
			8h	Selects Function GP1[8]
			9h-Fh	*Reserved*
23-20	PINMUX16_23_20	N10		**EMA_A[7]/LCD_D[0]/GP1[7] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMA_A[7]
			2h	Selects Function LCD_D[0]
			3h-7h	*Reserved*
			8h	Selects Function GP1[7]
			9h-Fh	*Reserved*
19-16	PINMUX16_19_16	P10		**EMA_A[6]/LCD_D[1]/GP1[6] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMA_A[6]
			2h	Selects Function LCD_D[1]
			3h-7h	*Reserved*
			8h	Selects Function GP1[6]
			9h-Fh	*Reserved*

Table 11-39. Pin Multiplexing Control 16 Register (PINMUX16) Field Descriptions (continued)

Bit	Field	ZKB Ball	Value	Description
15-12	PINMUX16_15_12	R10		**EMA_A[5]/LCD_D[2]/GP1[5] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMA_A[5]
			2h	Selects Function LCD_D[2]
			3h-7h	*Reserved*
			8h	Selects Function GP1[5]
			9h-Fh	*Reserved*
11-8	PINMUX16_11_8	T10		**EMA_A[4]/LCD_D[3]/GP1[4] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMA_A[4]
			2h	Selects Function LCD_D[3]
			3h-7h	*Reserved*
			8h	Selects Function GP1[4]
			9h-Fh	*Reserved*
7-4	PINMUX16_7_4	N9		**EMA_A[3]/LCD_D[6]/GP1[3] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMA_A[3]
			2h	Selects Function LCD_D[6]
			3h-7h	*Reserved*
			8h	Selects Function GP1[3]
			9h-Fh	*Reserved*
3-0	PINMUX16_3_0	P9		**EMA_A[2]/MMCSD_CMD/UHPI_HCNTL1/GP1[2] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMA_A[2]
			2h	Selects Function MMCSD_CMD
			3h	*Reserved*
			4h	Selects Function UHPI_HCNTL1
			5h-7h	*Reserved*
			8h	Selects Function GP1[2]
			9h-Fh	*Reserved*

11.5.11.18 Pin Multiplexing Control 17 Register (PINMUX17)

Figure 11-36. Pin Multiplexing Control 17 Register (PINMUX17)

31–28	27–24	23–20	19–16
PINMUX17_31_28	PINMUX17_27_24	PINMUX17_23_20	PINMUX17_19_16
R/W-0	R/W-0	R/W-0	R/W-0
15–12	**11–8**	**7–4**	**3–0**
PINMUX17_15_12	PINMUX17_11_8	PINMUX17_7_4	PINMUX17_3_0
R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; *-n* = value after reset

Table 11-40. Pin Multiplexing Control 17 Register (PINMUX17) Field Descriptions

Bit	Field	ZKB Ball	Value	Description
31-28	PINMUX17_31_28	L16		**$\overline{\text{EMA\_CAS}}$/EMA_CS[4]/GP2[1] Control**
			0	Pin is 3-stated.
			1h	Selects Function $\overline{\text{EMA\_CAS}}$
			2h	Selects Function EMA_CS[4]
			3h-7h	*Reserved*
			8h	Selects Function GP2[1]
			9h-Fh	*Reserved*
27-24	PINMUX17_27_24	T12		**EMA_SDCKE/GP2[0] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMA_SDCKE
			2h-7h	*Reserved*
			8h	Selects Function GP2[0]
			9h-Fh	*Reserved*
23-20	PINMUX17_23_20	R12		**EMA_CLK/OBSCLK/AHCLKR2/GP1[15] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMA_CLK
			2h	Selects Function OBSCLK.
			3h	*Reserved*
			4h	Selects Function AHCLKR2
			5h-7h	*Reserved*
			8h	Selects Function GP1[15]
			9h-Fh	*Reserved*
19-16	PINMUX17_19_16	R8		**EMA_BA[0]/LCD_D[4]/GP1[14] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMA_BA[0]
			2h	Selects Function LCD_D[4]
			3h-7h	*Reserved*
			8h	Selects Function GP1[14]
			9h-Fh	*Reserved*

Table 11-40. Pin Multiplexing Control 17 Register (PINMUX17) Field Descriptions (continued)

Bit	Field	ZKB Ball	Value	Description
15-12	PINMUX17_15_12	P8		**EMA_BA[1]/LCD_D[5]/UHPI_HHWIL/GP1[13] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMA_BA[1]
			2h	Selects Function LCD_D[5]
			3h	*Reserved*
			4h	Selects Function UHPI_HHWIL
			5h-7h	*Reserved*
			8h	Selects Function GP1[13]
			9h-Fh	*Reserved*
11-8	PINMUX17_11_8	N11		**EMA_A[12]/LCD_MCLK/GP1[12] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMA_A[12]
			2h	Selects Function LCD_MCLK
			3h-7h	*Reserved*
			8h	Selects Function GP1[12]
			9h-Fh	*Reserved*
7-4	PINMUX17_7_4	P11		**EMA_A[11]/$\overline{\text{LCD\_AC\_ENB\_CS}}$/GP1[11] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMA_A[11]
			2h	Selects Function $\overline{\text{LCD\_AC\_ENB\_CS}}$
			3h-7h	*Reserved*
			8h	Selects Function GP1[11]
			9h-Fh	*Reserved*
3-0	PINMUX17_3_0	N8		**EMA_A[10]/LCD_VSYNC/GP1[10] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMA_A[10]
			2h	Selects Function LCD_VSYNC
			3h-7h	*Reserved*
			8h	Selects Function GP1[10]
			9h-Fh	*Reserved*

11.5.11.19 Pin Multiplexing Control 18 Register (PINMUX18)

Figure 11-37. Pin Multiplexing Control 18 Register (PINMUX18)

31–28	27–24	23–20	19–16
PINMUX18_31_28	PINMUX18_27_24	PINMUX18_23_20	PINMUX18_19_16
R/W-0	R/W-0	R/W-0	R/W-0
15–12	**11–8**	**7–4**	**3–0**
PINMUX18_15_12	PINMUX18_11_8	PINMUX18_7_4	PINMUX18_3_0
R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; *-n* = value after reset

Table 11-41. Pin Multiplexing Control 18 Register (PINMUX18) Field Descriptions

Bit	Field	ZKB Ball	Value	Description
31-28	PINMUX18_31_28	M14		**$\overline{\text{EMA\_WE\_DQM[0]}}$/$\overline{\text{UHPI\_HINT}}$/AXR0[15]/GP2[9] Control**
			0	Pin is 3-stated.
			1h	Selects Function $\overline{\text{EMA\_WE\_DQM[0]}}$
			2h	Selects Function $\overline{\text{UHPI\_HINT}}$
			3h	*Reserved*
			4h	Selects Function AXR0[15]
			5h-7h	*Reserved*
			8h	Selects Function GP2[9]
			9h-Fh	*Reserved*
27-24	PINMUX18_27_24	P12		**$\overline{\text{EMA\_WE\_DQM[1]}}$/$\overline{\text{UHPI\_HDS2}}$/AXR0[14]/GP2[8] Control**
			0	Pin is 3-stated.
			1h	Selects Function $\overline{\text{EMA\_WE\_DQM[1]}}$
			2h	Selects Function $\overline{\text{UHPI\_HDS2}}$
			3h	*Reserved*
			4h	Selects Function AXR0[14]
			5h-7h	*Reserved*
			8h	Selects Function GP2[8]
			9h-Fh	*Reserved*
23-20	PINMUX18_23_20	R7		**$\overline{\text{EMA\_OE}}$/$\overline{\text{UHPI\_HDS1}}$/AXR0[13]/GP2[7] Control**
			0	Pin is 3-stated.
			1h	Selects Function $\overline{\text{EMA\_OE}}$
			2h	Selects Function $\overline{\text{UHPI\_HDS1}}$
			3h	*Reserved*
			4h	Selects Function AXR0[13]
			5h-7h	*Reserved*
			8h	Selects Function GP2[7]
			9h-Fh	*Reserved*

Table 11-41. Pin Multiplexing Control 18 Register (PINMUX18) Field Descriptions (continued)

Bit	Field	ZKB Ball	Value	Description
19-16	PINMUX18_19_16	T7		**$\overline{\text{EMA\_CS[3]}}$/AMUTE2/GP2[6] Control**
			0	Pin is 3-stated.
			1h	Selects Function $\overline{\text{EMA\_CS[3]}}$
			2h-3h	*Reserved*
			4h	Selects Function AMUTE2
			5h-7h	*Reserved*
			8h	Selects Function GP2[6]
			9h-Fh	*Reserved*
15-12	PINMUX18_15_12	P7		**$\overline{\text{EMA\_CS[2]}}$/$\overline{\text{UHPI\_HCS}}$/GP2[5]/BOOT[15] Control**
			0	Pin is 3-stated.
			1h	Selects Function $\overline{\text{EMA\_CS[2]}}$
			2h	Selects Function $\overline{\text{UHPI\_HCS}}$
			3h-7h	*Reserved*
			8h	Selects Function GP2[5]
			9h-Fh	*Reserved*
11-8	PINMUX18_11_8	T8		**$\overline{\text{EMA\_CS[0]}}$/$\overline{\text{UHPI\_HAS}}$/GP2[4] Control**
			0	Pin is 3-stated.
			1h	Selects Function $\overline{\text{EMA\_CS[0]}}$
			2h	Selects Function $\overline{\text{UHPI\_HAS}}$
			3h-7h	*Reserved*
			8h	Selects Function GP2[4]
			9h-Fh	*Reserved*
7-4	PINMUX18_7_4	M13		**$\overline{\text{EMA\_WE}}$/UHPI_HR$\overline{\text{W}}$/AXR0[12]/GP2[3]/BOOT[14] Control**
			0	Pin is 3-stated.
			1h	Selects Function $\overline{\text{EMA\_WE}}$
			2h	Selects Function UHPI_HR$\overline{\text{W}}$
			3h	*Reserved*
			4h	Selects Function AXR0[12]
			5h-7h	*Reserved*
			8h	Selects Function GP2[3]
			9h-Fh	*Reserved*
3-0	PINMUX18_3_0	N7		**$\overline{\text{EMA\_RAS}}$/$\overline{\text{EMA\_CS[5]}}$/GP2[2] Control**
			0	Pin is 3-stated.
			1h	Selects Function $\overline{\text{EMA\_RAS}}$
			2h	Selects Function $\overline{\text{EMA\_CS[5]}}$
			3h-7h	*Reserved*
			8h	Selects Function GP2[2]
			9h-Fh	*Reserved*

11.5.11.20 Pin Multiplexing Control 19 Register (PINMUX19)

Figure 11-38. Pin Multiplexing Control 19 Register (PINMUX19)

31	16
Reserved	
R/W-0	

15	4	3	0
Reserved		PINMUX19_3_0	
R/W-0		R/W-0	

LEGEND: R/W = Read/Write; *-n* = value after reset

Table 11-42. Pin Multiplexing Control 19 Register (PINMUX19) Field Descriptions

Bit	Field	ZKB Ball	Value	Description
31-4	Reserved	—	0	Reserved
3-0	PINMUX19_3_0	N6		**EMA_WAIT[0]/$\overline{\text{UHPI\_HRDY}}$/GP2[10] Control**
			0	Pin is 3-stated.
			1h	Selects Function EMA_WAIT[0]
			2h	Selects Function $\overline{\text{UHPI\_HRDY}}$
			3h-7h	*Reserved*
			8h	Selects Function GP2[10]
			9h-Fh	*Reserved*

11.5.12 Suspend Source Register (SUSPSRC)

The flexibility of the OMAP-L137 Applications Processor architecture allows either the ARM or the DSP to control the various peripherals (setup registers, service interrupts, etc.). While this assignment is a matter of software convention, during an emulation halt, the device must know which peripherals are associated with the halting processor, so that only those modules receive the suspend signal. This allows peripherals associated with the other (unhalted) processor to continue normal operation.

The suspend source register (SUSPSRC) indicates the emulation suspend source for those peripherals that support emulation suspend. When the associated SUSPSRC bit is 0, the ARM emulator controls the peripheral's emulation suspend signal; when the associated SUSPSRC bit is 1, the DSP emulator controls the peripheral's emulation suspend signal. By default (bit is set to 1) for all peripherals, the emulation suspend signal is controlled by the DSP.

The SUSPSRC is shown in Figure 11-39 and described in Table 11-43.

Figure 11-39. Suspend Source Register (SUSPSRC)

31	30	29	28	27	26	25	24
Reserved	Reserved	Reserved	TIMER64_1SRC	TIMER64_0SRC	Reserved	EPWM2SRC	EPWM1SRC
R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1
23	22	21	20	19	18	17	16
EPWM0SRC	SPI1SRC	SPI0SRC	UART2SRC	UART1SRC	UART0SRC	I2C1SRC	I2C0SRC
R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1
15	14	13	12	11	10	9	8
Reserved	Reserved	Reserved	HPISRC	Reserved	Reserved	USB0SRC	Reserved
R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1
7	6	5	4	3	2	1	0
Reserved	PRUSRC	EMACSRC	EQEP1SRC	EQEP0SRC	ECAP2SRC	ECAP1SRC	ECAP0SRC
R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1

LEGEND: R/W = Read/Write; *-n* = value after reset

Table 11-43. Suspend Source Register (SUSPSRC) Field Descriptions

Bit	Field	Value	Description
31-29	Reserved	1	Reserved. Write the default value to all bits when modifying this register.
28	TIMER64_1SRC		**Timer1 64 Emulation Suspend Source.**
		0	ARM is the source of the emulation suspend.
		1	DSP is the source of the emulation suspend.
27	TIMER64_0SRC		**Timer0 64 Emulation Suspend Source.**
		0	ARM is the source of the emulation suspend.
		1	DSP is the source of the emulation suspend.
26	Reserved	1	Reserved. Write the default value to all bits when modifying this register.
25	EPWM2SRC		**EPWM2 Emulation Suspend Source.**
		0	ARM is the source of the emulation suspend.
		1	DSP is the source of the emulation suspend.
24	EPWM1SRC		**EPWM1 Emulation Suspend Source.**
		0	ARM is the source of the emulation suspend.
		1	DSP is the source of the emulation suspend.
23	EPWM0SRC		**EPWM0 Emulation Suspend Source.**
		0	ARM is the source of the emulation suspend.
		1	DSP is the source of the emulation suspend.

Table 11-43. Suspend Source Register (SUSPSRC) Field Descriptions (continued)

Bit	Field	Value	Description
22	SPI1SRC		**SPI1 Emulation Suspend Source.**
		0	ARM is the source of the emulation suspend.
		1	DSP is the source of the emulation suspend.
21	SPI0SRC		**SPI0 Emulation Suspend Source.**
		0	ARM is the source of the emulation suspend.
		1	DSP is the source of the emulation suspend.
20	UART2SRC		**UART2 Emulation Suspend Source.**
		0	ARM is the source of the emulation suspend.
		1	DSP is the source of the emulation suspend.
19	UART1SRC		**UART1 Emulation Suspend Source.**
		0	ARM is the source of the emulation suspend.
		1	DSP is the source of the emulation suspend.
18	UART0SRC		**UART0 Emulation Suspend Source.**
		0	ARM is the source of the emulation suspend.
		1	DSP is the source of the emulation suspend.
17	I2C1SRC		**I2C1 Emulation Suspend Source.**
		0	ARM is the source of the emulation suspend.
		1	DSP is the source of the emulation suspend.
16	I2C0SRC		**I2C0 Emulation Suspend Source.**
		0	ARM is the source of the emulation suspend.
		1	DSP is the source of the emulation suspend.
15-13	Reserved	1	Reserved. Write the default value to all bits when modifying this register.
12	HPISRC		**HPI Emulation Suspend Source.**
		0	ARM is the source of the emulation suspend.
		1	DSP is the source of the emulation suspend.
11-10	Reserved	1	Reserved. Write the default value to all bits when modifying this register.
9	USB0SRC		**USB0 Emulation Suspend Source.**
		0	ARM is the source of the emulation suspend.
		1	DSP is the source of the emulation suspend.
8-7	Reserved	1	Reserved. Write the default value to all bits when modifying this register.
6	PRUSRC		**PRU Emulation Suspend Source.**
		0	ARM is the source of the emulation suspend.
		1	DSP is the source of the emulation suspend.
5	EMACSRC		**EMAC Emulation Suspend Source.**
		0	ARM is the source of the emulation suspend.
		1	DSP is the source of the emulation suspend.
4	EQEP1SRC		**EQEP1 Emulation Suspend Source.**
		0	ARM is the source of the emulation suspend.
		1	DSP is the source of the emulation suspend.
3	EQEP0SRC		**EQEP0 Emulation Suspend Source.**
		0	ARM is the source of the emulation suspend.
		1	DSP is the source of the emulation suspend.
2	ECAP2SRC		**ECAP2 Emulation Suspend Source.**
		0	ARM is the source of the emulation suspend.
		1	DSP is the source of the emulation suspend.

Table 11-43. Suspend Source Register (SUSPSRC) Field Descriptions (continued)

Bit	Field	Value	Description
1	ECAP1SRC		**ECAP1 Emulation Suspend Source.**
		0	ARM is the source of the emulation suspend.
		1	DSP is the source of the emulation suspend.
0	ECAP0SRC		**ECAP0 Emulation Suspend Source.**
		0	ARM is the source of the emulation suspend.
		1	DSP is the source of the emulation suspend.

11.5.13 Chip Signal Register (CHIPSIG)

The DSP has access to 4 ARM interrupt events in the ARM interrupt map: SYSCFG_CHIPINT0, SYSCFG_CHIPINT1, SYSCFG_CHIPINT2, and SYSCFG_CHIPINT3. The ARM has access to 3 DSP interrupt events in the DSP interrupt event map: SYSCFG_CHIPINT2, SYSCFG_CHIPINT3, and NMI.

NOTE: SYSCFG_CHIPINT2 and SYSCFG_CHIPINT3 are essentially for the ARM to interrupt the DSP. However, these are additionally mapped to the ARM interrupt controller (AINTC), so that it can be used as debug interrupts, in case there is a need to halt both processors simultaneously.

The ARM may generate an interrupt to the DSP by setting one of the two CHIPSIG[3-2] bits or an NMI interrupt by setting the CHIPSIG[4] bit in the chip signal register (CHIPSIG). The DSP may generate an interrupt to the ARM by setting one of the four CHIPSIG[3-0] bits. Writing a 1 to these bits sets the interrupts, writing a 0 has no effect. Reads return the value of these bits and can also be used as status bits. The CHIPSIG is shown in Figure 11-40 and described in Table 11-44.

Figure 11-40. Chip Signal Register (CHIPSIG)

31	16
Reserved	
R-0	

15	5	4	3	2	1	0
Reserved		CHIPSIG4	CHIPSIG3	CHIPSIG2	CHIPSIG1	CHIPSIG0
R-0		R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 11-44. Chip Signal Register (CHIPSIG) Field Descriptions

Bit	Field	Value	Description
31-5	Reserved	0	Reserved
4	CHIPSIG4		**Asserts DSP NMI interrupt.**
		0	No effect
		1	Asserts interrupt
3	CHIPSIG3		**Asserts SYSCFG_CHIPINT3 interrupt.**
		0	No effect
		1	Asserts interrupt
2	CHIPSIG2		**Asserts SYSCFG_CHIPINT2 interrupt.**
		0	No effect
		1	Asserts interrupt
1	CHIPSIG1		**Asserts SYSCFG_CHIPINT1 interrupt.**
		0	No effect
		1	Asserts interrupt
0	CHIPSIG0		**Asserts SYSCFG_CHIPINT0 interrupt.**
		0	No effect
		1	Asserts interrupt

11.5.14 Chip Signal Clear Register (CHIPSIG_CLR)

The chip signal clear register (CHIPSIG_CLR) is used to clear the bits set in the chip signal register (CHIPSIG). Writing a 1 to a CHIPSIG[*n*] bit in CHIPSIG_CLR clears the corresponding CHIPSIG[*n*] bit in CHIPSIG; writing a 0 has no effect. After servicing the interrupt, the interrupted processor can clear the bits set in CHIPSIG by writing 1 to the corresponding bits in CHIPSIG_CLR. The other processor may poll the CHIPSIG[*n*] bit to determine when the interrupted processor has completed the interrupt service. The CHIPSIG_CLR is shown in Figure 11-41 and described in Table 11-45.

For more information on ARM interrupts, see the *ARM Interrupt Controller (AINTC)* chapter. For more information on DSP interrupts, see the *DSP Subsystem* chapter.

Figure 11-41. Chip Signal Clear Register (CHIPSIG_CLR)

31	16
Reserved	
R-0	

15	5	4	3	2	1	0
Reserved		CHIPSIG4	CHIPSIG3	CHIPSIG2	CHIPSIG1	CHIPSIG0
R-0		R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 11-45. Chip Signal Clear Register (CHIPSIG_CLR) Field Descriptions

Bit	Field	Value	Description
31-5	Reserved	0	Reserved
4	CHIPSIG4		**Clears DSP NMI interrupt.**
		0	No effect
		1	Clears interrupt
3	CHIPSIG3		**Clears SYSCFG_CHIPINT3 interrupt.**
		0	No effect
		1	Clears interrupt
2	CHIPSIG2		**Clears SYSCFG_CHIPINT2 interrupt.**
		0	No effect
		1	Clears interrupt
1	CHIPSIG1		**Clears SYSCFG_CHIPINT1 interrupt.**
		0	No effect
		1	Clears interrupt
0	CHIPSIG0		**Clears SYSCFG_CHIPINT0 interrupt.**
		0	No effect
		1	Clears interrupt

11.5.15 Chip Configuration 0 Register (CFGCHIP0)

The chip configuration 0 register (CFGCHIP0) controls the following functions:

- PLL Controller memory-mapped register lock: Used to lock out writes to the PLL controller memory-mapped registers (MMRs) to prevent any erroneous writes in software to the PLL controller register space.
- EDMA3 Transfer Controller Default Burst Size (DBS) Control: This controls the maximum number of bytes issued per read/write command or the burst size for the individual transfer controllers (TCs) on the device. By default for all transfer controllers, the burst size is set to 16 bytes. However, CFGCHIP0 allows configurability of this parameter so that the TC can have a burst size of 16, 32, or 64 bytes. The burst size determines the intra packet efficiency for the EDMA3 transfers. Additionally, it also facilitates preemption at a system level, as all transfer requests are internally broken down by the transfer controller up to DBS size byte chunks and on a system level, each master's priority (configured by the MSTPRI register) is evaluated at burst size boundaries. The DBS value can significantly impact the standalone throughput performance depending on the source and destination (bus width/frequency/burst support etc) and the TC FIFO size, etc. Therefore, the DBS size configuration should be carefully analyzed to meet the system's throughput/performance requirements.

The CFGCHIP0 is shown in Figure 11-42 and described in Table 11-46.

Figure 11-42. Chip Configuration 0 Register (CFGCHIP0)

31	16
Reserved	
R-0	

15	5	4	3	2	1	0
Reserved		PLL_MASTER_LOCK	TC1DBS		TC0DBS	
R-0		R/W-0	R/W-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; *-n* = value after reset

Table 11-46. Chip Configuration 0 Register (CFGCHIP0) Field Descriptions

Bit	Field	Value	Description
31-5	Reserved	0	Reserved
4	PLL_MASTER_LOCK		**PLL MMRs lock.**
		0	PLLC MMRs are freely accessible.
		1	All PLLC MMRs are locked.
3-2	TC1DBS		**TC1 Default Burst Size (DBS).**
		0	16 bytes
		1h	32 bytes
		2h	64 bytes
		3h	*Reserved*
1-0	TC0DBS		**TC0 Default Burst Size (DBS).**
		0	16 bytes
		1h	32 bytes
		2h	64 bytes
		3h	*Reserved*

11.5.16 Chip Configuration 1 Register (CFGCHIP1)

The chip configuration 1 register (CFGCHIP1) controls the following functions:

- eCAP0/1/2 event input source: Allows using McASP TX/RX events or various EMAC TX/RX threshold, pulse, or miscellaneous interrupt events as eCAP event input sources.
- HPI Control: Allows HPIEN bit control that determines whether or not the HPI module has control over the HPI pins (multiplexed with other peripheral pins). It also provides configurability to select whether the host address is a word address or a byte address mode.
- eHRPWM Time Base Clock (TBCLK) Synchronization: Allows the software to globally synchronize all enabled eHRPWM modules to the time base clock (TBCLK).
- McASP AMUTEIN signal source control: Allows selecting GPIO interrupt from different banks as source for the McASP AMUTEIN signal. CFGCHIP1 provides this signal source control for all McASPs on the device.

The CFGCHIP1 is shown in Figure 11-43 and described in Table 11-47.

Figure 11-43. Chip Configuration 1 Register (CFGCHIP1)

31	27	26	22	21	17	16
CAP2SRC		CAP1SRC		CAP0SRC		HPIBYTEAD
R/W-0		R/W-0		R/W-0		R/W-0

15	14	13	12	11	8
HPIENA	Reserved		TBCLKSYNC	AMUTESEL2	
R/W-0	R-0		R/W-0	R/W-0	

7	4	3	0
AMUTESEL1		AMUTESEL0	
R/W-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 11-47. Chip Configuration 1 Register (CFGCHIP1) Field Descriptions

Bit	Field	Value	Description
31-27	CAP2SRC		**Selects the eCAP2 module event input.**
		0	eCAP2 Pin input
		1h	McASP0 TX DMA Event
		2h	McASP0 RX DMA Event
		3h	McASP1 TX DMA Event
		4h	McASP1 RX DMA Event
		5h	McASP2 TX DMA Event
		6h	McASP2 RX DMA Event
		7h	EMAC C0 RX Threshold Pulse Interrupt
		8h	EMAC C0 RX Pulse Interrupt
		9h	EMAC C0 TX Pulse Interrupt
		Ah	EMAC C0 Miscellaneous Interrupt
		Bh	EMAC C1 RX Threshold Pulse Interrupt
		Ch	EMAC C1 RX Pulse Interrupt
		Dh	EMAC C1 TX Pulse Interrupt
		Eh	EMAC C1 Miscellaneous Interrupt
		Fh	EMAC C2 RX Threshold Pulse Interrupt
		10h	EMAC C2 RX Pulse Interrupt
		11h	EMAC C2 TX Pulse Interrupt
		12h	EMAC C2 Miscellaneous Interrupt
		13h-1Fh	*Reserved*

Table 11-47. Chip Configuration 1 Register (CFGCHIP1) Field Descriptions (continued)

Bit	Field	Value	Description
26-22	CAP1SRC		**Selects the eCAP1 module event input.**
		0	eCAP1 Pin input
		1h	McASP0 TX DMA Event
		2h	McASP0 RX DMA Event
		3h	McASP1 TX DMA Event
		4h	McASP1 RX DMA Event
		5h	McASP2 TX DMA Event
		6h	McASP2 RX DMA Event
		7h	EMAC C0 RX Threshold Pulse Interrupt
		8h	EMAC C0 RX Pulse Interrupt
		9h	EMAC C0 TX Pulse Interrupt
		Ah	EMAC C0 Miscellaneous Interrupt
		Bh	EMAC C1 RX Threshold Pulse Interrupt
		Ch	EMAC C1 RX Pulse Interrupt
		Dh	EMAC C1 TX Pulse Interrupt
		Eh	EMAC C1 Miscellaneous Interrupt
		Fh	EMAC C2 RX Threshold Pulse Interrupt
		10h	EMAC C2 RX Pulse Interrupt
		11h	EMAC C2 TX Pulse Interrupt
		12h	EMAC C2 Miscellaneous Interrupt
		13h-1Fh	*Reserved*
21-17	CAP0SRC		**Selects the eCAP0 module event input.**
		0	eCAP0 Pin input
		1h	McASP0 TX DMA Event
		2h	McASP0 RX DMA Event
		3h	McASP1 TX DMA Event
		4h	McASP1 RX DMA Event
		5h	McASP2 TX DMA Event
		6h	McASP2 RX DMA Event
		7h	EMAC C0 RX Threshold Pulse Interrupt
		8h	EMAC C0 RX Pulse Interrupt
		9h	EMAC C0 TX Pulse Interrupt
		Ah	EMAC C0 Miscellaneous Interrupt
		Bh	EMAC C1 RX Threshold Pulse Interrupt
		Ch	EMAC C1 RX Pulse Interrupt
		Dh	EMAC C1 TX Pulse Interrupt
		Eh	EMAC C1 Miscellaneous Interrupt
		Fh	EMAC C2 RX Threshold Pulse Interrupt
		10h	EMAC C2 RX Pulse Interrupt
		11h	EMAC C2 TX Pulse Interrupt
		12h	EMAC C2 Miscellaneous Interrupt
		13h-1Fh	*Reserved*
16	HPIBYTEAD		**HPI Byte/Word Address Mode select.**
		0	Host address is a word address.
		1	Host address is a byte address.

Table 11-47. Chip Configuration 1 Register (CFGCHIP1) Field Descriptions (continued)

Bit	Field	Value	Description
15	HPIENA		**HPI Enable Bit.**
		0	HPI is disabled.
		1	HPI is enabled.
14-13	Reserved	0	Reserved. Always read as 0.
12	TBCLKSYNC		**eHRPWM Module Time Base Clock (TBCLK) Synchronization.** Allows you to globally synchronize all enabled eHRPWM modules to the time base clock (TBCLK).
		0	Time base clock (TBCLK) within each enabled eHRPWM module is stopped.
		1	All enabled eHRPWM module clocks are started with the first rising edge of TBCLK aligned. For perfectly synchronized TBCLKs, the prescaler bits in the TBCTL register of each eHRPWM module must be set identically.
11-8	AMUTESEL2		**Selects the source of McASP2 AMUTEIN signal.**
		0	Drive McASP2 AMUTEIN signal low
		1h	GPIO Interrupt from Bank 0
		2h	GPIO Interrupt from Bank 1
		3h	GPIO Interrupt from Bank 2
		4h	GPIO Interrupt from Bank 3
		5h	GPIO Interrupt from Bank 4
		6h	GPIO Interrupt from Bank 5
		7h	GPIO Interrupt from Bank 6
		8h	GPIO Interrupt from Bank 7
		9h-Fh	*Reserved*
7-4	AMUTESEL1		**Selects the source of McASP1 AMUTEIN signal.**
		0	Drive McASP1 AMUTEIN signal low
		1h	GPIO Interrupt from Bank 0
		2h	GPIO Interrupt from Bank 1
		3h	GPIO Interrupt from Bank 2
		4h	GPIO Interrupt from Bank 3
		5h	GPIO Interrupt from Bank 4
		6h	GPIO Interrupt from Bank 5
		7h	GPIO Interrupt from Bank 6
		8h	GPIO Interrupt from Bank 7
		9h-Fh	*Reserved*
3-0	AMUTESEL0		**Selects the source of McASP0 AMUTEIN signal.**
		0	Drive McASP0 AMUTEIN signal low
		1h	GPIO Interrupt from Bank 0
		2h	GPIO Interrupt from Bank 1
		3h	GPIO Interrupt from Bank 2
		4h	GPIO Interrupt from Bank 3
		5h	GPIO Interrupt from Bank 4
		6h	GPIO Interrupt from Bank 5
		7h	GPIO Interrupt from Bank 6
		8h	GPIO Interrupt from Bank 7
		9h-Fh	*Reserved*

11.5.17 Chip Configuration 2 Register (CFGCHIP2)

The chip configuration 2 register (CFGCHIP2) controls the following functions:

- USB1.1 OHCI
- USB2.0 OTG PHY

The CFGCHIP2 is shown in Figure 11-44 and described in Table 11-48.

Figure 11-44. Chip Configuration 2 Register (CFGCHIP2)

31	30	29	28	27	26	25	24
Reserved							
R-0							

23	22	21	20	19	18	17	16
Reserved						USB0PHYCLKGD	USB0VBUSSENSE
R-0						R-0	R-0

15	14	13	12	11	10	9	8
RESET	USB0OTGMODE		USB1PHYCLKMUX	USB0PHYCLKMUX	USB0PHYPWDN	USB0OTGPWRDN	USB0DATPOL
R/W-1	R/W-3h		R/W-0	R/W-1	R/W-1	R/W-1	R/W-1

7	6	5	4	3	2	1	0
USB1SUSPENDM	USB0PHY_PLLON	USB0SESNDEN	USB0VBDTCTEN	USB0REF_FREQ			
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0			

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 11-48. Chip Configuration 2 Register (CFGCHIP2) Field Descriptions

Bit	Field	Value	Description
31-18	Reserved	0	Reserved
17	USB0PHYCLKGD		**Status of USB2.0 PHY.**
		0	Clock is not present, power is not good, and PLL has not locked.
		1	Clock is present, power is good, and PLL has locked.
16	USB0VBUSSENSE		**Status of USB2.0 PHY VBUS sense.**
		0	PHY is not sensing voltage presence on the VBUS pin.
		1	PHY is sensing voltage presence on the VBUS pin.
15	RESET		**USB2.0 PHY reset.**
		0	Not in reset
		1	USB2.0 PHY in reset
14-13	USB0OTGMODE		**USB2.0 OTG subsystem mode.**
		0	No override. PHY drive signals to controller based on its comparators for VBUS and ID pins.
		1h	Override phy values to force USB host operation.
		2h	Override phy values to force USB device operation.
		3h	Override phy values to force USB host operation with VBUS low.
12	USB1PHYCLKMUX		**USB1.1 PHY reference clock input mux.** Controls clock mux to USB1.1.
		0	USB1.1 PHY reference clock is sourced by output of USB2.0 PHY.
		1	USB1.1 PHY reference clock (USB_REFCLKIN) is sourced by an external pin.
11	USB0PHYCLKMUX		**USB2.0 PHY reference clock input mux.**
		0	USB2.0 PHY reference clock (USB_REFCLKIN) is sourced by an external pin.
		1	USB2.0 PHY reference clock (AUXCLK) is internally generated from the PLL.
10	USB0PHYPWDN		**USB2.0 PHY operation state control.**
		0	USB2.0 PHY is enabled and is in operating state (normal operation).
		1	USB2.0 PHY is disabled and powered down.

Table 11-48. Chip Configuration 2 Register (CFGCHIP2) Field Descriptions (continued)

Bit	Field	Value	Description
9	USB0OTGPWRDN		**USB2.0 OTG subsystem (SS) operation state control.**
		0	OTG SS is enabled and is in operating state (normal operation).
		1	OTG SS is disabled and is powered down.
8	USB0DATPOL		**USB2.0 differential data lines polarity selector.**
		0	Differential data polarities are inverted (USB_DP is connected to D- and USB_DM is connected to D+).
		1	Differential data polarity are not altered (USB_DP is connected to D+ and USB_DM is connected to D-).
7	USB1SUSPENDM		**USB1.1 suspend mode.**
		0	Needs to be 0 whenever USB1.1 PHY is unpowered
		1	Enable USB1.1 PHY
6	USB0PHY_PLLON		**Drives USB2.0 PHY, allowing or preventing it from stopping the 48 MHz clock during USB SUSPEND.**
		0	USB2.0 PHY is allowed to stop the 48 MHz clock during USB SUSPEND.
		1	USB2.0 PHY is prevented from stopping the 48 MHz clock during USB SUSPEND
5	USB0SESNDEN		**USB2.0 Session End comparator enable.**
		0	Session End comparator is disabled.
		1	Session End comparator is enabled.
4	USB0VBDTCTEN		**USB2.0 VBUS line comparators enable.**
		0	All VBUS line comparators are disabled.
		1	All VBUS line comparators are enabled.
3-0	USB0REF_FREQ		**USB2.0 PHY reference clock input frequencies.**
		0	*Reserved*
		1h	12 MHz
		2h	24 MHz
		3h	48 MHz
		4h	19.2 MHz
		5h	38.4 MHz
		6h	13 MHz
		7h	26 MHz
		8h	20 MHz
		9h	40 MHz
		Ah-Fh	*Reserved*

11.5.18 Chip Configuration 3 Register (CFGCHIP3)

The CFGCHIP3 register controls the following peripheral/module functions:

- DIV4p5 Clock Enable/Disable: The DIV4p5 (/4.5) hardware clock divider is provided to generate 133 MHz from the 600 MHz PLL clock for use as clocks to the EMIFs. Allows enabling/disabling this clock divider.
- EMIFA Module Clock Source Control: Allows control for the source for the EMIFA module clock.
- EMIFB Memory Clock Source Control: Allows control for the source for the EMIFB SDRAM memory clock.

The CFGCHIP3 is shown in Figure 11-45 and described in Table 11-49.

Figure 11-45. Chip Configuration 3 Register (CFGCHIP3)

31	16
Reserved	
R-0	

15	8	7	3	2	1	0
Reserved		Reserved		DIV4P5ENA	EMA_CLKSRC	EMB_CLKSRC
R/W-FFh		R/W-0		R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; *-n* = value after reset

Table 11-49. Chip Configuration 3 Register (CFGCHIP3) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	Reserved
15-8	Reserved	FFh	Reserved. Write the default value when modifying this register.
7-3	Reserved	0	Reserved. Write the default value to all bits when modifying this register.
2	DIV4P5ENA		**Controls the fixed DIV4.5 divider in the PLL controller.**
		0	Divide by 4.5 is disabled.
		1	Divide by 4.5 is enabled.
1	EMA_CLKSRC		**Clock source for EMIFA clock domain.**
		0	Clock driven by PLLC SYSCLK3
		1	Clock driven by DIV4.5 PLL output
0	EMB_CLKSRC		**Clock source for EMIFB clock domain.**
		0	Clock driven by PLLC SYSCLK5
		1	Clock driven by DIV4.5 PLL output

11.5.19 Chip Configuration 4 Register (CFGCHIP4)

The CFGCHIP4 register is used for clearing the AMUNTEIN signal for the McASPs. Writing a 1 causes a single pulse that clears the 'latched' GPIO interrupt for AMUTEIN of McASP if it was previously set. Reads always return a value of 0. The register has individual bits for each McASP supported on the device. The CFGCHIP4 is shown in Figure 11-46 and described in Table 11-50.

Figure 11-46. Chip Configuration 4 Register (CFGCHIP4)

31	16
Reserved	
R-0	

15	8	7	3	2	1	0
Reserved		Reserved		AMUTECLR2	AMUTECLR1	AMUTECLR0
R/W-FFh		R/W-0		R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 11-50. Chip Configuration 4 Register (CFGCHIP4) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	Reserved
15-8	Reserved	FFh	Reserved. Write the default value when modifying this register.
7-3	Reserved	0	Reserved. Write the default value to all bits when modifying this register.
2	AMUTECLR2		**Clears the 'latched' GPIO interrupt for AMUTEIN of McASP2 when set to 1.**
		0	No effect
		1	Clears interrupt
1	AMUTECLR1		**Clears the 'latched' GPIO interrupt for AMUTEIN of McASP1 when set to 1.**
		0	No effect
		1	Clears interrupt
0	AMUTECLR0		**Clears the 'latched' GPIO interrupt for AMUTEIN of McASP0 when set to 1.**
		0	No effect
		1	Clears interrupt

ARM Interrupt Controller (AINTC)

Topic **Page**

12.1 Introduction

The ARM interrupt controller (AINTC) is an interface between interrupts coming from different parts of the system (these are referred to as system interrupts in the document), and the ARM9 interrupt interface. ARM9 supports two types of interrupts: FIQ and IRQ. These are referred to as host interrupts in this document. The AINTC has the following features:

- Supports up to 91 system interrupts.
- Supports up to 32 interrupt channels.
- Channels 0 and 1 are mapped (actually hardwired) to the FIQ ARM interrupt and channels 2-31 are mapped to IRQ ARM interrupt.
- Each system interrupt can be enabled and disabled.
- Each host interrupt can be enabled and disabled.
- Hardware prioritization of interrupts.
- Combining of interrupts from IPs to a single system interrupt.
- Supports two active low debug interrupts.

See the ARM926EJ Technical Reference Manual for information about the ARM's FIQ and IRQ interrupts.

12.2 Interrupt Mapping

The AINTC supports up to 91 system interrupts from different peripherals to be mapped to 32 channels inside the AINTC (see Figure 12-1). Interrupts from these 32 channels are further mapped to either an ARM FIQ interrupt or an ARM IRQ interrupt.

- Any of the 91 system interrupts can be mapped to any of the 32 channels.
- Multiple interrupts can be mapped to a single channel.
- An interrupt should not be mapped to more than one channel.
- Interrupts from channels 0 and 1 are mapped to FIQ ARM interrupt on host side.
- Interrupts from channels 2 to 31 are mapped to IRQ ARM interrupt on host side.
- For I < k, interrupts on channel-I have higher priority than interrupts on channel-k.
- For interrupts on same channel, priority is determined by the hardware interrupt number. The lower the interrupt number, the higher the priority.

Table 12-1 shows the system interrupt assignments for the AINTC.

Figure 12-1. AINTC Interrupt Mapping

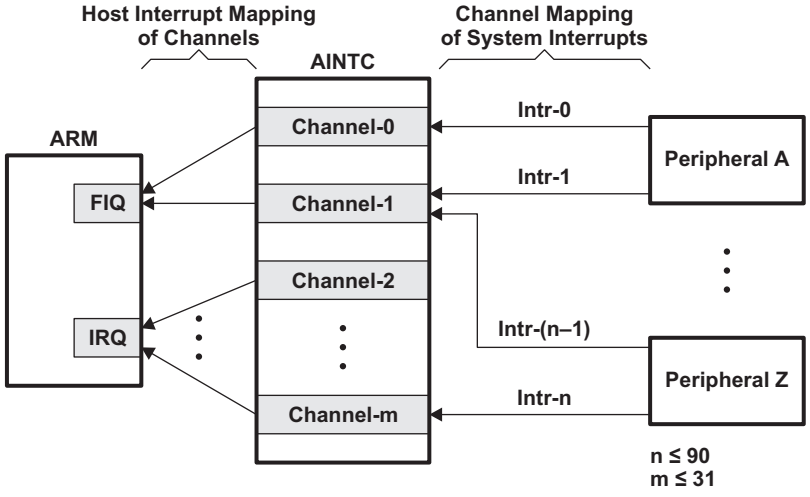


Table 12-1. AINTC System Interrupt Assignments

System Interrupt	Interrupt Name	Source
0	COMMTX	ARM
1	COMMRX	ARM
2	NINT	ARM
3	PRU_EVTOUT0	PRUSS Interrupt
4	PRU_EVTOUT1	PRUSS Interrupt
5	PRU_EVTOUT2	PRUSS Interrupt
6	PRU_EVTOUT3	PRUSS Interrupt
7	PRU_EVTOUT4	PRUSS Interrupt
8	PRU_EVTOUT5	PRUSS Interrupt
9	PRU_EVTOUT6	PRUSS Interrupt
10	PRU_EVTOUT7	PRUSS Interrupt
11	EDMA3_CC0_CCINT	EDMA CC Region 0
12	EDMA3_CC0_CCERRINT	EDMA CC
13	EDMA3_TC0_TCERRINT	EDMA TC0
14	EMIFA_INT	EMIFA
15	IIC0_INT	I2C0
16	MMCSD_INT0	MMC/SD
17	MMCSD_INT1	MMC/SD
18	PSC0_ALLINT	PSC0
19	RTC_IRQS[1:0]	RTC
20	SPI0_INT	SPI0
21	T64P0_TINT12	Timer64P0 Interrupt 12
22	T64P0_TINT34	Timer64P0 Interrupt 34
23	T64P1_TINT12	Timer64P1 Interrupt 12
24	T64P1_TINT34	Timer64P1 Interrupt 34
25	UART0_INT	UART0
26	—	Reserved
27	MPU_BOOTCFG_ERR	MPU Shared Interrupt
28	SYSCFG_CHIPINT0	SYSCFG CHIPSIG Register
29	SYSCFG_CHIPINT1	SYSCFG CHIPSIG Register
30	SYSCFG_CHIPINT2	SYSCFG CHIPSIG Register
31	SYSCFG_CHIPINT3	SYSCFG CHIPSIG Register
32	EDMA3_TC1_TCERRINT	EDMA TC1
33	EMAC_C0RXTHRESH	EMAC - Core 0 Receive Threshold Interrupt
34	EMAC_C0RX	EMAC - Core 0 Receive Interrupt
35	EMAC_C0TX	EMAC - Core 0 Transmit Interrupt
36	EMAC_C0MISC	EMAC - Core 0 Miscellaneous Interrupt
37	EMAC_C1RXTHRESH	EMAC - Core 1 Receive Threshold Interrupt
38	EMAC_C1RX	EMAC - Core 1 Receive Interrupt
39	EMAC_C1TX	EMAC - Core 1 Transmit Interrupt
40	EMAC_C1MISC	EMAC - Core 1 Miscellaneous Interrupt
41	EMIF_MEMERR	EMIFB
42	GPIO_B0INT	GPIO Bank 0 Interrupt
43	GPIO_B1INT	GPIO Bank 1 Interrupt
44	GPIO_B2INT	GPIO Bank 2 Interrupt
45	GPIO_B3INT	GPIO Bank 3 Interrupt
46	GPIO_B4INT	GPIO Bank 4 Interrupt
47	GPIO_B5INT	GPIO Bank 5 Interrupt

Table 12-1. AINTC System Interrupt Assignments (continued)

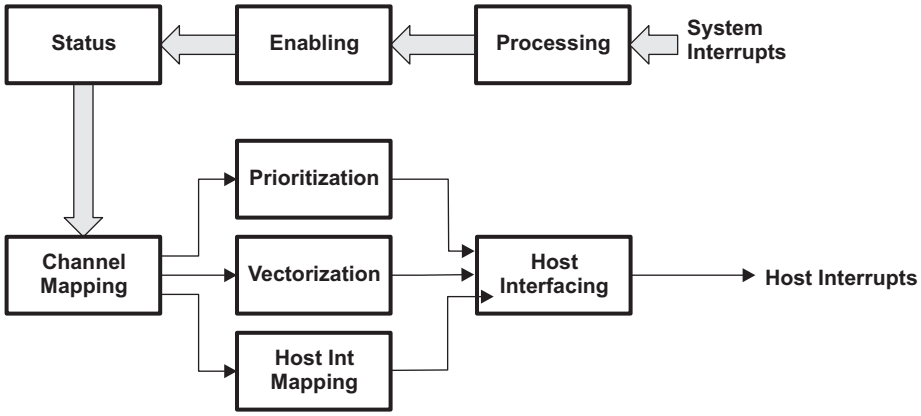
System Interrupt	Interrupt Name	Source
48	GPIO_B6INT	GPIO Bank 6 Interrupt
49	GPIO_B7INT	GPIO Bank 7 Interrupt
50	—	Reserved
51	IIC1_INT	I2C1
52	LCDC_INT	LCD Controller
53	UART_INT1	UART1
54	MCASP_INT	McASP0, 1, 2 Combined RX / TX Interrupts
55	PSC1_ALLINT	PSC1
56	SPI1_INT	SPI1
57	UHPI_ARMINT	HPI ARM Interrupt
58	USB0_INT	USB0 (USB2.0) Interrupt
59	USB1_HCINT	USB1 (USB1.1) OHCI Host Controller
60	USB1_R/WAKEUP	USB1 (USB1.1) Remote Wakeup Interrupt
61	UART2_INT	UART2
62	—	Reserved
63	EHRPWM0	HiResTimer / PWM0 Interrupt
64	EHRPWM0TZ	HiResTimer / PWM0 Trip Zone Interrupt
65	EHRPWM1	HiResTimer / PWM1 Interrupt
66	EHRPWM1TZ	HiResTimer / PWM1 Trip Zone Interrupt
67	EHRPWM2	HiResTimer / PWM2 Interrupt
68	EHRPWM2TZ	HiResTimer / PWM2 Trip Zone Interrupt
69	ECAP0	HiResTimer / PWM
70	ECAP1	HiResTimer / PWM
71	ECAP2	HiResTimer / PWM
72	EQEP0	HiResTimer / PWM
73	EQEP1	HiResTimer / PWM
74	T64P0_CMPINT0	Timer64P0 - Compare 0
75	T64P0_CMPINT1	Timer64P0 - Compare 1
76	T64P0_CMPINT2	Timer64P0 - Compare 2
77	T64P0_CMPINT3	Timer64P0 - Compare 3
78	T64P0_CMPINT4	Timer64P0 - Compare 4
79	T64P0_CMPINT5	Timer64P0 - Compare 5
80	T64P0_CMPINT6	Timer64P0 - Compare 6
81	T64P0_CMPINT7	Timer64P0 - Compare 7
82	T64P1_CMPINT0	Timer64P1 - Compare 0
83	T64P1_CMPINT1	Timer64P1 - Compare 1
84	T64P1_CMPINT2	Timer64P1 - Compare 2
85	T64P1_CMPINT3	Timer64P1 - Compare 3
86	T64P1_CMPINT4	Timer64P1 - Compare 4
87	T64P1_CMPINT5	Timer64P1 - Compare 5
88	T64P1_CMPINT6	Timer64P1 - Compare 6
89	T64P1_CMPINT7	Timer64P1 - Compare 7
90	ARMCLKSTOPREQ	PSC0
91-100	—	Reserved

12.3 AINTC Methodology

The AINTC module controls the system interrupt mapping to the host interrupt interface. System interrupts are generated by the device peripherals. The AINTC receives the system interrupts and maps them to internal channels. The channels are used to combine and prioritize system interrupts. These channels are then mapped onto the host interface that is typically a smaller number of host interrupts or a vector input. Interrupts from system side are active high in polarity. Also, they are pulse type of interrupts.

The AINTC encompasses many functions to process the system interrupts and prepare them for the host interface. These functions are: processing, enabling, status, channel mapping, host interrupt mapping, prioritization, vectorization, debug, and host interfacing. Figure 12-2 illustrates the flow of system interrupts through the functions to the host. The following subsections describe each part of the flow.

Figure 12-2. Flow of System Interrupts to Host



12.3.1 Interrupt Processing

The interrupt processing block does the following tasks:

- Synchronization of slower and asynchronous interrupts
- Conversion of polarity to active high
- Conversion of interrupt type to pulse interrupts

After the processing block, all interrupts will be active-high pulses.

12.3.2 Interrupt Enabling

The AINTC interrupt enable system allows individual interrupts to be enabled or disabled. Use the following sequence to enable interrupts:

1. Enable global host interrupts. All host interrupts are enabled by setting the ENABLE bit in the global enable register (GER). Individual host interrupts are enabled or disabled from their individual enables and are not overridden by the global enable.
2. Enable host interrupt lines. Host interrupt lines (FIQ and IRQ) can be enabled through one of two methods:
   (a) Set the desired mapped bit(s) in the host interrupt enable register (HIER), or
   (b) Write the host interrupt index (0-1) to the host interrupt enable indexed set register (HIEISR) for every interrupt line to enable.
3. Enable system interrupts. System interrupts can be individually enabled through one of two methods:
   (a) Set the desired mapped bit(s) in the system interrupt enable set registers (ESR1-ESR3), or
   (b) Write the system interrupt index (0-90) to the system interrupt enable indexed set register (EISR) for every system interrupt to enable.

12.3.3 Interrupt Status Checking

The next stage is to capture which system interrupts are pending. There are two kinds of pending status: raw status and enabled status. Raw status is the pending status of the system interrupt without regards to the enable bit for the system interrupt. Enabled status is the pending status of the system interrupts with the enable bits active. When the enable bit is inactive, the enabled status will always be inactive.

The enabled status of system interrupts is captured in system interrupt status enabled/clear registers (SECR1-SECR3). Status of system interrupt 'N' is indicated by the Nth bit of SECR1-SECR3. Since there are 91 system interrupts, three 32-bit registers are used to capture the enabled status of interrupts.

The pending status reflects whether the system interrupt occurred since the last time the status register bit was cleared. Each bit in the status register is individually clearable.

12.3.4 Interrupt Channel Mapping

The AINTC has 32 internal channels to which enabled system interrupts can be mapped. Higher priority interrupts should be mapped to channels 0 and 1. Other interrupts can be mapped to any of the channels from 2 to 31. Channel 0 has highest priority and channel 31 has the lowest priority. Channels 0 and 1 are connected to FIQ ARM interrupt. Channels 2 to 31 are connected to IRQ ARM interrupt. Channels are used to group the system interrupts into a smaller number of priorities that can be given to a host interface with a very small number of interrupt inputs. When multiple system interrupts are mapped to the same channel their interrupts are ORed together so that when either is active the output is active.

The channel map registers (CMR*m*) define the channel for each system interrupt. There is one register per 4 system interrupts; therefore, there are 23 channel map registers for a system of 91 interrupts. Channel for each system interrupt can be set using these registers.

12.3.5 Host Interrupt Mapping Interrupts

The Host is ARM9, which has two lines: FIQ and IRQ. The 32 channels from the AINTC are mapped to these two lines. The AINTC has a fixed host interrupt mapping scheme. Channels 0 and 1 are mapped to FIQ and channels 2-31 are mapped to IRQ. Thus, system interrupts mapped to channels 0 and 1 are propagated as FIQ to the host and system interrupts mapped to channels 2-31 are propagated as IRQ to the host. When multiple channels are mapped to the same host interrupt, then prioritization is done to select which interrupt is in the highest-priority channel and which should be sent first to the host.

12.3.6 Interrupt Prioritization

The next stage of the AINTC is prioritization. Since multiple interrupts feed into a single channel and multiple channels feed into a single host interrupt, it is necessary to prioritize between all the system interrupts/channels to decide on a single system interrupt to handle. The AINTC provides hardware to perform this prioritization with a given scheme so that software does not have to do this. There are two levels of prioritizations:

1. The first level of prioritization is between the active channels for a host interrupt. Channel 0 has the highest priority and channel 31 has the lowest. So the first level of prioritization picks the lowest numbered active channel.
2. The second level of prioritization is between the active system interrupts for the prioritized channel. The system interrupt in vector position 0 has the highest priority and system interrupt 90 has the lowest priority. So the second level of prioritization picks the lowest vector position active system interrupt.

The prioritized system interrupt for each host interrupt line (FIQ and IRQ) can be obtained from the host interrupt prioritized index registers (HIPIR1 and HIPIR2). The host interrupt prioritized index register values update dynamically as interrupts arrive at AINTC so care should be taken to avoid register race conditions.

The AINTC features a prioritization hold mode that is intended to prevent race conditions while servicing interrupts. This mode is enabled by setting the priority hold mode (PRHOLDMODE) bit in the control register (CR). When enabled, a read of either the host interrupt prioritized index register (HIPIR*n*) or the host interrupt prioritized vector register (HIPVR*n*) will freeze both the HIPIR*n* and HIPVR*n* values for the respective host interrupt *n*. The values are frozen until one of the following actions is taken to release the registers:

1. Write to the host interrupt prioritized index register (HIPIR*n*)
2. Write to the host interrupt prioritized vector register (HIPVR*n*)
3. Write-set bit *n* of the host interrupt enable register (HIER)
4. Write-set the active interrupt index to the host interrupt enable index set register (HIEISR)
5. Write-clear the active interrupt index to the host interrupt enable index clear register (HIEICR)

12.3.7 Interrupt Nesting

If interrupt service routines (ISRs) consume a large number of CPU cycles and may delay the servicing of other interrupts, the AINTC can perform a nesting function in its prioritization. Nesting is a method of disabling certain interrupts (usually lower-priority interrupts) when an interrupt is taken so that only those desired interrupts can trigger to the host while it is servicing the current interrupt. The typical usage is to nest on the current interrupt and disable all interrupts of the same or lower priority (or channel). Then the host will only be interrupted from a higher priority interrupt.

Nesting is available in 1 of 3 methods selectable by the NESTMODE bit in the control register (CR):

1. Nesting for all host interrupts, based on channel priority: When an interrupt is taken, the nesting level is set to its channel priority. From then, that channel priority and all lower priority channels will be disabled from generating host interrupts and only higher priority channels are allowed. When the interrupt is completely serviced, the nesting level is returned to its original value. When there is no interrupt being serviced, there are no channels disabled due to nesting. The global nesting level register (GNLR) allows the checking and setting of the global nesting level across all host interrupts. The nesting level is the channel (and all of lower priority channels) that are nested out because of a current interrupt.
2. Nesting for individual host interrupts, based on channel priority: Always nest based on channel priority for each host interrupt individually. When an interrupt is taken on a host interrupt, then, the nesting level is set to its channel priority for just that host interrupt, and other host interrupts do not have their nesting affected. Then for that host interrupt, equal or lower priority channels will not interrupt the host but may on other host interrupts if programmed. When the interrupt is completely serviced the nesting level for the host interrupt is returned to its original value. The host interrupt nesting level registers (HINLR1 and HINLR2) display and control the nesting level for each host interrupt. The nesting level controls which channel and lower priority channels are nested. There is one register per host interrupt.
3. Software manually performs the nesting of interrupts. When an interrupt is taken, the software will disable all the host interrupts, manually update the enables for any or all the system interrupts, and then re-enable all the host interrupts. This now allows only the system interrupts that are still enabled to trigger to the host. When the interrupt is completely serviced the software must reverse the changes to re-enable the nested out system interrupts. This method requires the most software interaction but gives the most flexibility if simple channel based nesting mechanisms are not adequate.

The recommended approach is the automatic host interrupt nesting method (second method). Because higher priority interrupts can preempt lower priority interrupts in this method, a software stack is used to keep track of nest priorities. The base stack value should be initialized to the default nest priority of the application. Take the following steps within the ARM hardware interrupt service routine to handle interrupts using host interrupt priority nesting:

1. Disable the ARM hardware interrupt.
2. Clear the OVERRIDE bit in the host interrupt nesting level register *n* (HINLR*n*) to expose the priority level of the active interrupt.
3. Push the active (or desired) interrupt priority value into the nest priority stack.
4. Write the active (or desired) priority level into HINLR*n* by setting the OVERRIDE bit.

5. Calculate and store the ISR address for the active interrupt. Unfreeze the host interrupt prioritized index register *n* (HIPIR*n*) and the host interrupt prioritized vector register *n* (HIPVR*n*), if the PRHOLDMODE bit in the control register (CR) is set.
6. Clear the system interrupt status by setting the appropriate bit in the system interrupt status enabled/clear register *n* (SECR*n*) or by writing the appropriate index to the system interrupt status indexed clear register (SICR).
7. Acknowledge and enable the ARM hardware interrupt.
8. Execute the ISR at the address stored from step 5. During this step, interrupts enabled by the new nest priority level will be able to preempt the ISR.
9. Disable the ARM hardware interrupt.
10. Discard the most recent priority level in the nest priority stack and restore the previous priority level to HINLR*n* by setting the OVERRIDE bit.
11. Enable the ARM hardware interrupt.

12.3.8 Interrupt Vectorization

The next stage of the AINTC is vectorization. Vectorization is an advanced feature that allows the host to receive an interrupt service routine (ISR) address in addition to just the interrupt status. Without vectorization the host would receive the interrupt and enter a general ISR that gets the prioritized system interrupt to service from the AINTC, looks up the specific ISR address for that system interrupt, and then jumps to that address. With vectorization the host can read a register that has the ISR address already calculated and jump to that address immediately.

Vectorization uses a base and universal size where all the ISR code is placed in a contiguous memory region with each ISR code a standard size. For this calculation, the vector base register (VBR) is programmed by software to hold the base address of all the ISR code and the vector size register (VSR) is programmed for the size in words between ISR code for each system interrupt. The index number of each system interrupt is used to calculate the final offset. The specific system interrupt ISR address is then calculated as:

ISR address = base + (index × size)

There is also a special case when there is no interrupt pending and then the ISR address is the ISR Null address. This is in case the vector address is executed when there is no pending interrupt so that a Null handler can be in place to just return from the interrupt. The vector null address register (VNR) holds the address of the ISR null address. When there is a pending interrupt then the ISR address is calculated as *exact base + offset* for that interrupt number.

12.3.9 Interrupt Status Clearing

After servicing the interrupt (after execution of the ISR), the interrupt status is to be cleared. If a system interrupt status is not cleared, then another host interrupt may not be triggered or another host interrupt may be triggered incorrectly. For clearing the status of an interrupt, whose interrupt number is N, write a 1 to the Nth bit position in the system interrupt status enabled/clear registers (SECR1-SECR3). System interrupt N can also be cleared by writing the value N into the system interrupt status indexed clear register (SICR).

12.3.10 Interrupt Disabling

At any time, if any interrupt is not to be propagated to the host, then that interrupt should be disabled. For disabling an interrupt whose interrupt number is N, write a 1 to the Nth bit in the system interrupt enable clear registers (ECR1-ECR3). System interrupt N can also be disabled by writing the value N in the system interrupt enable indexed clear register (EICR).

12.4 AINTC Registers

Table 12-2 lists the memory-mapped registers for the AINTC.

Table 12-2. ARM Interrupt Controller (AINTC) Registers

Address	Acronym	Register Description	Section
FFFE E000h	REVID	Revision Identification Register	Section 12.4.1
FFFE E004h	CR	Control Register	Section 12.4.2
FFFE E010h	GER	Global Enable Register	Section 12.4.3
FFFE E01Ch	GNLR	Global Nesting Level Register	Section 12.4.4
FFFE E020h	SISR	System Interrupt Status Indexed Set Register	Section 12.4.5
FFFE E024h	SICR	System Interrupt Status Indexed Clear Register	Section 12.4.6
FFFE E028h	EISR	System Interrupt Enable Indexed Set Register	Section 12.4.7
FFFE E02Ch	EICR	System Interrupt Enable Indexed Clear Register	Section 12.4.8
FFFE E034h	HIEISR	Host Interrupt Enable Indexed Set Register	Section 12.4.9
FFFE E038h	HIEICR	Host Interrupt Enable Indexed Clear Register	Section 12.4.10
FFFE E050h	VBR	Vector Base Register	Section 12.4.11
FFFE E054h	VSR	Vector Size Register	Section 12.4.12
FFFE E058h	VNR	Vector Null Register	Section 12.4.13
FFFE E080h	GPIR	Global Prioritized Index Register	Section 12.4.14
FFFE E084h	GPVR	Global Prioritized Vector Register	Section 12.4.15
FFFE E200h	SRSR1	System Interrupt Status Raw/Set Register 1	Section 12.4.16
FFFE E204h	SRSR2	System Interrupt Status Raw/Set Register 2	Section 12.4.17
FFFE E208h	SRSR3	System Interrupt Status Raw/Set Register 3	Section 12.4.18
FFFE E280h	SECR1	System Interrupt Status Enabled/Clear Register 1	Section 12.4.19
FFFE E284h	SECR2	System Interrupt Status Enabled/Clear Register 2	Section 12.4.20
FFFE E288h	SECR3	System Interrupt Status Enabled/Clear Register 3	Section 12.4.21
FFFE E300h	ESR1	System Interrupt Enable Set Register 1	Section 12.4.22
FFFE E304h	ESR2	System Interrupt Enable Set Register 2	Section 12.4.23
FFFE E308h	ESR3	System Interrupt Enable Set Register 3	Section 12.4.24
FFFE E380h	ECR1	System Interrupt Enable Clear Register 1	Section 12.4.25
FFFE E384h	ECR2	System Interrupt Enable Clear Register 2	Section 12.4.26
FFFE E388h	ECR3	System Interrupt Enable Clear Register 3	Section 12.4.27
FFFE E400h–FFFE E458h	CMR0-CMR22	Channel Map Registers 0-22	Section 12.4.28
FFFE E900h	HIPIR1	Host Interrupt Prioritized Index Register 1	Section 12.4.29
FFFE E904h	HIPIR2	Host Interrupt Prioritized Index Register 2	Section 12.4.30
FFFE F100h	HINLR1	Host Interrupt Nesting Level Register 1	Section 12.4.31
FFFE F104h	HINLR2	Host Interrupt Nesting Level Register 2	Section 12.4.32
FFFE F500 h	HIER	Host Interrupt Enable Register	Section 12.4.33
FFFE F600h	HIPVR1	Host Interrupt Prioritized Vector Register 1	Section 12.4.34
FFFE F604h	HIPVR2	Host Interrupt Prioritized Vector Register 2	Section 12.4.35

12.4.1 Revision Identification Register (REVID)

The revision identification register (REVID) is shown in Figure 12-3 and described in Table 12-3.

Figure 12-3. Revision Identification Register (REVID)

31	0
REV	
R-4E82 A900h	

LEGEND: R = Read only; -*n* = value after reset

Table 12-3. Revision Identification Register (REVID) Field Descriptions

Bit	Field	Value	Description
31-0	REV	4E82 A900h	Revision ID of the AINTC.

12.4.2 Control Register (CR)

The control register (CR) holds global control parameters. The CR is shown in Figure 12-4 and described in Table 12-4.

Figure 12-4. Control Register (CR)

31	16
Reserved	
R-0	

15	5	4	3	2	1	0
Reserved		PRHOLDMODE	NESTMODE		Reserved	
R-0		R/W-0	R/W-0		R-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

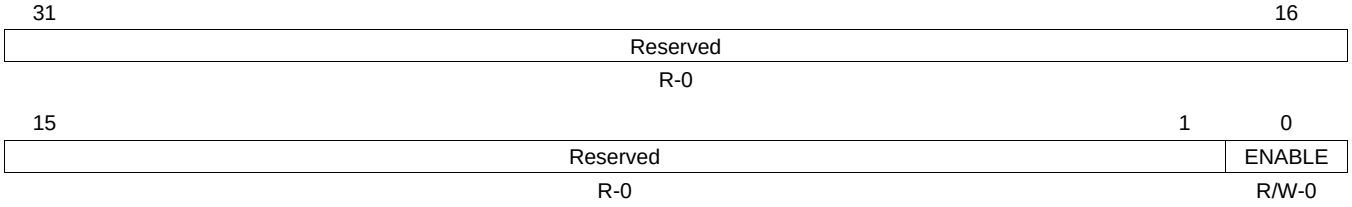
Table 12-4. Control Register (CR) Field Descriptions

Bit	Field	Value	Description
31-5	Reserved	0	Reserved
4	PRHOLDMODE		Enables priority holding mode.
		0	No priority holding. Prioritized MMRs will continually update.
		1	Priority holding enabled. Prioritized Index and Vector Address MMRs will hold their value after the first is read. See Section 12.3.6 for details.
3-2	NESTMODE	0-3h	Nesting mode.
		0	No nesting
		1h	Automatic individual nesting (per host interrupt)
		2h	Automatic global nesting (over all host interrupts)
		3h	Manual nesting
1-0	Reserved	0	Reserved

12.4.3 Global Enable Register (GER)

The global enable register (GER) enables all the host interrupts. Individual host interrupts are still enabled or disabled from their individual enables and are not overridden by the global enable. The GER is shown in Figure 12-5 and described in Table 12-5.

Figure 12-5. Global Enable Register (GER)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

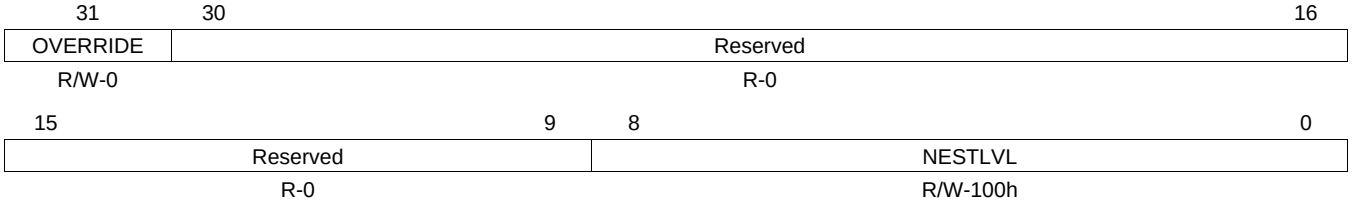
Table 12-5. Global Enable Register (GER) Field Descriptions

Bit	Field	Value	Description
31-1	Reserved	0	Reserved
0	ENABLE	0-1	The current global enable value when read. Writes set the global enable.

12.4.4 Global Nesting Level Register (GNLR)

The global nesting level register (GNLR) allows the checking and setting of the global nesting level across all host interrupts when automatic global nesting mode is set. The nesting level is the channel (and all of lower priority) that are nested out because of a current interrupt. The GNLR is shown in Figure 12-6 and described in Table 12-6.

Figure 12-6. Global Nesting Level Register (GNLR)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

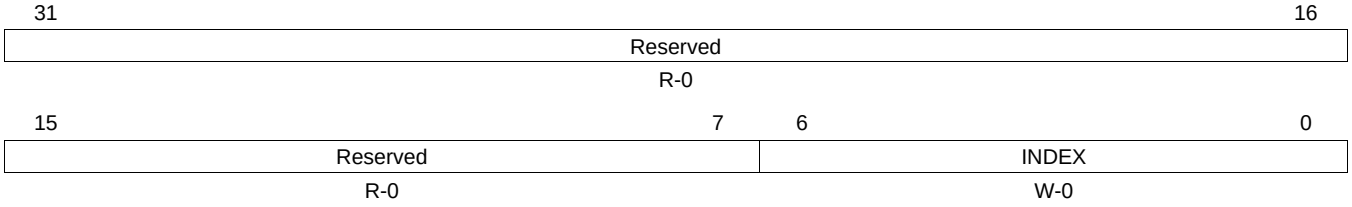
Table 12-6. Global Nesting Level Register (GNLR) Field Descriptions

Bit	Field	Value	Description
31	OVERRIDE	0-1	Always read as 0. Writes of 1 override the automatic nesting and set the NESTLVL to the written data.
30-9	Reserved	0	Reserved
8-0	NESTLVL	0-1FFh	The current global nesting level (highest channel that is nested). Writes set the nesting level. In autonesting mode this value is updated internally, unless the OVERRIDE bit is set.

12.4.5 System Interrupt Status Indexed Set Register (SISR)

The system interrupt status indexed set register (SISR) allows setting the status of an interrupt. The interrupt to set is the INDEX value written. This sets the Raw Status Register bit of the given INDEX. The SISR is shown in Figure 12-7 and described in Table 12-7.

Figure 12-7. System Interrupt Status Indexed Set Register (SISR)



LEGEND: R = Read only; W = Write only; -*n* = value after reset

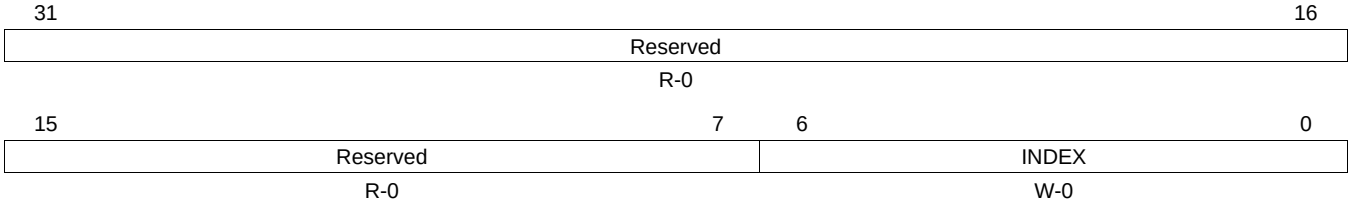
Table 12-7. System Interrupt Status Indexed Set Register (SISR) Field Descriptions

Bit	Field	Value	Description
31-7	Reserved	0	Reserved
6-0	INDEX	0-7Fh	Writes set the status of the interrupt given in the INDEX value. Reads return 0.

12.4.6 System Interrupt Status Indexed Clear Register (SICR)

The system interrupt status indexed clear register (SICR) allows clearing the status of an interrupt. The interrupt to clear is the INDEX value written. This clears the Raw Status Register bit of the given INDEX. The SICR is shown in Figure 12-8 and described in Table 12-8.

Figure 12-8. System Interrupt Status Indexed Clear Register (SICR)



LEGEND: R = Read only; W = Write only; -*n* = value after reset

Table 12-8. System Interrupt Status Indexed Clear Register (SICR) Field Descriptions

Bit	Field	Value	Description
31-7	Reserved	0	Reserved
6-0	INDEX	0-7Fh	Writes clear the status of the interrupt given in the INDEX value. Reads return 0.

12.4.7 System Interrupt Enable Indexed Set Register (EISR)

The system interrupt enable indexed set register (EISR) allows enabling an interrupt. The interrupt to enable is the INDEX value written. This sets the Enable Register bit of the given INDEX. The EISR is shown in Figure 12-9 and described in Table 12-9.

Figure 12-9. System Interrupt Enable Indexed Set Register (EISR)

31	16
Reserved	
R-0	

15	7	6	0
Reserved		INDEX	
R-0		W-0	

LEGEND: R = Read only; W = Write only; -*n* = value after reset

Table 12-9. System Interrupt Enable Indexed Set Register (EISR) Field Descriptions

Bit	Field	Value	Description
31-7	Reserved	0	Reserved
6-0	INDEX	0-7Fh	Writes set the enable of the interrupt given in the INDEX value. Reads return 0.

12.4.8 System Interrupt Enable Indexed Clear Register (EICR)

The system interrupt enable indexed clear register (EICR) allows disabling an interrupt. The interrupt to disable is the INDEX value written. This clears the Enable Register bit of the given INDEX. The EICR is shown in Figure 12-10 and described in Table 12-10.

Figure 12-10. System Interrupt Enable Indexed Clear Register (EICR)

31	16
Reserved	
R-0	

15	7	6	0
Reserved		INDEX	
R-0		W-0	

LEGEND: R = Read only; W = Write only; -*n* = value after reset

Table 12-10. System Interrupt Enable Indexed Clear Register (EICR) Field Descriptions

Bit	Field	Value	Description
31-7	Reserved	0	Reserved
6-0	INDEX	0-7Fh	Writes clear the enable of the interrupt given in the INDEX value. Reads return 0.

12.4.9 Host Interrupt Enable Indexed Set Register (HIEISR)

The host interrupt enable indexed set register (HIEISR) allows enabling a host interrupt output. The host interrupt to enable is the INDEX value written. This enables the host interrupt output or triggers the output again if already enabled. The HEISR is shown in Figure 12-11 and described in Table 12-11.

Figure 12-11. Host Interrupt Enable Indexed Set Register (HIEISR)

31	16
Reserved	
R-0	

15	1	0
Reserved		INDEX
R-0		W-0

LEGEND: R = Read only; W = Write only; -*n* = value after reset

Table 12-11. Host Interrupt Enable Indexed Set Register (HIEISR) Field Descriptions

Bit	Field	Value	Description
31-1	Reserved	0	Reserved
0	INDEX		Writes set the enable of the host interrupt given in the INDEX value. Reads return 0.
		Write 0	Set FIQ.
		Write 1	Set IRQ.

12.4.10 Host Interrupt Enable Indexed Clear Register (HIEICR)

The host interrupt enable indexed clear register (HIEICR) allows disabling a host interrupt output. The host interrupt to disable is the INDEX value written. This disables the host interrupt output. The HIEICR is shown in Figure 12-12 and described in Table 12-12.

Figure 12-12. Host Interrupt Enable Indexed Clear Register (HIEICR)

31	16
Reserved	
R-0	

15	1	0
Reserved		INDEX
R-0		W-0

LEGEND: R = Read only; W = Write only; -*n* = value after reset

Table 12-12. Host Interrupt Enable Indexed Clear Register (HIEICR) Field Descriptions

Bit	Field	Value	Description
31-1	Reserved	0	Reserved
0	INDEX		Writes clear the enable of the host interrupt given in the INDEX value. Reads return 0.
		Write 0	Clear FIQ.
		Write 1	Clear IRQ.

12.4.11 Vector Base Register (VBR)

The vector base register (VBR) holds the base address of the ISR vector addresses. The VBR is shown in Figure 12-13 and described in Table 12-13.

Figure 12-13. Vector Base Register (VBR)

31	0
BASE	
R/W-0	

LEGEND: R/W = Read/Write; *-n* = value after reset

Table 12-13. Vector Base Register (VBR) Field Descriptions

Bit	Field	Value	Description
31-0	BASE	0-FFFF FFFFh	ISR Base Address.

12.4.12 Vector Size Register (VSR)

The vector size register (VSR) holds the sizes of the individual ISR routines in the vector table. This is only the sizes to space the calculated vector addresses for the initial ISR targets (the ISR targets could branch off to the full ISR routines). The VSR is shown in Figure 12-14 and described in Table 12-14.

NOTE: The VSR must be configured even if the desired value is equal to the default value.

Figure 12-14. Vector Size Register (VSR)

31	16
Reserved	
R-0	

15	8	7	0
Reserved		SIZE	
R-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; *-n* = value after reset

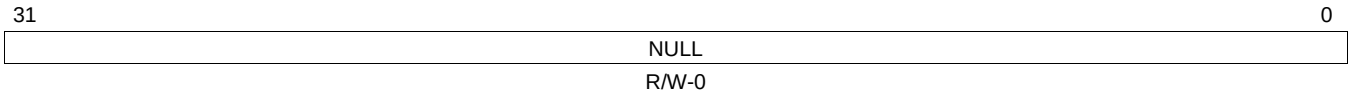
Table 12-14. Vector Size Register (VSR) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved
7-0	SIZE	0-FFh	Size of ISR address spaces.
		0	4 bytes
		1h	8 bytes
		2h	16 bytes
		3h	32 bytes
		4h	64 bytes
		5h-FFh	...

12.4.13 Vector Null Register (VNR)

The vector null register (VNR) holds the address of the ISR null address that handles no pending interrupts (if accidentally branched to when no interrupts are pending). The VNR is shown in Figure 12-15 and described in Table 12-15.

Figure 12-15. Vector Null Register (VNR)



LEGEND: R/W = Read/Write; -*n* = value after reset

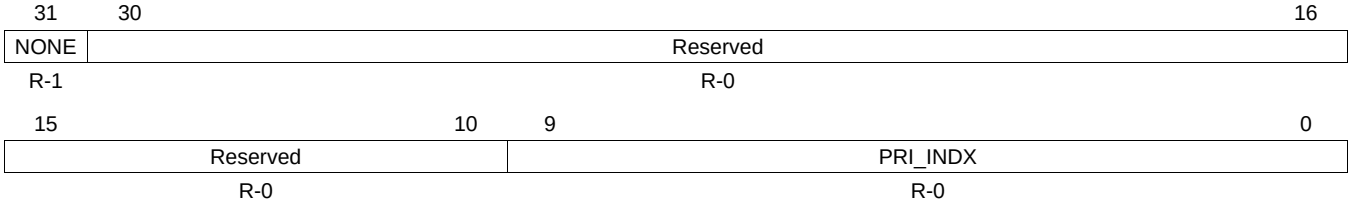
Table 12-15. Vector Null Register (VNR) Field Descriptions

Bit	Field	Value	Description
31-0	NULL	0-FFFF FFFFh	ISR Null Address.

12.4.14 Global Prioritized Index Register (GPIR)

The global prioritized index register (GPIR) shows the interrupt number of the highest priority interrupt pending across all the host interrupts. The GPIR is shown in Figure 12-16 and described in Table 12-16.

Figure 12-16. Global Prioritized Index Register (GPIR)



LEGEND: R = Read only; -*n* = value after reset

Table 12-16. Global Prioritized Index Register (GPIR) Field Descriptions

Bit	Field	Value	Description
31	NONE	0-1	No Interrupt is pending. Can be used by host to test for a negative value to see if no interrupts are pending.
30-10	Reserved	0	Reserved
9-0	PRI_INDX	0-3FFh	The currently highest priority interrupt index pending across all the host interrupts.

12.4.15 Global Prioritized Vector Register (GPVR)

The global prioritized vector register (GPVR) shows the interrupt vector address of the highest priority interrupt pending across all the host interrupts. The GPVR is shown in Figure 12-17 and described in Table 12-17.

Figure 12-17. Global Prioritized Vector Register (GPVR)

31	0
ADDR	
R-0	

LEGEND: R = Read only; -*n* = value after reset

Table 12-17. Global Prioritized Vector Register (GPVR) Field Descriptions

Bit	Field	Value	Description
31-0	ADDR	0-FFFF FFFFh	The currently highest priority interrupts vector address across all the host interrupts.

12.4.16 System Interrupt Status Raw/Set Register 1 (SRSR1)

The system interrupt status raw/set register 1 (SRSR1) shows the pending enabled status of the system interrupts 0 to 31. Software can write to SRSR1 to set a system interrupt without a hardware trigger. There is one bit per system interrupt. The SRSR1 is shown in Figure 12-18 and described in Table 12-18.

Figure 12-18. System Interrupt Status Raw/Set Register 1 (SRSR1)

31	0
RAW_STATUS[*n*]	
W-0	

LEGEND: W = Write only; -*n* = value after reset

Table 12-18. System Interrupt Status Raw/Set Register 1 (SRSR1) Field Descriptions

Bit	Field	Value	Description
31-0	RAW_STATUS[*n*]		System interrupt raw status and setting of the system interrupts 0 to 31. Reads return the raw status.
		0	Writing a 0 has no effect.
		1	Write a 1 in bit position [*n*] to set the status of the system interrupt *n*.

12.4.17 System Interrupt Status Raw/Set Register 2 (SRSR2)

The system interrupt status raw/set register 2 (SRSR2) shows the pending enabled status of the system interrupts 32 to 63. Software can write to SRSR2 to set a system interrupt without a hardware trigger. There is one bit per system interrupt. The SRSR2 is shown in Figure 12-19 and described in Table 12-19.

Figure 12-19. System Interrupt Status Raw/Set Register 2 (SRSR2)

31	0
RAW_STATUS[*n*]	
W-0	

LEGEND: W = Write only; -*n* = value after reset

Table 12-19. System Interrupt Status Raw/Set Register 2 (SRSR2) Field Descriptions

Bit	Field	Value	Description
31-0	RAW_STATUS[*n*]		System interrupt raw status and setting of the system interrupts 32 to 63. Reads return the raw status.
		0	Writing a 0 has no effect.
		1	Write a 1 in bit position [*n*] to set the status of the system interrupt *n* + 32.

12.4.18 System Interrupt Status Raw/Set Register 3 (SRSR3)

The system interrupt status raw/set register 3 (SRSR3) shows the pending enabled status of the system interrupts 64 to 90. Software can write to SRSR3 to set a system interrupt without a hardware trigger. There is one bit per system interrupt. The SRSR3 is shown in Figure 12-20 and described in Table 12-20.

Figure 12-20. System Interrupt Status Raw/Set Register 3 (SRSR3)

31	27	26	0
Reserved		RAW_STATUS[*n*]	
R-0		W-0	

LEGEND: R = Read only; W = Write only; -*n* = value after reset

Table 12-20. System Interrupt Status Raw/Set Register 3 (SRSR3) Field Descriptions

Bit	Field	Value	Description
31-27	Reserved	0	Reserved
26-0	RAW_STATUS[*n*]		System interrupt raw status and setting of the system interrupts 64 to 90. Reads return the raw status.
		0	Writing a 0 has no effect.
		1	Write a 1 in bit position [*n*] to set the status of the system interrupt *n* + 64.

12.4.19 System Interrupt Status Enabled/Clear Register 1 (SECR1)

The system interrupt status enabled/clear register 1 (SECR1) shows the pending enabled status of the system interrupts 0 to 31. Software can write to SECR1 to clear a system interrupt after it has been serviced. If a system interrupt status is not cleared then another host interrupt may not be triggered or another host interrupt may be triggered incorrectly. There is one bit per system interrupt. The SECR1 is shown in Figure 12-21 and described in Table 12-21.

Figure 12-21. System Interrupt Status Enabled/Clear Register 1 (SECR1)

31	0
ENBL_STATUS[*n*]	
W-0	

LEGEND: W = Write only; -*n* = value after reset

Table 12-21. System Interrupt Status Enabled/Clear Register 1 (SECR1) Field Descriptions

Bit	Field	Value	Description
31-0	ENBL_STATUS[*n*]		System interrupt enabled status and clearing of the system interrupts 0 to 31. Reads return the enabled status (before enabling with the Enable Registers).
		0	Writing a 0 has no effect.
		1	Write a 1 in bit position [*n*] to clear the status of the system interrupt *n*.

12.4.20 System Interrupt Status Enabled/Clear Register 2 (SECR2)

The system interrupt status enabled/clear register 2 (SECR2) shows the pending enabled status of the system interrupts 32 to 63. Software can write to SECR2 to clear a system interrupt after it has been serviced. If a system interrupt status is not cleared then another host interrupt may not be triggered or another host interrupt may be triggered incorrectly. There is one bit per system interrupt. The SECR2 is shown in Figure 12-22 and described in Table 12-22.

Figure 12-22. System Interrupt Status Enabled/Clear Register 2 (SECR2)

31	0
ENBL_STATUS[*n*]	
W-0	

LEGEND: W = Write only; -*n* = value after reset

Table 12-22. System Interrupt Status Enabled/Clear Register 2 (SECR2) Field Descriptions

Bit	Field	Value	Description
31-0	ENBL_STATUS[*n*]		System interrupt enabled status and clearing of the system interrupts 32 to 63. Reads return the enabled status (before enabling with the Enable Registers).
		0	Writing a 0 has no effect.
		1	Write a 1 in bit position [*n*] to clear the status of the system interrupt *n* + 32.

12.4.21 System Interrupt Status Enabled/Clear Register 3 (SECR3)

The system interrupt status enabled/clear register 3 (SECR3) shows the pending enabled status of the system interrupts 64 to 90. Software can write to SECR3 to clear a system interrupt after it has been serviced. If a system interrupt status is not cleared then another host interrupt may not be triggered or another host interrupt may be triggered incorrectly. There is one bit per system interrupt. The SECR3 is shown in Figure 12-23 and described in Table 12-23.

Figure 12-23. System Interrupt Status Enabled/Clear Register 3 (SECR3)

31 27	26 0
Reserved	ENBL_STATUS[*n*]
R-0	W-0

LEGEND: R = Read only; W = Write only; -*n* = value after reset

Table 12-23. System Interrupt Status Enabled/Clear Register 3 (SECR3) Field Descriptions

Bit	Field	Value	Description
31-27	Reserved	0	Reserved
26-0	ENBL_STATUS[*n*]		System interrupt enabled status and clearing of the system interrupts 64 to 90. Reads return the enabled status (before enabling with the Enable Registers).
		0	Writing a 0 has no effect.
		1	Write a 1 in bit position [*n*] to clear the status of the system interrupt *n* + 64.

12.4.22 System Interrupt Enable Set Register 1 (ESR1)

The system interrupt enable set register 1 (ESR1) enables system interrupts 0 to 31 to trigger outputs. System interrupts that are not enabled do not interrupt the host. There is one bit per system interrupt. The ESR1 is shown in Figure 12-24 and described in Table 12-24.

Figure 12-24. System Interrupt Enable Set Register 1 (ESR1)

31 0
ENABLE[*n*]
W-0

LEGEND: W = Write only; -*n* = value after reset

Table 12-24. System Interrupt Enable Set Register 1 (ESR1) Field Descriptions

Bit	Field	Value	Description
31-0	ENABLE[*n*]		System interrupt 0 to 31 enable. Read returns the enable value (0 = disabled, 1 = enabled).
		0	Writing a 0 has no effect.
		1	Write a 1 in bit position [*n*] to set the enable for system interrupt *n*.

12.4.23 System Interrupt Enable Set Register 2 (ESR2)

The system interrupt enable set register 2 (ESR2) enables system interrupts 32 to 63 to trigger outputs. System interrupts that are not enabled do not interrupt the host. There is one bit per system interrupt. The ESR2 is shown in Figure 12-25 and described in Table 12-25.

Figure 12-25. System Interrupt Enable Set Register 2 (ESR2)

31	0
ENABLE[*n*]	
W-0	

LEGEND: W = Write only; -*n* = value after reset

Table 12-25. System Interrupt Enable Set Register 2 (ESR2) Field Descriptions

Bit	Field	Value	Description
31-0	ENABLE[*n*]		System interrupt 32 to 63 enable. Read returns the enable value (0 = disabled, 1 = enabled).
		0	Writing a 0 has no effect.
		1	Write a 1 in bit position [*n*] to set the enable for system interrupt *n* + 32.

12.4.24 System Interrupt Enable Set Register 3 (ESR3)

The system interrupt enable set register 3 (ESR3) enables system interrupts 64 to 90 to trigger outputs. System interrupts that are not enabled do not interrupt the host. There is one bit per system interrupt. The ESR3 is shown in Figure 12-26 and described in Table 12-26.

Figure 12-26. System Interrupt Enable Set Register 3 (ESR3)

31	27	26	0
Reserved		ENABLE[*n*]	
R-0		W-0	

LEGEND: R = Read only; W = Write only; -*n* = value after reset

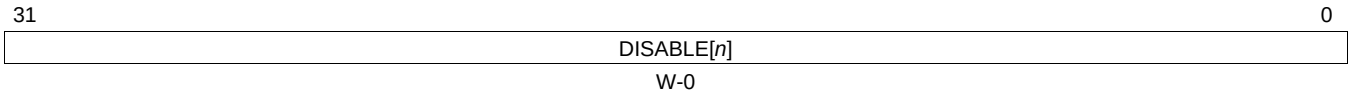
Table 12-26. System Interrupt Enable Set Register 3 (ESR3) Field Descriptions

Bit	Field	Value	Description
31-27	Reserved	0	Reserved
26-0	ENABLE[*n*]		System interrupt 64 to 90 enable. Read returns the enable value (0 = disabled, 1 = enabled).
		0	Writing a 0 has no effect.
		1	Write a 1 in bit position [*n*] to set the enable for system interrupt *n* + 64.

12.4.25 System Interrupt Enable Clear Register 1 (ECR1)

The system interrupt enable clear register 1 (ECR1) disables system interrupts 0 to 31 to map to channels. System interrupts that are not enabled do not interrupt the host. There is one bit per system interrupt. The ECR1 is shown in Figure 12-27 and described in Table 12-27.

Figure 12-27. System Interrupt Enable Clear Register 1 (ECR1)



LEGEND: W = Write only; -*n* = value after reset

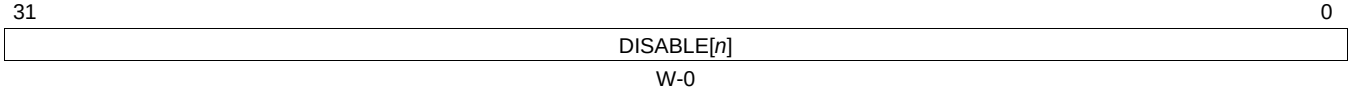
Table 12-27. System Interrupt Enable Clear Register 1 (ECR1) Field Descriptions

Bit	Field	Value	Description
31-0	DISABLE[*n*]		System interrupt 0 to 31 disable. Read returns the enable value (0 = disabled, 1 = enabled).
		0	Writing a 0 has no effect.
		1	Write a 1 in bit position [*n*] to clear the enable for system interrupt *n*.

12.4.26 System Interrupt Enable Clear Register 2 (ECR2)

The system interrupt enable clear register 2 (ECR2) disables system interrupts 32 to 63 to map to channels. System interrupts that are not enabled do not interrupt the host. There is one bit per system interrupt. The ECR2 is shown in Figure 12-28 and described in Table 12-28.

Figure 12-28. System Interrupt Enable Clear Register 2 (ECR2)



LEGEND: W = Write only; -*n* = value after reset

Table 12-28. System Interrupt Enable Clear Register 2 (ECR2) Field Descriptions

Bit	Field	Value	Description
31-0	DISABLE[*n*]		System interrupt 32 to 63 disable. Read returns the enable value (0 = disabled, 1 = enabled).
		0	Writing a 0 has no effect.
		1	Write a 1 in bit position [*n*] to clear the enable for system interrupt *n* + 32.

12.4.27 System Interrupt Enable Clear Register 3 (ECR3)

The system interrupt enable clear register 3 (ECR3) disables system interrupts 64 to 90 to map to channels. System interrupts that are not enabled do not interrupt the host. There is one bit per system interrupt. The ECR3 is shown in Figure 12-29 and described in Table 12-29.

Figure 12-29. System Interrupt Enable Clear Register 3 (ECR3)

31 27	26 0
Reserved	DISABLE[*n*]
R-0	W-0

LEGEND: R = Read only; W = Write only; -*n* = value after reset

Table 12-29. System Interrupt Enable Clear Register 3 (ECR3) Field Descriptions

Bit	Field	Value	Description
31-27	Reserved	0	Reserved
26-0	DISABLE[*n*]		System interrupt 64 to 90 disable. Read returns the enable value (0 = disabled, 1 = enabled).
		0	Writing a 0 has no effect.
		1	Write a 1 in bit position [*n*] to clear the enable for system interrupt *n* + 64.

12.4.28 Channel Map Registers (CMR0-CMR22)

The channel map registers (CMR0-CMR22) define the channel for each system interrupt. There is one register per 4 system interrupts. The CMR*n* is shown in Figure 12-30 and described in Table 12-30.

Figure 12-30. Channel Map Registers (CMR*n*)

31 24	23 16
CHNL_NPLUS3	CHNL_NPLUS2
R/W-0	R/W-0
15 8	**7 0**
CHNL_NPLUS1	CHNL_N
R/W-0	R/W-0

LEGEND: R/W = Read/Write; -*n* = value after reset

Table 12-30. Channel Map Registers (CMR*n*) Field Descriptions

Bit	Field	Value	Description
31-24	CHNL_NPLUS3	0-FFh	Sets the host interrupt for channel N + 3.
23-16	CHNL_NPLUS2	0-FFh	Sets the host interrupt for channel N + 2.
15-8	CHNL_NPLUS1	0-FFh	Sets the host interrupt for channel N + 1.
7-0	CHNL_N	0-FFh	Sets the channel for the system interrupt N. (N ranges from 0 to 90).

12.4.29 Host Interrupt Prioritized Index Register 1 (HIPIR1)

The host interrupt prioritized index register 1 (HIPIR1) shows the highest priority current pending interrupt for the FIQ interrupt. The HIPIR1 is shown in Figure 12-31 and described in Table 12-31.

Figure 12-31. Host Interrupt Prioritized Index Register 1 (HIPIR1)

31	30	16
NONE	Reserved	
R-1	R-0	

15	10	9	0
Reserved		PRI_INDX	
R-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 12-31. Host Interrupt Prioritized Index Register 1 (HIPIR1) Field Descriptions

Bit	Field	Value	Description
31	NONE	0-1	No Interrupt is pending.
30-10	Reserved	0	Reserved
9-0	PRI_INDX	0-3FFh	Interrupt number of the highest priority pending interrupt for FIQ host interrupt. A write procedure does not directly modify the read value of PRI_INDX; however, a write procedure unfreezes register values held by the priority hold mode. See Section 12.3.6 for details.

12.4.30 Host Interrupt Prioritized Index Register 2 (HIPIR2)

The host interrupt prioritized index register 2 (HIPIR2) shows the highest priority current pending interrupt for the IRQ interrupt. The HIPIR2 is shown in Figure 12-32 and described in Table 12-32.

Figure 12-32. Host Interrupt Prioritized Index Register 2 (HIPIR2)

31	30	16
NONE	Reserved	
R-1	R-0	

15	10	9	0
Reserved		PRI_INDX	
R-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 12-32. Host Interrupt Prioritized Index Register 2 (HIPIR2) Field Descriptions

Bit	Field	Value	Description
31	NONE	0-1	No Interrupt is pending.
30-10	Reserved	0	Reserved
9-0	PRI_INDX	0-3FFh	Interrupt number of the highest priority pending interrupt for IRQ host interrupt. A write procedure does not directly modify the read value of PRI_INDX; however, a write procedure unfreezes register values held by the priority hold mode. See Section 12.3.6 for details.

12.4.31 Host Interrupt Nesting Level Register 1 (HINLR1)

The host interrupt nesting level register 1 (HINLR1) displays and controls the nesting level for FIQ host interrupt. The nesting level controls which channel and lower priority channels are nested. The HINLR1 is shown in Figure 12-33 and described in Table 12-33.

Figure 12-33. Host Interrupt Nesting Level Register 1 (HINLR1)

31	30	16
OVERRIDE	Reserved	
W-0	R-0	

15	9	8	0
Reserved		NEST_LVL	
R-0		R/W-100h	

LEGEND: R/W = Read/Write; R = Read only; W = Write only; -*n* = value after reset

Table 12-33. Host Interrupt Nesting Level Register 1 (HINLR1) Field Descriptions

Bit	Field	Value	Description
31	OVERRIDE	0-1	Reads return 0. Writes of a 1 override the auto updating of the NEST_LVL and use the write data.
30-9	Reserved	0	Reserved
8-0	NEST_LVL	0-1FFh	Reads return the current nesting level for the FIQ host interrupt. Writes set the nesting level for the FIQ host interrupt. In auto mode the value is updated internally, unless the OVERRIDE is set and then the write data is used.

12.4.32 Host Interrupt Nesting Level Register 2 (HINLR2)

The host interrupt nesting level register 2 (HINLR2) displays and controls the nesting level for IRQ host interrupt. The nesting level controls which channel and lower priority channels are nested. The HINLR2 is shown in Figure 12-34 and described in Table 12-34.

Figure 12-34. Host Interrupt Nesting Level Register 2 (HINLR2)

31	30	16
OVERRIDE	Reserved	
W-0	R-0	

15	9	8	0
Reserved		NEST_LVL	
R-0		R/W-100h	

LEGEND: R/W = Read/Write; R = Read only; W = Write only; -*n* = value after reset

Table 12-34. Host Interrupt Nesting Level Register 2 (HINLR2) Field Descriptions

Bit	Field	Value	Description
31	OVERRIDE	0-1	Reads return 0. Writes of a 1 override the auto updating of the NEST_LVL and use the write data.
30-9	Reserved	0	Reserved
8-0	NEST_LVL	0-1FFh	Reads return the current nesting level for the IRQ host interrupt. Writes set the nesting level for the IRQ host interrupt. In auto mode the value is updated internally, unless the OVERRIDE is set and then the write data is used.

12.4.33 Host Interrupt Enable Register (HIER)

The host interrupt enable register (HIER) enables or disables individual host interrupts (FIQ and IRQ). These work separately from the global enables. There is one bit per host interrupt. These bits are updated when writing to the host interrupt enable indexed set register (HIEISR) and the host interrupt enable indexed clear register (HIEICR). The HIER is shown in Figure 12-35 and described in Table 12-35.

Figure 12-35. Host Interrupt Enable Register (HIER)

31	16
Reserved	
R-0	

15	2	1	0
Reserved		IRQ	FIQ
R-0		R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 12-35. Host Interrupt Enable Register (HIER) Field Descriptions

Bit	Field	Value	Description
31-2	Reserved	0	Reserved
1	IRQ		Enable of IRQ
		0	IRQ is disabled.
		1	IRQ is enabled.
0	FIQ		Enable of FIQ
		0	FIQ is disabled.
		1	FIQ is enabled.

12.4.34 Host Interrupt Prioritized Vector Register 1 (HIPVR1)

The host interrupt prioritized vector register 1 (HIPVR1) shows the interrupt vector address of the highest priority interrupt pending for FIQ host interrupt. The HIPVR1 is shown in Figure 12-36 and described in Table 12-36.

Figure 12-36. Host Interrupt Prioritized Vector Register 1 (HIPVR1)

31	0
ADDR	
R/W-0	

LEGEND: R/W = Read/Write; -*n* = value after reset

Table 12-36. Host Interrupt Prioritized Vector Register 1 (HIPVR1) Field Descriptions

Bit	Field	Value	Description
31-0	ADDR	0-FFFF FFFFh	The currently highest priority interrupt vector address across for the FIQ host interrupt. A write procedure does not directly modify the read value of ADDR; however, a write procedure unfreezes register values held by the priority hold mode. See Section 12.3.6 for details.

12.4.35 Host Interrupt Prioritized Vector Register 2 (HIPVR2)

The host interrupt prioritized vector register 2 (HIPVR2) shows the interrupt vector address of the highest priority interrupt pending for IRQ host interrupt. The HIPVR2 is shown in Figure 12-37 and described in Table 12-37.

Figure 12-37. Host Interrupt Prioritized Vector Register 2 (HIPVR2)

31	0
ADDR	
R/W-0	

LEGEND: R/W = Read/Write; -*n* = value after reset

Table 12-37. Host Interrupt Prioritized Vector Register 2 (HIPVR2) Field Descriptions

Bit	Field	Value	Description
31-0	ADDR	0-FFFF FFFFh	The currently highest priority interrupt vector address across for the IRQ host interrupt. A write procedure does not directly modify the read value of ADDR; however, a write procedure unfreezes register values held by the priority hold mode. See Section 12.3.6 for details.

Boot Considerations

Topic **Page**

13.1 Introduction

This device supports a variety of boot modes through an internal ARM ROM bootloader. This device does not support dedicated hardware boot modes; therefore, all boot modes utilize the internal ARM ROM. The input states of the BOOT pins are sampled and latched into the BOOTCFG register, which is part of the system configuration (SYSCFG) module, when device reset is deasserted. Boot mode selection is determined by the values of the BOOT pins.

The following boot modes are supported:

- NAND Flash boot
  - 8-bit NAND
  - 16-bit NAND
- NOR Flash boot
  - NOR Direct boot
  - NOR Legacy boot
  - NOR AIS boot
- HPI Boot
- I2C0/I2C1 Boot
  - Master boot
  - Slave boot
- SPI0/SPI1 Boot
  - Master boot
  - Slave boot
- UART0/1/2 Boot

See *Using the OMAP-L1x7 Bootloader Application Report* (SPRAB04) for more details on the ROM Boot Loader, a list of boot pins used, and the complete list of supported boot modes.

13.2 ARM Wake Up

Following deassertion of device reset, the ARM926 is held in reset and clock gated (SwRstDisable state) by the LPSC and held in reset by the SYSCFG module. The ARM ROM will not wake the ARM926 from this state.

The follow steps must be followed to wake up the ARM926:

1. Write a 83E7 0B13h to the KICK0R register in the SYSCFG module.
2. Write a 95A4 F1E0h to the KICK1R register in the SYSCFG module.
3. Write a 1 to the BOOTRDY bit in the host 0 configuration register (HOST0CFG) in the SYSCFG module. The SYSCFG module releases the ARM reset.
4. Write a 3h to the NEXT bit in the ARM local power sleep controller (LPSC) module control register (PSC0.MDCTL14) to prepare the ARM module for an enable transition (to enable the clocks and all transitioning from the SwRstDisable state to Enable state).
5. Write a 1 to the GO[0] bit (ARM subsystem is part of the PD_ALWAYSON domain) in the power domain transition command register (PSC0.PTCMD) to start the state transition sequence for the ARM module.
6. Check (poll for 0) the GOSTAT[0] bit in the power domain transition status register (PSC0.PTSTAT) for power transition sequence completion. The domain is only safely in the new state after the GOSTAT[0] bit is cleared to 0.
7. Wait for the STATE bit field in the ARM LPSC module status register (PSC0.MDSTAT14) to change to 3h. The module is only safely in the new state after the STATE bit field changes to reflect the new state.
8. Write a 1 to the LRST bit in PSC0.MDCTL14 to release the ARM local reset controlled by the PSC module.

NOTE: Step 8 can also be combined with Step 4. You can write a 103h to the PSC0.MDCTL14 in Step 4 to release the ARM local reset and transition it from a SwRstDisable to Enable state.

The steps to release the ARM reset by the SYSCFG module (Steps 1-3) are only required at device reset/system reset/warm reset. For disabling/enabling clocks to the ARM module at any other time can be independently controlled by the PSC module alone. Guidelines to enable/disable clocks for power management are provided in the *Power Management* chapter.

Programmable Real-Time Unit Subsystem (PRUSS)

The Programmable Real-Time Unit Subsystem (PRUSS) consists of:

- Two programmable real-time units (PRU0 and PRU1) and their associated memories.
- An interrupt controller (INTC) for handling system interrupt events. The INTC also supports posting events back to the device level host CPU.
- A Switched Central Resource (SCR) for connecting the various internal and external masters to the resources inside the PRUSS.

The two PRUs can operate completely independently or in coordination with each other. The two PRUs can also work in coordination with the device level host CPU. This is determined by the nature of the program that is loaded into the two PRUs instruction memory. Several different signaling mechanisms are available between the two PRUs and the device level host CPU.

The two PRUs are optimized for performing embedded tasks that require manipulation of packed memory-mapped data structures, handling of system events that have tight real-time constraints and interfacing with systems external to the device.

The PRUSS documentation (peripheral guide) is on the external wiki: Programmable_Realtime_Unit.

Enhanced Capture (eCAP) Module

The enhanced capture (eCAP) module is essential in systems where accurate timing of external events is important. This chapter describes the eCAP module.

Topic **Page**

15.1 Introduction

15.1.1 Purpose of the Peripheral

Uses for eCAP include:

- Sample rate measurements of audio inputs
- Speed measurements of rotating machinery (for example, toothed sprockets sensed via Hall sensors)
- Elapsed time measurements between position sensor pulses
- Period and duty cycle measurements of pulse train signals
- Decoding current or voltage amplitude derived from duty cycle encoded current/voltage sensors

15.1.2 Features

The eCAP module includes the following features:

- 32-bit time base counter
- 4-event time-stamp registers (each 32 bits)
- Edge polarity selection for up to four sequenced time-stamp capture events
- Interrupt on either of the four events
- Single shot capture of up to four event time-stamps
- Continuous mode capture of time-stamps in a four-deep circular buffer
- Absolute time-stamp capture
- Difference (Delta) mode time-stamp capture
- All above resources dedicated to a single input pin
- When not used in capture mode, the ECAP module can be configured as a single channel PWM output

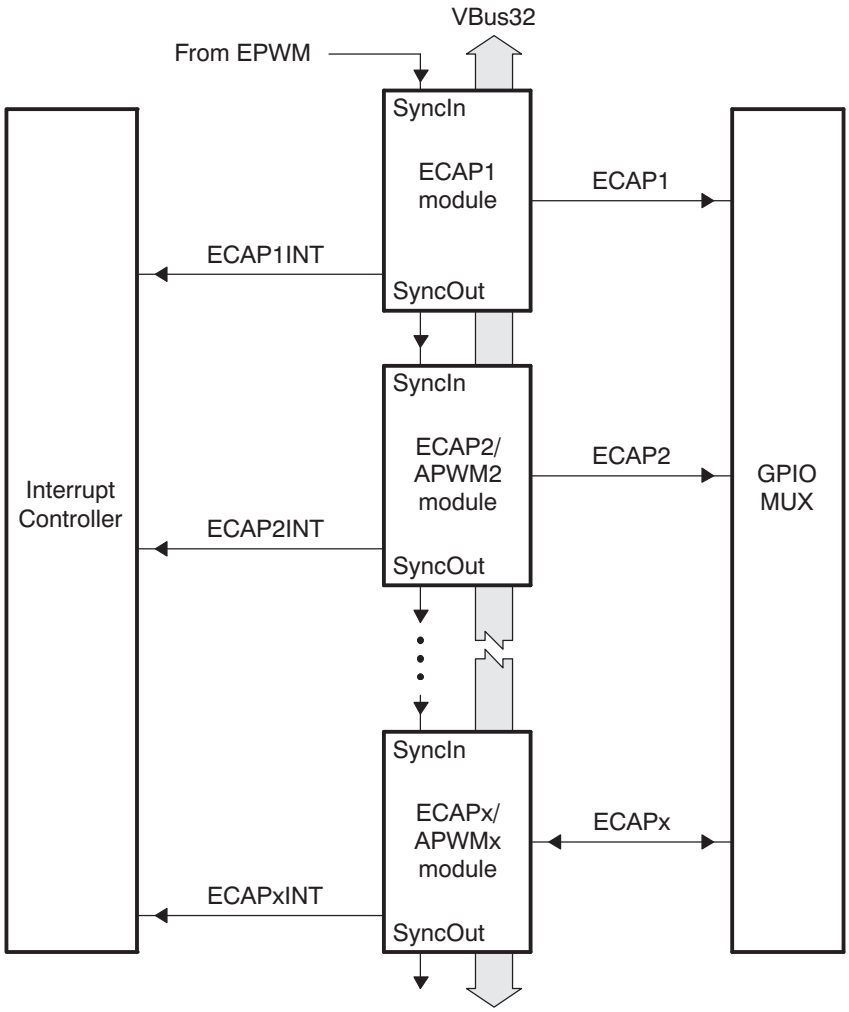
15.2 Architecture

The eCAP module represents one complete capture channel that can be instantiated multiple times depending on the target device. In the context of this guide, one eCAP channel has the following independent key resources:

- Dedicated input capture pin
- 32-bit time base counter
- 4 × 32-bit time-stamp capture registers (CAP1-CAP4)
- 4-stage sequencer (Modulo4 counter) that is synchronized to external events, ECAP pin rising/falling edges.
- Independent edge polarity (rising/falling edge) selection for all 4 events
- Input capture signal prescaling (from 2-62)
- One-shot compare register (2 bits) to freeze captures after 1 to 4 time-stamp events
- Control for continuous time-stamp captures using a 4-deep circular buffer (CAP1-CAP4) scheme
- Interrupt capabilities on any of the 4 capture events

Multiple identical eCAP modules can be contained in a system as shown in Figure 15-1. The number of modules is device-dependent and is based on target application needs. In this chapter, the letter x within a signal or module name is used to indicate a generic eCAP instance on a device.

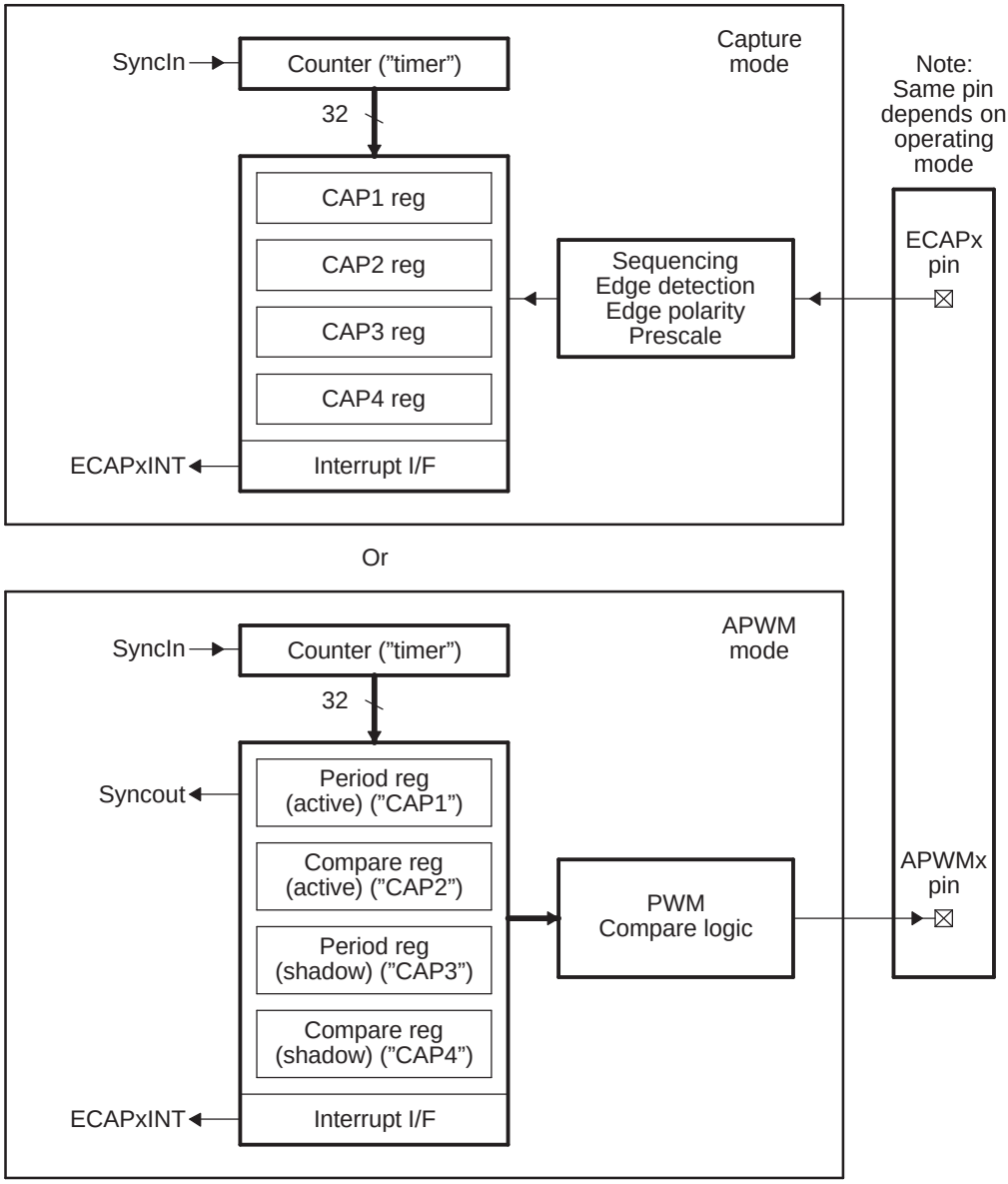
Figure 15-1. Multiple eCAP Modules



15.2.1 Capture and APWM Operating Mode

You can use the eCAP module resources to implement a single-channel PWM generator (with 32 bit capabilities) when it is not being used for input captures. The counter operates in count-up mode, providing a time-base for asymmetrical pulse width modulation (PWM) waveforms. The CAP1 and CAP2 registers become the active period and compare registers, respectively, while CAP3 and CAP4 registers become the period and capture shadow registers, respectively. Figure 15-2 is a high-level view of both the capture and auxiliary pulse-width modulator (APWM) modes of operation.

Figure 15-2. Capture and APWM Modes of Operation



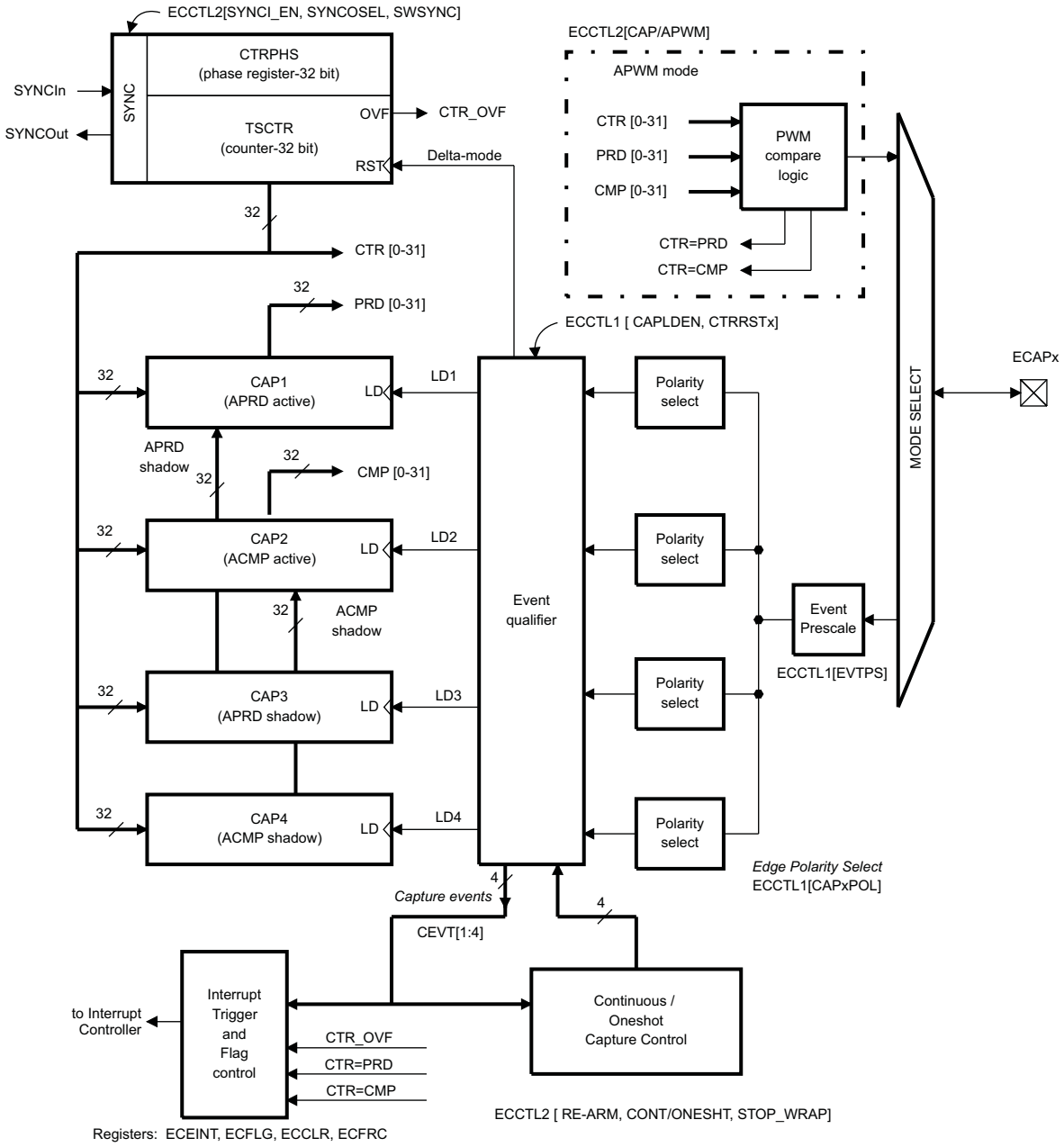
(1) A single pin is shared between CAP and APWM functions. In capture mode, it is an input; in APWM mode, it is an output.

(2) In APWM mode, writing any value to CAP1/CAP2 active registers also writes the same value to the corresponding shadow registers CAP3/CAP4. This emulates immediate mode. Writing to the shadow registers CAP3/CAP4 invokes the shadow mode.

15.2.2 Capture Mode Description

Figure 15-3 shows the various components that implement the capture function.

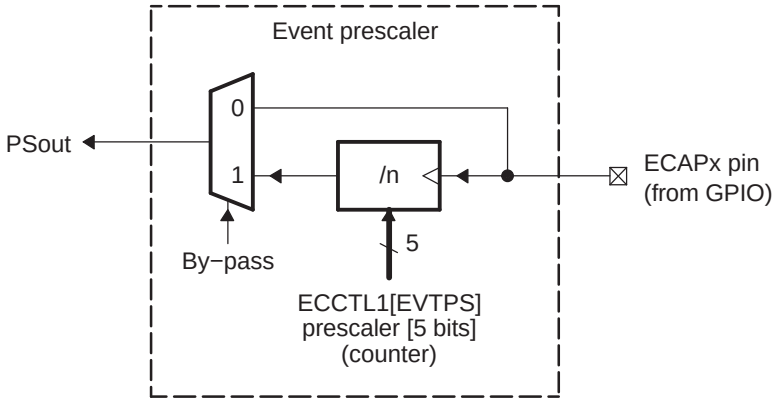
Figure 15-3. Capture Function Diagram



15.2.2.1 Event Prescaler

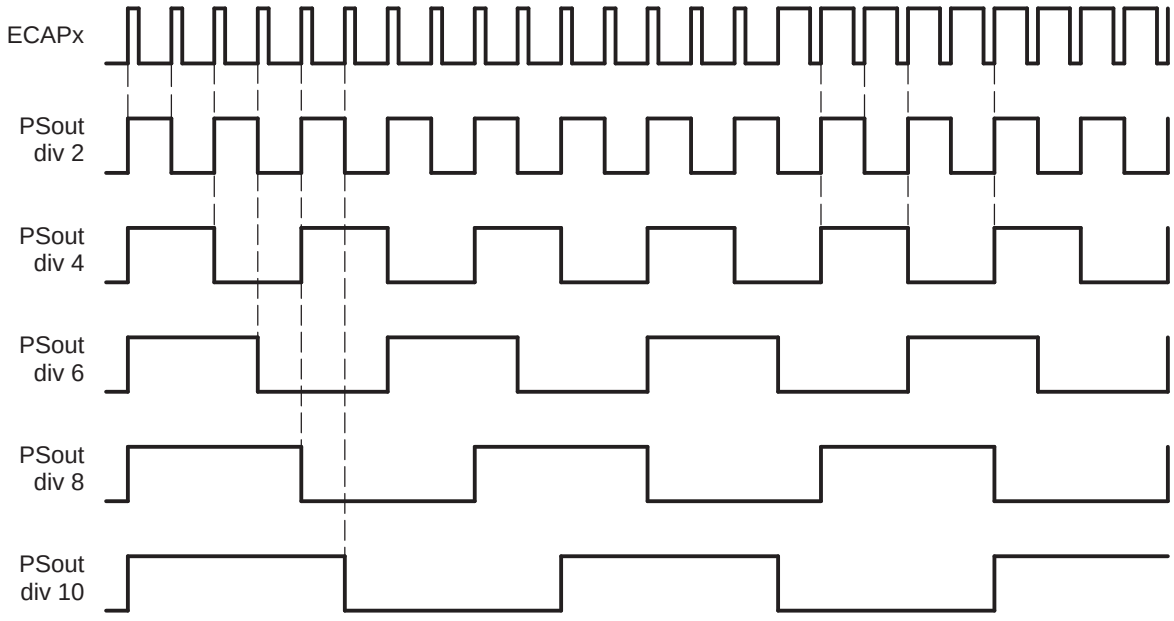
An input capture signal (pulse train) can be prescaled by N = 2-62 (in multiples of 2) or can bypass the prescaler. This is useful when very high frequency signals are used as inputs. Figure 15-4 shows a functional diagram and Figure 15-5 shows the operation of the prescale function.

Figure 15-4. Event Prescale Control



(1) When a prescale value of 1 is chosen (ECCTL1[13:9] = 0000) the input capture signal by-passes the prescale logic completely.

Figure 15-5. Prescale Function Waveforms



15.2.2.2 Edge Polarity Select and Qualifier

- Four independent edge polarity (rising edge/falling edge) selection multiplexers are used, one for each capture event.
- Each edge (up to 4) is event qualified by the Modulo4 sequencer.
- The edge event is gated to its respective CAP*n* register by the Mod4 counter. The CAP*n* register is loaded on the falling edge.

15.2.2.3 Continuous/One-Shot Control

- The Mod4 (2 bit) counter is incremented via edge qualified events (CEVT1-CEVT4).
- The Mod4 counter continues counting (0->1->2->3->0) and wraps around unless stopped.
- A 2-bit stop register is used to compare the Mod4 counter output, and when equal stops the Mod4 counter and inhibits further loads of the CAP1-CAP4 registers. This occurs during one-shot operation.

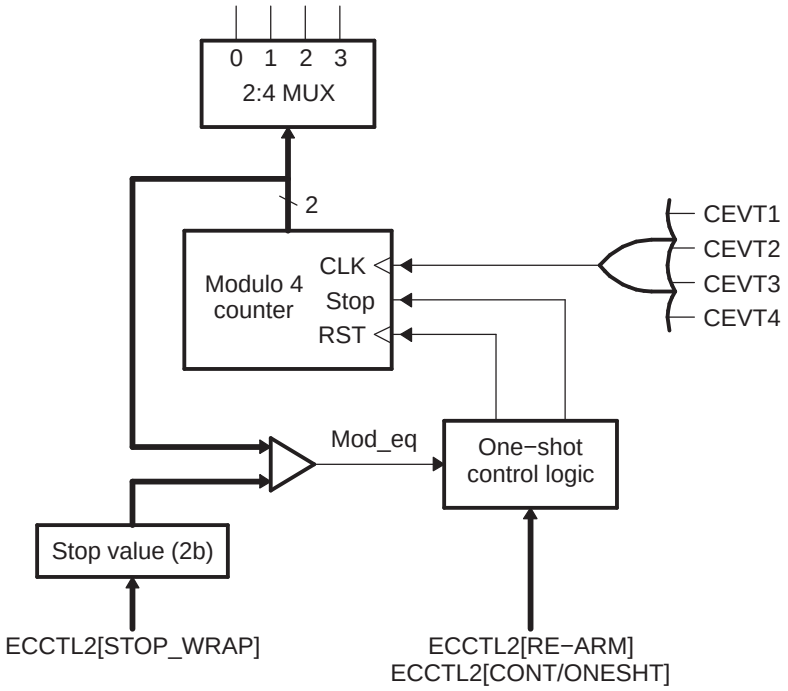
The continuous/one-shot block (Figure 15-6) controls the start/stop and reset (zero) functions of the Mod4 counter via a mono-shot type of action that can be triggered by the stop-value comparator and re-armed via software control.

Once armed, the eCAP module waits for 1-4 (defined by stop-value) capture events before freezing both the Mod4 counter and contents of CAP1-4 registers (time-stamps).

Re-arming prepares the eCAP module for another capture sequence. Also re-arming clears (to zero) the Mod4 counter and permits loading of CAP1-4 registers again, providing the CAPLDEN bit is set.

In continuous mode, the Mod4 counter continues to run (0->1->2->3->0, the one-shot action is ignored, and capture values continue to be written to CAP1-4 in a circular buffer sequence.

Figure 15-6. Continuous/One-shot Block Diagram



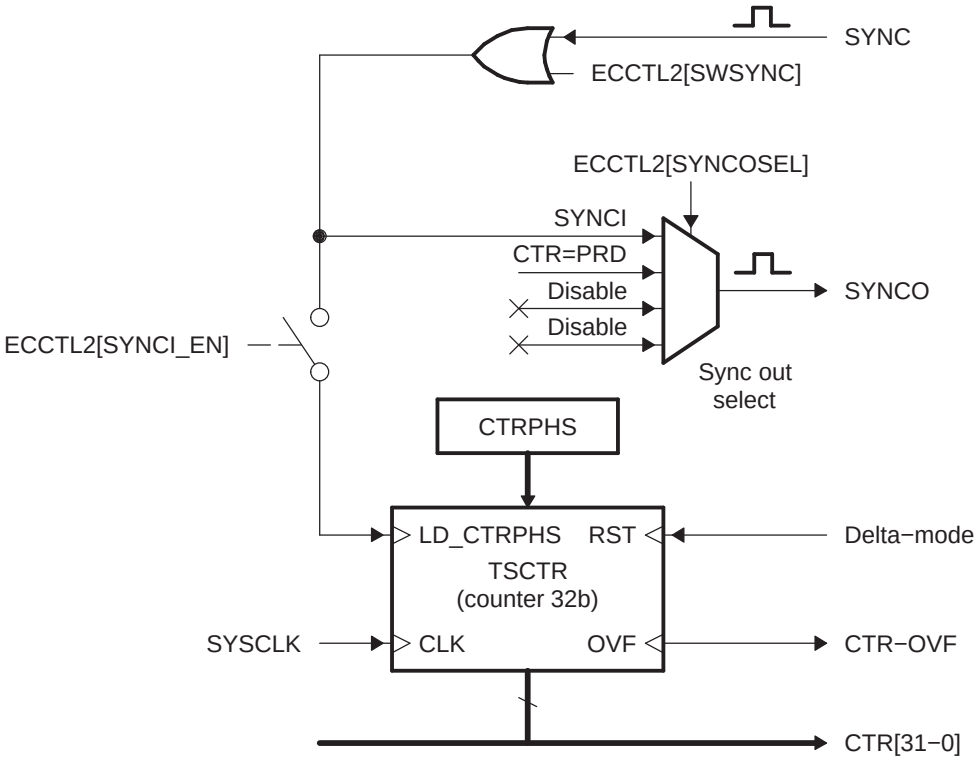
15.2.2.4 32-Bit Counter and Phase Control

This counter (Figure 15-7) provides the time-base for event captures, and is clocked via the system clock.

A phase register is provided to achieve synchronization with other counters, via a hardware and software forced sync. This is useful in APWM mode when a phase offset between modules is needed.

On any of the four event loads, an option to reset the 32-bit counter is given. This is useful for time difference capture. The 32-bit counter value is captured first, then it is reset to 0 by any of the LD1-LD4 signals.

Figure 15-7. Counter and Synchronization Block Diagram



15.2.2.5 CAP1-CAP4 Registers

These 32-bit registers are fed by the 32-bit counter timer bus, CTR[0-31] and are loaded (capture a time-stamp) when their respective LD inputs are strobed.

Loading of the capture registers can be inhibited via control bit CAPLDEN. During one-shot operation, this bit is cleared (loading is inhibited) automatically when a stop condition occurs, StopValue = Mod4.

CAP1 and CAP2 registers become the active period and compare registers, respectively, in APWM mode.

CAP3 and CAP4 registers become the respective shadow registers (APRD and ACMP) for CAP1 and CAP2 during APWM operation.

15.2.2.6 Interrupt Control

An Interrupt can be generated on capture events (CEVT1-CEVT4, CTROVF) or APWM events (CTR = PRD, CTR = CMP). See Figure 15-8.

A counter overflow event (FFFF FFFFh->0000 0000h) is also provided as an interrupt source (CTROVF).

The capture events are edge and sequencer qualified (that is, ordered in time) by the polarity select and Mod4 gating, respectively.

One of these events can be selected as the interrupt source (from the eCAP*n* module) going to the interrupt controller.

Seven interrupt events (CEVT1, CEVT2, CEVT3, CEVT4, CNTOVF, CTR = PRD, CTR = CMP) can be generated. The interrupt enable register (ECEINT) is used to enable/disable individual interrupt event sources. The interrupt flag register (ECFLG) indicates if any interrupt event has been latched and contains the global interrupt flag bit (INT). An interrupt pulse is generated to the interrupt controller only if any of the interrupt events are enabled, the flag bit is 1, and the INT flag bit is 0. The interrupt service routine must clear the global interrupt flag bit and the serviced event via the interrupt clear register (ECCLR) before any other interrupt pulses are generated. You can force an interrupt event via the interrupt force register (ECFRC). This is useful for test purposes.

15.2.2.7 Shadow Load and Lockout Control

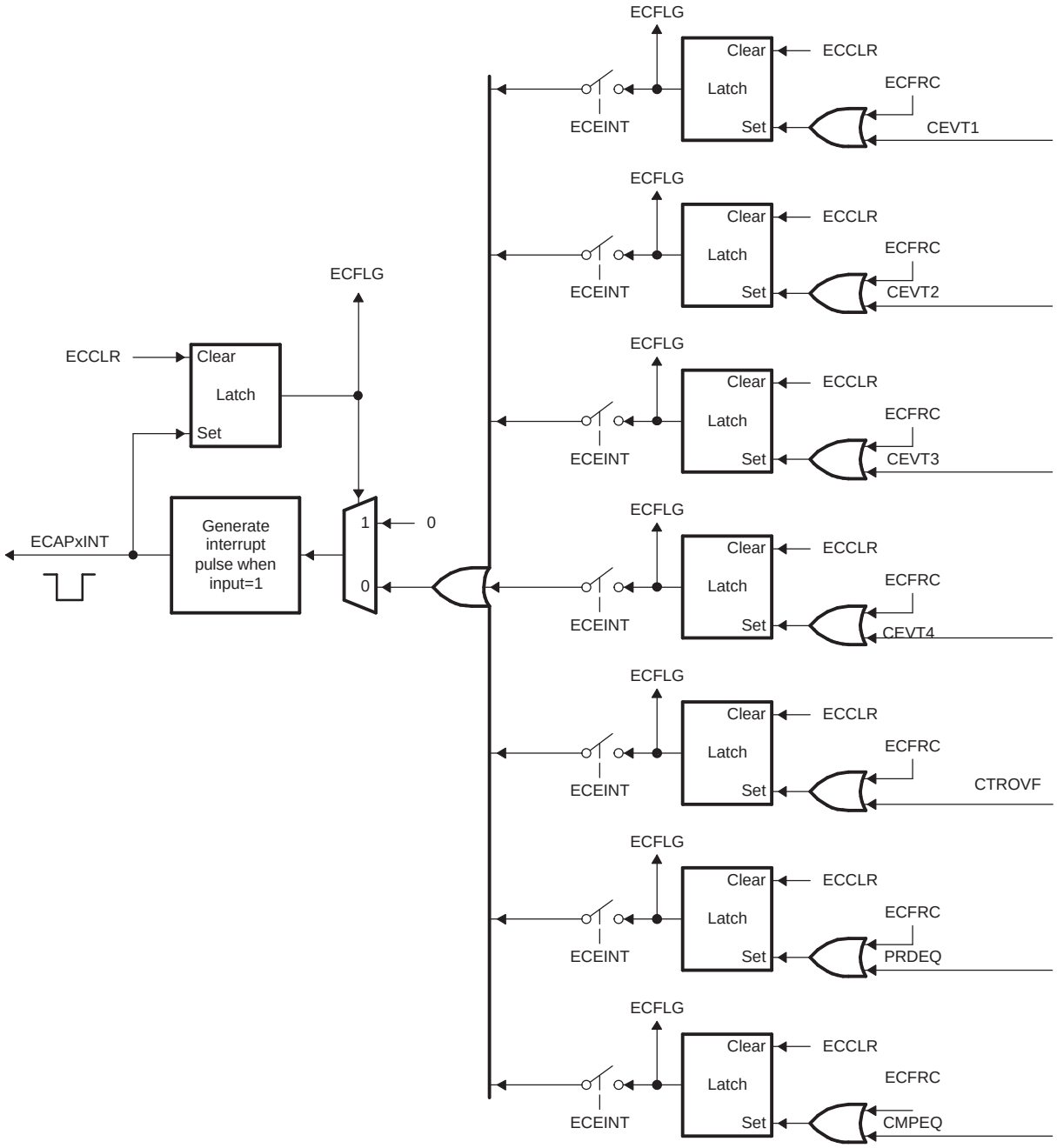
In capture mode, this logic inhibits (locks out) any shadow loading of CAP1 or CAP2 from APRD and ACMP registers, respectively.

In APWM mode, shadow loading is active and two choices are permitted:

- Immediate - APRD or ACMP are transferred to CAP1 or CAP2 immediately upon writing a new value.
- On period equal, CTR[31:0] = PRD[31:0]

NOTE: The CEVT1, CEVT2, CEVT3, CEVT4 flags are only active in capture mode (ECCTL2[CAP/APWM == 0]). The CTR = PRD, CTR = CMP flags are only valid in APWM mode (ECCTL2[CAP/APWM == 1]). CNTOVF flag is valid in both modes.

Figure 15-8. Interrupts in eCAP Module

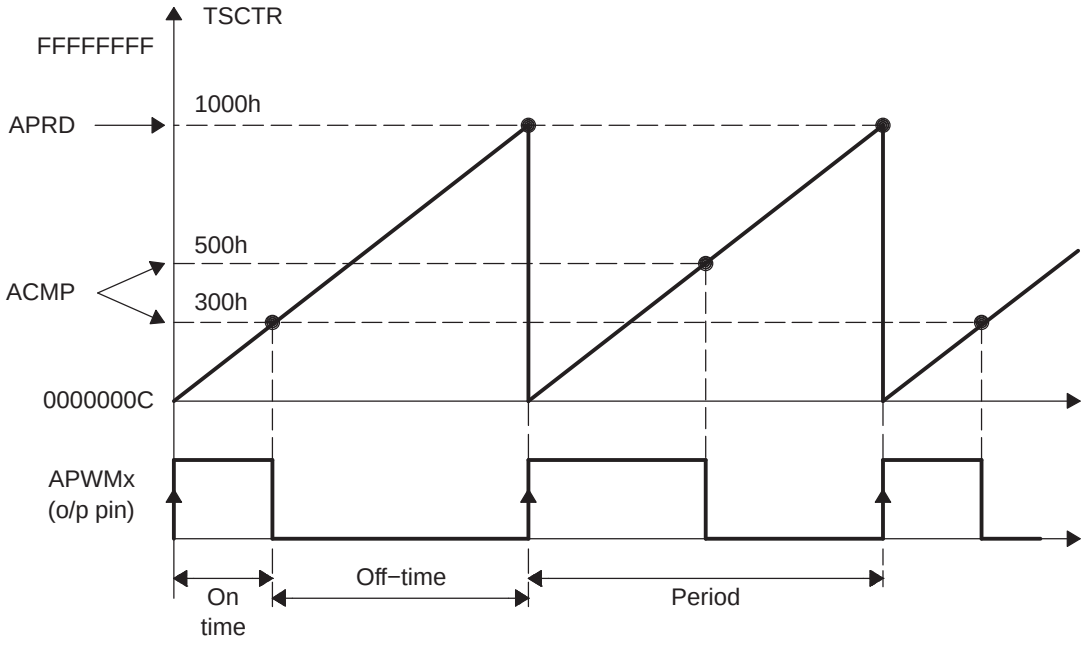


15.2.2.8 APWM Mode Operation

Main operating highlights of the APWM section:

- The time-stamp counter bus is made available for comparison via 2 digital (32-bit) comparators.
- When CAP1/2 registers are not used in capture mode, their contents can be used as Period and Compare values in APWM mode.
- Double buffering is achieved via shadow registers APRD and ACMP (CAP3/4). The shadow register contents are transferred over to CAP1/2 registers either immediately upon a write, or on a CTR = PRD trigger.
- In APWM mode, writing to CAP1/CAP2 active registers will also write the same value to the corresponding shadow registers CAP3/CAP4. This emulates immediate mode. Writing to the shadow registers CAP3/CAP4 will invoke the shadow mode.
- During initialization, you must write to the active registers for both period and compare. This automatically copies the initial values into the shadow values. For subsequent compare updates, during run-time, you only need to use the shadow registers.

Figure 15-9. PWM Waveform Details Of APWM Mode Operation



The behavior of APWM active-high mode (APWMPOL == 0) is:

```
CMP = 0x00000000, output low for duration of period (0% duty)
CMP = 0x00000001, output high 1 cycle
CMP = 0x00000002, output high 2 cycles
CMP = PERIOD, output high except for 1 cycle (<100% duty)
CMP = PERIOD+1, output high for complete period (100% duty)
CMP > PERIOD+1, output high for complete period
```

The behavior of APWM active-low mode (APWMPOL == 1) is:

```
CMP = 0x00000000, output high for duration of period (0% duty)
CMP = 0x00000001, output low 1 cycle
CMP = 0x00000002, output low 2 cycles
CMP = PERIOD, output low except for 1 cycle (<100% duty)
CMP = PERIOD+1, output low for complete period (100% duty)
```

```
CMP > PERIOD+1, output low for complete period
```

15.3 Applications

The following sections will provide Applications examples and code snippets to show how to configure and operate the eCAP module. For clarity and ease of use, below are useful #defines which will help in the understanding of the examples.

```
// ECCTL1 ( ECAP Control Reg 1)
//==========================
// CAPxPOL bits
#define    EC_RISING              0x0
#define    EC_FALLING             0x1

// CTRRSTx bits
#define    EC_ABS_MODE            0x0
#define    EC_DELTA_MODE          0x1

// PRESCALE bits
#define    EC_BYPASS              0x0
#define    EC_DIV1                0x0
#define    EC_DIV2                0x1
#define    EC_DIV4                0x2
#define    EC_DIV6                0x3
#define    EC_DIV8                0x4
#define    EC_DIV10               0x5

// ECCTL2 ( ECAP Control Reg 2)
//==========================
// CONT/ONESHOT bit
#define    EC_CONTINUOUS          0x0
#define    EC_ONESHOT             0x1

// STOPVALUE bit
#define    EC_EVENT1              0x0
#define    EC_EVENT2              0x1
#define    EC_EVENT3              0x2
#define    EC_EVENT4              0x3

// RE-ARM bit
#define    EC_ARM                 0x1

// TSCTRSTOP bit
#define    EC_FREEZE              0x0
#define    EC_RUN                 0x1

// SYNCO_SEL bit
#define    EC_SYNCIN              0x0
#define    EC_CTR_PRD             0x1
#define    EC_SYNCO_DIS           0x2

// CAP/APWM mode bit
#define    EC_CAP_MODE            0x0
#define    EC_APWM_MODE           0x1

// APWMPOL bit
#define    EC_ACTV_HI             0x0
#define    EC_ACTV_LO             0x1

// Generic
#define    EC_DISABLE             0x0
#define    EC_ENABLE              0x1
#define    EC_FORCE               0x1
```

15.3.1 Absolute Time-Stamp Operation Rising Edge Trigger Example

Figure 15-10 shows an example of continuous capture operation (Mod4 counter wraps around). In this figure, TSCTR counts-up without resetting and capture events are qualified on the rising edge only, this gives period (and frequency) information.

On an event, the TSCTR contents (time-stamp) is first captured, then Mod4 counter is incremented to the next state. When the TSCTR reaches FFFF FFFFh (maximum value), it wraps around to 0000 0000h (not shown in Figure 15-10), if this occurs, the CTROVF (counter overflow) flag is set, and an interrupt (if enabled) occurs, CTROVF (counter overflow) Flag is set, and an Interrupt (if enabled) occurs. Captured time-stamps are valid at the point indicated by the diagram, after the 4th event, hence event CEVT4 can conveniently be used to trigger an interrupt and the CPU can read data from the CAP*n* registers.

Figure 15-10. Capture Sequence for Absolute Time-Stamp, Rising Edge Detect

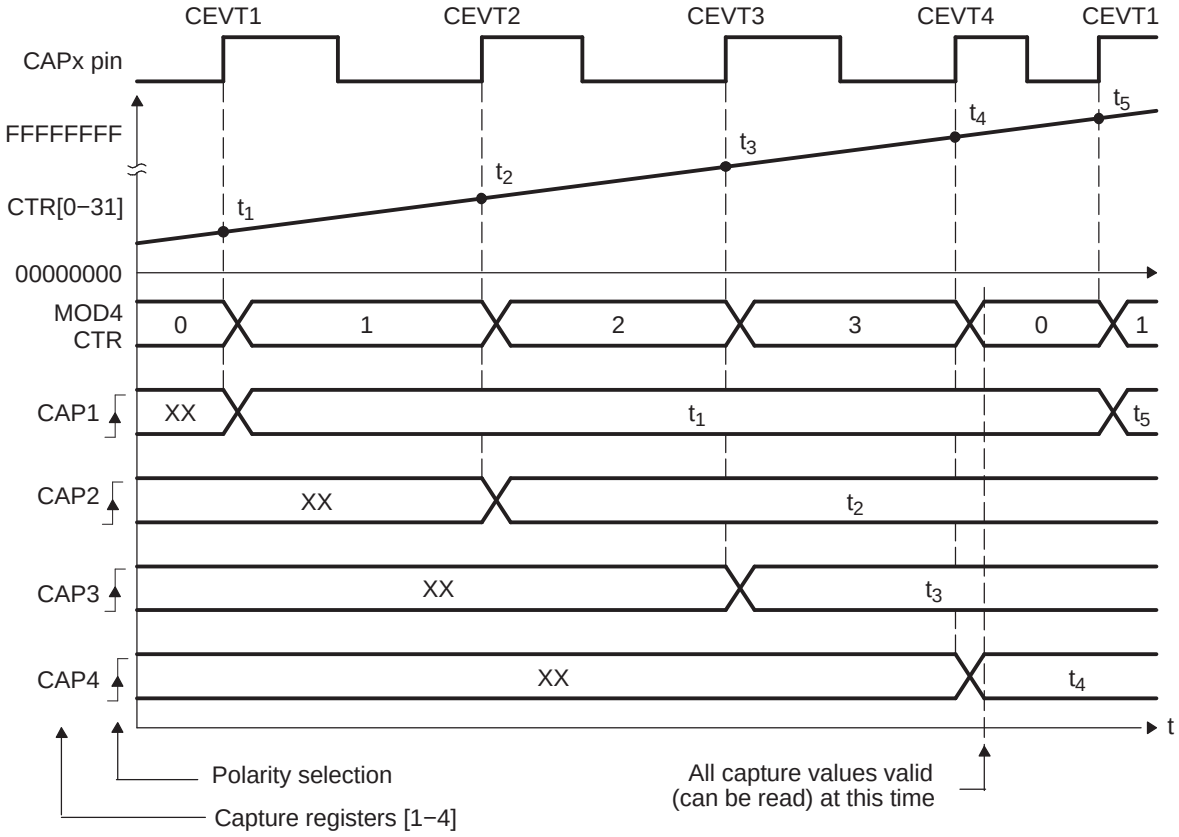


Table 15-1. ECAP Initialization for CAP Mode Absolute Time, Rising Edge Trigger

Register	Bit	Value
ECCTL1	CAP1POL	EC_RISING
ECCTL1	CAP2POL	EC_RISING
ECCTL1	CAP3POL	EC_RISING
ECCTL1	CAP4POL	EC_RISING
ECCTL1	CTRRST1	EC_ABS_MODE
ECCTL1	CTRRST2	EC_ABS_MODE
ECCTL1	CTRRST3	EC_ABS_MODE
ECCTL1	CTRRST4	EC_ABS_MODE
ECCTL1	CAPLDEN	EC_ENABLE
ECCTL1	PRESCALE	EC_DIV1
ECCTL2	CAP_APWM	EC_CAP_MODE
ECCTL2	CONT_ONESHT	EC_CONTINUOUS
ECCTL2	SYNCO_SEL	EC_SYNCO_DIS
ECCTL2	SYNCI_EN	EC_DISABLE
ECCTL2	TSCTRSTOP	EC_RUN

Example 15-1. Code Snippet for CAP Mode Absolute Time, Rising Edge Trigger

```
// Code snippet for CAP mode Absolute Time, Rising edge trigger

// Run Time ( e.g. CEVT4 triggered ISR call)
//=========================================
    TSt1 = ECAPxRegs.CAP1;        // Fetch Time-Stamp captured at t1
    TSt2 = ECAPxRegs.CAP2;        // Fetch Time-Stamp captured at t2
    TSt3 = ECAPxRegs.CAP3;        // Fetch Time-Stamp captured at t3
    TSt4 = ECAPxRegs.CAP4;        // Fetch Time-Stamp captured at t4

    Period1 = TSt2-TSt1;        // Calculate 1st period
    Period2 = TSt3-TSt2;        // Calculate 2nd period
    Period3 = TSt4-TSt3;        // Calculate 3rd period
```

15.3.2 Absolute Time-Stamp Operation Rising and Falling Edge Trigger Example

In Figure 15-11 the eCAP operating mode is almost the same as in the previous section except capture events are qualified as either rising or falling edge, this now gives both period and duty cycle information: Period1 = $t_3 - t_1$, Period2 = $t_5 - t_3$, …etc. Duty Cycle1 (on-time %) = ($t_2 - t_1$) / Period1 x 100%, etc. Duty Cycle1 (off-time %) = ($t_3 - t_2$) / Period1 x 100%, etc.

Figure 15-11. Capture Sequence for Absolute Time-Stamp, Rising and Falling Edge Detect

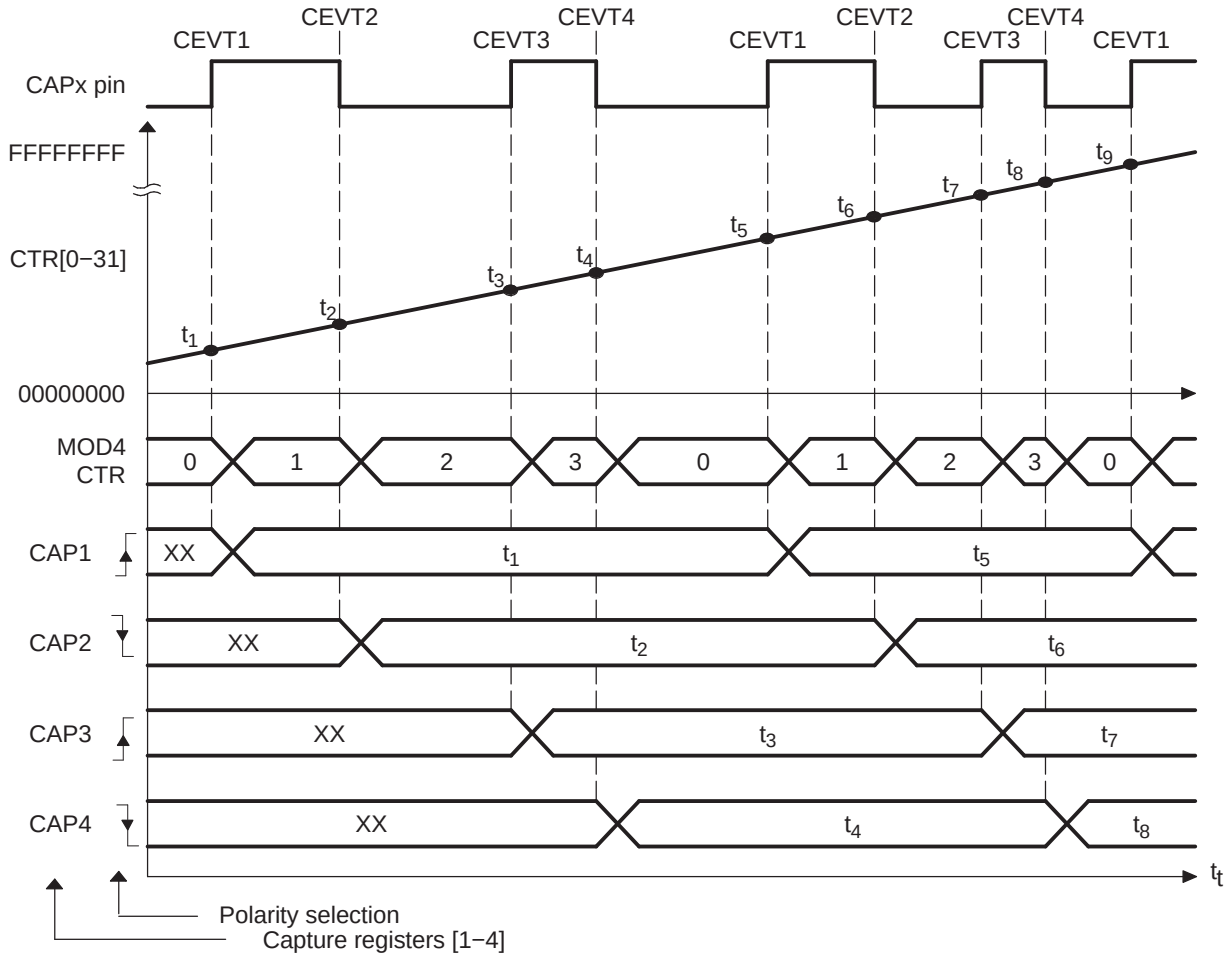


Table 15-2. ECAP Initialization for CAP Mode Absolute Time, Rising and Falling Edge Trigger

Register	Bit	Value
ECCTL1	CAP1POL	EC_RISING
ECCTL1	CAP2POL	EC_FALLING
ECCTL1	CAP3POL	EC_RISING
ECCTL1	CAP4POL	EC_FALLING
ECCTL1	CTRRST1	EC_ABS_MODE
ECCTL1	CTRRST2	EC_ABS_MODE
ECCTL1	CTRRST3	EC_ABS_MODE
ECCTL1	CTRRST4	EC_ABS_MODE
ECCTL1	CAPLDEN	EC_ENABLE
ECCTL1	PRESCALE	EC_DIV1
ECCTL2	CAP_APWM	EC_CAP_MODE
ECCTL2	CONT_ONESHT	EC_CONTINUOUS
ECCTL2	SYNCO_SEL	EC_SYNCO_DIS
ECCTL2	SYNCI_EN	EC_DISABLE
ECCTL2	TSCTRSTOP	EC_RUN

Example 15-2. Code Snippet for CAP Mode Absolute Time, Rising and Falling Edge Trigger

```
// Code snippet for CAP mode Absolute Time, Rising & Falling edge triggers

// Run Time ( e.g. CEVT4 triggered ISR call)
//=========================================
    TSt1 = ECAPxRegs.CAP1;        // Fetch Time-Stamp captured at t1
    TSt2 = ECAPxRegs.CAP2;        // Fetch Time-Stamp captured at t2
    TSt3 = ECAPxRegs.CAP3;        // Fetch Time-Stamp captured at t3
    TSt4 = ECAPxRegs.CAP4;        // Fetch Time-Stamp captured at t4

    Period1 = TSt3-TSt1;        // Calculate 1st period
    DutyOnTime1 = TSt2-TSt1;    // Calculate On time
    DutyOffTime1 = TSt3-TSt2;    // Calculate Off time
```

15.3.3 Time Difference (Delta) Operation Rising Edge Trigger Example

Figure 15-12 shows how the eCAP module can be used to collect Delta timing data from pulse train waveforms. Here Continuous Capture mode (TSCTR counts-up without resetting, and Mod4 counter wraps around) is used. In Delta-time mode, TSCTR is Reset back to Zero on every valid event. Here Capture events are qualified as Rising edge only. On an event, TSCTR contents (time-stamp) is captured first, and then TSCTR is reset to Zero. The Mod4 counter then increments to the next state. If TSCTR reaches FFFF FFFFh (maximum value), before the next event, it wraps around to 0000 0000h and continues, a CNTOVF (counter overflow) Flag is set, and an Interrupt (if enabled) occurs. The advantage of Delta-time Mode is that the CAP*n* contents directly give timing data without the need for CPU calculations: Period1 = T_1, Period2 = T_2,…etc. As shown in Figure 15-12, the CEVT1 event is a good trigger point to read the timing data, T_1, T_2, T_3, T_4 are all valid here.

Figure 15-12. Capture Sequence for Delta Mode Time-Stamp, Rising Edge Detect

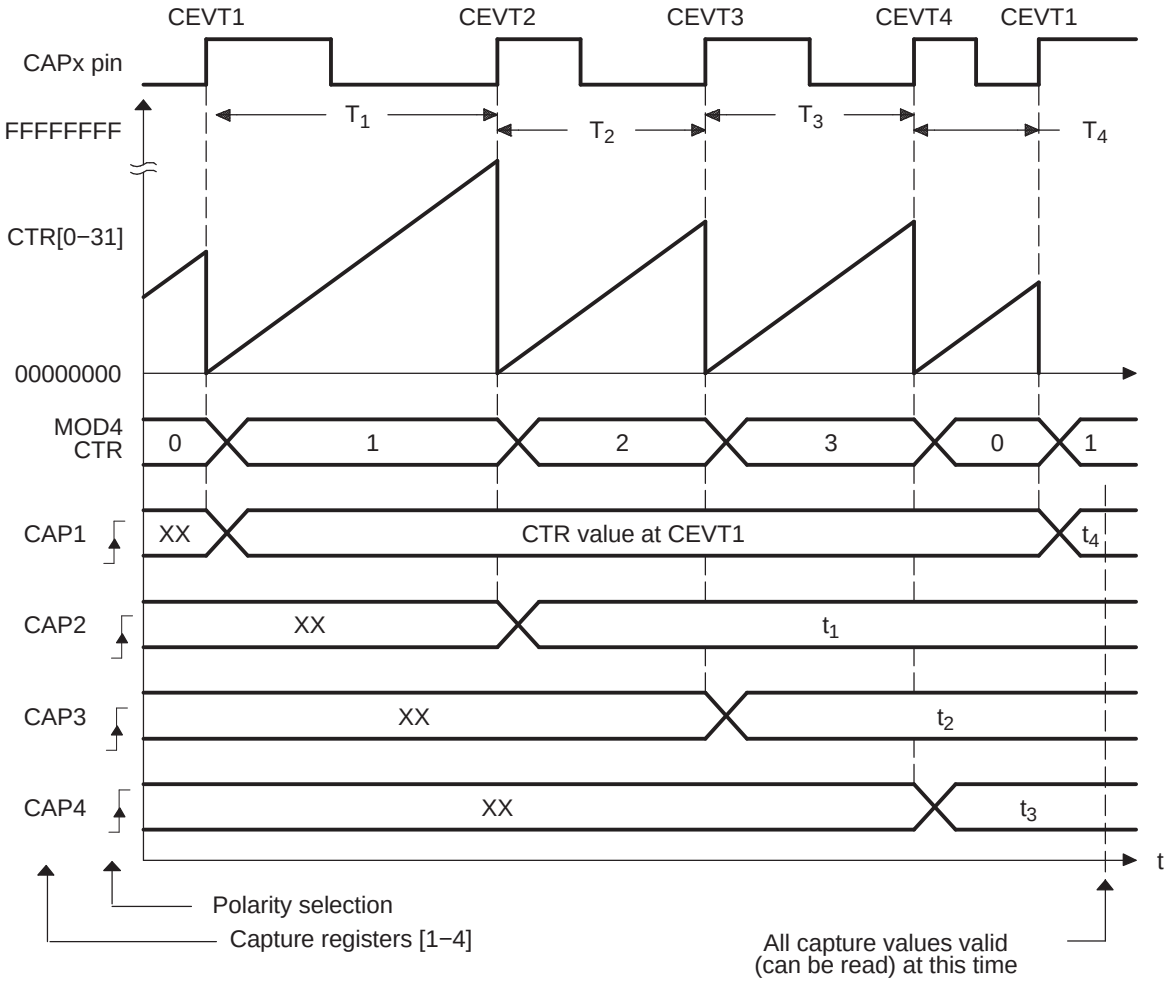


Table 15-3. ECAP Initialization for CAP Mode Delta Time, Rising Edge Trigger

Register	Bit	Value
ECCTL1	CAP1POL	EC_RISING
ECCTL1	CAP2POL	EC_RISING
ECCTL1	CAP3POL	EC_RISING
ECCTL1	CAP4POL	EC_RISING
ECCTL1	CTRRST1	EC_DELTA_MODE
ECCTL1	CTRRST2	EC_DELTA_MODE
ECCTL1	CTRRST3	EC_DELTA_MODE
ECCTL1	CTRRST4	EC_DELTA_MODE
ECCTL1	CAPLDEN	EC_ENABLE
ECCTL1	PRESCALE	EC_DIV1
ECCTL2	CAP_APWM	EC_CAP_MODE
ECCTL2	CONT_ONESHT	EC_CONTINUOUS
ECCTL2	SYNCO_SEL	EC_SYNCO_DIS
ECCTL2	SYNCI_EN	EC_DISABLE
ECCTL2	TSCTRSTOP	EC_RUN

Example 15-3. Code Snippet for CAP Mode Delta Time, Rising Edge Trigger

```
// Code snippet for CAP mode Delta Time, Rising edge trigger

// Run Time ( e.g. CEVT1 triggered ISR call)
//=========================================
// Note: here Time-stamp directly represents the Period value.
    Period4 = ECAPxRegs.CAP1;    // Fetch Time-Stamp captured at T1
    Period1 = ECAPxRegs.CAP2;    // Fetch Time-Stamp captured at T2
    Period2 = ECAPxRegs.CAP3;    // Fetch Time-Stamp captured at T3
    Period3 = ECAPxRegs.CAP4;    // Fetch Time-Stamp captured at T4
```

15.3.4 Time Difference (Delta) Operation Rising and Falling Edge Trigger Example

In Figure 15-13 the eCAP operating mode is almost the same as in previous section except Capture events are qualified as either Rising or Falling edge, this now gives both Period and Duty cycle information: Period1 = T_1 + T_2, Period2 = T_3 + T_4, …etc Duty Cycle1 (on-time %) = T_1 / Period1 × 100%, etc Duty Cycle1 (off-time %) = T_2 / Period1 × 100%, etc

During initialization, you must write to the active registers for both period and compare. This will then automatically copy the init values into the shadow values. For subsequent compare updates, that is, during run-time, only the shadow registers must be used.

Figure 15-13. Capture Sequence for Delta Mode Time-Stamp, Rising and Falling Edge Detect

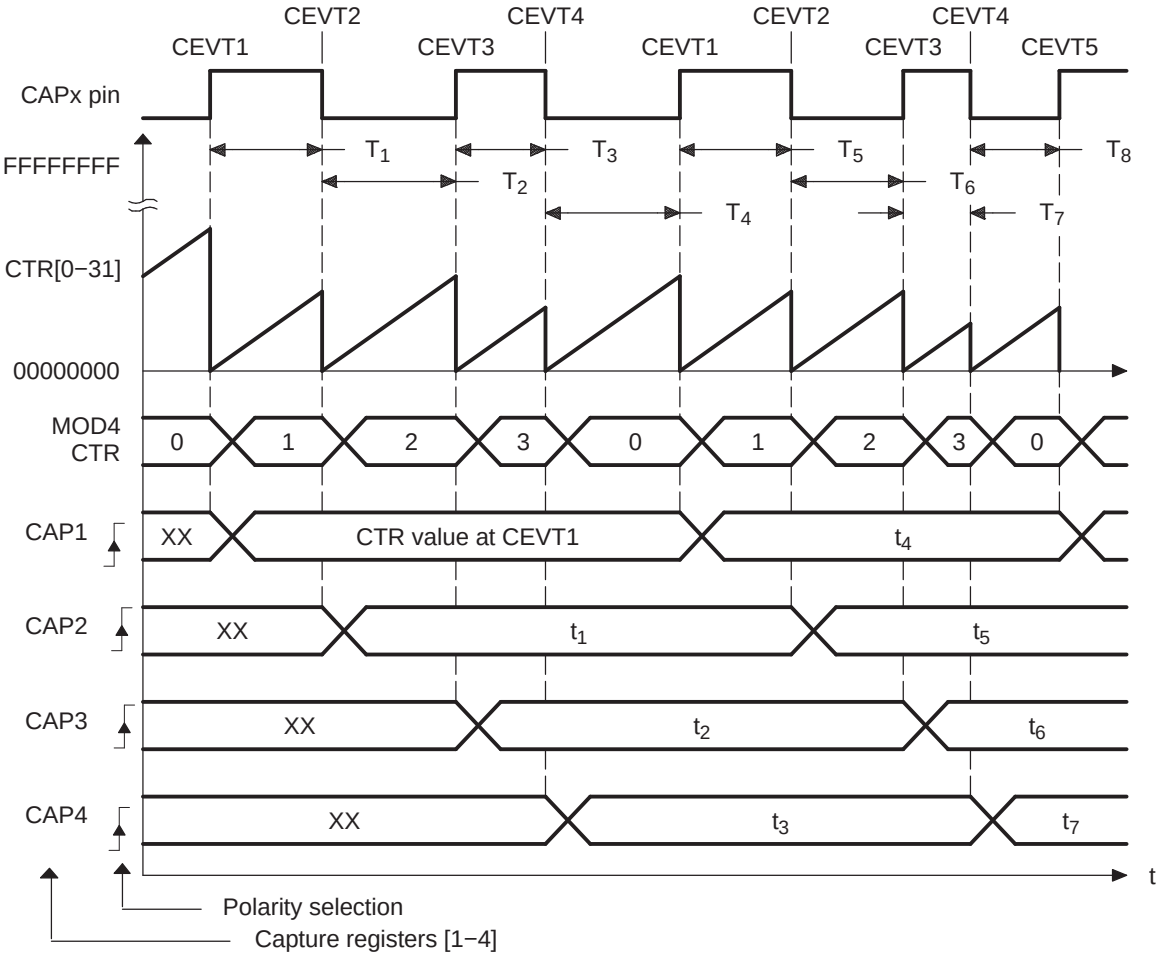


Table 15-4. ECAP Initialization for CAP Mode Delta Time, Rising and Falling Edge Triggers

Register	Bit	Value
ECCTL1	CAP1POL	EC_RISING
ECCTL1	CAP2POL	EC_FALLING
ECCTL1	CAP3POL	EC_RISING
ECCTL1	CAP4POL	EC_FALLING
ECCTL1	CTRRST1	EC_DELTA_MODE
ECCTL1	CTRRST2	EC_DELTA_MODE
ECCTL1	CTRRST3	EC_DELTA_MODE
ECCTL1	CTRRST4	EC_DELTA_MODE
ECCTL1	CAPLDEN	EC_ENABLE
ECCTL1	PRESCALE	EC_DIV1
ECCTL2	CAP_APWM	EC_CAP_MODE
ECCTL2	CONT_ONESHT	EC_CONTINUOUS
ECCTL2	SYNCO_SEL	EC_SYNCO_DIS
ECCTL2	SYNCI_EN	EC_DISABLE
ECCTL2	TSCTRSTOP	EC_RUN

Example 15-4. Code Snippet for CAP Mode Delta Time, Rising and Falling Edge Triggers

```
// Code snippet for CAP mode Delta Time, Rising and Falling edge triggers

// Run Time ( e.g. CEVT1 triggered ISR call)
//=========================================
// Note: here Time-stamp directly represents the Duty cycle values.
    DutyOnTime1 =  ECAPxRegs.CAP2;    // Fetch Time-Stamp captured at T2
    DutyOffTime1 = ECAPxRegs.CAP3;    // Fetch Time-Stamp captured at T3
    DutyOnTime2 =  ECAPxRegs.CAP4;    // Fetch Time-Stamp captured at T4
    DutyOffTime2 = ECAPxRegs.CAP1;    // Fetch Time-Stamp captured at T1

    Period1 = DutyOnTime1 + DutyOffTime1;
    Period2 = DutyOnTime2 + DutyOffTime2;
```

15.3.5 Application of the APWM Mode

15.3.5.1 Simple PWM Generation (Independent Channel/s) Example

In this example, the eCAP module is configured to operate as a PWM generator. Here a very simple single channel PWM waveform is generated from output pin APWM*n*. The PWM polarity is active high, which means that the compare value (CAP2 reg is now a compare register) represents the on-time (high level) of the period. Alternatively, if the APWMPOL bit is configured for active low, then the compare value represents the off-time.

Figure 15-14. PWM Waveform Details of APWM Mode Operation

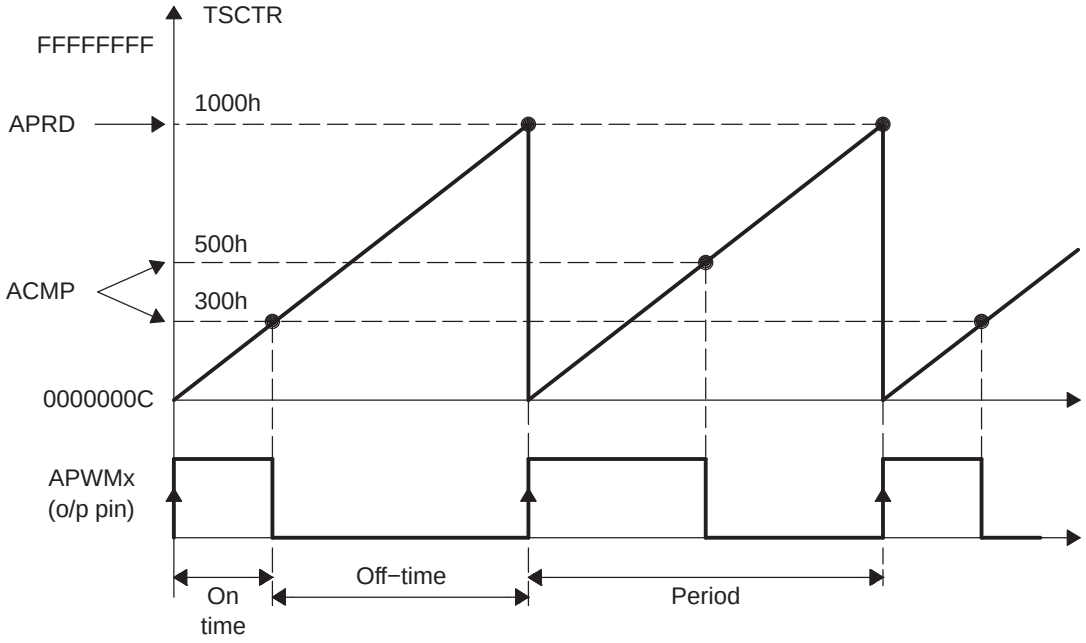


Table 15-5. ECAP Initialization for APWM Mode

Register	Bit	Value
CAP1	CAP1	0x1000
CTRPHS	CTRPHS	0x0
ECCTL2	CAP_APWM	EC_APWM_MODE
ECCTL2	APWMPOL	EC_ACTV_HI
ECCTL2	SYNCI_EN	EC_DISABLE
ECCTL2	SYNCO_SEL	EC_SYNCO_DIS
ECCTL2	TSCTRSTOP	EC_RUN

Example 15-5. Code Snippet for APWM Mode

```
// Code snippet for APWM mode Example 1

// Run Time (Instant 1, e.g. ISR call)
//======================
   ECAPxRegs.CAP2 = 0x300;      // Set Duty cycle i.e. compare value

// Run Time (Instant 2, e.g. another ISR call)
//======================
   ECAPxRegs.CAP2 = 0x500;      // Set Duty cycle i.e. compare value
```

15.3.5.2 Multichannel PWM Generation with Synchronization Example

Figure 15-15 takes advantage of the synchronization feature between eCAP modules. Here 4 independent PWM channels are required with different frequencies, but at integer multiples of each other to avoid "beat" frequencies. Hence one eCAP module is configured as the Master and the remaining 3 are Slaves all receiving their synch pulse (CTR = PRD) from the master. Note the Master is chosen to have the lower frequency (F1 = 1/20,000) requirement. Here Slave2 Freq = 2 × F1, Slave3 Freq = 4 × F1 and Slave4 Freq = 5 × F1. Note here values are in decimal notation. Also, only the APWM1 output waveform is shown.

Figure 15-15. Multichannel PWM Example Using 4 eCAP Modules

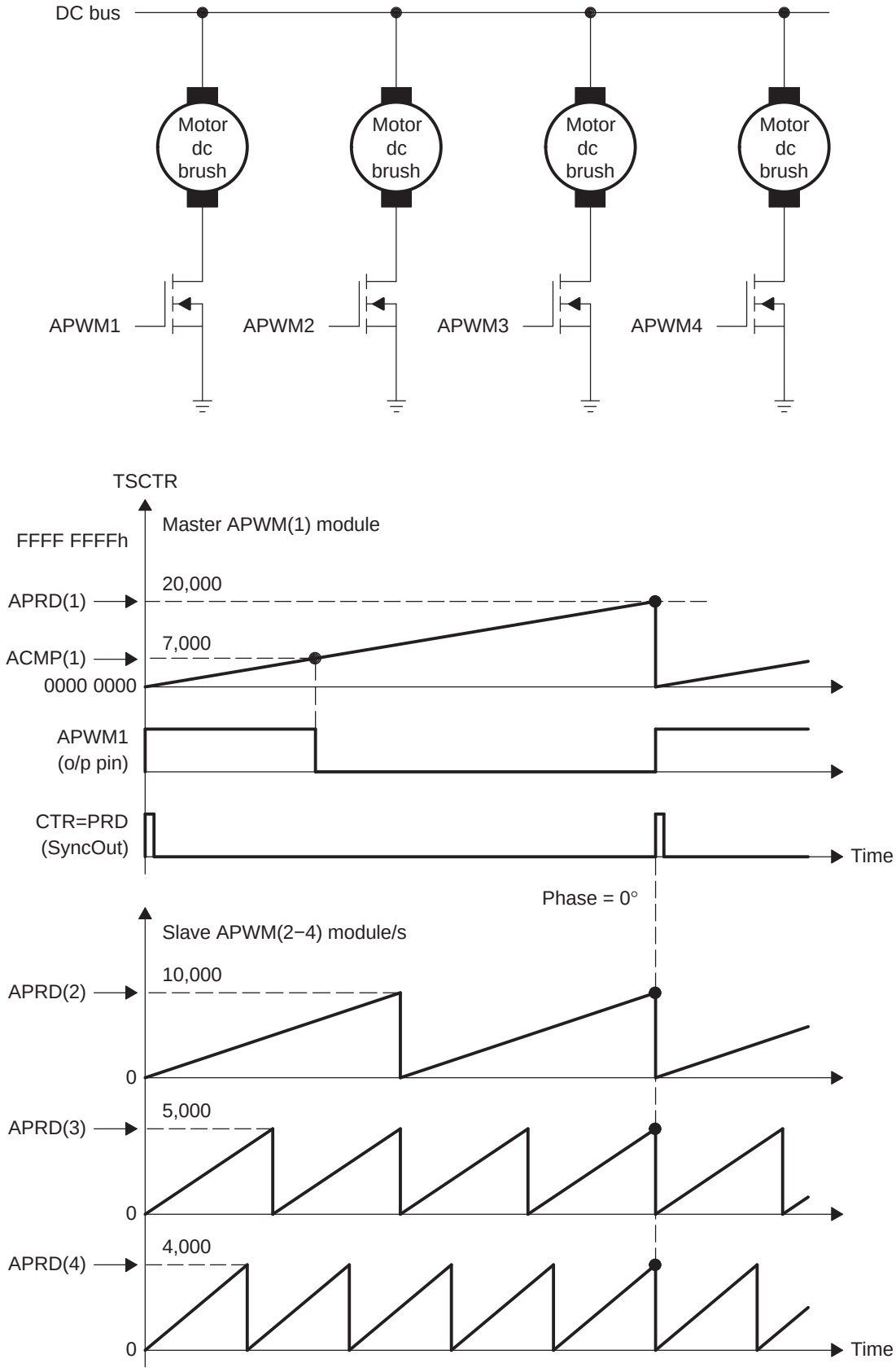


Table 15-6. ECAP1 Initialization for Multichannel PWM Generation with Synchronization

Register	Bit	Value
CAP1	CAP1	20000
CTRPHS	CTRPHS	0
ECCTL2	CAP_APWM	EC_APWM_MODE
ECCTL2	APWMPOL	EC_ACTV_HI
ECCTL2	SYNCI_EN	EC_DISABLE
ECCTL2	SYNCO_SEL	EC_CTR_PRD
ECCTL2	TSCTRSTOP	EC_RUN

Table 15-7. ECAP2 Initialization for Multichannel PWM Generation with Synchronization

Register	Bit	Value
CAP1	CAP1	10000
CTRPHS	CTRPHS	0
ECCTL2	CAP_APWM	EC_APWM_MODE
ECCTL2	APWMPOL	EC_ACTV_HI
ECCTL2	SYNCI_EN	EC_ENABLE
ECCTL2	SYNCO_SEL	EC_SYNCI
ECCTL2	TSCTRSTOP	EC_RUN

Table 15-8. ECAP3 Initialization for Multichannel PWM Generation with Synchronization

Register	Bit	Value
CAP1	CAP1	5000
CTRPHS	CTRPHS	0
ECCTL2	CAP_APWM	EC_APWM_MODE
ECCTL2	APWMPOL	EC_ACTV_HI
ECCTL2	SYNCI_EN	EC_ENABLE
ECCTL2	SYNCO_SEL	EC_SYNCI
ECCTL2	TSCTRSTOP	EC_RUN

Table 15-9. ECAP4 Initialization for Multichannel PWM Generation with Synchronization

Register	Bit	Value
CAP1	CAP1	4000
CTRPHS	CTRPHS	0
ECCTL2	CAP_APWM	EC_APWM_MODE
ECCTL2	APWMPOL	EC_ACTV_HI
ECCTL2	SYNCI_EN	EC_ENABLE
ECCTL2	SYNCO_SEL	EC_SYNCO_DIS
ECCTL2	TSCTRSTOP	EC_RUN

Example 15-6. Code Snippet for Multichannel PWM Generation with Synchronization

```
// Code snippet for APWM mode Example 2

// Run Time (Note: Example execution of one run-time instant)
//=============================================================
   ECAP1Regs.CAP2 = 7000;    // Set Duty cycle i.e., compare value = 7000
   ECAP2Regs.CAP2 = 2000;    // Set Duty cycle i.e., compare value = 2000
   ECAP3Regs.CAP2 = 550;     // Set Duty cycle i.e., compare value = 550
   ECAP4Regs.CAP2 = 6500;    // Set Duty cycle i.e., compare value = 6500
```

15.3.5.3 Multichannel PWM Generation with Phase Control Example

In Figure 15-16, the Phase control feature of the APWM mode is used to control a 3 phase Interleaved DC/DC converter topology. This topology requires each phase to be off-set by 120° from each other. Hence if “Leg” 1 (controlled by APWM1) is the reference Leg (or phase), that is, 0°, then Leg 2 need 120° off-set and Leg 3 needs 240° off-set. The waveforms in Figure 15-16 show the timing relationship between each of the phases (Legs). Note eCAP1 module is the Master and issues a sync out pulse to the slaves (modules 2, 3) whenever TSCTR = Period value.

Figure 15-16. Multiphase (channel) Interleaved PWM Example Using 3 eCAP Modules

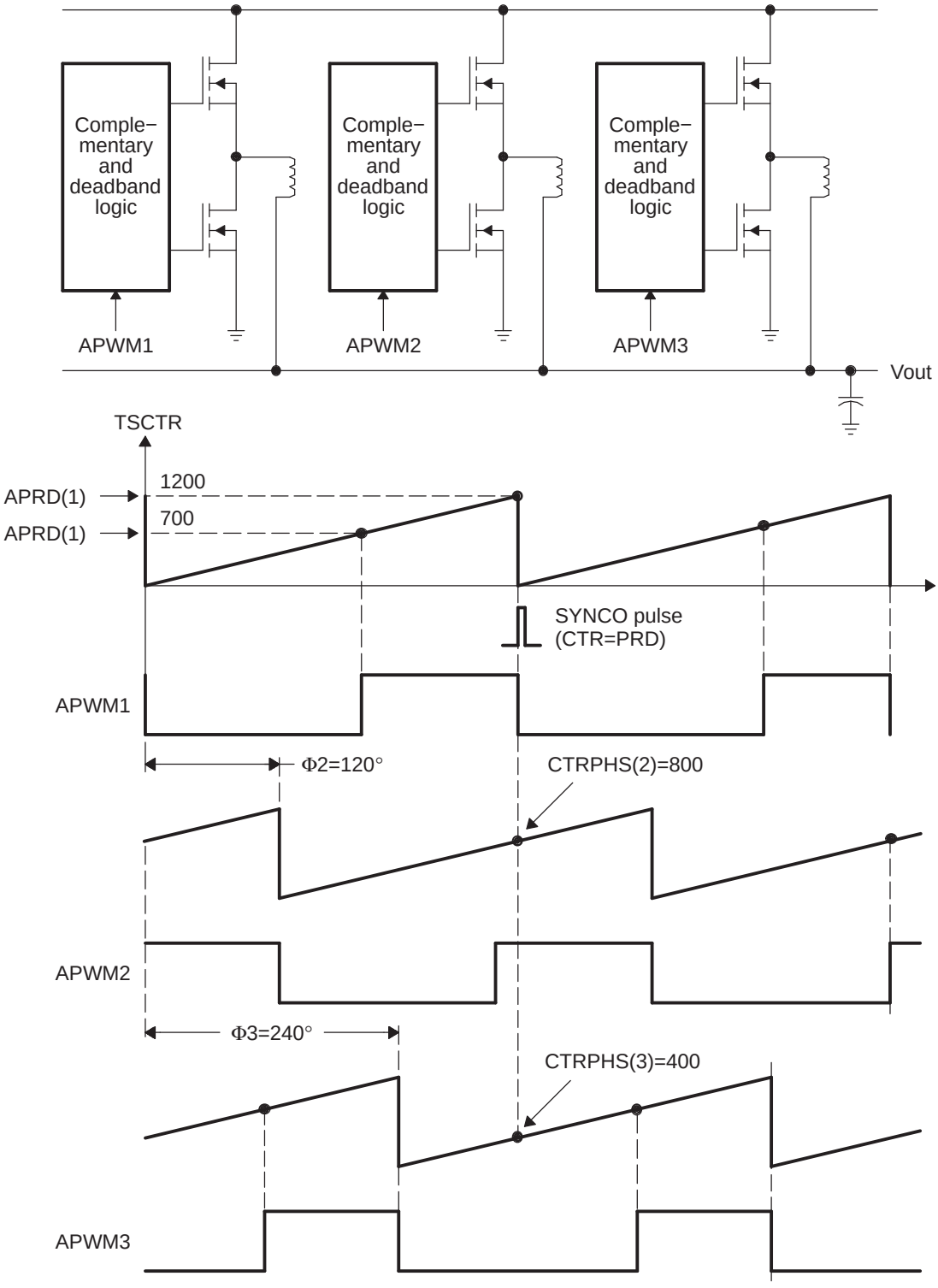


Table 15-10. ECAP1 Initialization for Multichannel PWM Generation with Phase Control

Register	Bit	Value
CAP1	CAP1	1200
CTRPHS	CTRPHS	0
ECCTL2	CAP_APWM	EC_APWM_MODE
ECCTL2	APWMPOL	EC_ACTV_HI
ECCTL2	SYNCI_EN	EC_DISABLE
ECCTL2	SYNCO_SEL	EC_CTR_PRD
ECCTL2	TSCTRSTOP	EC_RUN

Table 15-11. ECAP2 Initialization for Multichannel PWM Generation with Phase Control

Register	Bit	Value
CAP1	CAP1	1200
CTRPHS	CTRPHS	800
ECCTL2	CAP_APWM	EC_APWM_MODE
ECCTL2	APWMPOL	EC_ACTV_HI
ECCTL2	SYNCI_EN	EC_ENABLE
ECCTL2	SYNCO_SEL	EC_SYNCI
ECCTL2	TSCTRSTOP	EC_RUN

Table 15-12. ECAP3 Initialization for Multichannel PWM Generation with Phase Control

Register	Bit	Value
CAP1	CAP1	1200
CTRPHS	CTRPHS	400
ECCTL2	CAP_APWM	EC_APWM_MODE
ECCTL2	APWMPOL	EC_ACTV_HI
ECCTL2	SYNCI_EN	EC_ENABLE
ECCTL2	SYNCO_SEL	EC_SYNCO_DIS
ECCTL2	TSCTRSTOP	EC_RUN

Example 15-7. Code Snippet for Multichannel PWM Generation with Phase Control

```
// Code snippet for APWM mode Example 3


// Run Time (Note: Example execution of one run-time instant)
//=====================================================
// All phases are set to the same duty cycle
  ECAP1Regs.CAP2 = 700;     // Set Duty cycle i.e. compare value = 700
  ECAP2Regs.CAP2 = 700;     // Set Duty cycle i.e. compare value = 700
  ECAP3Regs.CAP2 = 700;     // Set Duty cycle i.e. compare value = 700
```

15.4 Registers

Table 15-13 shows the eCAP module control and status register set. All 32-bit registers are aligned on even address boundaries and are organized in little-endian mode. The 16 least-significant bits of a 32-bit register are located on lowest address (even address).

NOTE: In APWM mode, writing to CAP1/CAP2 active registers also writes the same value to the corresponding shadow registers CAP3/CAP4. This emulates immediate mode. Writing to the shadow registers CAP3/CAP4 invokes the shadow mode.

Table 15-13. Control and Status Register Set

Offset	Acronym	Description	Size (×16)	Section
0h	TSCTR	Time-Stamp Counter Register	2	Section 15.4.1
4h	CTRPHS	Counter Phase Offset Value Register	2	Section 15.4.2
8h	CAP1	Capture 1 Register	2	Section 15.4.3
Ch	CAP2	Capture 2 Register	2	Section 15.4.4
10h	CAP3	Capture 3 Register	2	Section 15.4.5
14h	CAP4	Capture 4 Register	2	Section 15.4.6
28h	ECCTL1	Capture Control Register 1	1	Section 15.4.7
2Ah	ECCTL2	Capture Control Register 2	1	Section 15.4.8
2Ch	ECEINT	Capture Interrupt Enable Register	1	Section 15.4.9
2Eh	ECFLG	Capture Interrupt Flag Register	1	Section 15.4.10
30h	ECCLR	Capture Interrupt Clear Register	1	Section 15.4.11
32h	ECFRC	Capture Interrupt Force Register	1	Section 15.4.12
5Ch	REVID	Revision ID Register	2	Section 15.4.13

15.4.1 Time-Stamp Counter Register (TSCTR)

The time-stamp counter register (TSCTR) is shown in Figure 15-17 and described in Table 15-14.

Figure 15-17. Time-Stamp Counter Register (TSCTR)

31	0
TSCTR	
R/W-0	

LEGEND: R/W = Read/Write; *-n* = value after reset

Table 15-14. Time-Stamp Counter Register (TSCTR) Field Descriptions

Bit	Field	Value	Description
31-0	TSCTR	0-FFFF FFFFh	Active 32-bit counter register that is used as the capture time-base

15.4.2 Counter Phase Control Register (CTRPHS)

The counter phase control register (CTRPHS) is shown in Figure 15-18 and described in Table 15-15.

Figure 15-18. Counter Phase Control Register (CTRPHS)

31	0
CTRPHS	
R/W-0	

LEGEND: R/W = Read/Write; -*n* = value after reset

Table 15-15. Counter Phase Control Register (CTRPHS) Field Descriptions

Bit	Field	Value	Description
31-0	CTRPHS	0-FFFF FFFFh	Counter phase value register that can be programmed for phase lag/lead. This register shadows TSCTR and is loaded into TSCTR upon either a SYNCI event or S/W force via a control bit. Used to achieve phase control synchronization with respect to other eCAP and EPWM time-bases.

15.4.3 Capture 1 Register (CAP1)

The capture 1 register (CAP1) is shown in Figure 15-19 and described in Table 15-16.

Figure 15-19. Capture 1 Register (CAP1)

31	0
CAP1	
R/W-0	

LEGEND: R/W = Read/Write; -*n* = value after reset

Table 15-16. Capture 1 Register (CAP1) Field Descriptions

Bit	Field	Value	Description
31-0	CAP1	0-FFFF FFFFh	This register can be loaded (written) by: • Time-Stamp (i.e., counter value) during a capture event • Software - may be useful for test purposes • APRD active register when used in APWM mode

15.4.4 Capture 2 Register (CAP2)

The capture 2 register (CAP2) is shown in Figure 15-20 and described in Table 15-17.

Figure 15-20. Capture 2 Register (CAP2)

31	0
CAP2	
R/W-0	

LEGEND: R/W = Read/Write; -*n* = value after reset

Table 15-17. Capture 2 Register (CAP2) Field Descriptions

Bit	Field	Value	Description
31-0	CAP2	0-FFFF FFFFh	This register can be loaded (written) by: • Time-Stamp (i.e., counter value) during a capture event • Software - may be useful for test purposes • ACMP active register when used in APWM mode

15.4.5 Capture 3 Register (CAP3)

The capture 3 register (CAP3) is shown in Figure 15-21 and described in Table 15-18.

Figure 15-21. Capture 3 Register (CAP3)

31	0
CAP3	
R/W-0	

LEGEND: R/W = Read/Write; -*n* = value after reset

Table 15-18. Capture 3 Register (CAP3) Field Descriptions

Bit	Field	Value	Description
31-0	CAP3	0-FFFF FFFFh	In CMP mode, this is a time-stamp capture register. In APWM mode, this is the period shadow (APRD) register. You update the PWM period value through this register. In this mode, CAP3 shadows CAP1.

15.4.6 Capture 4 Register (CAP4)

The capture 4 register (CAP4) is shown in Figure 15-22 and described in Table 15-19.

Figure 15-22. Capture 4 Register (CAP4)

31	0
CAP4	
R/W-0	

LEGEND: R/W = Read/Write; -*n* = value after reset

Table 15-19. Capture 4 Register (CAP4) Field Descriptions

Bit	Field	Value	Description
31-0	CAP4	0-FFFF FFFFh	In CMP mode, this is a time-stamp capture register. In APWM mode, this is the compare shadow (ACMP) register. You update the PWM compare value through this register. In this mode, CAP4 shadows CAP2.

15.4.7 ECAP Control Register 1 (ECCTL1)

The ECAP control register 1 (ECCTL1) is shown in Figure 15-23 and described in Table 15-20.

Figure 15-23. ECAP Control Register 1 (ECCTL1)

15	14	13	9	8
FREE/SOFT		PRESCALE		CAPLDEN
R/W-0		R/W-0		R/W-0

7	6	5	4	3	2	1	0
CTRRST4	CAP4POL	CTRRST3	CAP3POL	CTRRST2	CAP2POL	CTRRST1	CAP1POL
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; -*n* = value after reset

Table 15-20. ECAP Control Register 1 (ECCTL1) Field Descriptions

Bit	Field	Value	Description
15-14	FREE/SOFT	0-3h	Emulation Control
		0	TSCTR counter stops immediately on emulation suspend
		1h	TSCTR counter runs until = 0
		2h-3h	TSCTR counter is unaffected by emulation suspend (Run Free)
13-9	PRESCALE	0-1Fh	Event Filter prescale select
		0	Divide by 1 (i.e,. no prescale, by-pass the prescaler)
		1	Divide by 2
		2h	Divide by 4
		3h	Divide by 6
		4h	Divide by 8
		5h	Divide by 10
		...	
		1Eh	Divide by 60
		1Fh	Divide by 62
8	CAPLDEN		Enable Loading of CAP1-4 registers on a capture event
		0	Disable CAP1-4 register loads at capture event time.
		1	Enable CAP1-4 register loads at capture event time.

Table 15-20. ECAP Control Register 1 (ECCTL1) Field Descriptions (continued)

Bit	Field	Value	Description
7	CTRRST4		Counter Reset on Capture Event 4
		0	*Do not* reset counter on Capture Event 4 (absolute time stamp operation)
		1	Reset counter after Capture Event 4 time-stamp has been captured (used in difference mode operation)
6	CAP4POL		Capture Event 4 Polarity select
		0	Capture Event 4 triggered on a rising edge (RE)
		1	Capture Event 4 triggered on a falling edge (FE)
5	CTRRST3		Counter Reset on Capture Event 3
		0	*Do not* reset counter on Capture Event 3 (absolute time stamp)
		1	Reset counter after Event 3 time-stamp has been captured (used in difference mode operation)
4	CAP3POL		Capture Event 3 Polarity select
		0	Capture Event 3 triggered on a rising edge (RE)
		1	Capture Event 3 triggered on a falling edge (FE)
3	CTRRST2		Counter Reset on Capture Event 2
		0	*Do not* reset counter on Capture Event 2 (absolute time stamp)
		1	Reset counter after Event 2 time-stamp has been captured (used in difference mode operation)
2	CAP2POL		Capture Event 2 Polarity select
		0	Capture Event 2 triggered on a rising edge (RE)
		1	Capture Event 2 triggered on a falling edge (FE)
1	CTRRST1		Counter Reset on Capture Event 1
		0	*Do not* reset counter on Capture Event 1 (absolute time stamp)
		1	Reset counter after Event 1 time-stamp has been captured (used in difference mode operation)
0	CAP1POL		Capture Event 1 Polarity select
		0	Capture Event 1 triggered on a rising edge (RE)
		1	Capture Event 1 triggered on a falling edge (FE)

15.4.8 ECAP Control Register 2 (ECCTL2)

The ECAP control register 2 (ECCTL2) is shown in Figure 15-24 and described in Table 15-21.

Figure 15-24. ECAP Control Register 2 (ECCTL2)

15	14	13	12	11	10	9	8
Reserved					APWMPOL	CAP/APWM	SWSYNC
R-0					R/W-0	R/W-0	R/W-0

7	6	5	4	3	2	1	0
SYNCO_SEL		SYNCI_EN	TSCTRSTOP	RE-ARM	STOP_WRAP		CONT/ONESHT
R/W-0		R/W-0	R/W-0	R/W-0	R/W-1		R/W-0

LEGEND: R/W = Read/Write; R = Read only; *-n* = value after reset

Table 15-21. ECAP Control Register 2 (ECCTL2) Field Descriptions

Bit	Field	Value	Description
15-11	Reserved	0	Reserved
10	APWMPOL		APWM output polarity select. This is applicable only in APWM operating mode
		0	Output is active high (Compare value defines high time)
		1	Output is active low (Compare value defines low time)
9	CAP/APWM		CAP/APWM operating mode select
		0	ECAP module operates in capture mode. This mode forces the following configuration: • Inhibits TSCTR resets via CTR = PRD event • Inhibits shadow loads on CAP1 and 2 registers • Permits user to enable CAP1-4 register load • ECAP*n*/APWM*n* pin operates as a capture input
		1	ECAP module operates in APWM mode. This mode forces the following configuration: • Resets TSCTR on CTR = PRD event (period boundary • Permits shadow loading on CAP1 and 2 registers • Disables loading of time-stamps into CAP1-4 registers • ECAP*n*/APWM*n* pin operates as a APWM output
8	SWSYNC		Software-forced Counter (TSCTR) Synchronizing. This provides a convenient software method to synchronize some or all ECAP time bases. In APWM mode, the synchronizing can also be done via the CTR = PRD event.
		0	Writing a zero has no effect. Reading always returns a zero
		1	Writing a one forces a TSCTR shadow load of current ECAP module and any ECAP modules down-stream providing the SYNCO_SEL bits are 0,0. After writing a 1, this bit returns to a zero. Note: Selection CTR = PRD is meaningful only in APWM mode; however, you can choose it in CAP mode if you find doing so useful.
7-6	SYNCO_SEL	0-3h	Sync-Out Select
		0	Select sync-in event to be the sync-out signal (pass through)
		1h	Select CTR = PRD event to be the sync-out signal
		2h	Disable sync out signal
		3h	Disable sync out signal
5	SYNCI_EN		Counter (TSCTR) Sync-In select mode
		0	Disable sync-in option
		1	Enable counter (TSCTR) to be loaded from CTRPHS register upon either a SYNCI signal or a S/W force event.
4	TSCTRSTOP		Time Stamp (TSCTR) Counter Stop (freeze) Control
		0	TSCTR stopped
		1	TSCTR free-running

Table 15-21. ECAP Control Register 2 (ECCTL2) Field Descriptions (continued)

Bit	Field	Value	Description
3	RE-ARM		One-Shot Re-Arming Control, that is, wait for stop trigger. Note: The re-arm function is valid in one shot or continuous mode.
		0	Has no effect (reading always returns a 0)
		1	Arms the one-shot sequence as follows: 1) Resets the Mod4 counter to zero 2) Unfreezes the Mod4 counter 3) Enables capture register loads
2-1	STOP_WRAP	0-3h	Stop value for one-shot mode. This is the number (between 1-4) of captures allowed to occur before the CAP(1-4) registers are frozen, that is, capture sequence is stopped. Wrap value for continuous mode. This is the number (between 1-4) of the capture register in which the circular buffer wraps around and starts again.
		0	Stop after Capture Event 1 in one-shot mode. Wrap after Capture Event 1 in continuous mode.
		1h	Stop after Capture Event 2 in one-shot mode. Wrap after Capture Event 2 in continuous mode.
		2h	Stop after Capture Event 3 in one-shot mode. Wrap after Capture Event 3 in continuous mode.
		3h	Stop after Capture Event 4 in one-shot mode. Wrap after Capture Event 4 in continuous mode.
			Notes: STOP_WRAP is compared to Mod4 counter and, when equal, 2 actions occur: • Mod4 counter is stopped (frozen) • Capture register loads are inhibited In one-shot mode, further interrupt events are blocked until re-armed.
0	CONT/ONESHT		Continuous or one-shot mode control (applicable only in capture mode)
		0	Operate in continuous mode
		1	Operate in one-shot mode

15.4.9 ECAP Interrupt Enable Register (ECEINT)

The ECAP interrupt enable register (ECEINT) is shown in Figure 15-25 and described in Table 15-22.

The interrupt enable bits (CEVT*n*) block any of the selected events from generating an interrupt. Events will still be latched into the flag bit (ECFLG register) and can be forced/cleared via the ECFRC/ECCLR registers.

The proper procedure for configuring peripheral modes and interrupts is:

1. Disable global interrupts
2. Stop eCAP counter
3. Disable eCAP interrupts
4. Configure peripheral registers
5. Clear spurious eCAP interrupt flags
6. Enable eCAP interrupts
7. Start eCAP counter
8. Enable global interrupts

Figure 15-25. ECAP Interrupt Enable Register (ECEINT)

15							8
Reserved							
R-0							
7	6	5	4	3	2	1	0
CTR=CMP	CTR=PRD	CTROVF	CEVT4	CEVT3	CEVT2	CETV1	Reserved
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 15-22. ECAP Interrupt Enable Register (ECEINT) Field Descriptions

Bit	Field	Value	Description
15-8	Reserved	0	Reserved
7	CTR=CMP		Counter Equal Compare Interrupt Enable
		0	Disable Compare Equal as an Interrupt source
		1	Enable Compare Equal as an Interrupt source
6	CTR=PRD		Counter Equal Period Interrupt Enable
		0	Disable Period Equal as an Interrupt source
		1	Enable Period Equal as an Interrupt source
5	CTROVF		Counter Overflow Interrupt Enable
		0	Disable counter Overflow as an Interrupt source
		1	Enable counter Overflow as an Interrupt source
4	CEVT4		Capture Event 4 Interrupt Enable
		0	Disable Capture Event 4 as an Interrupt source
		1	Enable Capture Event 4 as an Interrupt source
3	CEVT3		Capture Event 3 Interrupt Enable
		0	Disable Capture Event 3 as an Interrupt source
		1	Enable Capture Event 3 as an Interrupt source
2	CEVT2		Capture Event 2 Interrupt Enable
		0	Disable Capture Event 2 as an Interrupt source
		1	Enable Capture Event 2 as an Interrupt source
1	CEVT1		Capture Event 1 Interrupt Enable
		0	Disable Capture Event 1 as an Interrupt source
		1	Enable Capture Event 1 as an Interrupt source
0	Reserved	0	Reserved

15.4.10 ECAP Interrupt Flag Register (ECFLG)

The ECAP interrupt flag register (ECFLG) is shown in Figure 15-26 and described in Table 15-23.

Figure 15-26. ECAP Interrupt Flag Register (ECFLG)

15							8
Reserved							
R-0							
7	6	5	4	3	2	1	0
CTR=CMP	CTR=PRD	CTROVF	CEVT4	CETV3	CEVT2	CETV1	INT
R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0

LEGEND: R = Read only; -*n* = value after reset

Table 15-23. ECAP Interrupt Flag Register (ECFLG) Field Descriptions

Bit	Field	Value	Description
15-8	Reserved	0	Reserved
7	CTR=CMP		Compare Equal Compare Status Flag. This flag is only active in APWM mode.
		0	Indicates no event occurred
		1	Indicates the counter (TSCTR) reached the compare register value (ACMP)
6	CTR=PRD		Counter Equal Period Status Flag. This flag is only active in APWM mode.
		0	Indicates no event occurred
		1	Indicates the counter (TSCTR) reached the period register value (APRD) and was reset.
5	CTROVF		Counter Overflow Status Flag. This flag is active in CAP and APWM mode.
		0	Indicates no event occurred.
		1	Indicates the counter (TSCTR) has made the transition from 0xFFFFFFFF to 0x00000000
4	CEVT4		Capture Event 4 Status Flag This flag is only active in CAP mode.
		0	Indicates no event occurred
		1	Indicates the fourth event occurred at ECAP*n* pin
3	CEVT3		Capture Event 3 Status Flag. This flag is active only in CAP mode.
		0	Indicates no event occurred.
		1	Indicates the third event occurred at ECAP*n* pin.
2	CEVT2		Capture Event 2 Status Flag. This flag is only active in CAP mode.
		0	Indicates no event occurred.
		1	Indicates the second event occurred at ECAP*n* pin.
1	CEVT1		Capture Event 1 Status Flag. This flag is only active in CAP mode.
		0	Indicates no event occurred.
		1	Indicates the first event occurred at ECAP*n* pin.
0	INT		Global Interrupt Status Flag
		0	Indicates no interrupt generated.
		1	Indicates that an interrupt was generated.

15.4.11 ECAP Interrupt Clear Register (ECCLR)

The ECAP interrupt clear register (ECCLR) is shown in Figure 15-27 and described in Table 15-24.

Figure 15-27. ECAP Interrupt Clear Register (ECCLR)

15							8
Reserved							
R-0							
7	6	5	4	3	2	1	0
CTR=CMP	CTR=PRD	CTROVF	CEVT4	CETV3	CETV2	CETV1	INT
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; *-n* = value after reset

Table 15-24. ECAP Interrupt Clear Register (ECCLR) Field Descriptions

Bit	Field	Value	Description
15-8	Reserved	0	Reserved
7	CTR=CMP		Counter Equal Compare Status Flag
		0	Writing a 0 has no effect. Always reads back a 0
		1	Writing a 1 clears the CTR=CMP flag condition
6	CTR=PRD		Counter Equal Period Status Flag
		0	Writing a 0 has no effect. Always reads back a 0
		1	Writing a 1 clears the CTR=PRD flag condition
5	CTROVF		Counter Overflow Status Flag
		0	Writing a 0 has no effect. Always reads back a 0
		1	Writing a 1 clears the CTROVF flag condition
4	CEVT4		Capture Event 4 Status Flag
		0	Writing a 0 has no effect. Always reads back a 0.
		1	Writing a 1 clears the CEVT3 flag condition.
3	CEVT3		Capture Event 3 Status Flag
		0	Writing a 0 has no effect. Always reads back a 0.
		1	Writing a 1 clears the CEVT3 flag condition.
2	CEVT2		Capture Event 2 Status Flag
		0	Writing a 0 has no effect. Always reads back a 0.
		0	Writing a 1 clears the CEVT2 flag condition.
1	CEVT1		Capture Event 1 Status Flag
		0	Writing a 0 has no effect. Always reads back a 0.
		1	Writing a 1 clears the CEVT1 flag condition.
0	INT		Global Interrupt Clear Flag
		0	Writing a 0 has no effect. Always reads back a 0.
		1	Writing a 1 clears the INT flag and enable further interrupts to be generated if any of the event flags are set to 1.

15.4.12 ECAP Interrupt Forcing Register (ECFRC)

The ECAP interrupt forcing register (ECFRC) is shown in Figure 15-28 and described in Table 15-25.

Figure 15-28. ECAP Interrupt Forcing Register (ECFRC)

15	14	13	12	11	10	9	8
Reserved							
R-0							

7	6	5	4	3	2	1	0
CTR=CMP	CTR=PRD	CTROVF	CEVT4	CETV3	CETV2	CETV1	Reserved
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R-0

LEGEND: R/W = Read/Write; R = Read only; *-n* = value after reset

Table 15-25. ECAP Interrupt Forcing Register (ECFRC) Field Descriptions

Bit	Field	Value	Description
15-8	Reserved	0	Reserved
7	CTR=CMP		Force Counter Equal Compare Interrupt
		0	No effect. Always reads back a 0.
		1	Writing a 1 sets the CTR=CMP flag bit.
6	CTR=PRD		Force Counter Equal Period Interrupt
		0	No effect. Always reads back a 0.
		1	Writing a 1 sets the CTR=PRD flag bit.
5	CTROVF		Force Counter Overflow
		0	No effect. Always reads back a 0.
		1	Writing a 1 to this bit sets the CTROVF flag bit.
4	CEVT4		Force Capture Event 4
		0	No effect. Always reads back a 0.
		1	Writing a 1 sets the CEVT4 flag bit
3	CEVT3		Force Capture Event 3
		0	No effect. Always reads back a 0.
		1	Writing a 1 sets the CEVT3 flag bit
2	CEVT2		Force Capture Event 2
		0	No effect. Always reads back a 0.
		1	Writing a 1 sets the CEVT2 flag bit.
1	CEVT1		Force Capture Event 1
		0	No effect. Always reads back a 0.
		1	Writing a 1 sets the CEVT1 flag bit.
0	Reserved	0	Reserved

15.4.13 Revision ID Register (REVID)

The revision ID register (REVID) is shown in Figure 15-29 and described in Table 15-26.

Figure 15-29. Revision ID Register (REVID)

31	0
REV	
R-44D2 2100h	

LEGEND: R = Read only; -*n* = value after reset

Table 15-26. Revision ID Register (REVID) Field Descriptions

Bit	Field	Value	Description
31-0	REV	44D2 2100h	Revision ID.

Enhanced High-Resolution Pulse-Width Modulator (eHRPWM)

This chapter describes the enhanced high-resolution pulse-width modulator (eHRPWM).

Topic **Page**

16.1 Introduction

16.1.1 Introduction

An effective PWM peripheral must be able to generate complex pulse width waveforms with minimal CPU overhead or intervention. It needs to be highly programmable and very flexible while being easy to understand and use. The ePWM unit described here addresses these requirements by allocating all needed timing and control resources on a per PWM channel basis. Cross coupling or sharing of resources has been avoided; instead, the ePWM is built up from smaller single channel modules with separate resources and that can operate together as required to form a system. This modular approach results in an orthogonal architecture and provides a more transparent view of the peripheral structure, helping users to understand its operation quickly.

In this chapter, the letter x within a signal or module name is used to indicate a generic ePWM instance on a device. For example, output signals EPWMxA and EPWMxB refer to the output signals from the ePWMx instance. Thus, EPWM1A and EPWM1B belong to ePWM1 and, likewise, EPWM4A and EPWM4B belong to ePWM4.

16.1.2 Submodule Overview

The ePWM module represents one complete PWM channel composed of two PWM outputs: EPWMxA and EPWMxB. Multiple ePWM modules are instanced within a device as shown in Figure 16-1. Each ePWM instance is identical with one exception. Some instances include a hardware extension that allows more precise control of the PWM outputs. This extension is the high-resolution pulse width modulator (HRPWM) and is described in Section 16.2.10. See your device-specific data manual to determine which ePWM instances include this feature. Each ePWM module is indicated by a numerical value starting with 1. For example ePWM1 is the first instance and ePWM3 is the 3rd instance in the system and ePWMx indicates any instance.

The ePWM modules are chained together via a clock synchronization scheme that allows them to operate as a single system when required. Additionally, this synchronization scheme can be extended to the capture peripheral modules (eCAP). The number of modules is device-dependent and based on target application needs. Modules can also operate stand-alone.

Each ePWM module supports the following features:

- Dedicated 16-bit time-base counter with period and frequency control
- Two PWM outputs (EPWMxA and EPWMxB) that can be used in the following configurations::
  - Two independent PWM outputs with single-edge operation
  - Two independent PWM outputs with dual-edge symmetric operation
  - One independent PWM output with dual-edge asymmetric operation
- Asynchronous override control of PWM signals through software.
- Programmable phase-control support for lag or lead operation relative to other ePWM modules.
- Hardware-locked (synchronized) phase relationship on a cycle-by-cycle basis.
- Dead-band generation with independent rising and falling edge delay control.
- Programmable trip zone allocation of both cycle-by-cycle trip and one-shot trip on fault conditions.
- A trip condition can force either high, low, or high-impedance state logic levels at PWM outputs.
- Programmable event prescaling minimizes CPU overhead on interrupts.
- PWM chopping by high-frequency carrier signal, useful for pulse transformer gate drives.

Each ePWM module is connected to the input/output signals shown in Figure 16-1. The signals are described in detail in subsequent sections.

The order in which the ePWM modules are connected may differ from what is shown in Figure 16-1. See Section 16.2.3.3.2 for the synchronization scheme for a particular device. Each ePWM module consists of seven submodules and is connected within a system via the signals shown in Figure 16-2.

Figure 16-1. Multiple ePWM Modules

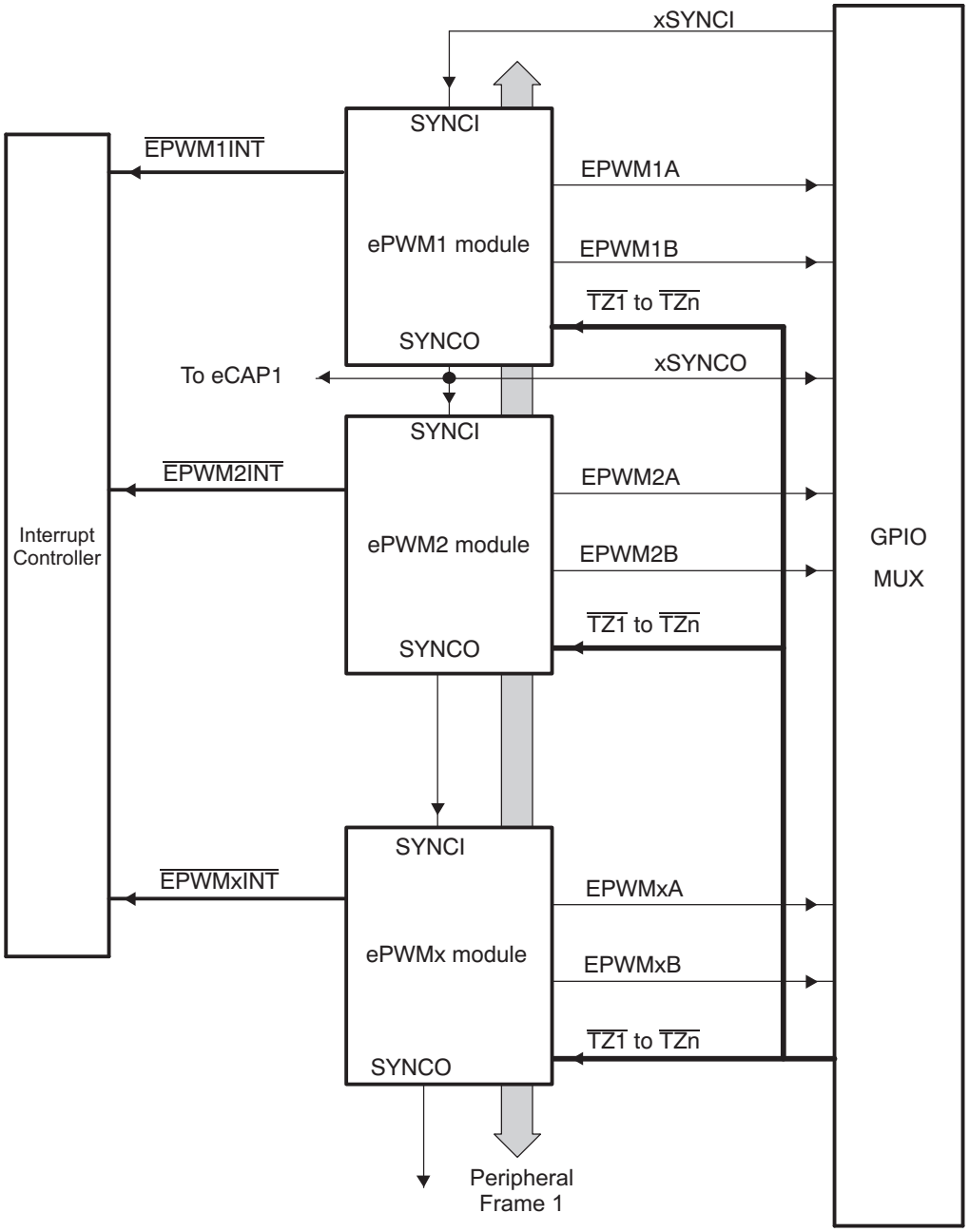


Figure 16-2. Submodules and Signal Connections for an ePWM Module

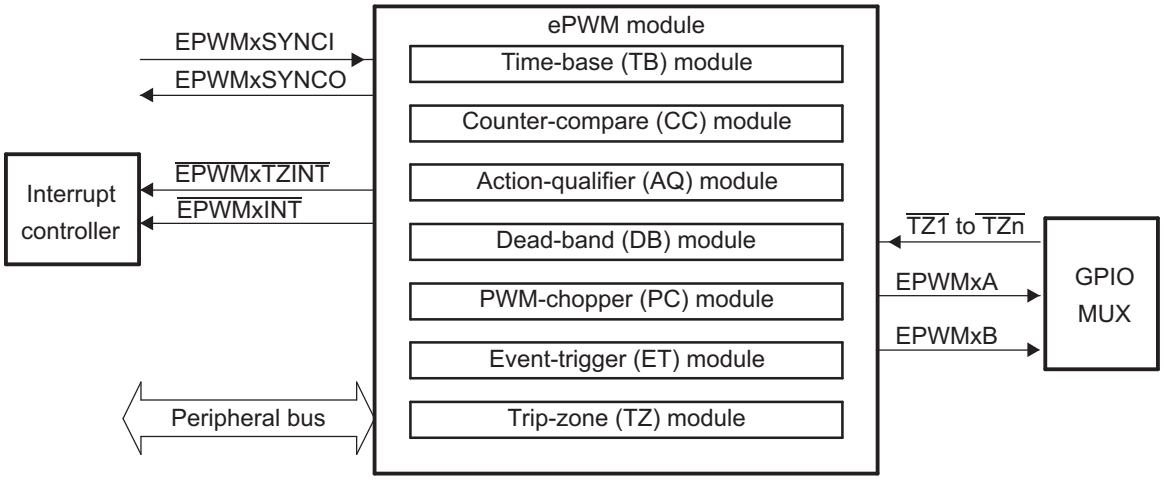
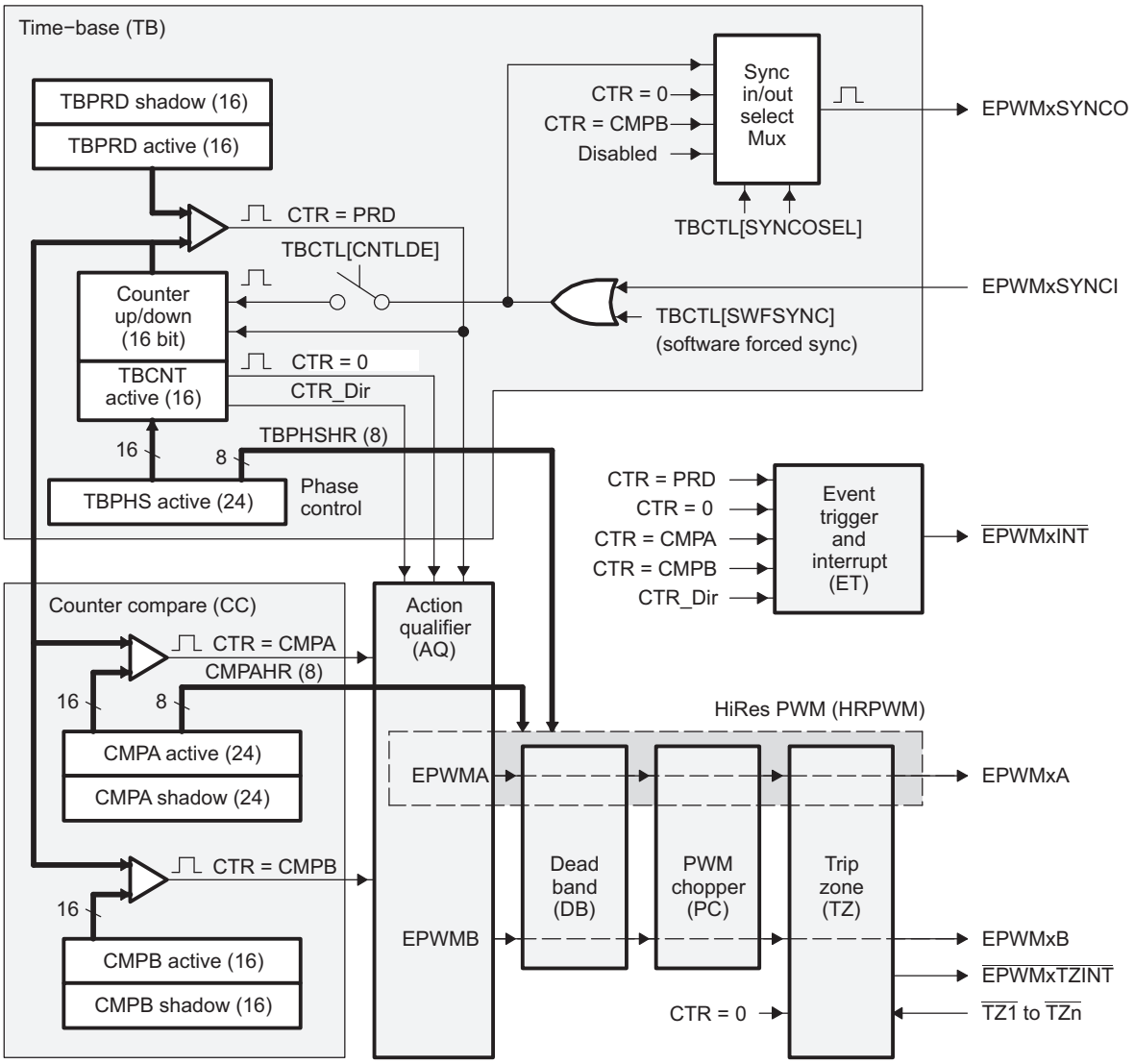


Figure 16-3 shows more internal details of a single ePWM module. The main signals used by the ePWM module are:

- **PWM output signals (EPWMxA and EPWMxB).** The PWM output signals are made available external to the device through the GPIO peripheral described in the system control and interrupts guide for your device.
- **Trip-zone signals ($\overline{\text{TZ1}}$ to $\overline{\text{TZn}}$).** These input signals alert the ePWM module of an external fault condition. Each module on a device can be configured to either use or ignore any of the trip-zone signals. The trip-zone signal can be configured as an asynchronous input through the GPIO peripheral. See your device-specific data manual to determine how many trip-zone pins are available in the device.
- **Time-base synchronization input (EPWMxSYNCI) and output (EPWMxSYNCO) signals.** The synchronization signals daisy chain the ePWM modules together. Each module can be configured to either use or ignore its synchronization input. The clock synchronization input and output signal are brought out to pins only for ePWM1 (ePWM module #1). The synchronization output for ePWM1 (EPWM1SYNCO) is also connected to the SYNCI of the first enhanced capture module (eCAP1).
- **Peripheral Bus.** The peripheral bus is 32-bits wide and allows both 16-bit and 32-bit writes to the ePWM register file.

Figure 16-3 also shows the key internal submodule interconnect signals. Each submodule is described in detail in Section 16.2.

Figure 16-3. ePWM Submodules and Critical Internal Signal Interconnects



16.1.3 Register Mapping

Table 16-1 shows the complete ePWM module control and status register set grouped by submodule. Each register set is duplicated for each instance of the ePWM module. The start address for each ePWM register file instance on a device is specified in the appropriate data manual.

Table 16-1. ePWM Module Control and Status Registers Grouped by Submodule

Acronym	Offset [1]	Size (×16)	Shadow	Register Description
Time-Base Submodule Registers				
TBCTL	0h	1	No	Time-Base Control Register
TBSTS	2h	1	No	Time-Base Status Register
TBPHSHR	4h	1	No	Extension for HRPWM Phase Register [2]
TBPHS	6h	1	No	Time-Base Phase Register
TBCNT	8h	1	No	Time-Base Counter Register
TBPRD	Ah	1	Yes	Time-Base Period Register
Counter-Compare Submodule Registers				
CMPCTL	Eh	1	No	Counter-Compare Control Register
CMPAHR	10h	1	No	Extension for HRPWM Counter-Compare A Register [2]
CMPA	12h	1	Yes	Counter-Compare A Register
CMPB	14h	1	Yes	Counter-Compare B Register
Action-Qualifier Submodule Registers				
AQCTLA	16h	1	No	Action-Qualifier Control Register for Output A (EPWMxA)
AQCTLB	18h	1	No	Action-Qualifier Control Register for Output B (EPWMxB)
AQSFRC	1Ah	1	No	Action-Qualifier Software Force Register
AQCSFRC	1Ch	1	Yes	Action-Qualifier Continuous S/W Force Register Set
Dead-Band Generator Submodule Registers				
DBCTL	1Eh	1	No	Dead-Band Generator Control Register
DBRED	20h	1	No	Dead-Band Generator Rising Edge Delay Count Register
DBFED	22h	1	No	Dead-Band Generator Falling Edge Delay Count Register
PWM-Chopper Submodule Registers				
PCCTL	3Ch	1	No	PWM-Chopper Control Register
Trip-Zone Submodule Registers				
TZSEL	24h	1	No	Trip-Zone Select Register
TZCTL	28h	1	No	Trip-Zone Control Register
TZEINT	2Ah	1	No	Trip-Zone Enable Interrupt Register
TZFLG	2Ch	1	No	Trip-Zone Flag Register
TZCLR	2Eh	1	No	Trip-Zone Clear Register
TZFRC	30h	1	No	Trip-Zone Force Register
Event-Trigger Submodule Registers				
ETSEL	32h	1	No	Event-Trigger Selection Register
ETPS	34h	1	No	Event-Trigger Pre-Scale Register
ETFLG	36h	1	No	Event-Trigger Flag Register
ETCLR	38h	1	No	Event-Trigger Clear Register
ETFRC	3Ah	1	No	Event-Trigger Force Register
High-Resolution PWM (HRPWM) Submodule Registers				
HRCNFG	1040h	1	No	HRPWM Configuration Register [2]

(1) Locations not shown are reserved.

(2) These registers are only available on ePWM instances that include the high-resolution PWM (HRPWM) extension; otherwise, these locations are reserved. See your device-specific data manual to determine which instances include the HRPWM.

16.2 Architecture

Seven submodules are included in every ePWM peripheral. There are some instances that include a high-resolution submodule that allows more precise control of the PWM outputs. Each of these submodules performs specific tasks that can be configured by software.

16.2.1 Overview

Table 16-2 lists the eight key submodules together with a list of their main configuration parameters. For example, if you need to adjust or control the duty cycle of a PWM waveform, then you should see the counter-compare submodule in Section 16.2.4 for relevant details.

Table 16-2. Submodule Configuration Parameters

Submodule	Configuration Parameter or Option	Reference
Time-base (TB)	• Scale the time-base clock (TBCLK) relative to the system clock (SYSCLKOUT). • Configure the PWM time-base counter (TBCNT) frequency or period. • Set the mode for the time-base counter: – count-up mode: used for asymmetric PWM – count-down mode: used for asymmetric PWM – count-up-and-down mode: used for symmetric PWM • Configure the time-base phase relative to another ePWM module. • Synchronize the time-base counter between modules through hardware or software. • Configure the direction (up or down) of the time-base counter after a synchronization event. • Configure how the time-base counter will behave when the device is halted by an emulator. • Specify the source for the synchronization output of the ePWM module: – Synchronization input signal – Time-base counter equal to zero – Time-base counter equal to counter-compare B (CMPB) – No output synchronization signal generated.	Section 16.2.3
Counter-compare (CC)	• Specify the PWM duty cycle for output EPWMxA and/or output EPWMxB • Specify the time at which switching events occur on the EPWMxA or EPWMxB output	Section 16.2.4
Action-qualifier (AQ)	• Specify the type of action taken when a time-base or counter-compare submodule event occurs: – No action taken – Output EPWMxA and/or EPWMxB switched high – Output EPWMxA and/or EPWMxB switched low – Output EPWMxA and/or EPWMxB toggled • Force the PWM output state through software control • Configure and control the PWM dead-band through software	Section 16.2.5
Dead-band (DB)	• Control of traditional complementary dead-band relationship between upper and lower switches • Specify the output rising-edge-delay value • Specify the output falling-edge delay value • Bypass the dead-band module entirely. In this case the PWM waveform is passed through without modification.	Section 16.2.6
PWM-chopper (PC)	• Create a chopping (carrier) frequency. • Pulse width of the first pulse in the chopped pulse train. • Duty cycle of the second and subsequent pulses. • Bypass the PWM-chopper module entirely. In this case the PWM waveform is passed through without modification.	Section 16.2.7

Table 16-2. Submodule Configuration Parameters (continued)

Submodule	Configuration Parameter or Option	Reference
Trip-zone (TZ)	• Configure the ePWM module to react to one, all, or none of the trip-zone pins. • Specify the tripping action taken when a fault occurs: – Force EPWMxA and/or EPWMxB high – Force EPWMxA and/or EPWMxB low – Force EPWMxA and/or EPWMxB to a high-impedance state – Configure EPWMxA and/or EPWMxB to ignore any trip condition. • Configure how often the ePWM will react to each trip-zone pin: – One-shot – Cycle-by-cycle • Enable the trip-zone to initiate an interrupt. • Bypass the trip-zone module entirely.	Section 16.2.8
Event-trigger (ET)	• Enable the ePWM events that will trigger an interrupt. • Specify the rate at which events cause triggers (every occurrence or every second or third occurrence) • Poll, set, or clear event flags	Section 16.2.9
High-Resolution PWM (HRPWM)	• Enable extended time resolution capabilities • Configure finer time granularity control or edge positioning	Section 16.2.10

Code examples are provided in the remainder of this chapter that show how to implement various ePWM module configurations. These examples use the constant definitions shown in Example 16-1.

Example 16-1. Constant Definitions Used in the Code Examples

```
// TBCTL (Time-Base Control)
// = = = = = = = = = = = = = = = = = = = = = = = = = = = = =
// TBCNT MODE bit
#define         TB_COUNT_UP        0x0
#define         TB_COUNT_DOWN      0x1
#define         TB_COUNT_UPDOWN    0x2
#define         TB_FREEZE          0x3
// PHSEN bit
#define         TB_DISABLE         0x0
#define         TB_ENABLE          0x1
// PRDLD bit
#define         TB_SHADOW          0x0
#define         TB_IMMEDIATE       0x1
// SYNCOSEL bit
#define         TB_SYNC_IN         0x0
#define         TB_CTR_ZERO        0x1
#define         TB_CTR_CMPB        0x2
#define         TB_SYNC_DISABLE    0x3
// HSPCLKDIV and CLKDIV bits
#define         TB_DIV1            0x0
#define         TB_DIV2            0x1
#define         TB_DIV4            0x2
// PHSDIR bit
#define         TB_DOWN            0x0
#define         TB_UP              0x1
// CMPCTL (Compare Control)
// = = = = = = = = = = = = = = = = = = = = = = = = = = = = =
// LOADAMODE and LOADBMODE bits
#define         CC_CTR_ZERO        0x0
#define         CC_CTR_PRD         0x1
#define         CC_CTR_ZERO_PRD    0x2
#define         CC_LD_DISABLE      0x3
// SHDWAMODE and SHDWBMODE bits
#define         CC_SHADOW          0x0
#define         CC_IMMEDIATE       0x1
// AQCTLA and AQCTLB (Action-qualifier Control)
// = = = = = = = = = = = = = = = = = = = = = = = = = = = = =
// ZRO, PRD, CAU, CAD, CBU, CBD bits
#define         AQ_NO_ACTION       0x0
#define         AQ_CLEAR           0x1
#define         AQ_SET             0x2
#define         AQ_TOGGLE          0x3
// DBCTL (Dead-Band Control)
// = = = = = = = = = = = = = = = = = = = = = = = = = = = = =
// MODE bit
#define         DB_DISABLE         0x0
#define         DBA_ENABLE         0x1
#define         DBB_ENABLE         0x2
#define         DB_FULL_ENABLE     0x3
// POLSEL bit
#define         DB_ACTV_HI         0x0
#define         DB_ACTV_LOC        0x1
#define         DB_ACTV_HIC        0x2
#define         DB_ACTV_LO         0x3
// PCCTL (chopper control)
// = = = = = = = = = = = = = = = = = = = = = = = = = = = = =
// CHPEN bit
#define         CHP_DISABLE        0x0
#define         CHP_ENABLE         0x1
```

Example 16-1. Constant Definitions Used in the Code Examples (continued)

```
// CHPFREQ bit
#define         CHP_DIV1           0x0
#define         CHP_DIV2           0x1
#define         CHP_DIV3           0x2
#define         CHP_DIV4           0x3
#define         CHP_DIV5           0x4
#define         CHP_DIV6           0x5
#define         CHP_DIV7           0x6
#define         CHP_DIV8           0x7
// CHPDUTY bit
#define         CHP1_8TH           0x0
#define         CHP2_8TH           0x1
#define         CHP3_8TH           0x2
#define         CHP4_8TH           0x3
#define         CHP5_8TH           0x4
#define         CHP6_8TH           0x5
#define         CHP7_8TH           0x6
// TZSEL (Trip-zone Select)
// = = = = = = = = = = = = = = = = = = = = = = = = = = = = =
// CBCn and OSHTn bits
#define         TZ_DISABLE         0x0
#define         TZ_ENABLE          0x1
// TZCTL (Trip-zone Control)
// = = = = = = = = = = = = = = = = = = = = = = = = = = = = =
// TZA and TZB bits
#define         TZ_HIZ             0x0
#define         TZ_FORCE_HI        0x1
#define         TZ_FORCE_LO        0x2
#define         TZ_NONE            0x3
// ETSEL (Event-trigger Select)
// = = = = = = = = = = = = = = = = = = = = = = = = = = = = =
// INTSEL bit
#define         ET_CTR_ZERO        0x1
#define         ET_CTR_PRD         0x2
#define         ET_CTRU_CMPA       0x4
#define         ET_CTRD_CMPA       0x5
#define         ET_CTRU_CMPB       0x6
#define         ET_CTRD_CMPB       0x7
// ETPS (Event-trigger Prescale)
// = = = = = = = = = = = = = = = = = = = = = = = = = = = = =
// INTPRD bit
#define         ET_DISABLE         0x0
#define         ET_1ST             0x1
#define         ET_2ND             0x2
#define         ET_3RD             0x3
```

16.2.2 Proper Interrupt Initialization Procedure

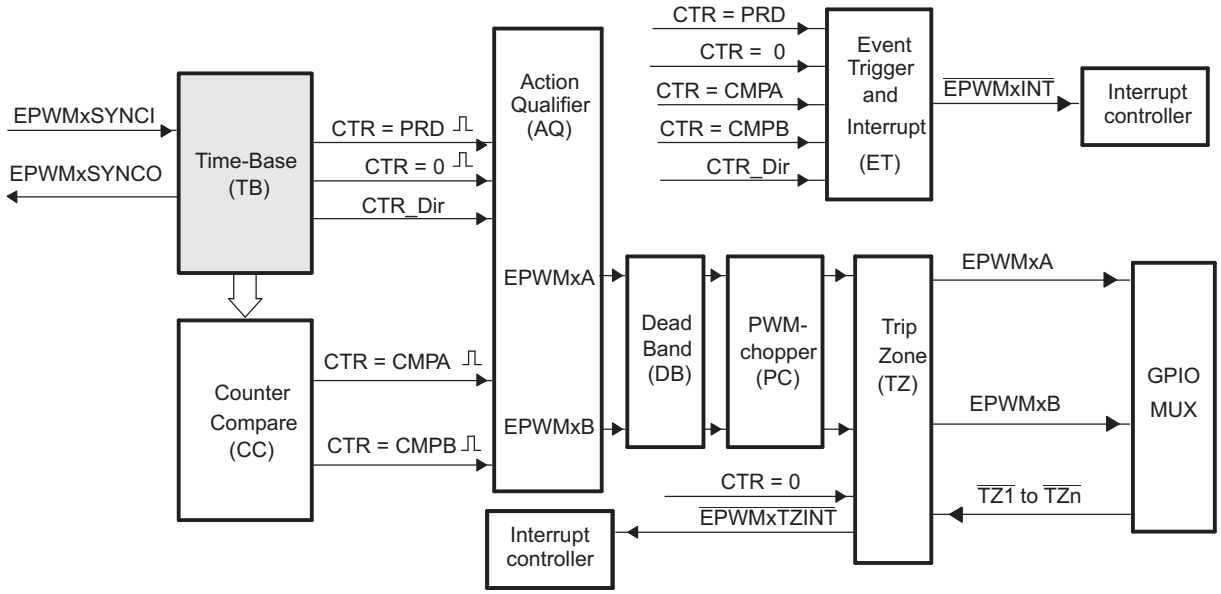
When the ePWM peripheral clock is enabled it may be possible that interrupt flags may be set due to spurious events due to the ePWM registers not being properly initialized. The proper procedure for initializing the ePWM peripheral is:

1. Disable global interrupts (CPU INTM flag)
2. Disable ePWM interrupts
3. Initialize peripheral registers
4. Clear any spurious ePWM flags
5. Enable ePWM interrupts
6. Enable global interrupts

16.2.3 Time-Base (TB) Submodule

Each ePWM module has its own time-base submodule that determines all of the event timing for the ePWM module. Built-in synchronization logic allows the time-base of multiple ePWM modules to work together as a single system. Figure 16-4 illustrates the time-base module's place within the ePWM.

Figure 16-4. Time-Base Submodule Block Diagram



16.2.3.1 Purpose of the Time-Base Submodule

You can configure the time-base submodule for the following:

- Specify the ePWM time-base counter (TBCNT) frequency or period to control how often events occur.
- Manage time-base synchronization with other ePWM modules.
- Maintain a phase relationship with other ePWM modules.
- Set the time-base counter to count-up, count-down, or count-up-and-down mode.
- Generate the following events:
  - CTR = PRD: Time-base counter equal to the specified period (TBCNT = TBPRD) .
  - CTR = 0: Time-base counter equal to zero (TBCNT = 0000h).
- Configure the rate of the time-base clock; a prescaled version of the CPU system clock (SYSCLKOUT). This allows the time-base counter to increment/decrement at a slower rate.

16.2.3.2 Controlling and Monitoring the Time-Base Submodule

Table 16-3 lists the registers used to control and monitor the time-base submodule.

Table 16-3. Time-Base Submodule Registers

Acronym	Register Description	Address Offset	Shadowed
TBCTL	Time-Base Control Register	0h	No
TBSTS	Time-Base Status Register	2h	No
TBPHSHR	HRPWM extension Phase Register (1)	4h	No
TBPHS	Time-Base Phase Register	6h	No
TBCNT	Time-Base Counter Register	8h	No
TBPRD	Time-Base Period Register	Ah	Yes

(1) This register is available only on ePWM instances that include the high-resolution extension (HRPWM). On ePWM modules that do not include the HRPWM, this location is reserved. See your device-specific data manual to determine which ePWM instances include this feature.

Figure 16-5 shows the critical signals and registers of the time-base submodule. Table 16-4 provides descriptions of the key signals associated with the time-base submodule.

Figure 16-5. Time-Base Submodule Signals and Registers

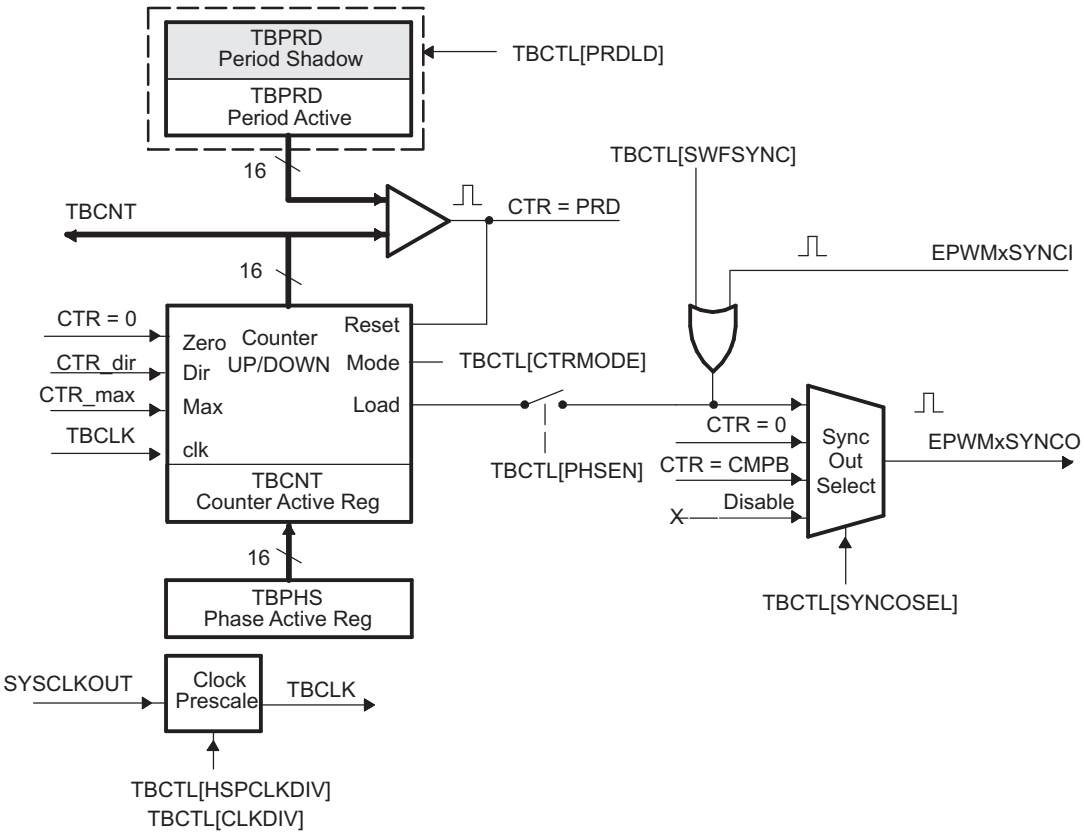


Table 16-4. Key Time-Base Signals

Signal	Description
EPWMxSYNCI	Time-base synchronization input.
	Input pulse used to synchronize the time-base counter with the counter of ePWM module earlier in the synchronization chain. An ePWM peripheral can be configured to use or ignore this signal. For the first ePWM module (EPWM1) this signal comes from a device pin. For subsequent ePWM modules this signal is passed from another ePWM peripheral. For example, EPWM2SYNCI is generated by the ePWM1 peripheral, EPWM3SYNCI is generated by ePWM2 and so forth. See Section 16.2.3.3.2 for information on the synchronization order of a particular device.
EPWMxSYNCO	Time-base synchronization output.
	This output pulse is used to synchronize the counter of an ePWM module later in the synchronization chain. The ePWM module generates this signal from one of three event sources: 1. EPWMxSYNCI (Synchronization input pulse) 2. CTR = 0: The time-base counter equal to zero (TBCNT = 0000h). 3. CTR = CMPB: The time-base counter equal to the counter-compare B (TBCNT = CMPB) register.
CTR = PRD	Time-base counter equal to the specified period.
	This signal is generated whenever the counter value is equal to the active period register value. That is when TBCNT = TBPRD.
CTR = 0	Time-base counter equal to zero.
	This signal is generated whenever the counter value is zero. That is when TBCNT equals 0000h.
CTR = CMPB	Time-base counter equal to active counter-compare B register (TBCNT = CMPB).
	This event is generated by the counter-compare submodule and used by the synchronization out logic.
CTR_dir	Time-base counter direction.
	Indicates the current direction of the ePWM's time-base counter. This signal is high when the counter is increasing and low when it is decreasing.
CTR_max	Time-base counter equal max value. (TBCNT = FFFFh)
	Generated event when the TBCNT value reaches its maximum value. This signal is only used only as a status bit.
TBCLK	Time-base clock.
	This is a prescaled version of the system clock (SYSCLKOUT) and is used by all submodules within the ePWM. This clock determines the rate at which time-base counter increments or decrements.

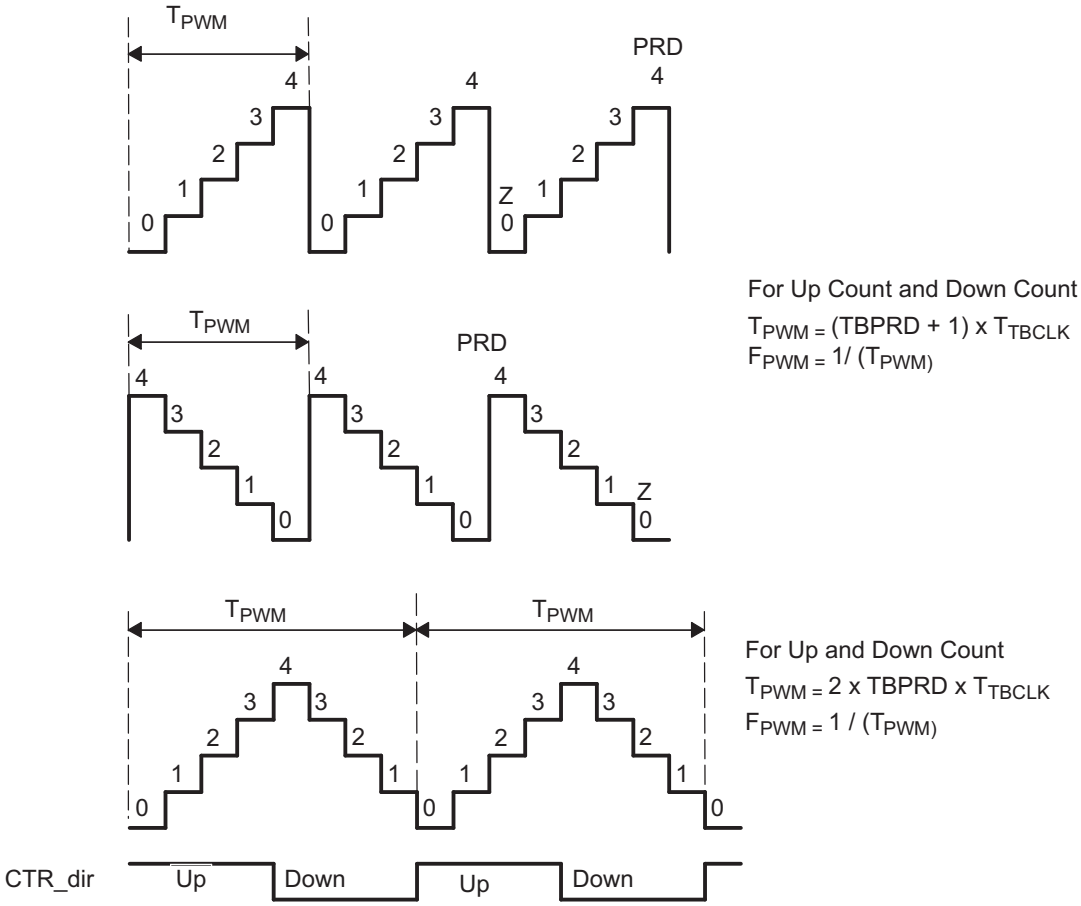
16.2.3.3 Calculating PWM Period and Frequency

The frequency of PWM events is controlled by the time-base period (TBPRD) register and the mode of the time-base counter. Figure 16-6 shows the period (T_{pwm}) and frequency (F_{pwm}) relationships for the up-count, down-count, and up-down-count time-base counter modes when when the period is set to 4 (TBPRD = 4). The time increment for each step is defined by the time-base clock (TBCLK) which is a prescaled version of the system clock (SYSCLKOUT).

The time-base counter has three modes of operation selected by the time-base control register (TBCTL):

- **Up-Down-Count Mode:** In up-down-count mode, the time-base counter starts from zero and increments until the period (TBPRD) value is reached. When the period value is reached, the time-base counter then decrements until it reaches zero. At this point the counter repeats the pattern and begins to increment.
- **Up-Count Mode:** In this mode, the time-base counter starts from zero and increments until it reaches the value in the period register (TBPRD). When the period value is reached, the time-base counter resets to zero and begins to increment once again.
- **Down-Count Mode:** In down-count mode, the time-base counter starts from the period (TBPRD) value and decrements until it reaches zero. When it reaches zero, the time-base counter is reset to the period value and it begins to decrement once again.

Figure 16-6. Time-Base Frequency and Period



16.2.3.3.1 Time-Base Period Shadow Register

The time-base period register (TBPRD) has a shadow register. Shadowing allows the register update to be synchronized with the hardware. The following definitions are used to describe all shadow registers in the ePWM module:

- **Active Register:** The active register controls the hardware and is responsible for actions that the hardware causes or invokes.
- **Shadow Register:** The shadow register buffers or provides a temporary holding location for the active register. It has no direct effect on any control hardware. At a strategic point in time the shadow register's content is transferred to the active register. This prevents corruption or spurious operation due to the register being asynchronously modified by software.

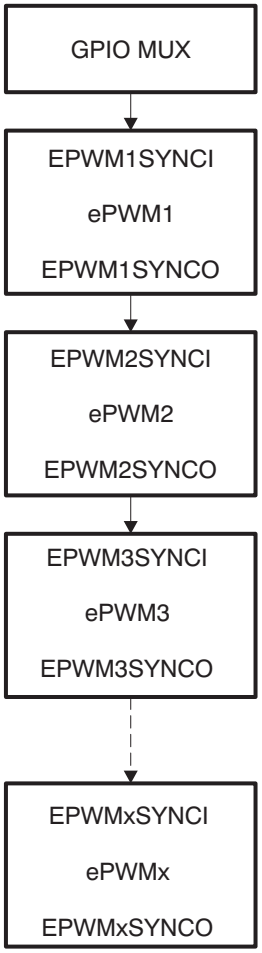
The memory address of the shadow period register is the same as the active register. Which register is written to or read from is determined by the TBCTL[PRDLD] bit. This bit enables and disables the TBPRD shadow register as follows:

- **Time-Base Period Shadow Mode:** The TBPRD shadow register is enabled when TBCTL[PRDLD] = 0. Reads from and writes to the TBPRD memory address go to the shadow register. The shadow register contents are transferred to the active register (TBPRD (Active) ← TBPRD (shadow)) when the time-base counter equals zero (TBCNT = 0000h). By default the TBPRD shadow register is enabled.
- **Time-Base Period Immediate Load Mode:** If immediate load mode is selected (TBCTL[PRDLD] = 1), then a read from or a write to the TBPRD memory address goes directly to the active register.

16.2.3.3.2 Time-Base Counter Synchronization

A time-base synchronization scheme connects all of the ePWM modules on a device. Each ePWM module has a synchronization input (EPWMxSYNCI) and a synchronization output (EPWMxSYNCO). The input synchronization for the first instance (ePWM1) comes from an external pin. The possible synchronization connections for the remaining ePWM modules is shown in Figure 16-7.

Figure 16-7. Time-Base Counter Synchronization Scheme 1



Each ePWM module can be configured to use or ignore the synchronization input. If the TBCTL[PHSEN] bit is set, then the time-base counter (TBCNT) of the ePWM module will be automatically loaded with the phase register (TBPHS) contents when one of the following conditions occur:

- **EPWMxSYNCI: Synchronization Input Pulse:** The value of the phase register is loaded into the counter register when an input synchronization pulse is detected (TBPHS → TBCNT). This operation occurs on the next valid time-base clock (TBCLK) edge.
- **Software Forced Synchronization Pulse:** Writing a 1 to the TBCTL[SWFSYNC] control bit invokes a software forced synchronization. This pulse is ORed with the synchronization input signal, and therefore has the same effect as a pulse on EPWMxSYNCI.

This feature enables the ePWM module to be automatically synchronized to the time base of another ePWM module. Lead or lag phase control can be added to the waveforms generated by different ePWM modules to synchronize them. In up-down-count mode, the TBCTL[PSHDIR] bit configures the direction of the time-base counter immediately after a synchronization event. The new direction is independent of the direction prior to the synchronization event. The TBPHS bit is ignored in count-up or count-down modes. See Figure 16-8 through Figure 16-11 for examples.

Clearing the TBCTL[PHSEN] bit configures the ePWM to ignore the synchronization input pulse. The synchronization pulse can still be allowed to flow-through to the EPWMxSYNCO and be used to synchronize other ePWM modules. In this way, you can set up a master time-base (for example, ePWM1) and downstream modules (ePWM2 - ePWMx) may elect to run in synchronization with the master.

16.2.3.4 Phase Locking the Time-Base Clocks of Multiple ePWM Modules

The TBCLKSYNC bit in the chip configuration register 1 (CFGCHIP1) in the System Module can be used to globally synchronize the time-base clocks of all enabled ePWM modules on a device. The TBCLKSYNC bit is part of the chip configuration registers and is described in the device-specific data manual. When TBCLKSYNC = 0, the time-base clock of all ePWM modules is stopped (default). When TBCLKSYNC = 1, all ePWM time-base clocks are started with the rising edge of TBCLK aligned. For perfectly synchronized TBCLKs, the prescaler bits in the TBCTL register of each ePWM module must be set identically. The proper procedure for enabling the ePWM clocks is as follows:

1. Enable the ePWM module clocks.
2. Set TBCLKSYNC = 0. This will stop the time-base clock within any enabled ePWM module.
3. Configure the prescaler values and desired ePWM modes.
4. Set TBCLKSYNC = 1.

16.2.3.5 Time-Base Counter Modes and Timing Waveforms

The time-base counter operates in one of four modes:

- Up-count mode which is asymmetrical.
- Down-count mode which is asymmetrical.
- Up-down-count which is symmetrical.
- Frozen where the time-base counter is held constant at the current value.

To illustrate the operation of the first three modes, Figure 16-8 to Figure 16-11 show when events are generated and how the time-base responds to an EPWMxSYNCI signal.

Figure 16-8. Time-Base Up-Count Mode Waveforms

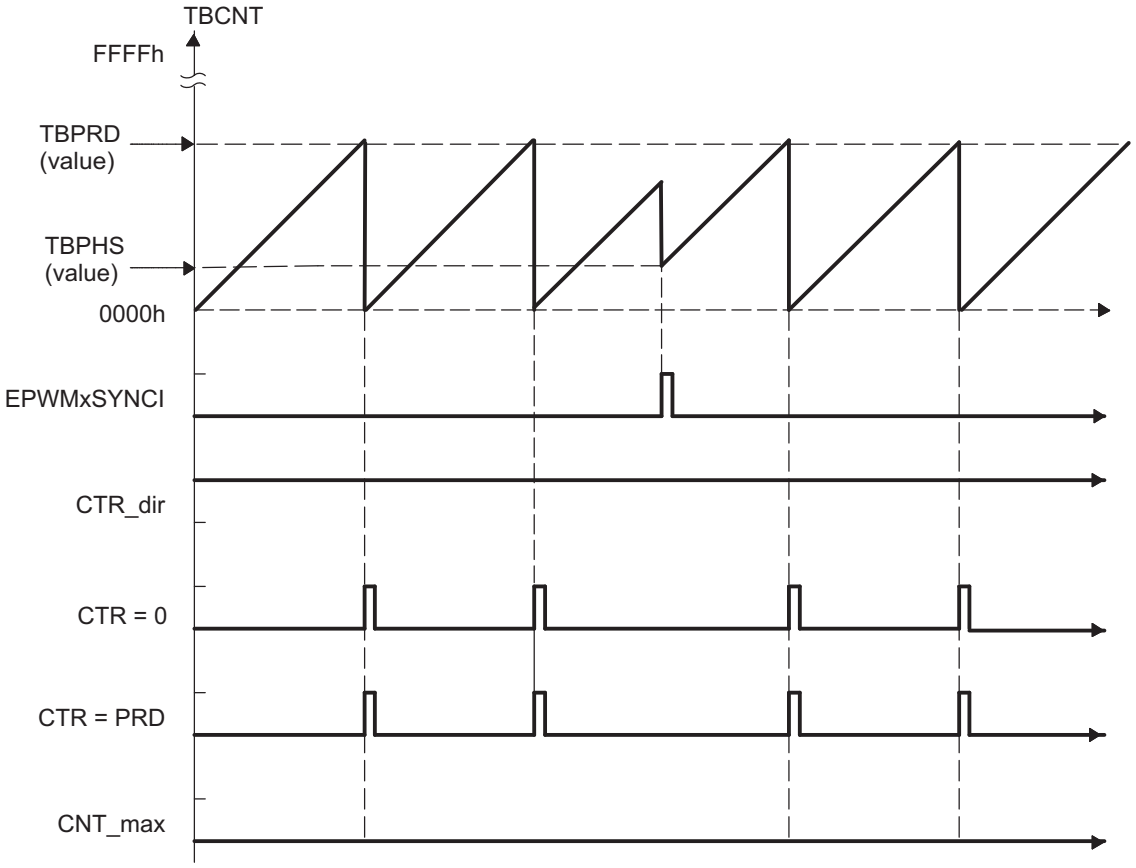


Figure 16-9. Time-Base Down-Count Mode Waveforms

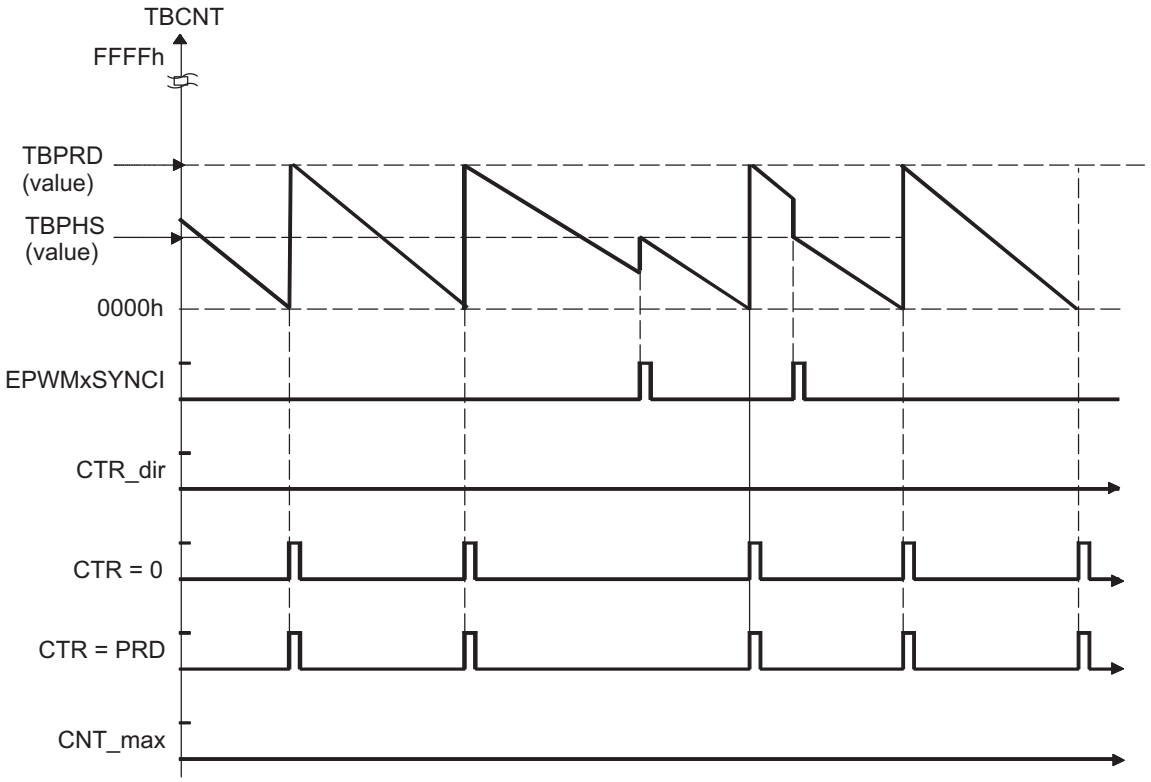


Figure 16-10. Time-Base Up-Down-Count Waveforms, TBCTL[PHSDIR = 0] Count Down on Synchronization Event

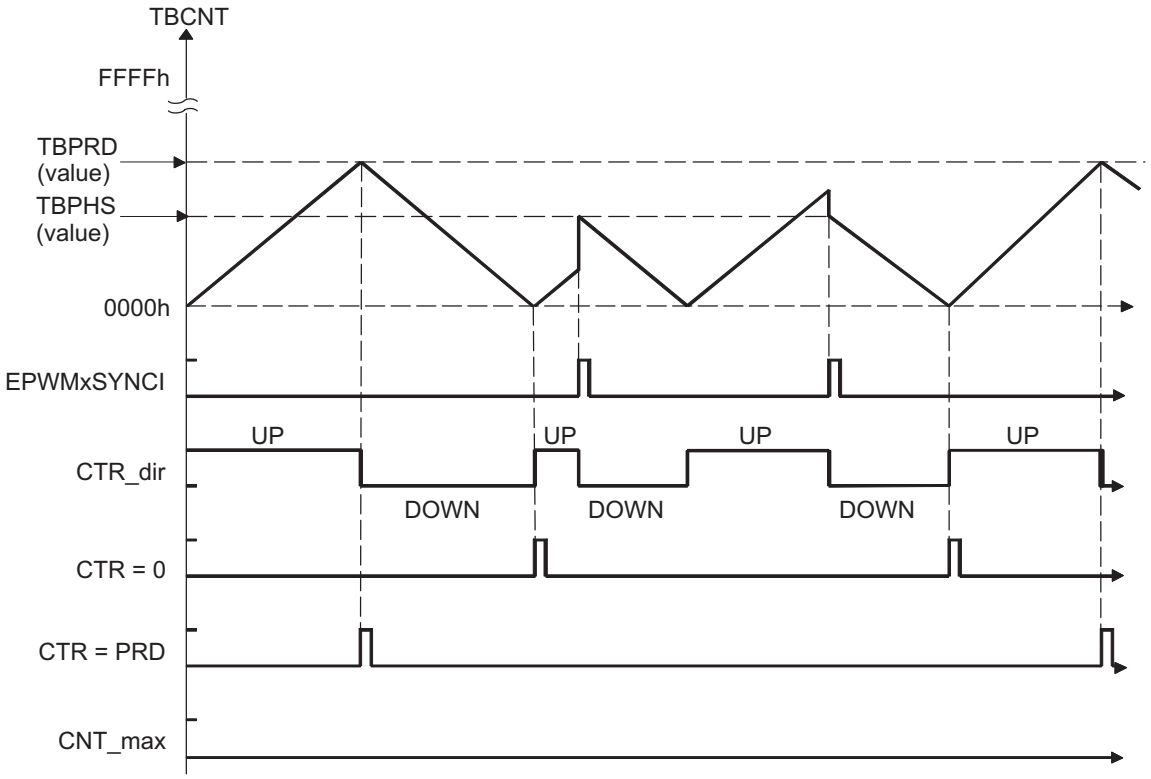
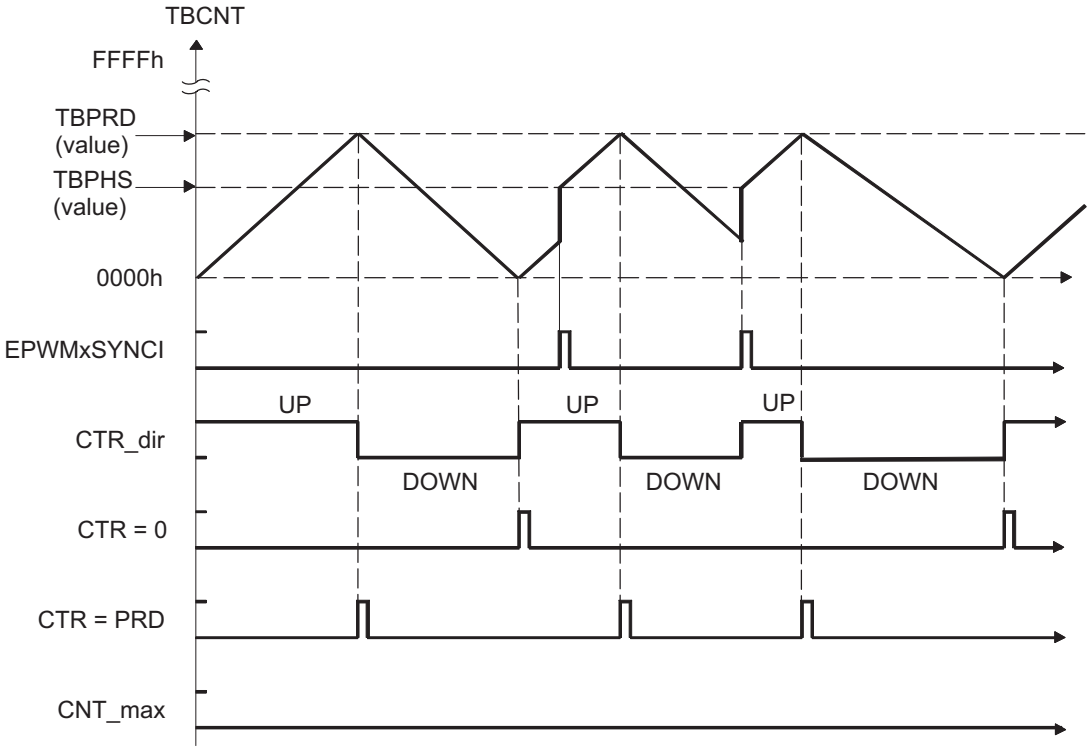


Figure 16-11. Time-Base Up-Down Count Waveforms, TBCTL[PHSDIR = 1] Count Up on Synchronization Event



16.2.4 Counter-Compare (CC) Submodule

Figure 16-12 illustrates the counter-compare submodule within the ePWM. Figure 16-13 shows the basic structure of the counter-compare submodule.

Figure 16-12. Counter-Compare Submodule

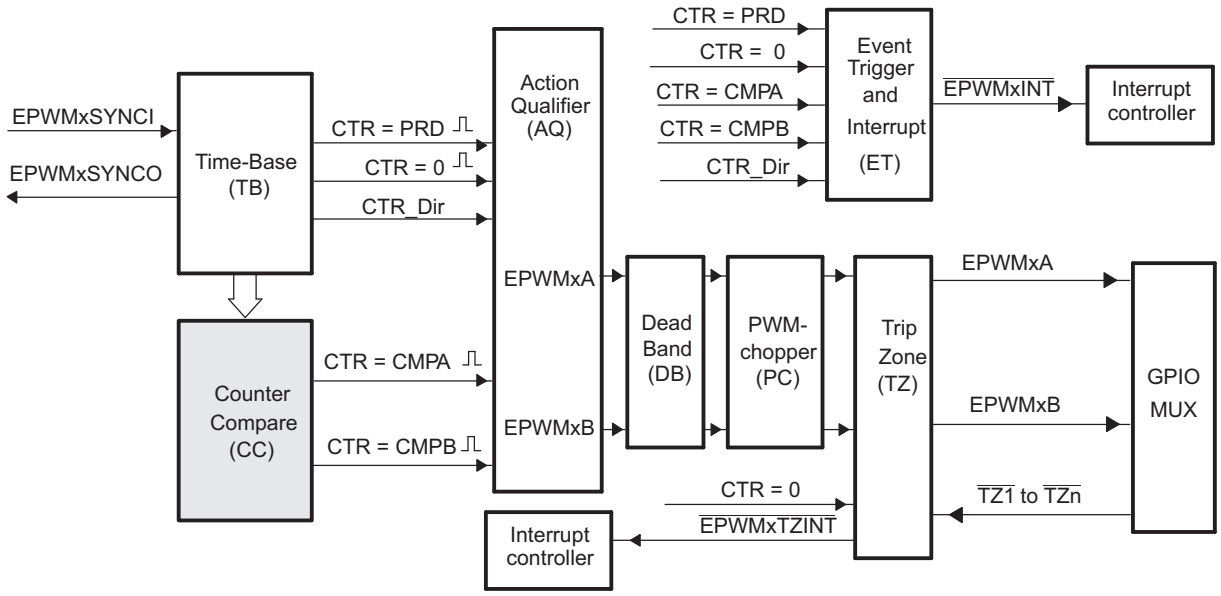
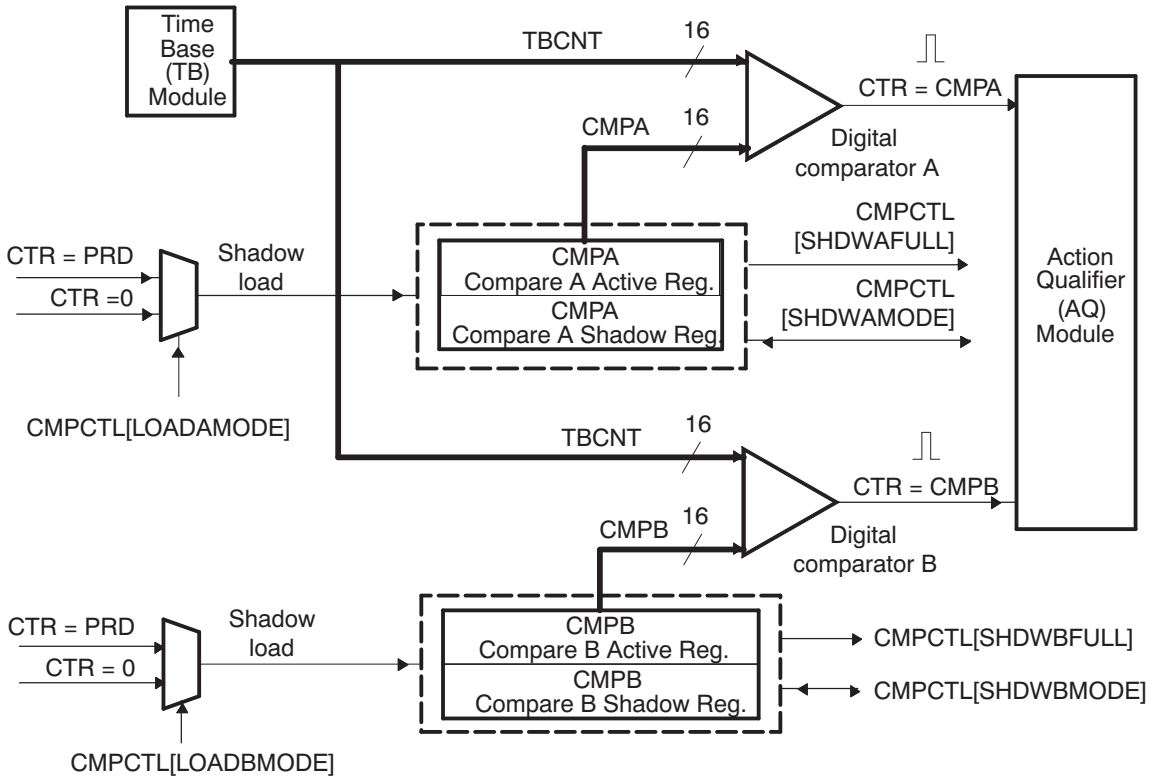


Figure 16-13. Counter-Compare Submodule Signals and Registers



16.2.4.1 Purpose of the Counter-Compare Submodule

The counter-compare submodule takes as input the time-base counter value. This value is continuously compared to the counter-compare A (CMPA) and counter-compare B (CMPB) registers. When the time-base counter is equal to one of the compare registers, the counter-compare unit generates an appropriate event.

The counter-compare submodule:

- Generates events based on programmable time stamps using the CMPA and CMPB registers
  - CTR = CMPA: Time-base counter equals counter-compare A register (TBCNT = CMPA).
  - CTR = CMPB: Time-base counter equals counter-compare B register (TBCNT = CMPB)
- Controls the PWM duty cycle if the action-qualifier submodule is configured appropriately
- Shadows new compare values to prevent corruption or glitches during the active PWM cycle

16.2.4.2 Controlling and Monitoring the Counter-Compare Submodule

Table 16-5 lists the registers used to control and monitor the counter-compare submodule. Table 16-6 lists the key signals associated with the counter-compare submodule.

Table 16-5. Counter-Compare Submodule Registers

Acronym	Register Description	Address Offset	Shadowed
CMPCTL	Counter-Compare Control Register.	Eh	No
CMPAHR	HRPWM Counter-Compare A Extension Register (1)	10h	Yes
CMPA	Counter-Compare A Register	12h	Yes
CMPB	Counter-Compare B Register	14h	Yes

(1) This register is available only on ePWM modules with the high-resolution extension (HRPWM). On ePWM modules that do not include the HRPWM, this location is reserved. Refer to the device-specific data manual to determine which ePWM instances include this feature.

Table 16-6. Counter-Compare Submodule Key Signals

Signal	Description of Event	Registers Compared
CTR = CMPA	Time-base counter equal to the active counter-compare A value	TBCNT = CMPA
CTR = CMPB	Time-base counter equal to the active counter-compare B value	TBCNT = CMPB
CTR = PRD	Time-base counter equal to the active period. Used to load active counter-compare A and B registers from the shadow register	TBCNT = TBPRD
CTR = 0	Time-base counter equal to zero. Used to load active counter-compare A and B registers from the shadow register	TBCNT = 0000h

16.2.4.3 Operational Highlights for the Counter-Compare Submodule

The counter-compare submodule is responsible for generating two independent compare events based on two compare registers:

1. CTR = CMPA: Time-base counter equal to counter-compare A register (TBCNT = CMPA).
2. CTR = CMPB: Time-base counter equal to counter-compare B register (TBCNT = CMPB).

For up-count or down-count mode, each event occurs only once per cycle. For up-down-count mode each event occurs twice per cycle, if the compare value is between 0000h and TBPRD; and occurs once per cycle, if the compare value is equal to 0000h or equal to TBPRD. These events are fed into the action-qualifier submodule where they are qualified by the counter direction and converted into actions if enabled. Refer to Section 16.2.5.1 for more details.

The counter-compare registers CMPA and CMPB each have an associated shadow register. Shadowing provides a way to keep updates to the registers synchronized with the hardware. When shadowing is used, updates to the active registers only occurs at strategic points. This prevents corruption or spurious operation due to the register being asynchronously modified by software. The memory address of the active register and the shadow register is identical. Which register is written to or read from is determined by the CMPCTL[SHDWAMODE] and CMPCTL[SHDWBMODE] bits. These bits enable and disable the CMPA shadow register and CMPB shadow register respectively. The behavior of the two load modes is described below:

- **Shadow Mode:** The shadow mode for the CMPA is enabled by clearing the CMPCTL[SHDWAMODE] bit and the shadow register for CMPB is enabled by clearing the CMPCTL[SHDWBMODE] bit. Shadow mode is enabled by default for both CMPA and CMPB.

  If the shadow register is enabled then the content of the shadow register is transferred to the active register on one of the following events:

  – CTR = PRD: Time-base counter equal to the period (TBCNT = TBPRD).
  – CTR = 0: Time-base counter equal to zero (TBCNT = 0000h)
  – Both CTR = PRD and CTR = 0

  Which of these three events is specified by the CMPCTL[LOADAMODE] and CMPCTL[LOADBMODE] register bits. Only the active register contents are used by the counter-compare submodule to generate events to be sent to the action-qualifier.
- **Immediate Load Mode:** If immediate load mode is selected (TBCTL[SHADWAMODE] = 1 or TBCTL[SHADWBMODE] = 1), then a read from or a write to the register will go directly to the active register.

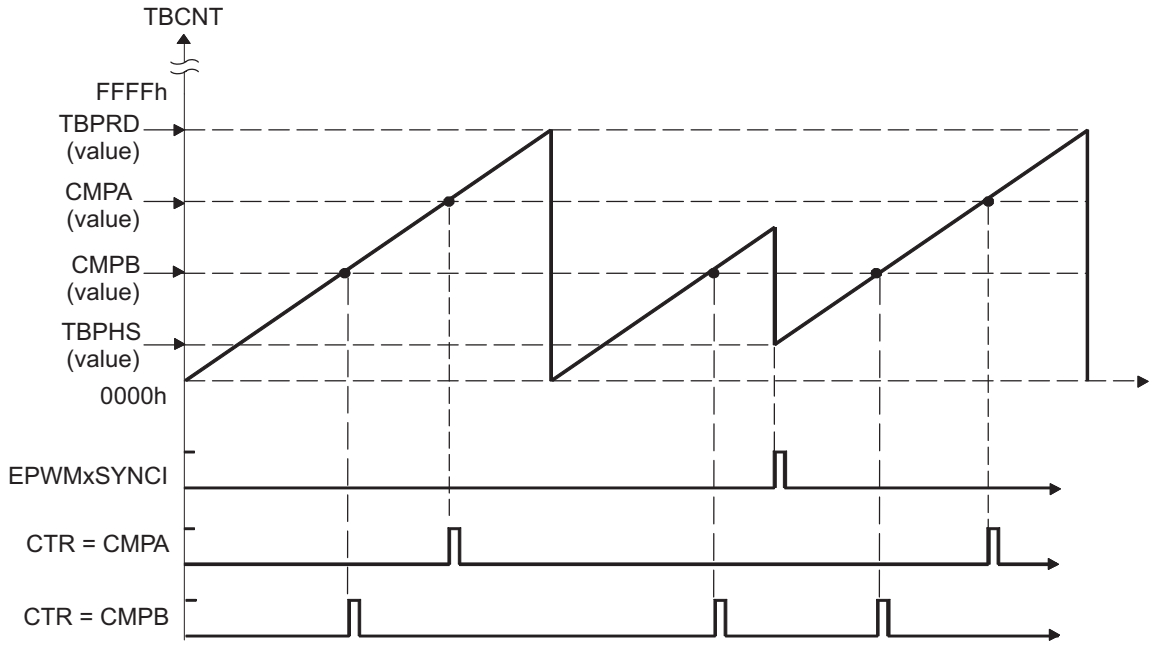
16.2.4.4 Count Mode Timing Waveforms

The counter-compare module can generate compare events in all three count modes:

- Up-count mode: used to generate an asymmetrical PWM waveform.
- Down-count mode: used to generate an asymmetrical PWM waveform.
- Up-down-count mode: used to generate a symmetrical PWM waveform.

To best illustrate the operation of the first three modes, the timing diagrams in Figure 16-14 to Figure 16-17 show when events are generated and how the EPWMxSYNCI signal interacts.

Figure 16-14. Counter-Compare Event Waveforms in Up-Count Mode



NOTE: An EPWMxSYNCI external synchronization event can cause a discontinuity in the TBCNT count sequence. This can lead to a compare event being skipped. This skipping is considered normal operation and must be taken into account.

Figure 16-15. Counter-Compare Events in Down-Count Mode

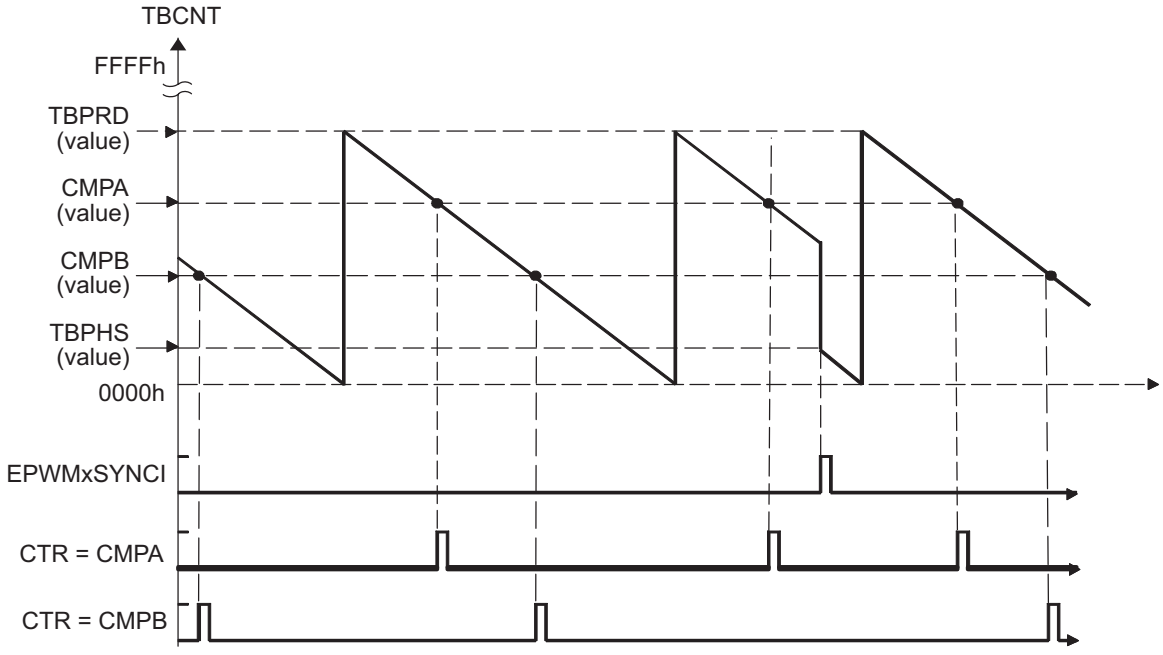


Figure 16-16. Counter-Compare Events in Up-Down-Count Mode, TBCTL[PHSDIR = 0] Count Down on Synchronization Event

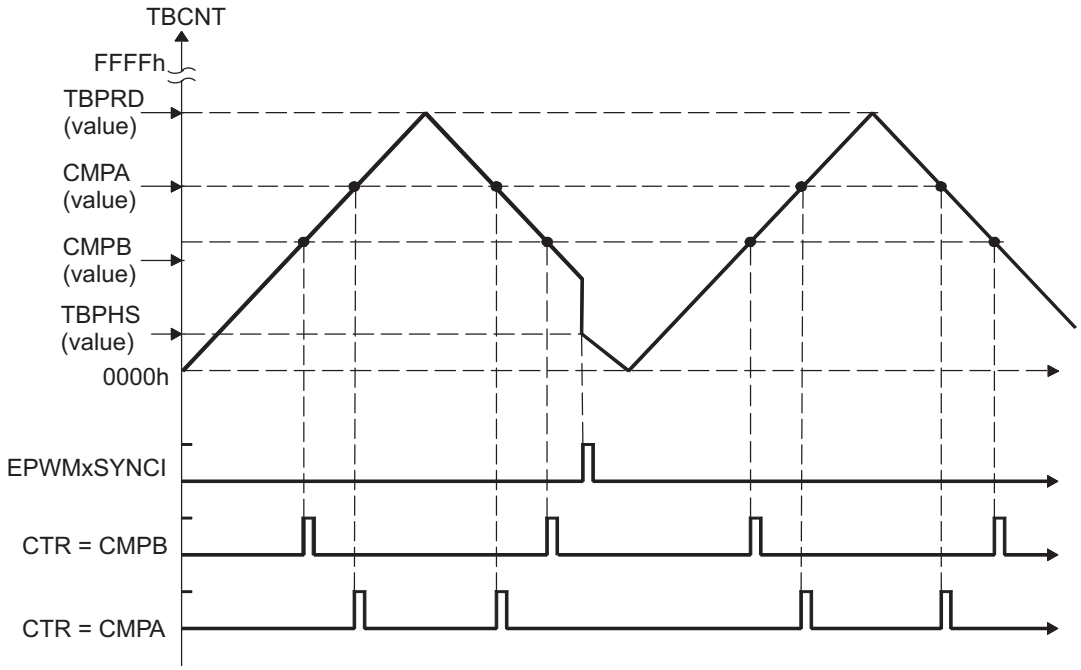
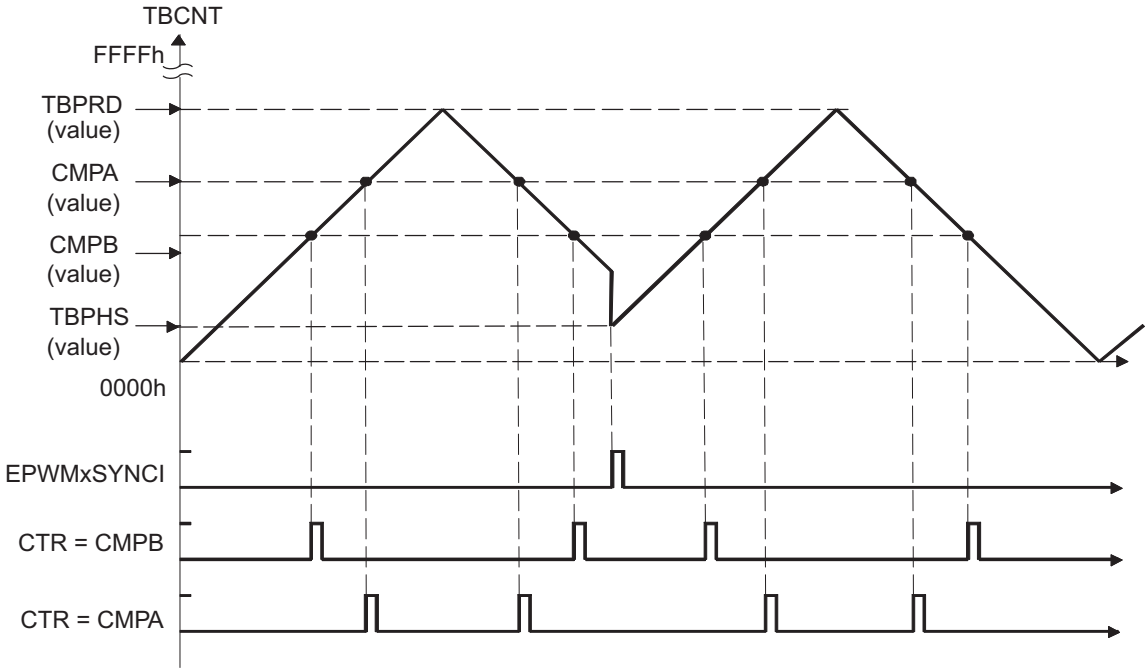


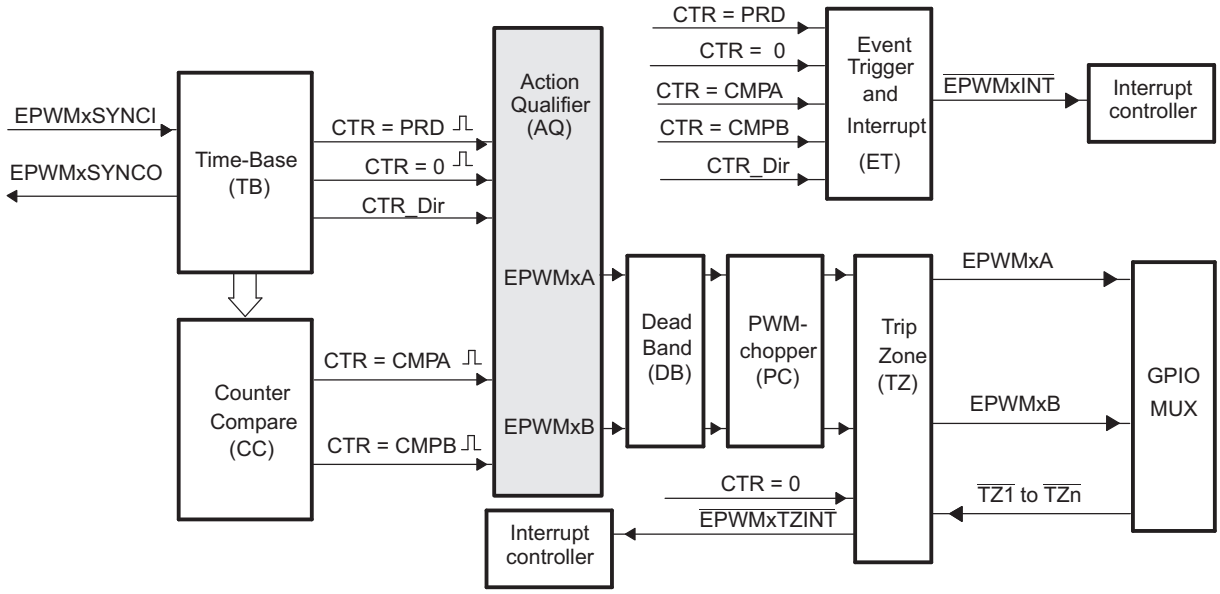
Figure 16-17. Counter-Compare Events in Up-Down-Count Mode, TBCTL[PHSDIR = 1] Count Up on Synchronization Event



16.2.5 Action-Qualifier (AQ) Submodule

Figure 16-18 shows the action-qualifier (AQ) submodule (see shaded block) in the ePWM system. The action-qualifier submodule has the most important role in waveform construction and PWM generation. It decides which events are converted into various action types, thereby producing the required switched waveforms at the EPWMxA and EPWMxB outputs.

Figure 16-18. Action-Qualifier Submodule



16.2.5.1 Purpose of the Action-Qualifier Submodule

The action-qualifier submodule is responsible for the following:

- Qualifying and generating actions (set, clear, toggle) based on the following events:
  - CTR = PRD: Time-base counter equal to the period (TBCNT = TBPRD)
  - CTR = 0: Time-base counter equal to zero (TBCNT = 0000h)
  - CTR = CMPA: Time-base counter equal to the counter-compare A register (TBCNT = CMPA)
  - CTR = CMPB: Time-base counter equal to the counter-compare B register (TBCNT = CMPB)
- Managing priority when these events occur concurrently
- Providing independent control of events when the time-base counter is increasing and when it is decreasing.

16.2.5.2 Controlling and Monitoring the Action-Qualifier Submodule

Table 16-7 lists the registers used to control and monitor the action-qualifier submodule.

Table 16-7. Action-Qualifier Submodule Registers

Acronym	Register Description	Address Offset	Shadowed
AQCTLA	Action-Qualifier Control Register For Output A (EPWMxA)	16h	No
AQCTLB	Action-Qualifier Control Register For Output B (EPWMxB)	18h	No
AQSFRC	Action-Qualifier Software Force Register	1Ah	No
AQCSFRC	Action-Qualifier Continuous Software Force	1Ch	Yes

The action-qualifier submodule is based on event-driven logic. It can be thought of as a programmable cross switch with events at the input and actions at the output, all of which are software controlled via the set of registers shown in Figure 16-19. The possible input events are summarized again in Table 16-8.

Figure 16-19. Action-Qualifier Submodule Inputs and Outputs

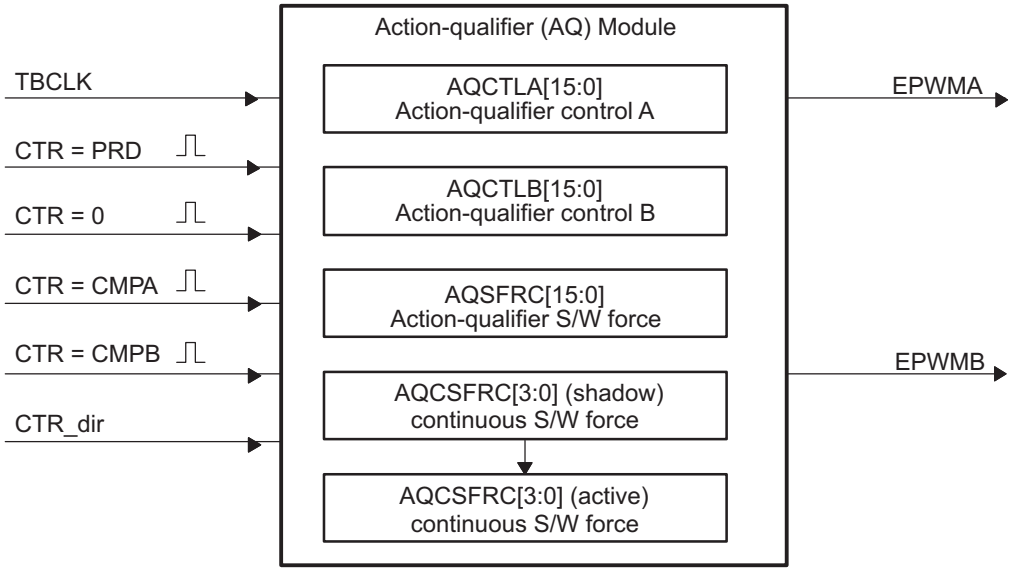


Table 16-8. Action-Qualifier Submodule Possible Input Events

Signal	Description	Registers Compared
CTR = PRD	Time-base counter equal to the period value	TBCNT = TBPRD
CTR = 0	Time-base counter equal to zero	TBCNT = 0000h
CTR = CMPA	Time-base counter equal to the counter-compare A	TBCNT = CMPA
CTR = CMPB	Time-base counter equal to the counter-compare B	TBCNT = CMPB
Software forced event	Asynchronous event initiated by software	

The software forced action is a useful asynchronous event. This control is handled by registers AQSFRC and AQCSFRC.

The action-qualifier submodule controls how the two outputs EPWMxA and EPWMxB behave when a particular event occurs. The event inputs to the action-qualifier submodule are further qualified by the counter direction (up or down). This allows for independent action on outputs on both the count-up and count-down phases.

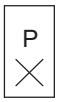
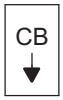
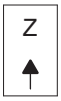
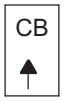
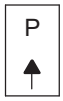
The possible actions imposed on outputs EPWMxA and EPWMxB are:

- **Set High:** Set output EPWMxA or EPWMxB to a high level.
- **Clear Low:** Set output EPWMxA or EPWMxB to a low level.
- **Toggle:** If EPWMxA or EPWMxB is currently pulled high, then pull the output low. If EPWMxA or EPWMxB is currently pulled low, then pull the output high.
- **Do Nothing:** Keep outputs EPWMxA and EPWMxB at same level as currently set. Although the "Do Nothing" option prevents an event from causing an action on the EPWMxA and EPWMxB outputs, this event can still trigger interrupts. See the event-trigger submodule description in Section 16.2.9 for details.

Actions are specified independently for either output (EPWMxA or EPWMxB). Any or all events can be configured to generate actions on a given output. For example, both CTR = CMPA and CTR = CMPB can operate on output EPWMxA. All qualifier actions are configured via the control registers found at the end of this section.

For clarity, the drawings in this chapter use a set of symbolic actions. These symbols are summarized in Figure 16-20. Each symbol represents an action as a marker in time. Some actions are fixed in time (zero and period) while the CMPA and CMPB actions are moveable and their time positions are programmed via the counter-compare A and B registers, respectively. To turn off or disable an action, use the "Do Nothing option"; it is the default at reset.

Figure 16-20. Possible Action-Qualifier Actions for EPWMxA and EPWMxB Outputs

S/W force	TB Counter equals:				Actions
	Zero	Comp A	Comp B	Period	
					Do Nothing
					Clear Low
					Set High
					Toggle

16.2.5.3 Action-Qualifier Event Priority

It is possible for the ePWM action qualifier to receive more than one event at the same time. In this case events are assigned a priority by the hardware. The general rule is events occurring later in time have a higher priority and software forced events always have the highest priority. The event priority levels for up-down-count mode are shown in Table 16-9. A priority level of 1 is the highest priority and level 7 is the lowest. The priority changes slightly depending on the direction of TBCNT.

Table 16-9. Action-Qualifier Event Priority for Up-Down-Count Mode

Priority Level	Event if TBCNT is Incrementing TBCNT = 0 up to TBCNT = TBPRD	Event if TBCNT is Decrementing TBCNT = TBPRD down to TBCNT = 1
1 (Highest)	Software forced event	Software forced event
2	Counter equals CMPB on up-count (CBU)	Counter equals CMPB on down-count (CBD)
3	Counter equals CMPA on up-count (CAU)	Counter equals CMPA on down-count (CAD)
4	Counter equals zero	Counter equals period (TBPRD)
5	Counter equals CMPB on down-count (CBD) (1)	Counter equals CMPB on up-count (CBU) (1)
6 (Lowest)	Counter equals CMPA on down-count (CAD) (1)	Counter equals CMPA on up-count (CBU) (1)

(1) To maintain symmetry for up-down-count mode, both up-events (CAU/CBU) and down-events (CAD/CBD) can be generated for TBPRD. Otherwise, up-events can occur only when the counter is incrementing and down-events can occur only when the counter is decrementing.

Table 16-10 shows the action-qualifier priority for up-count mode. In this case, the counter direction is always defined as up and thus down-count events will never be taken.

Table 16-10. Action-Qualifier Event Priority for Up-Count Mode

Priority Level	Event
1 (Highest)	Software forced event
2	Counter equal to period (TBPRD)
3	Counter equal to CMPB on up-count (CBU)
4	Counter equal to CMPA on up-count (CAU)
5 (Lowest)	Counter equal to Zero

Table 16-11 shows the action-qualifier priority for down-count mode. In this case, the counter direction is always defined as down and thus up-count events will never be taken.

Table 16-11. Action-Qualifier Event Priority for Down-Count Mode

Priority Level	Event
1 (Highest)	Software forced event
2	Counter equal to Zero
3	Counter equal to CMPB on down-count (CBD)
4	Counter equal to CMPA on down-count (CAD)
5 (Lowest)	Counter equal to period (TBPRD)

It is possible to set the compare value greater than the period. In this case the action will take place as shown in Table 16-12.

Table 16-12. Behavior if CMPA/CMPB is Greater than the Period

Counter Mode	Compare on Up-Count Event CAU/CBU	Compare on Down-Count Event CAU/CBU
Up-Count Mode	If CMPA/CMPB ≤ TBPRD period, then the event occurs on a compare match (TBCNT = CMPA or CMPB). If CMPA/CMPB > TBPRD, then the event will not occur.	Never occurs.
Down-Count Mode	Never occurs.	If CMPA/CMPB < TBPRD, the event will occur on a compare match (TBCNT = CMPA or CMPB). If CMPA/CMPB ≥ TBPRD, the event will occur on a period match (TBCNT = TBPRD).
Up-Down-Count Mode	If CMPA/CMPB < TBPRD and the counter is incrementing, the event occurs on a compare match (TBCNT = CMPA or CMPB). If CMPA/CMPB is ≥ TBPRD, the event will occur on a period match (TBCNT = TBPRD).	If CMPA/CMPB < TBPRD and the counter is decrementing, the event occurs on a compare match (TBCNT = CMPA or CMPB). If CMPA/CMPB ≥ TBPRD, the event occurs on a period match (TBCNT = TBPRD).

16.2.5.4 Waveforms for Common Configurations

NOTE: The waveforms in this chapter show the ePWMs behavior for a static compare register value. In a running system, the active compare registers (CMPA and CMPB) are typically updated from their respective shadow registers once every period. The user specifies when the update will take place; either when the time-base counter reaches zero or when the time-base counter reaches period. There are some cases when the action based on the new value can be delayed by one period or the action based on the old value can take effect for an extra period. Some PWM configurations avoid this situation. These include, but are not limited to, the following:

Use up-down-count mode to generate a symmetric PWM:

- If you load CMPA/CMPB on zero, then use CMPA/CMPB values greater than or equal to 1.
- If you load CMPA/CMPB on period, then use CMPA/CMPB values less than or equal to TBPRD - 1.

  This means there will always be a pulse of at least one TBCLK cycle in a PWM period which, when very short, tend to be ignored by the system.

Use up-down-count mode to generate an asymmetric PWM:

- To achieve 50%-0% asymmetric PWM use the following configuration: Load CMPA/CMPB on period and use the period action to clear the PWM and a compare-up action to set the PWM. Modulate the compare value from 0 to TBPRD to achieve 50%-0% PWM duty.

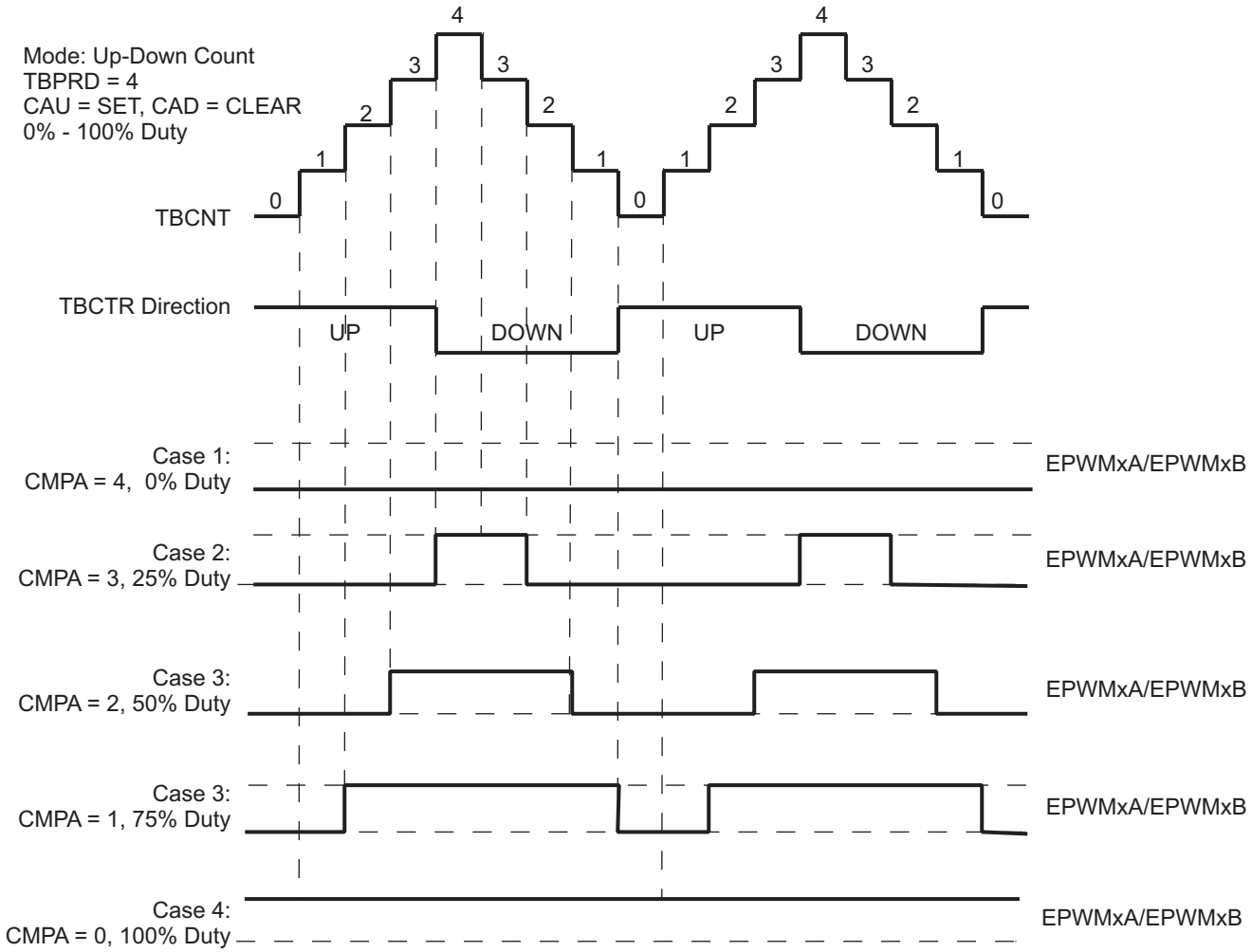
When using up-count mode to generate an asymmetric PWM:

- To achieve 0-100% asymmetric PWM use the following configuration: Load CMPA/CMPB on TBPRD. Use the Zero action to set the PWM and a compare-up action to clear the PWM. Modulate the compare value from 0 to TBPRD+1 to achieve 0-100% PWM duty.

Figure 16-21 shows how a symmetric PWM waveform can be generated using the up-down-count mode of the TBCNT. In this mode 0%-100% DC modulation is achieved by using equal compare matches on the up count and down count portions of the waveform. In the example shown, CMPA is used to make the comparison. When the counter is incrementing the CMPA match will pull the PWM output high. Likewise, when the counter is decrementing the compare match will pull the PWM signal low. When CMPA = 0, the PWM signal is low for the entire period giving the 0% duty waveform. When CMPA = TBPRD, the PWM signal is high achieving 100% duty.

When using this configuration in practice, if you load CMPA/CMPB on zero, then use CMPA/CMPB values greater than or equal to 1. If you load CMPA/CMPB on period, then use CMPA/CMPB values less than or equal to TBPRD-1. This means there will always be a pulse of at least one TBCLK cycle in a PWM period which, when very short, tend to be ignored by the system.

Figure 16-21. Up-Down-Count Mode Symmetrical Waveform

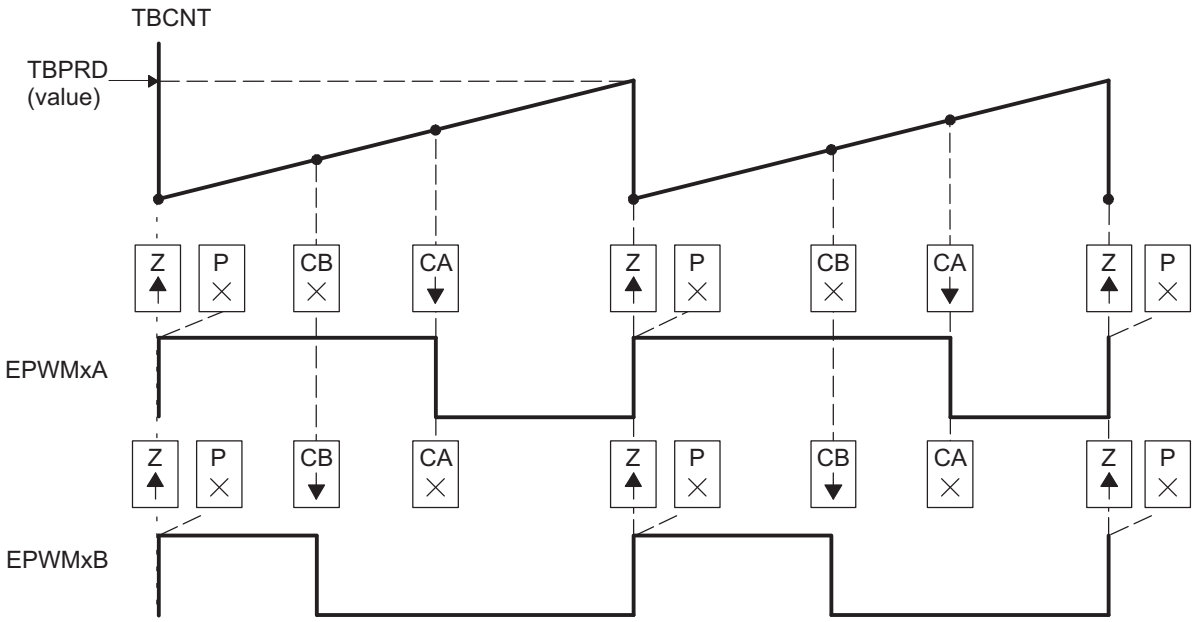


The PWM waveforms in Figure 16-22 through Figure 16-27 show some common action-qualifier configurations. Some conventions used in the figures are as follows:

- TBPRD, CMPA, and CMPB refer to the value written in their respective registers. The active register, not the shadow register, is used by the hardware.
- CMPx, refers to either CMPA or CMPB.
- EPWMxA and EPWMxB refer to the output signals from ePWMx
- Up-Down means Count-up-and-down mode, Up means up-count mode and Dwn means down-count mode
- Sym = Symmetric, Asym = Asymmetric

Table 16-13 and Table 16-14 contains initialization and runtime register configurations for the waveforms in Figure 16-22.

Figure 16-22. Up, Single Edge Asymmetric Waveform, With Independent Modulation on EPWMxA and EPWMxB—Active High



(1) PWM period = (TBPRD + 1) × T_{TBCLK}

(2) Duty modulation for EPWMxA is set by CMPA, and is active high (that is, high time duty proportional to CMPA).

(3) Duty modulation for EPWMxB is set by CMPB and is active high (that is, high time duty proportional to CMPB).

(4) The "Do Nothing" actions (X) are shown for completeness, but will not be shown on subsequent diagrams.

(5) Actions at zero and period, although appearing to occur concurrently, are actually separated by one TBCLK period. TBCNT wraps from period to 0000h.

Table 16-13. EPWMx Initialization for Figure 16-22

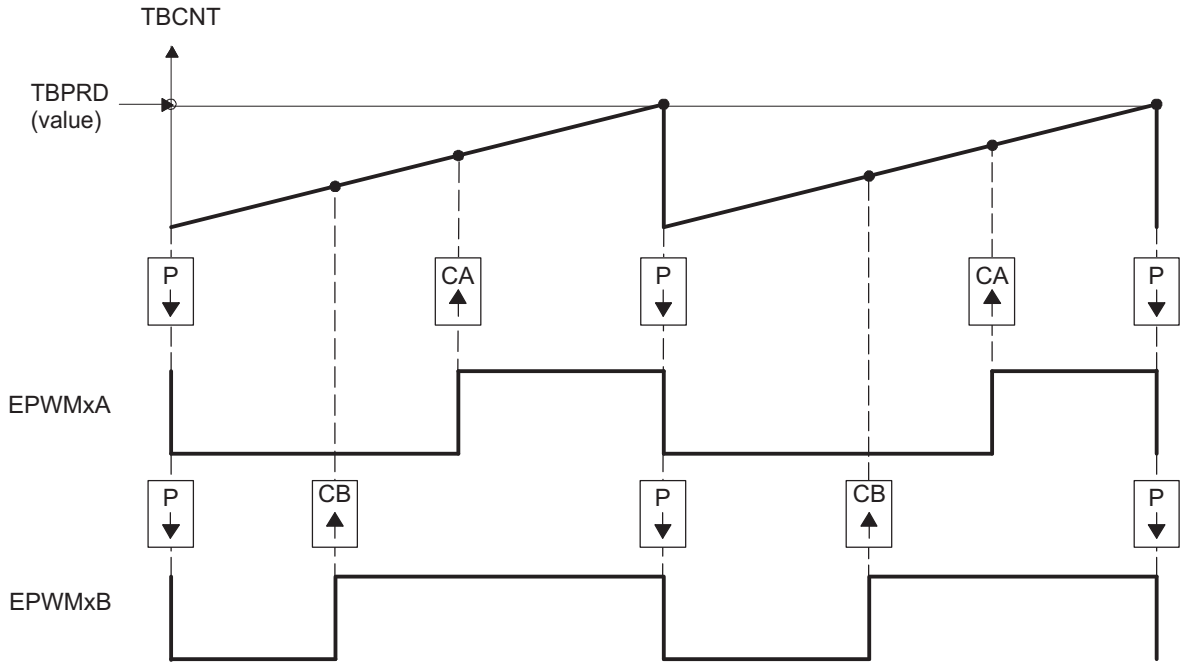
Register	Bit	Value	Comments
TBPRD	TBPRD	600 (258h)	Period = 601 TBCLK counts
TBPHS	TBPHS	0	Clear Phase Register to 0
TBCNT	TBCNT	0	Clear TB counter
TBCTL	CTRMODE	TB_UP	
	PHSEN	TB_DISABLE	Phase loading disabled
	PRDLD	TB_SHADOW	
	SYNCOSEL	TB_SYNC_DISABLE	
	HSPCLKDIV	TB_DIV1	TBCLK = SYSCLK
	CLKDIV	TB_DIV1	
CMPA	CMPA	350 (15Eh)	Compare A = 350 TBCLK counts
CMPB	CMPB	200 (C8h)	Compare B = 200 TBCLK counts
CMPCTL	SHDWAMODE	CC_SHADOW	
	SHDWBMODE	CC_SHADOW	
	LOADAMODE	CC_CTR_ZERO	Load on CTR = 0
	LOADBMODE	CC_CTR_ZERO	Load on CTR = 0
AQCTLA	ZRO	AQ_SET	
	CAU	AQ_CLEAR	
AQCTLB	ZRO	AQ_SET	
	CBU	AQ_CLEAR	

Table 16-14. EPWMx Run Time Changes for Figure 16-22

Register	Bit	Value	Comments
CMPA	CMPA	Duty1A	Adjust duty for output EPWM1A
CMPB	CMPB	Duty1B	Adjust duty for output EPWM1B

Table 16-15 and Table 16-16 contains initialization and runtime register configurations for the waveforms in Figure 16-23.

Figure 16-23. Up, Single Edge Asymmetric Waveform With Independent Modulation on EPWMxA and EPWMxB—Active Low



(1) PWM period = (TBPRD + 1) × T_{TBCLK}

(2) Duty modulation for EPWMxA is set by CMPA, and is active low (that is, the low time duty is proportional to CMPA).

(3) Duty modulation for EPWMxB is set by CMPB and is active low (that is, the low time duty is proportional to CMPB).

(4) The Do Nothing actions (X) are shown for completeness here, but will not be shown on subsequent diagrams.

(5) Actions at zero and period, although appearing to occur concurrently, are actually separated by one TBCLK period. TBCNT wraps from period to 0000h.

Table 16-15. EPWMx Initialization for Figure 16-23

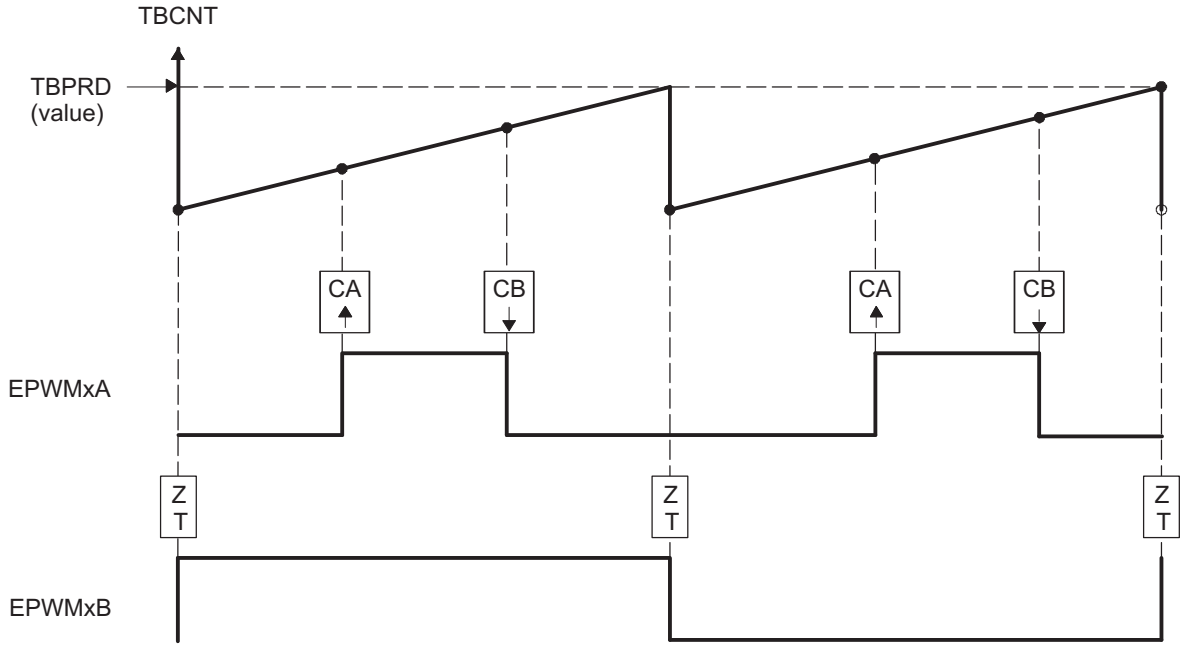
Register	Bit	Value	Comments
TBPRD	TBPRD	600 (258h)	Period = 601 TBCLK counts
TBPHS	TBPHS	0	Clear Phase Register to 0
TBCNT	TBCNT	0	Clear TB counter
TBCTL	CTRMODE	TB_UP	
	PHSEN	TB_DISABLE	Phase loading disabled
	PRDLD	TB_SHADOW	
	SYNCOSEL	TB_SYNC_DISABLE	
	HSPCLKDIV	TB_DIV1	TBCLK = SYSCLK
	CLKDIV	TB_DIV1	
CMPA	CMPA	350 (15Eh)	Compare A = 350 TBCLK counts
CMPB	CMPB	200 (C8h)	Compare B = 200 TBCLK counts
CMPCTL	SHDWAMODE	CC_SHADOW	
	SHDWBMODE	CC_SHADOW	
	LOADAMODE	CC_CTR_ZERO	Load on CTR = 0
	LOADBMODE	CC_CTR_ZERO	Load on CTR = 0
AQCTLA	PRD	AQ_CLEAR	
	CAU	AQ_SET	
AQCTLB	PRD	AQ_CLEAR	
	CBU	AQ_SET	

Table 16-16. EPWMx Run Time Changes for Figure 16-23

Register	Bit	Value	Comments
CMPA	CMPA	Duty1A	Adjust duty for output EPWM1A
CMPB	CMPB	Duty1B	Adjust duty for output EPWM1B

Table 16-17 and Table 16-18 contains initialization and runtime register configurations for the waveforms Figure 16-24. Use the code in Example 16-1 to define the headers.

Figure 16-24. Up-Count, Pulse Placement Asymmetric Waveform With Independent Modulation on EPWMxA



(1) PWM frequency = 1/((TBPRD + 1) × T_{TBCLK})

(2) Pulse can be placed anywhere within the PWM cycle (0000h - TBPRD)

(3) High time duty proportional to (CMPB - CMPA)

(4) EPWMxB can be used to generate a 50% duty square wave with frequency = 1/2 × ((TBPRD + 1) × TBCLK)

Table 16-17. EPWMx Initialization for Figure 16-24

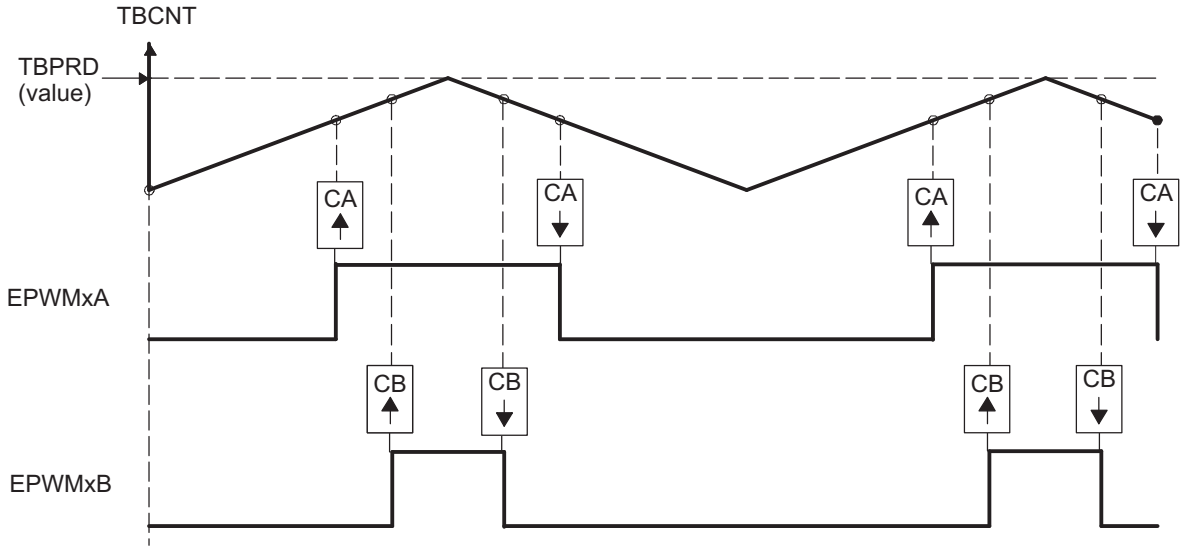
Register	Bit	Value	Comments
TBPRD	TBPRD	600 (258h)	Period = 601 TBCLK counts
TBPHS	TBPHS	0	Clear Phase Register to 0
TBCNT	TBCNT	0	Clear TB counter
TBCTL	CTRMODE	TB_UP	
	PHSEN	TB_DISABLE	Phase loading disabled
	PRDLD	TB_SHADOW	
	SYNCOSEL	TB_SYNC_DISABLE	
	HSPCLKDIV	TB_DIV1	TBCLK = SYSCLK
	CLKDIV	TB_DIV1	
CMPA	CMPA	200 (C8h)	Compare A = 200 TBCLK counts
CMPB	CMPB	400 (190h)	Compare B = 400 TBCLK counts
CMPCTL	SHDWAMODE	CC_SHADOW	
	SHDWBMODE	CC_SHADOW	
	LOADAMODE	CC_CTR_ZERO	Load on CTR = 0
	LOADBMODE	CC_CTR_ZERO	Load on CTR = 0
AQCTLA	CAU	AQ_SET	
	CBU	AQ_CLEAR	
AQCTLB	ZRO	AQ_TOGGLE	

Table 16-18. EPWMx Run Time Changes for Figure 16-24

Register	Bit	Value	Comments
CMPA	CMPA	EdgePosA	Adjust duty for output EPWM1A
CMPB	CMPB	EdgePosB	

Table 16-19 and Table 16-20 contains initialization and runtime register configurations for the waveforms in Figure 16-25. Use the code in Example 16-1 to define the headers.

Figure 16-25. Up-Down-Count, Dual Edge Symmetric Waveform, With Independent Modulation on EPWMxA and EPWMxB — Active Low



(1) PWM period = 2 x TBPRD × T_{TBCLK}

(2) Duty modulation for EPWMxA is set by CMPA, and is active low (that is, the low time duty is proportional to CMPA).

(3) Duty modulation for EPWMxB is set by CMPB and is active low (that is, the low time duty is proportional to CMPB).

(4) Outputs EPWMxA and EPWMxB can drive independent power switches

Table 16-19. EPWMx Initialization for Figure 16-25

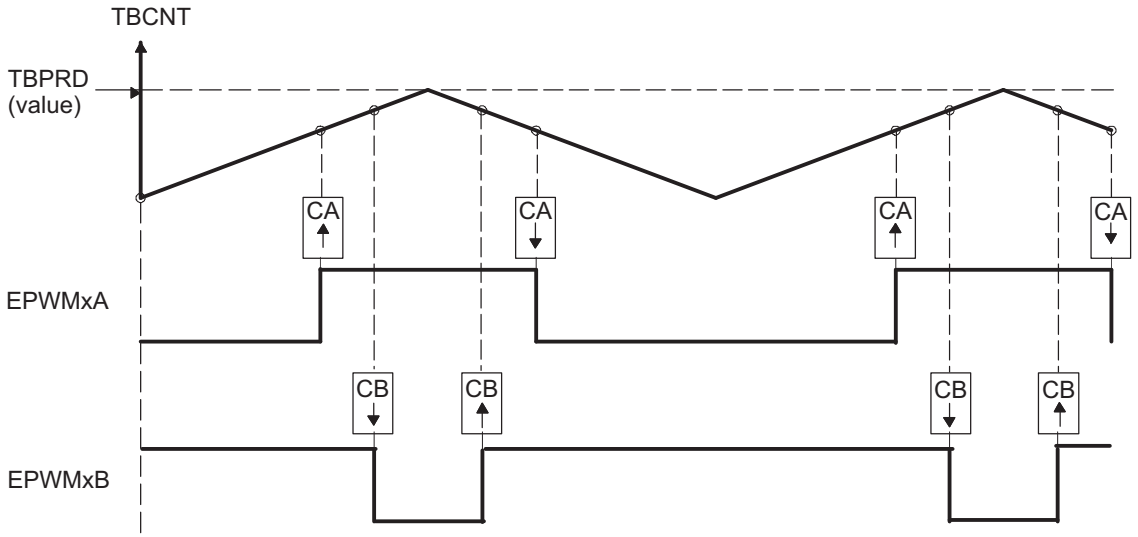
Register	Bit	Value	Comments
TBPRD	TBPRD	600 (258h)	Period = 601 TBCLK counts
TBPHS	TBPHS	0	Clear Phase Register to 0
TBCNT	TBCNT	0	Clear TB counter
TBCTL	CTRMODE	TB_UPDOWN	
	PHSEN	TB_DISABLE	Phase loading disabled
	PRDLD	TB_SHADOW	
	SYNCOSEL	TB_SYNC_DISABLE	
	HSPCLKDIV	TB_DIV1	TBCLK = SYSCLK
	CLKDIV	TB_DIV1	
CMPA	CMPA	400 (190h)	Compare A = 400 TBCLK counts
CMPB	CMPB	500 (1F4h)	Compare B = 500 TBCLK counts
CMPCTL	SHDWAMODE	CC_SHADOW	
	SHDWBMODE	CC_SHADOW	
	LOADAMODE	CC_CTR_ZERO	Load on CTR = 0
	LOADBMODE	CC_CTR_ZERO	Load on CTR = 0
AQCTLA	CAU	AQ_SET	
	CAD	AQ_CLEAR	
AQCTLB	CBU	AQ_SET	
	CBD	AQ_CLEAR	

Table 16-20. EPWMx Run Time Changes for Figure 16-25

Register	Bit	Value	Comments
CMPA	CMPA	Duty1A	Adjust duty for output EPWM1A
CMPB	CMPB	Duty1B	Adjust duty for output EPWM1B

Table 16-21 and Table 16-22 contains initialization and runtime register configurations for the waveforms in Figure 16-26. Use the code in Example 16-1 to define the headers.

Figure 16-26. Up-Down-Count, Dual Edge Symmetric Waveform, With Independent Modulation on EPWMxA and EPWMxB — Complementary



(1) PWM period = 2 × TBPRD × T_{TBCLK}

(2) Duty modulation for EPWMxA is set by CMPA, and is active low, i.e., low time duty proportional to CMPA

(3) Duty modulation for EPWMxB is set by CMPB and is active high, i.e., high time duty proportional to CMPB

(4) Outputs EPWMx can drive upper/lower (complementary) power switches

(5) Dead-band = CMPB - CMPA (fully programmable edge placement by software). Note the dead-band module is also available if the more classical edge delay method is required.

Table 16-21. EPWMx Initialization for Figure 16-26

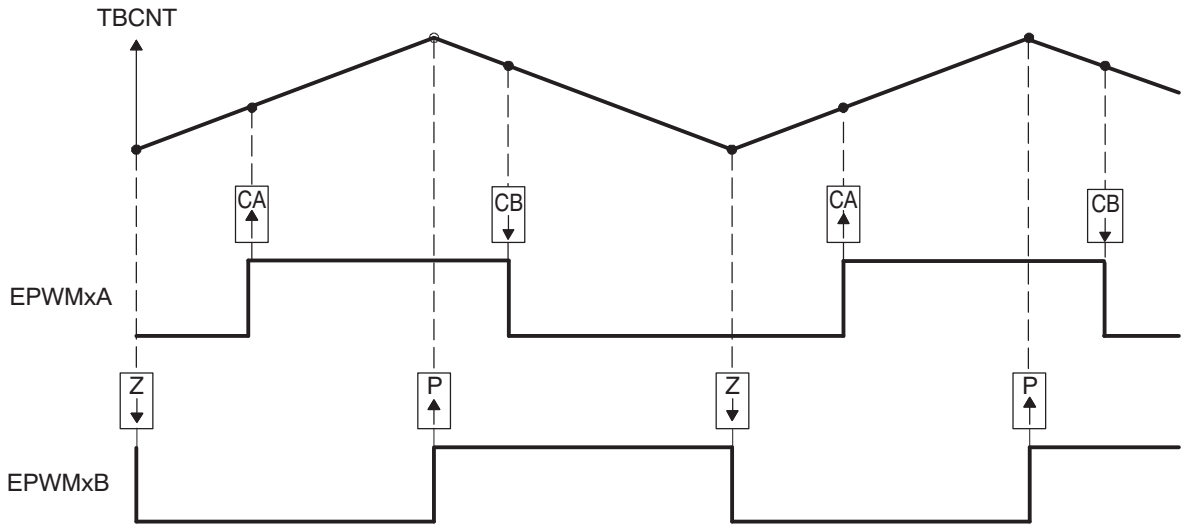
Register	Bit	Value	Comments
TBPRD	TBPRD	600 (258h)	Period = 601 TBCLK counts
TBPHS	TBPHS	0	Clear Phase Register to 0
TBCNT	TBCNT	0	Clear TB counter
TBCTL	CTRMODE	TB_UPDOWN	
	PHSEN	TB_DISABLE	Phase loading disabled
	PRDLD	TB_SHADOW	
	SYNCOSEL	TB_SYNC_DISABLE	
	HSPCLKDIV	TB_DIV1	TBCLK = SYSCLK
	CLKDIV	TB_DIV1	
CMPA	CMPA	350 (15Eh)	Compare A = 350 TBCLK counts
CMPB	CMPB	400 (190h)	Compare B = 400 TBCLK counts
CMPCTL	SHDWAMODE	CC_SHADOW	
	SHDWBMODE	CC_SHADOW	
	LOADAMODE	CC_CTR_ZERO	Load on CTR = 0
	LOADBMODE	CC_CTR_ZERO	Load on CTR = 0
AQCTLA	CAU	AQ_SET	
	CAD	AQ_CLEAR	
AQCTLB	CBU	AQ_CLEAR	
	CBD	AQ_SET	

Table 16-22. EPWMx Run Time Changes for Figure 16-26

Register	Bit	Value	Comments
CMPA	CMPA	Duty1A	Adjust duty for output EPWM1A
CMPB	CMPB	Duty1B	Adjust duty for output EPWM1B

Table 16-23 and Table 16-24 contains initialization and runtime register configurations for the waveforms in Figure 16-27. Use the code in Example 16-1 to define the headers.

Figure 16-27. Up-Down-Count, Dual Edge Asymmetric Waveform, With Independent Modulation on EPWMxA—Active Low



(1) PWM period = 2 × TBPRD × TBCLK

(2) Rising edge and falling edge can be asymmetrically positioned within a PWM cycle. This allows for pulse placement techniques.

(3) Duty modulation for EPWMxA is set by CMPA and CMPB.

(4) Low time duty for EPWMxA is proportional to (CMPA + CMPB).

(5) To change this example to active high, CMPA and CMPB actions need to be inverted (i.e., Set ! Clear and Clear Set).

(6) Duty modulation for EPWMxB is fixed at 50% (utilizes spare action resources for EPWMxB)

Table 16-23. EPWMx Initialization for Figure 16-27

Register	Bit	Value	Comments
TBPRD	TBPRD	600 (258h)	Period = 601 TBCLK counts
TBPHS	TBPHS	0	Clear Phase Register to 0
TBCNT	TBCNT	0	Clear TB counter
TBCTL	CTRMODE	TB_UPDOWN	
	PHSEN	TB_DISABLE	Phase loading disabled
	PRDLD	TB_SHADOW	
	SYNCOSEL	TB_SYNC_DISABLE	
	HSPCLKDIV	TB_DIV1	TBCLK = SYSCLK
	CLKDIV	TB_DIV1	
CMPA	CMPA	250 (FAh)	Compare A = 250 TBCLK counts
CMPB	CMPB	450 (1C2h)	Compare B = 450 TBCLK counts
CMPCTL	SHDWAMODE	CC_SHADOW	
	SHDWBMODE	CC_SHADOW	
	LOADAMODE	CC_CTR_ZERO	Load on CTR = 0
	LOADBMODE	CC_CTR_ZERO	Load on CTR = 0
AQCTLA	CAU	AQ_SET	
	CBD	AQ_CLEAR	
AQCTLB	ZRO	AQ_CLEAR	
	PRD	AQ_SET	

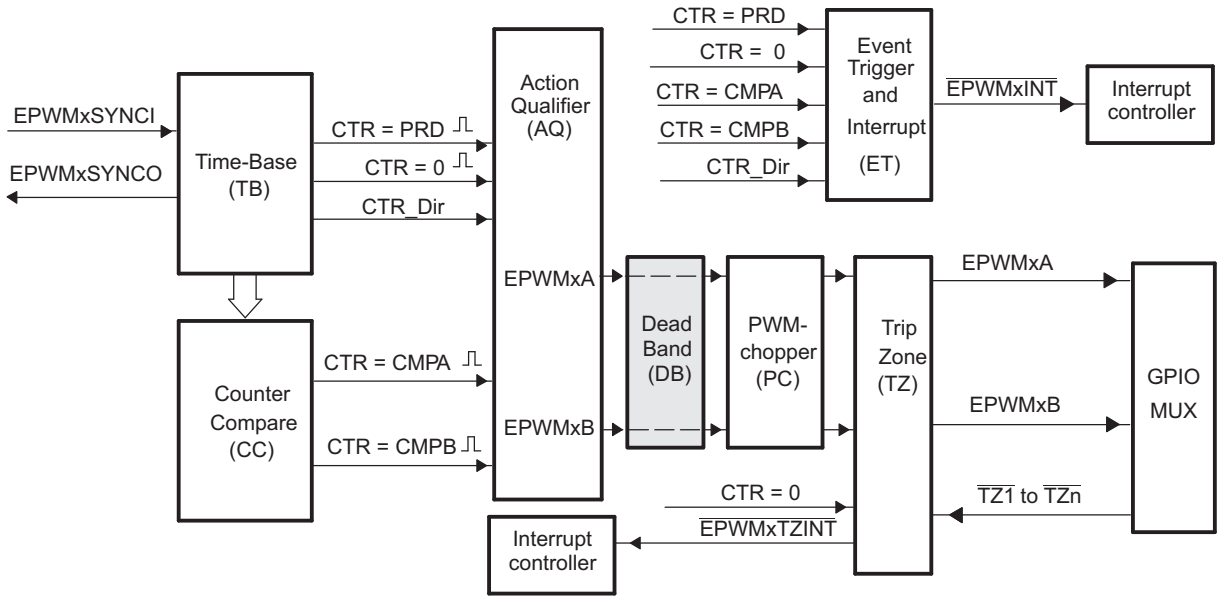
Table 16-24. EPWMx Run Time Changes for Figure 16-27

Register	Bit	Value	Comments
CMPA	CMPA	EdgePosA	Adjust duty for output EPWM1A
CMPB	CMPB	EdgePosB	

16.2.6 Dead-Band Generator (DB) Submodule

Figure 16-28 illustrates the dead-band generator submodule within the ePWM module.

Figure 16-28. Dead-Band Generator Submodule



16.2.6.1 Purpose of the Dead-Band Submodule

The "Action-qualifier (AQ) Module" section discussed how it is possible to generate the required dead-band by having full control over edge placement using both the CMPA and CMPB resources of the ePWM module. However, if the more classical edge delay-based dead-band with polarity control is required, then the dead-band generator submodule should be used.

The key functions of the dead-band generator submodule are:

- Generating appropriate signal pairs (EPWMxA and EPWMxB) with dead-band relationship from a single EPWMxA input
- Programming signal pairs for:
  - Active high (AH)
  - Active low (AL)
  - Active high complementary (AHC)
  - Active low complementary (ALC)
- Adding programmable delay to rising edges (RED)
- Adding programmable delay to falling edges (FED)
- Can be totally bypassed from the signal path (note dotted lines in diagram)

16.2.6.2 Controlling and Monitoring the Dead-Band Submodule

The dead-band generator submodule operation is controlled and monitored via the following registers:

Table 16-25. Dead-Band Generator Submodule Registers

Acronym	Register Description	Address Offset	Shadowed
DBCTL	Dead-Band Control Register	1Eh	No
DBRED	Dead-Band Rising Edge Delay Count Register	20h	No
DBFED	Dead-Band Falling Edge Delay Count Register	22h	No

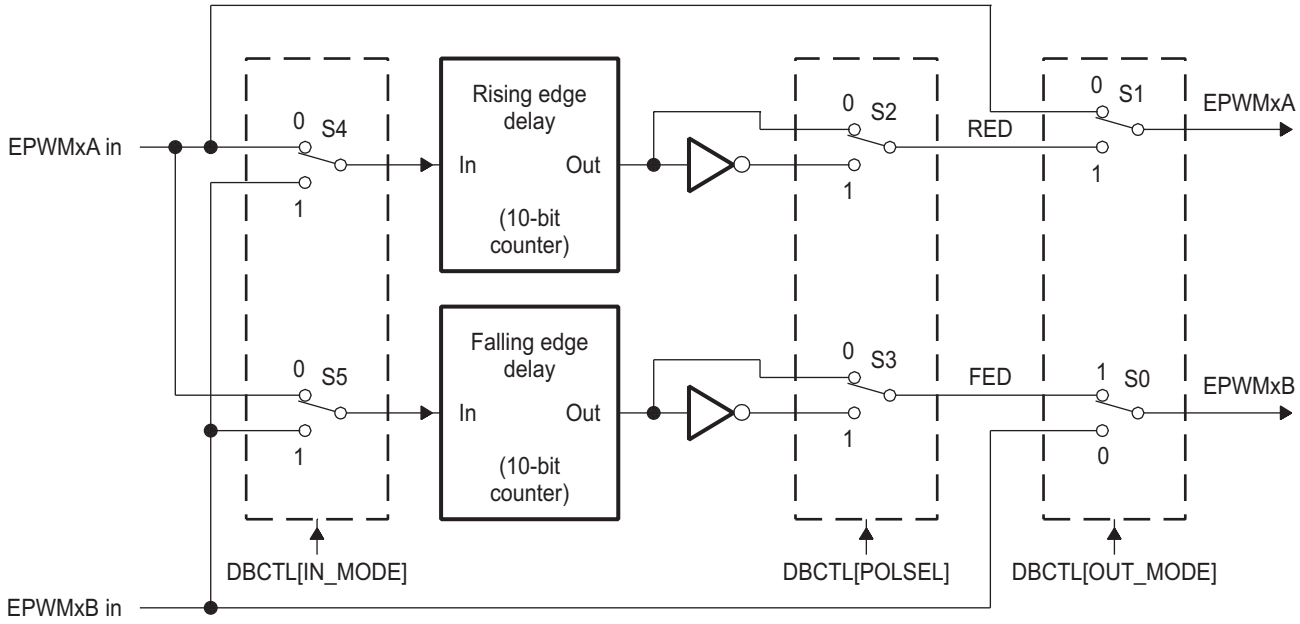
16.2.6.3 Operational Highlights for the Dead-Band Generator Submodule

The following sections provide the operational highlights.

The dead-band submodule has two groups of independent selection options as shown in Figure 16-29.

- **Input Source Selection:** The input signals to the dead-band module are the EPWMxA and EPWMxB output signals from the action-qualifier. In this section they will be referred to as EPWMxA In and EPWMxB In. Using the DBCTL[IN_MODE) control bits, the signal source for each delay, falling-edge or rising-edge, can be selected:
  - EPWMxA In is the source for both falling-edge and rising-edge delay. This is the default mode.
  - EPWMxA In is the source for falling-edge delay, EPWMxB In is the source for rising-edge delay.
  - EPWMxA In is the source for rising edge delay, EPWMxB In is the source for falling-edge delay.
  - EPWMxB In is the source for both falling-edge and rising-edge delay.
- **Output Mode Control:** The output mode is configured by way of the DBCTL[OUT_MODE] bits. These bits determine if the falling-edge delay, rising-edge delay, neither, or both are applied to the input signals.
- **Polarity Control:** The polarity control (DBCTL[POLSEL]) allows you to specify whether the rising-edge delayed signal and/or the falling-edge delayed signal is to be inverted before being sent out of the dead-band submodule.

Figure 16-29. Configuration Options for the Dead-Band Generator Submodule



Although all combinations are supported, not all are typical usage modes. Table 16-26 lists some classical dead-band configurations. These modes assume that the DBCTL[IN_MODE] is configured such that EPWMxA In is the source for both falling-edge and rising-edge delay. Enhanced, or non-traditional modes can be achieved by changing the input signal source. The modes shown in Table 16-26 fall into the following categories:

- **Mode 1: Bypass both falling-edge delay (FED) and rising-edge delay (RED)** Allows you to fully disable the dead-band submodule from the PWM signal path.
- **Mode 2-5: Classical Dead-Band Polarity Settings** These represent typical polarity configurations that should address all the active high/low modes required by available industry power switch gate drivers. The waveforms for these typical cases are shown in Figure 16-30. Note that to generate equivalent waveforms to Figure 16-30, configure the action-qualifier submodule to generate the signal as shown for EPWMxA.
- **Mode 6: Bypass rising-edge-delay and Mode 7: Bypass falling-edge-delay** Finally the last two entries in Table 16-26 show combinations where either the falling-edge-delay (FED) or rising-edge-delay (RED) blocks are bypassed.

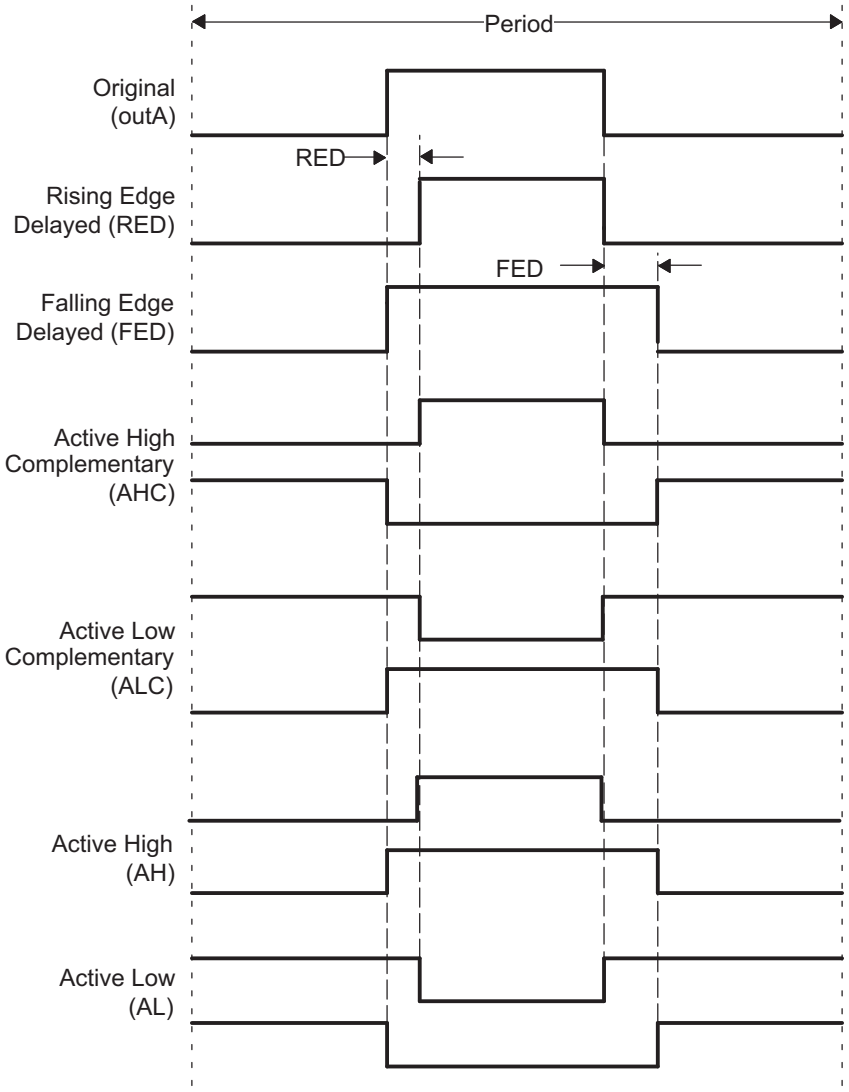
Table 16-26. Classical Dead-Band Operating Modes

		DBCTL[POLSEL]		DBCTL[OUT_MODE]	
Mode	**Mode Description** [1]	**S3**	**S2**	**S1**	**S0**
1	EPWMxA and EPWMxB Passed Through (No Delay)	x	x	0	0
2	Active High Complementary (AHC)	1	0	1	1
3	Active Low Complementary (ALC)	0	1	1	1
4	Active High (AH)	0	0	1	1
5	Active Low (AL)	1	1	1	1
6	EPWMxA Out = EPWMxA In (No Delay) EPWMxB Out = EPWMxA In with Falling Edge Delay	0 or 1	0 or 1	0	1
7	EPWMxA Out = EPWMxA In with Rising Edge Delay EPWMxB Out = EPWMxB In with No Delay	0 or 1	0 or 1	1	0

(1) These are classical dead-band modes and assume that DBCTL[IN_MODE] = 0,0. That is, EPWMxA in is the source for both the falling-edge and rising-edge delays. Enhanced, non-traditional modes can be achieved by changing the IN_MODE configuration.

Figure 16-30 shows waveforms for typical cases where 0% < duty < 100%.

Figure 16-30. Dead-Band Waveforms for Typical Cases (0% < Duty < 100%)



The dead-band submodule supports independent values for rising-edge (RED) and falling-edge (FED) delays. The amount of delay is programmed using the DBRED and DBFED registers. These are 10-bit registers and their value represents the number of time-base clock, TBCLK, periods a signal edge is delayed by. For example, the formula to calculate falling-edge-delay and rising-edge-delay are:

$FED = DBFED \times T_{TBCLK}$

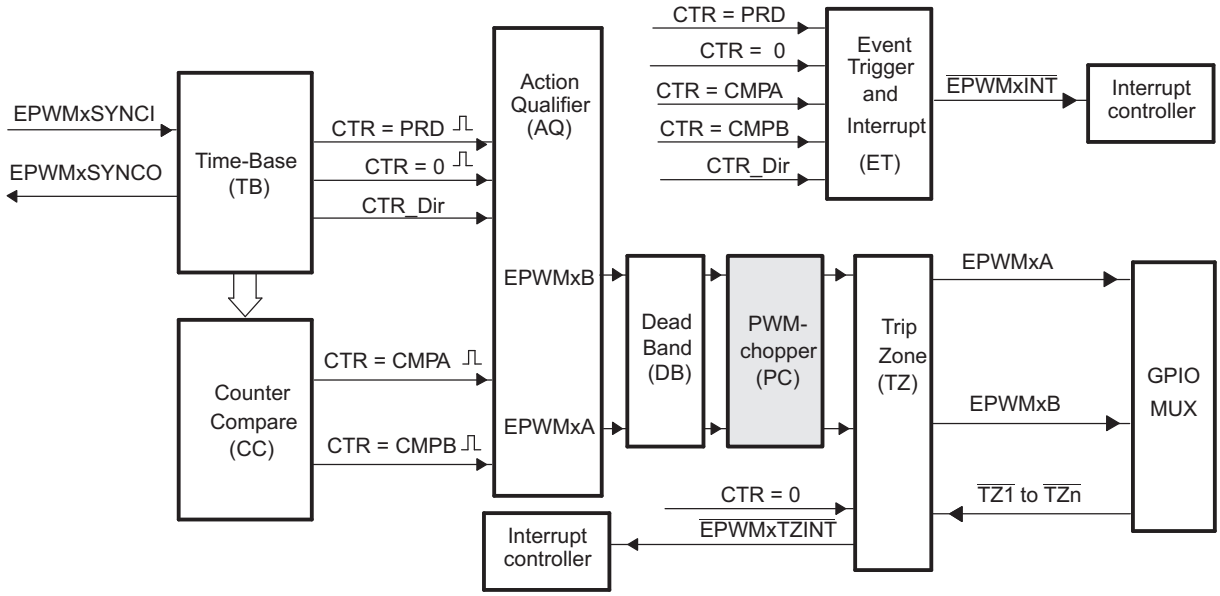
$RED = DBRED \times T_{TBCLK}$

Where T_{TBCLK} is the period of TBCLK, the prescaled version of SYSCLKOUT.

16.2.7 PWM-Chopper (PC) Submodule

Figure 16-31 illustrates the PWM-chopper (PC) submodule within the ePWM module. The PWM-chopper submodule allows a high-frequency carrier signal to modulate the PWM waveform generated by the action-qualifier and dead-band submodules. This capability is important if you need pulse transformer-based gate drivers to control the power switching elements.

Figure 16-31. PWM-Chopper Submodule



16.2.7.1 Purpose of the PWM-Chopper Submodule

The key functions of the PWM-chopper submodule are:

- Programmable chopping (carrier) frequency
- Programmable pulse width of first pulse
- Programmable duty cycle of second and subsequent pulses
- Can be fully bypassed if not required

16.2.7.2 Controlling the PWM-Chopper Submodule

The PWM-chopper submodule operation is controlled via the register in Table 16-27.

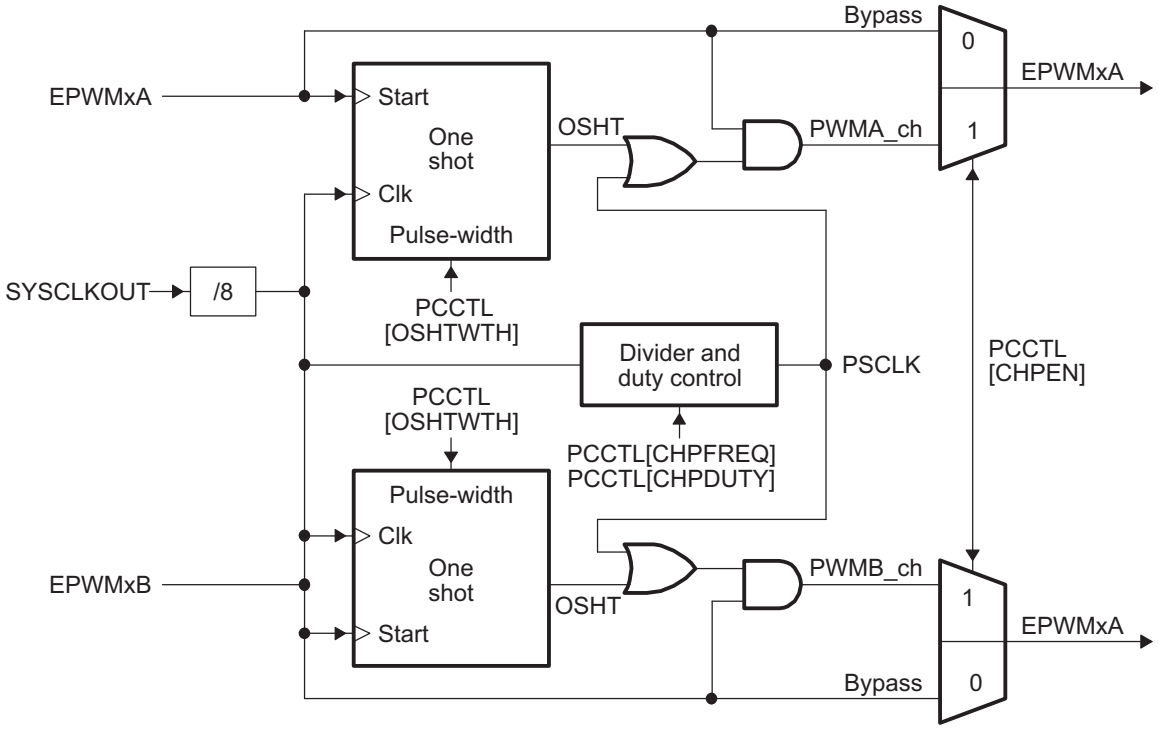
Table 16-27. PWM-Chopper Submodule Registers

Acronym	Register Description	Address Offset	Shadowed
PCCTL	PWM-chopper Control Register	3Ch	No

16.2.7.3 Operational Highlights for the PWM-Chopper Submodule

Figure 16-32 shows the operational details of the PWM-chopper submodule. The carrier clock is derived from SYSCLKOUT. Its frequency and duty cycle are controlled via the CHPFREQ and CHPDUTY bits in the PCCTL register. The one-shot block is a feature that provides a high energy first pulse to ensure hard and fast power switch turn on, while the subsequent pulses sustain pulses, ensuring the power switch remains on. The one-shot width is programmed via the OSHTWTH bits. The PWM-chopper submodule can be fully disabled (bypassed) via the CHPEN bit.

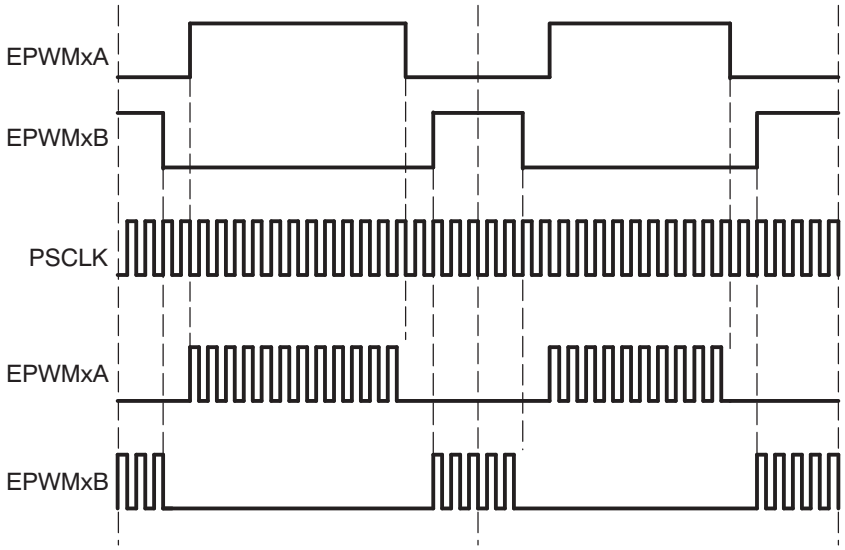
Figure 16-32. PWM-Chopper Submodule Signals and Registers



16.2.7.4 Waveforms

Figure 16-33 shows simplified waveforms of the chopping action only; one-shot and duty-cycle control are not shown. Details of the one-shot and duty-cycle control are discussed in the following sections.

Figure 16-33. Simple PWM-Chopper Submodule Waveforms Showing Chopping Action Only



16.2.7.4.1 One-Shot Pulse

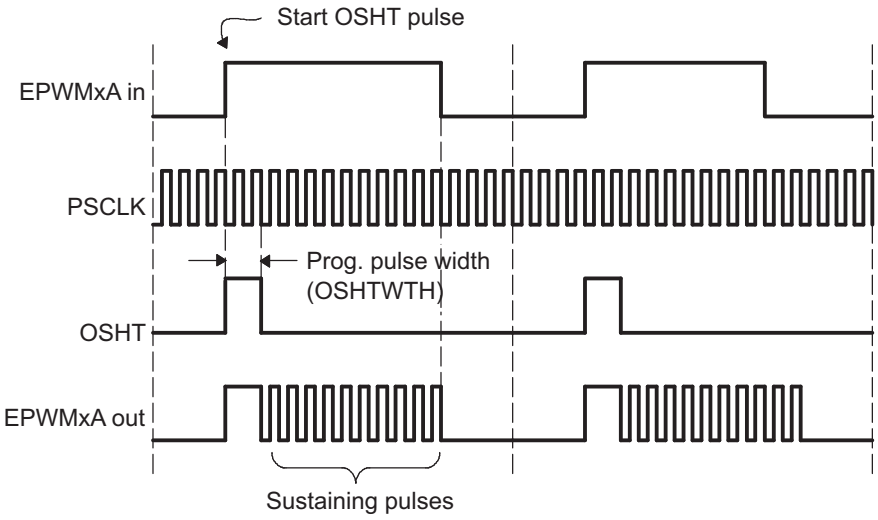
The width of the first pulse can be programmed to any of 16 possible pulse width values. The width or period of the first pulse is given by:

$T_{1stpulse} = T_{SYSCLKOUT} \times 8 \times OSHTWTH$

Where $T_{SYSCLKOUT}$ is the period of the system clock (SYSCLKOUT) and OSHTWTH is the four control bits (value from 1 to 16)

Figure 16-34 shows the first and subsequent sustaining pulses.

Figure 16-34. PWM-Chopper Submodule Waveforms Showing the First Pulse and Subsequent Sustaining Pulses

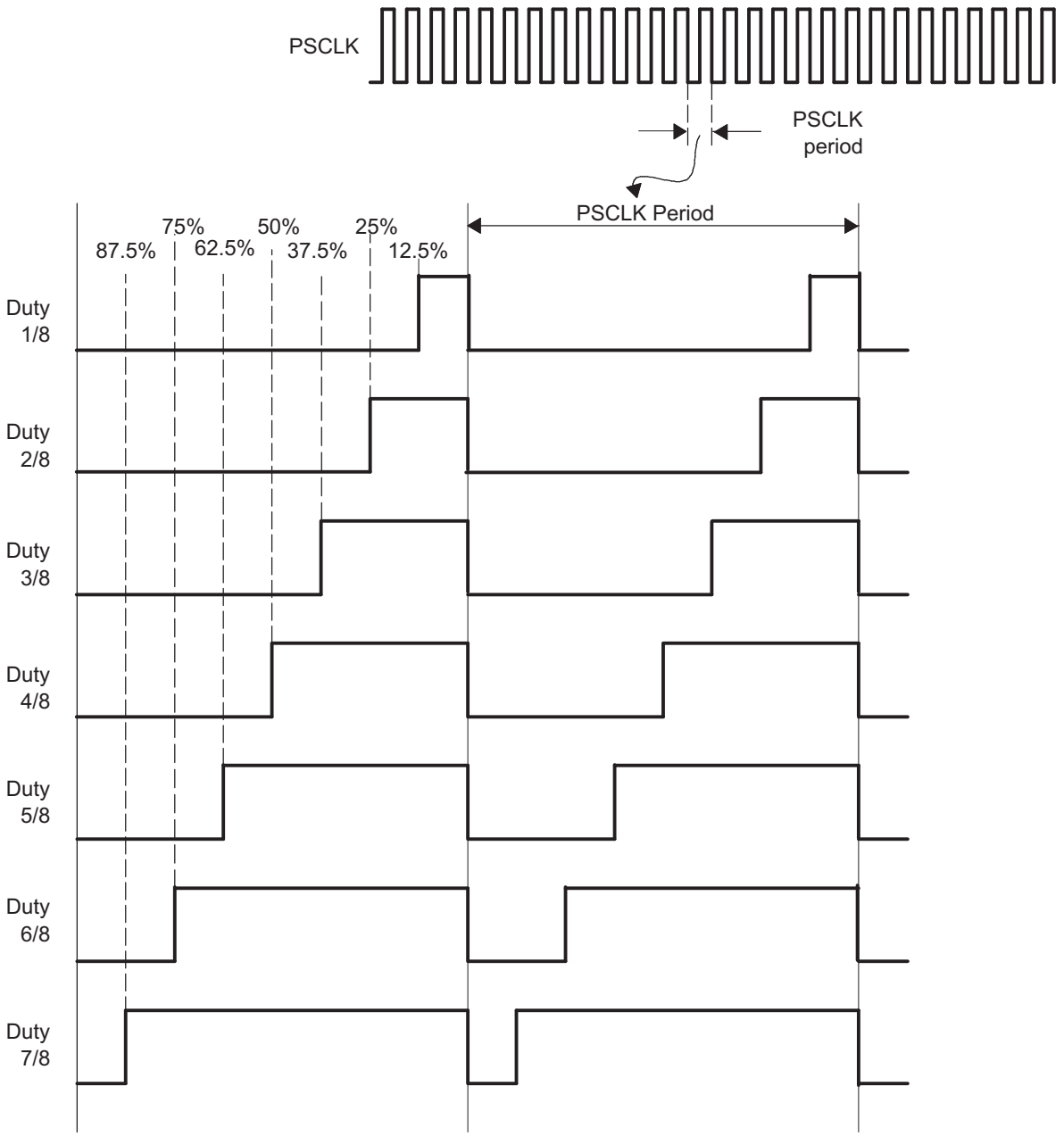


16.2.7.4.2 Duty Cycle Control

Pulse transformer-based gate drive designs need to comprehend the magnetic properties or characteristics of the transformer and associated circuitry. Saturation is one such consideration. To assist the gate drive designer, the duty cycles of the second and subsequent pulses have been made programmable. These sustaining pulses ensure the correct drive strength and polarity is maintained on the power switch gate during the on period, and hence a programmable duty cycle allows a design to be tuned or optimized via software control.

Figure 16-35 shows the duty cycle control that is possible by programming the CHPDUTY bits. One of seven possible duty ratios can be selected ranging from 12.5% to 87.5%.

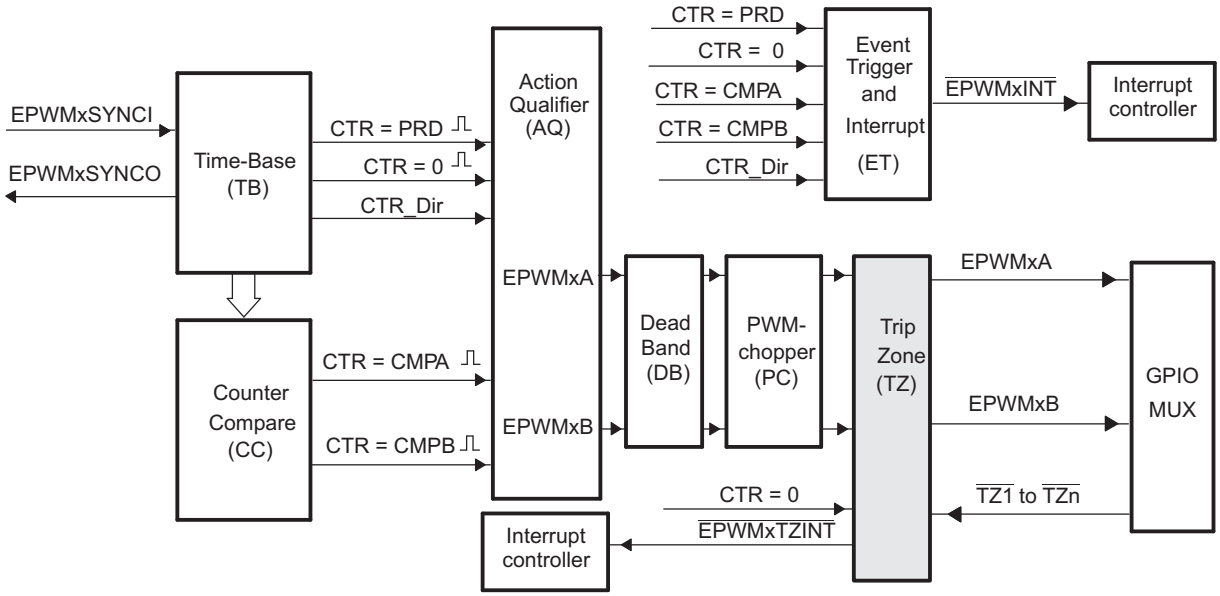
Figure 16-35. PWM-Chopper Submodule Waveforms Showing the Pulse Width (Duty Cycle) Control of Sustaining Pulses



16.2.8 Trip-Zone (TZ) Submodule

Figure 16-36 shows how the trip-zone (TZ) submodule fits within the ePWM module. Each ePWM module is connected to every $\overline{TZ}$ signal that are sourced from the GPIO MUX. These signals indicates external fault or trip conditions, and the ePWM outputs can be programmed to respond accordingly when faults occur. See your device-specific data manual to determine the number of trip-zone pins available for the device.

Figure 16-36. Trip-Zone Submodule



16.2.8.1 Purpose of the Trip-Zone Submodule

The key functions of the trip-zone submodule are:

- Trip inputs $\overline{TZ1}$ to $\overline{TZn}$ can be flexibly mapped to any ePWM module.
- Upon a fault condition, outputs EPWMxA and EPWMxB can be forced to one of the following:
  - High
  - Low
  - High-impedance
  - No action taken
- Support for one-shot trip (OSHT) for major short circuits or over-current conditions.
- Support for cycle-by-cycle tripping (CBC) for current limiting operation.
- Each trip-zone input pin can be allocated to either one-shot or cycle-by-cycle operation.
- Interrupt generation is possible on any trip-zone pin.
- Software-forced tripping is also supported.
- The trip-zone submodule can be fully bypassed if it is not required.

16.2.8.2 Controlling and Monitoring the Trip-Zone Submodule

The trip-zone submodule operation is controlled and monitored through the following registers:

Table 16-28. Trip-Zone Submodule Registers

Acronym	Register Description	Address Offset	Shadowed
TZSEL	Trip-Zone Select Register	24h	No
TZCTL	Trip-Zone Control Register	28h	No
TZEINT	Trip-Zone Enable Interrupt Register	2Ah	No
TZFLG	Trip-Zone Flag Register	2Ch	No
TZCLR	Trip-Zone Clear Register	2Eh	No
TZFRC	Trip-Zone Force Register	30h	No

16.2.8.3 Operational Highlights for the Trip-Zone Submodule

The following sections describe the operational highlights and configuration options for the trip-zone submodule.

The trip-zone signals at pin $\overline{TZ1}$ to $\overline{TZn}$ is an active-low input signal. When the pin goes low, it indicates that a trip event has occurred. Each ePWM module can be individually configured to ignore or use each of the trip-zone pins. Which trip-zone pins are used by a particular ePWM module is determined by the TZSEL register for that specific ePWM module. The trip-zone signal may or may not be synchronized to the system clock (SYSCLKOUT). A minimum of 1 SYSCLKOUT low pulse on the $\overline{TZ}$ $\overline{n}$ inputs is sufficient to trigger a fault condition in the ePWM module. The asynchronous trip makes sure that if clocks are missing for any reason, the outputs can still be tripped by a valid event present on the $\overline{TZn}$ inputs.

The $\overline{TZ}$ $\overline{n}$ input can be individually configured to provide either a cycle-by-cycle or one-shot trip event for a ePWM module. The configuration is determined by the TZSEL[CBCn] and TZSEL[OSHTn] bits (where n corresponds to the trip pin) respectively.

- **Cycle-by-Cycle (CBC):** When a cycle-by-cycle trip event occurs, the action specified in the TZCTL register is carried out immediately on the EPWMxA and/or EPWMxB output. Table 16-29 lists the possible actions. In addition, the cycle-by-cycle trip event flag (TZFLG[CBC]) is set and a EPWMxTZINT interrupt is generated if it is enabled in the TZEINT register.

  The specified condition on the pins is automatically cleared when the ePWM time-base counter reaches zero (TBCNT = 0000h) if the trip event is no longer present. Therefore, in this mode, the trip event is cleared or reset every PWM cycle. The TZFLG[CBC] flag bit will remain set until it is manually cleared by writing to the TZCLR[CBC] bit. If the cycle-by-cycle trip event is still present when the TZFLG[CBC] bit is cleared, then it will again be immediately set.
- **One-Shot (OSHT):** When a one-shot trip event occurs, the action specified in the TZCTL register is carried out immediately on the EPWMxA and/or EPWMxB output. Table 16-29 lists the possible actions. In addition, the one-shot trip event flag (TZFLG[OST]) is set and a EPWMxTZINT interrupt is generated if it is enabled in the TZEINT register. The one-shot trip condition must be cleared manually by writing to the TZCLR[OST] bit.

The action taken when a trip event occurs can be configured individually for each of the ePWM output pins by way of the TZCTL[TZA] and TZCTL[TZB] register bits. One of four possible actions, shown in Table 16-29, can be taken on a trip event.

Table 16-29. Possible Actions On a Trip Event

TZCTL[TZA] and/or TZCTL[TZB]	EPWMxA and/or EPWMxB	Comment
0	High-Impedance	Tripped
1h	Force to High State	Tripped
2h	Force to Low State	Tripped
3h	No Change	Do Nothing. No change is made to the output.

Example 16-2. Trip-Zone Configurations

Scenario A:
A one-shot trip event on $\overline{TZ1}$ pulls both EPWM1A, EPWM1B low and also forces EPWM2A and EPWM2B high.

- Configure the ePWM1 registers as follows:
  - TZSEL[OSHT1] = 1: enables $\overline{TZ}$ as a one-shot event source for ePWM1
  - TZCTL[TZA] = 2: EPWM1A will be forced low on a trip event.
  - TZCTL[TZB] = 2: EPWM1B will be forced low on a trip event.
- Configure the ePWM2 registers as follows:
  - TZSEL[OSHT1] = 1: enables $\overline{TZ}$ as a one-shot event source for ePWM2
  - TZCTL[TZA] = 1: EPWM2A will be forced high on a trip event.
  - TZCTL[TZB] = 1: EPWM2B will be forced high on a trip event.

Scenario B:
A cycle-by-cycle event on $\overline{TZ5}$ pulls both EPWM1A, EPWM1B low.

A one-shot event on $\overline{TZ1}$ or $\overline{TZ6}$ puts EPWM2A into a high impedance state.

- Configure the ePWM1 registers as follows:
  - TZSEL[CBC5] = 1: enables $\overline{TZ5}$ as a one-shot event source for ePWM1
  - TZCTL[TZA] = 2: EPWM1A will be forced low on a trip event.
  - TZCTL[TZB] = 2: EPWM1B will be forced low on a trip event.
- Configure the ePWM2 registers as follows:
  - TZSEL[OSHT1] = 1: enables $\overline{TZ1}$ as a one-shot event source for ePWM2
  - TZSEL[OSHT6] = 1: enables $\overline{TZ6}$ as a one-shot event source for ePWM1
  - TZCTL[TZA] = 0: EPWM1A will be put into a high-impedance state on a trip event.
  - TZCTL[TZB] = 3: EPWM1B will ignore the trip event.

16.2.8.4 Generating Trip Event Interrupts

Figure 16-37 and Figure 16-38 illustrate the trip-zone submodule control and interrupt logic, respectively.

Figure 16-37. Trip-Zone Submodule Mode Control Logic

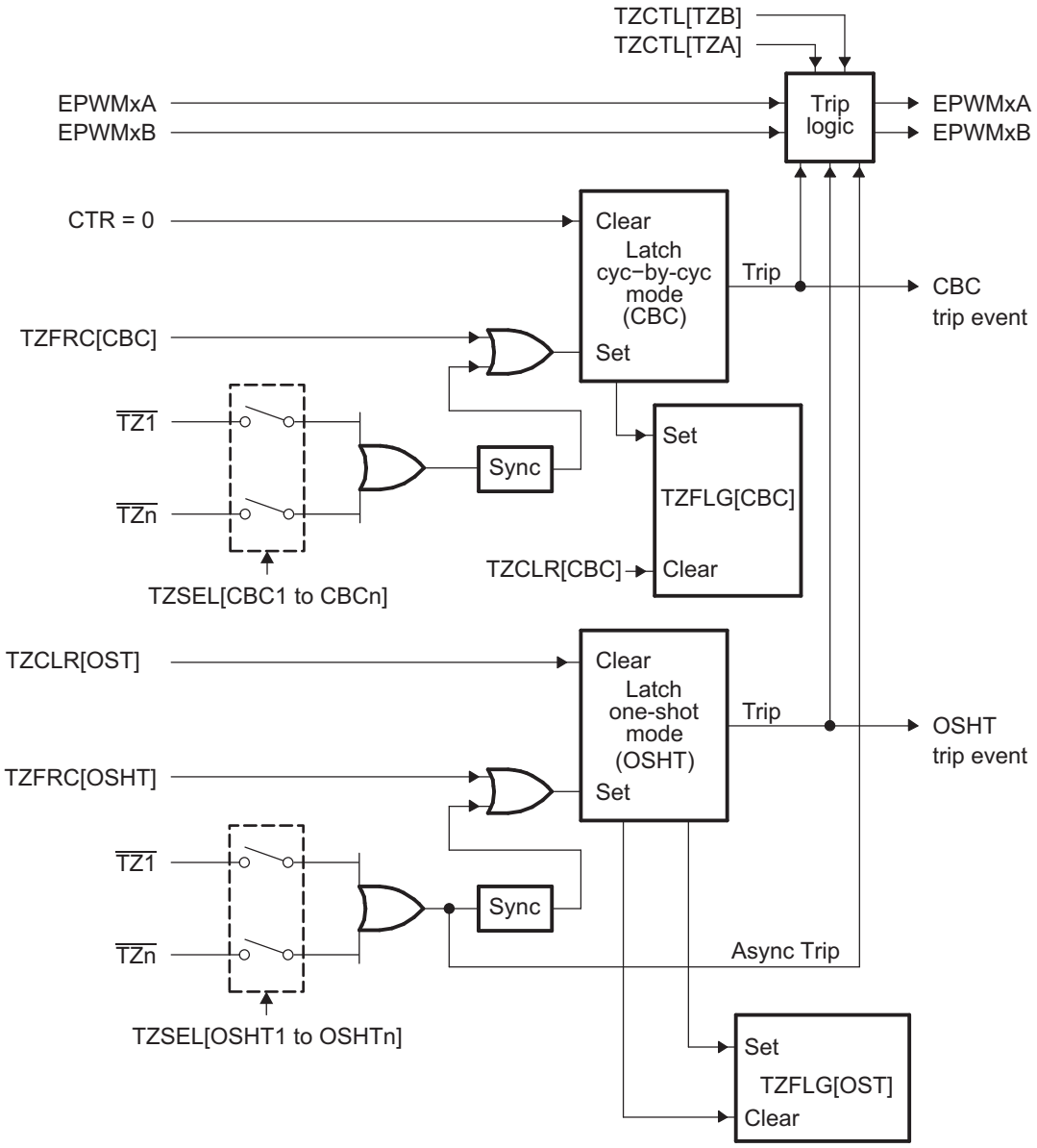
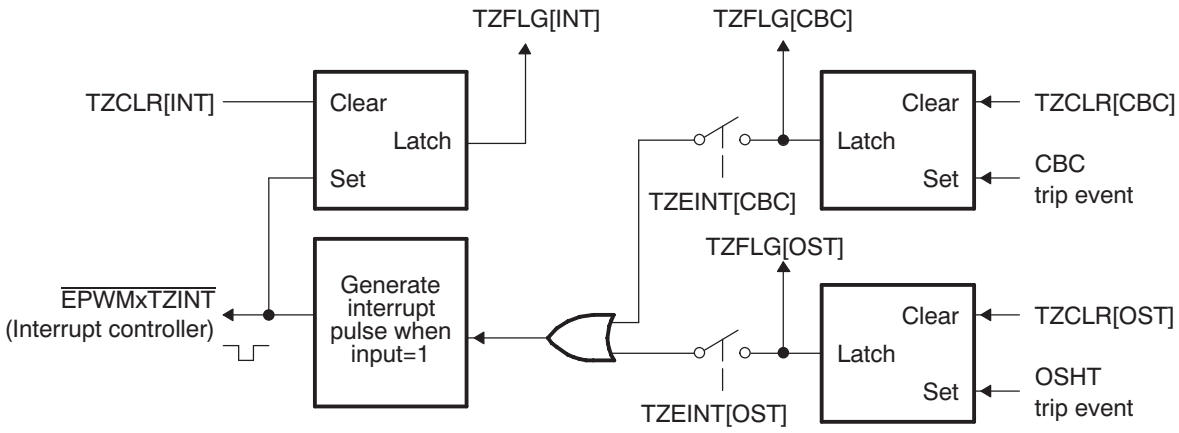


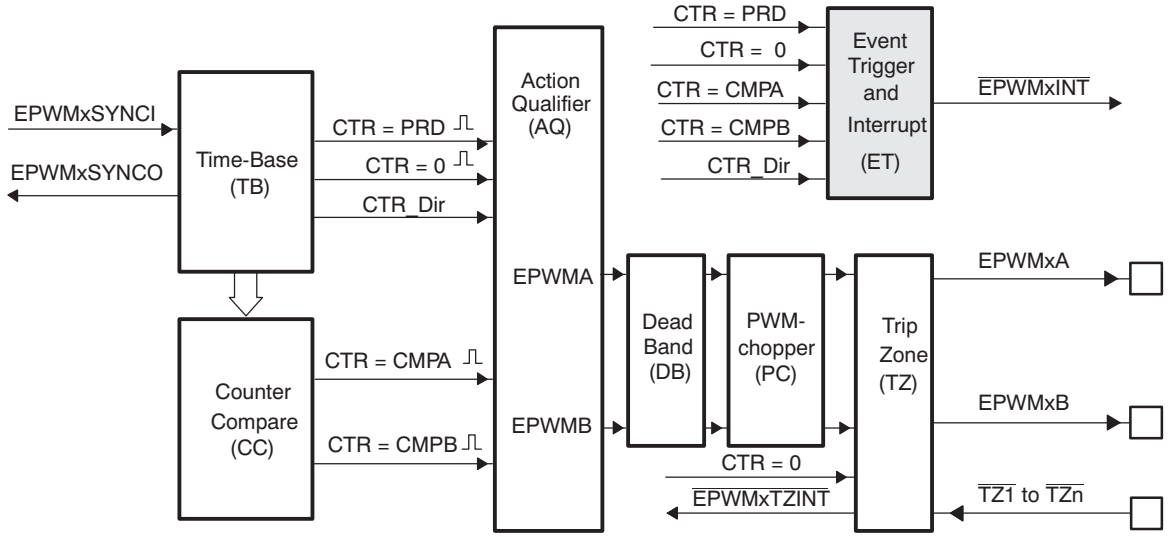
Figure 16-38. Trip-Zone Submodule Interrupt Logic



16.2.9 Event-Trigger (ET) Submodule

Figure 16-39 shows the event-trigger (ET) submodule in the ePWM system. The event-trigger submodule manages the events generated by the time-base submodule and the counter-compare submodule to generate an interrupt to the CPU.

Figure 16-39. Event-Trigger Submodule



16.2.9.1 Purpose of the Event-Trigger Submodule

The key functions of the event-trigger submodule are:

- Receives event inputs generated by the time-base and counter-compare submodules
- Uses the time-base direction information for up/down event qualification
- Uses prescaling logic to issue interrupt requests at:
  - Every event
  - Every second event
  - Every third event
- Provides full visibility of event generation via event counters and flags

16.2.9.2 Controlling and Monitoring the Event-Trigger Submodule

The key registers used to configure the event-trigger submodule are shown in Table 16-30:

Table 16-30. Event-Trigger Submodule Registers

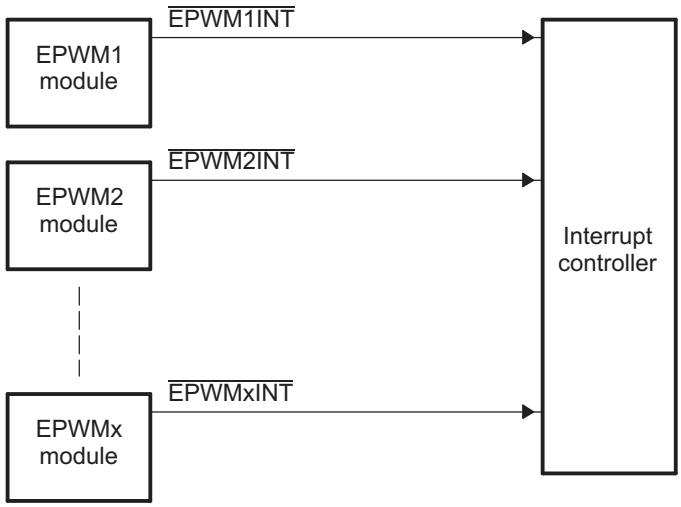
Acronym	Register Description	Address Offset	Shadowed
ETSEL	Event-Trigger Selection Register	32h	No
ETPS	Event-Trigger Prescale Register	34h	No
ETFLG	Event-Trigger Flag Register	36h	No
ETCLR	Event-Trigger Clear Register	38h	No
ETFRC	Event-Trigger Force Register	3Ah	No

16.2.9.3 Operational Overview of the Event-Trigger Submodule

The following sections describe the event-trigger submodule's operational highlights.

Each ePWM module has one interrupt request line connected to the interrupt controller as shown in Figure 16-40.

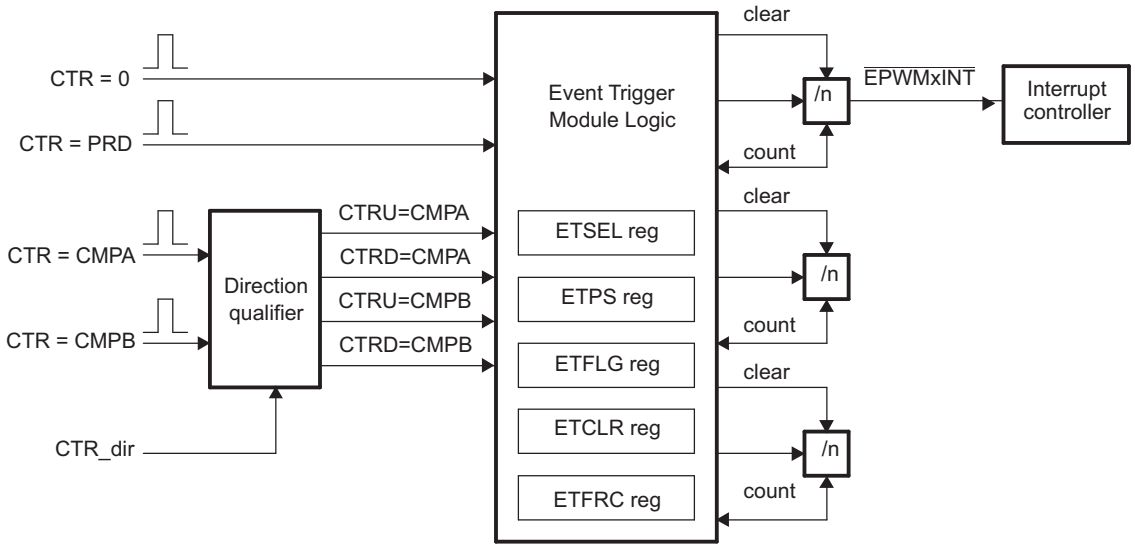
Figure 16-40. Event-Trigger Submodule Inter-Connectivity to Interrupt Controller



The event-trigger submodule monitors various event conditions (the left side inputs to event-trigger submodule shown in Figure 16-41) and can be configured to prescale these events before issuing an Interrupt request. The event-trigger prescaling logic can issue Interrupt requests at:

- Every event
- Every second event
- Every third event

Figure 16-41. Event-Trigger Submodule Showing Event Inputs and Prescaled Outputs



- ETSEL—This selects which of the possible events will trigger an interrupt.
- ETPS—This programs the event prescaling options previously mentioned.
- ETFLG—These are flag bits indicating status of the selected and prescaled events.
- ETCLR—These bits allow you to clear the flag bits in the ETFLG register via software.
- ETFRC—These bits allow software forcing of an event. Useful for debugging or software intervention.

A more detailed look at how the various register bits interact with the Interrupt is shown in Figure 16-42.

Figure 16-42 shows the event-trigger's interrupt generation logic. The interrupt-period (ETPS[INTPRD]) bits specify the number of events required to cause an interrupt pulse to be generated. The choices available are:

- Do not generate an interrupt
- Generate an interrupt on every event
- Generate an interrupt on every second event
- Generate an interrupt on every third event

An interrupt cannot be generated on every fourth or more events.

Which event can cause an interrupt is configured by the interrupt selection (ETSEL[INTSEL]) bits. The event can be one of the following:

- Time-base counter equal to zero (TBCNT = 0000h).
- Time-base counter equal to period (TBCNT = TBPRD).
- Time-base counter equal to the compare A register (CMPA) when the timer is incrementing.
- Time-base counter equal to the compare A register (CMPA) when the timer is decrementing.
- Time-base counter equal to the compare B register (CMPB) when the timer is incrementing.
- Time-base counter equal to the compare B register (CMPB) when the timer is decrementing.

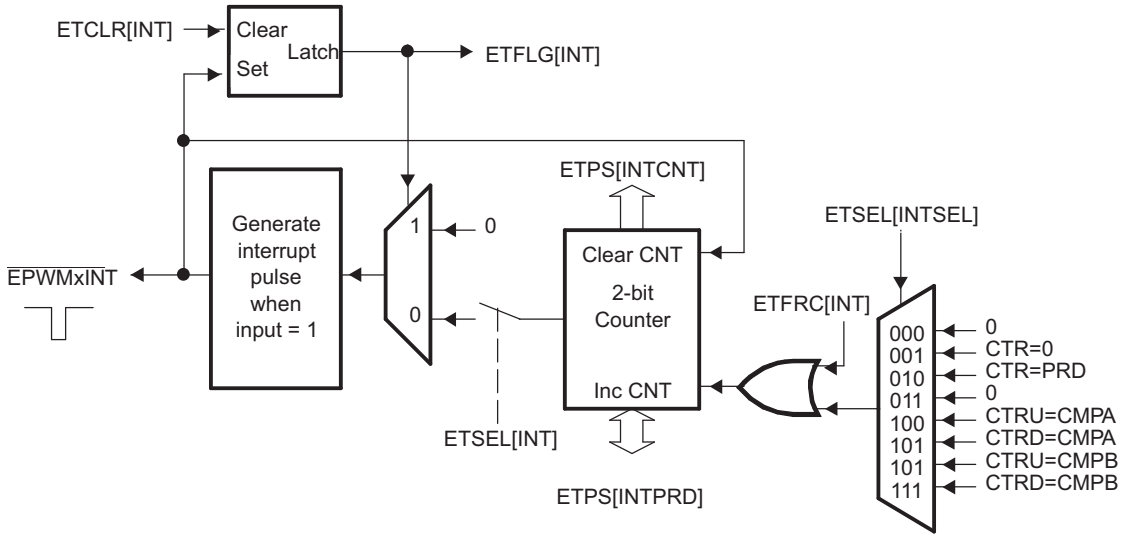
The number of events that have occurred can be read from the interrupt event counter (ETPS[INTCNT]) register bits. That is, when the specified event occurs the ETPS[INTCNT] bits are incremented until they reach the value specified by ETPS[INTPRD]. When ETPS[INTCNT] = ETPS[INTPRD] the counter stops counting and its output is set. The counter is only cleared when an interrupt is sent to the interrupt controller.

When ETPS[INTCNT] reaches ETPS[INTPRD], one of the following behaviors will occur:

- If interrupts are enabled, ETSEL[INTEN] = 1 and the interrupt flag is clear, ETFLG[INT] = 0, then an interrupt pulse is generated and the interrupt flag is set, ETFLG[INT] = 1, and the event counter is cleared ETPS[INTCNT] = 0. The counter will begin counting events again.
- If interrupts are disabled, ETSEL[INTEN] = 0, or the interrupt flag is set, ETFLG[INT] = 1, the counter stops counting events when it reaches the period value ETPS[INTCNT] = ETPS[INTPRD].
- If interrupts are enabled, but the interrupt flag is already set, then the counter will hold its output high until the ENTFLG[INT] flag is cleared. This allows for one interrupt to be pending while one is serviced.

Writing to the INTPRD bits will automatically clear the counter INTCNT = 0 and the counter output will be reset (so no interrupts are generated). Writing a 1 to the ETFRC[INT] bit will increment the event counter INTCNT. The counter will behave as described above when INTCNT = INTPRD. When INTPRD = 0, the counter is disabled and hence no events will be detected and the ETFRC[INT] bit is also ignored.

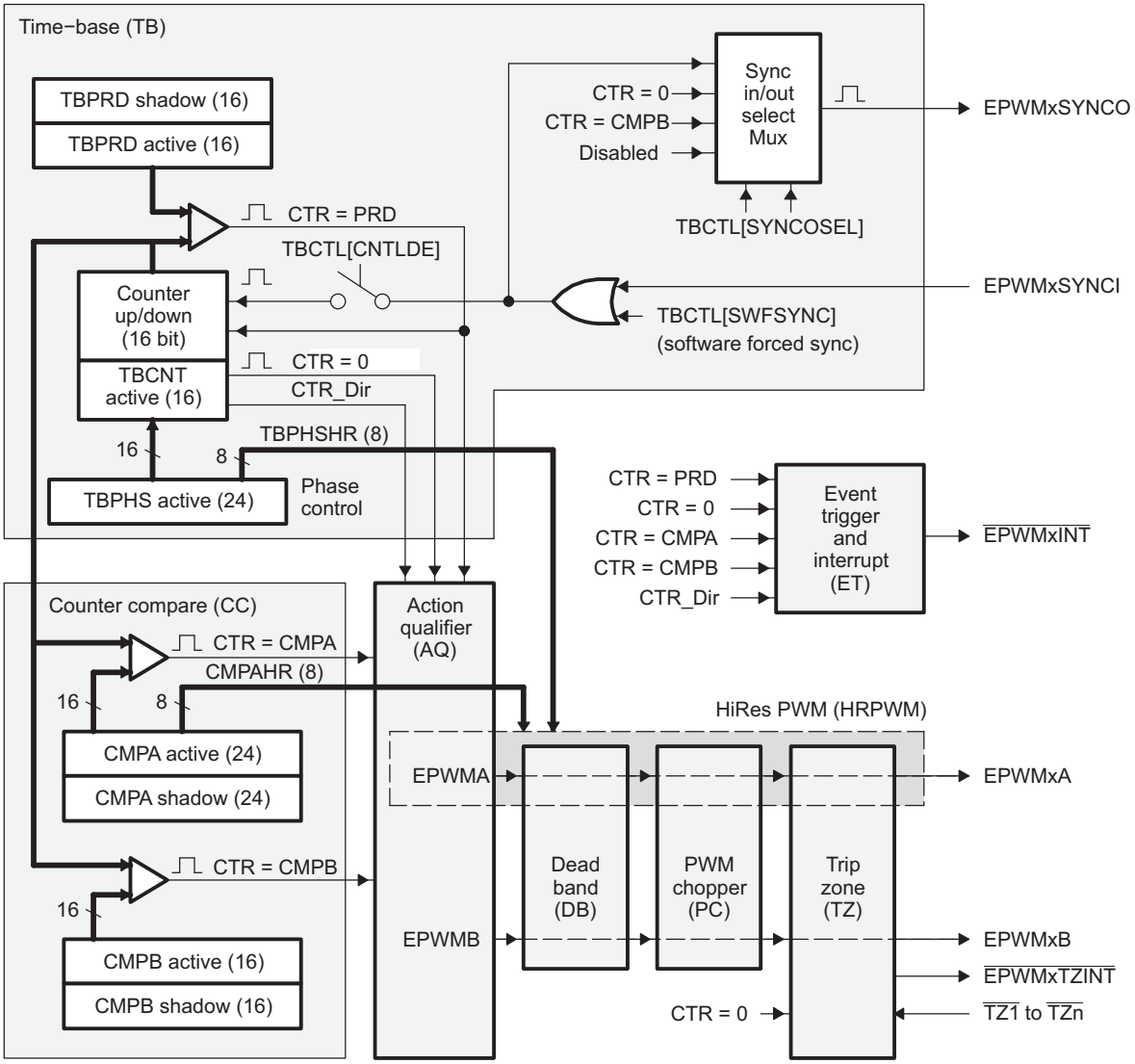
Figure 16-42. Event-Trigger Interrupt Generator



16.2.10 High-Resolution PWM (HRPWM) Submodule

Figure 16-43 shows the high-resolution PWM (HRPWM) submodule in the ePWM system. Some devices include the high-resolution PWM submodule, see your device-specific data manual to determine which ePWM instances include this feature.

Figure 16-43. HRPWM System Interface



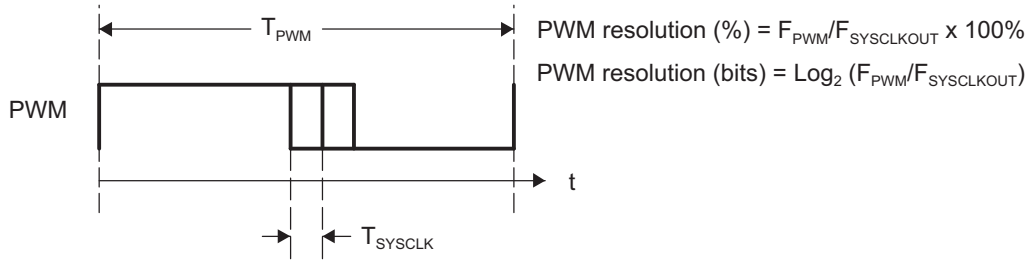
16.2.10.1 Purpose of the High-Resolution PWM Submodule

The enhanced high-resolution pulse-width modulator (eHRPWM) extends the time resolution capabilities of the conventionally derived digital pulse-width modulator (PWM). HRPWM is typically used when PWM resolution falls below ~9-10 bits. The key features of HRPWM are:

- Extended time resolution capability
- Used in both duty cycle and phase-shift control methods
- Finer time granularity control or edge positioning using extensions to the Compare A and Phase registers
- Implemented using the A signal path of PWM, that is, on the EPWMxA output. EPWMxB output has conventional PWM capabilities

The ePWM peripheral is used to perform a function that is mathematically equivalent to a digital-to-analog converter (DAC). As shown in Figure 16-44, the effective resolution for conventionally generated PWM is a function of PWM frequency (or period) and system clock frequency.

Figure 16-44. Resolution Calculations for Conventionally Generated PWM



If the required PWM operating frequency does not offer sufficient resolution in PWM mode, you may want to consider HRPWM. As an example of improved performance offered by HRPWM, Table 16-31 shows resolution in bits for various PWM frequencies. Table 16-31 values assume a MEP step size of 180 ps. See your device-specific data manual for typical and maximum performance specifications for the MEP.

Table 16-31. Resolution for PWM and HRPWM

	Regular Resolution (PWM)		High Resolution (HRPWM)	
PWM Frequency (kHz)	Bits	%	Bits	%
20	12.3	0.0	18.1	0.000
50	11.0	0.0	16.8	0.001
100	10.0	0.1	15.8	0.002
150	9.4	0.2	15.2	0.003
200	9.0	0.2	14.8	0.004
250	8.6	0.3	14.4	0.005
500	7.6	0.5	13.8	0.007
1000	6.6	1.0	12.4	0.018
1500	6.1	1.5	11.9	0.027
2000	5.6	2.0	11.4	0.036

Although each application may differ, typical low-frequency PWM operation (below 250 kHz) may not require HRPWM. HRPWM capability is most useful for high-frequency PWM requirements of power conversion topologies such as:

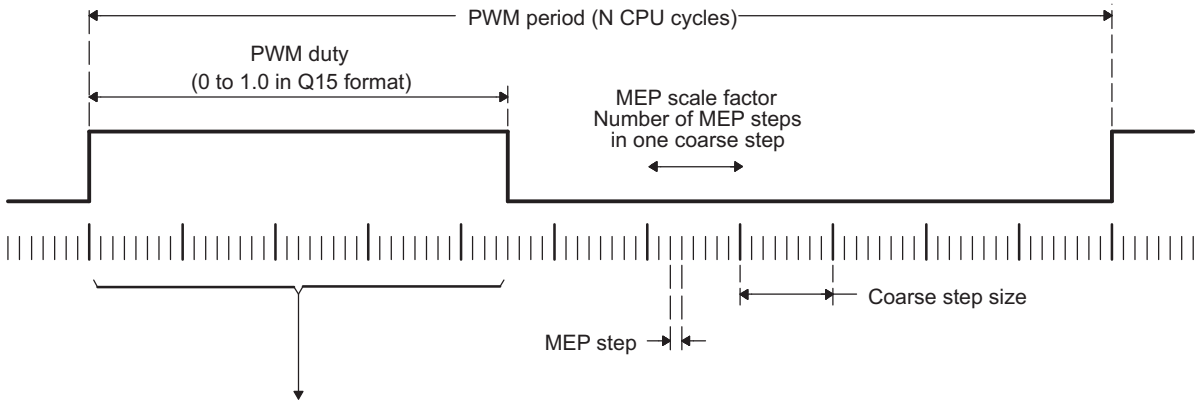
- Single-phase buck, boost, and flyback
- Multi-phase buck, boost, and flyback
- Phase-shifted full bridge
- Direct modulation of D-Class power amplifiers

16.2.10.2 Architecture of the High-Resolution PWM Submodule

The HRPWM is based on micro edge positioner (MEP) technology. MEP logic is capable of positioning an edge very finely by sub-dividing one coarse system clock of a conventional PWM generator. The time step accuracy is on the order of 150 ps. The HRPWM also has a self-check software diagnostics mode to check if the MEP logic is running optimally, under all operating conditions.

Figure 16-45 shows the relationship between one coarse system clock and edge position in terms of MEP steps, which are controlled via an 8-bit field in the Compare A extension register (CMPAHR).

Figure 16-45. Operating Logic Using MEP



Number of coarse steps = integer(PWMduty * PWMperiod)
Number of MEP steps = fraction(PWMduty * PWMperiod) * (MEPScaleFactor)

16−bit CMPA register value	= number of coarse steps
16−bit CMPAHR register value	= (number of MEP steps) << 8 + 0x180 (rounding) (A)

A For MEP range and rounding adjustment.

To generate an HRPWM waveform, configure the TBM, CCM, and AQM registers as you would to generate a conventional PWM of a given frequency and polarity. The HRPWM works together with the TBM, CCM, and AQM registers to extend edge resolution, and should be configured accordingly. Although many programming combinations are possible, only a few are needed and practical.

16.2.10.3 Controlling and Monitoring the High-Resolution PWM Submodule

The MEP of the HRPWM is controlled by two extension registers, each 8-bits wide. These two HRPWM registers are concatenated with the 16-bit TBPHS and CMPA registers used to control PWM operation.

- TBPHSHR - Time-Base Phase High-Resolution Register
- CMPAHR - Counter-Compare A High-Resolution Register

Table 16-32 lists the registers used to control and monitor the high-resolution PWM submodule.

Table 16-32. HRPWM Submodule Registers

Acronym	Register Description	Address Offset	Shadowed
TBPHSHR	Extension Register for HRPWM Phase	4h	No
CMPAHR	Extension Register for HRPWM Duty	10h	Yes
HRCNFG	HRPWM Configuration Register	1040h	No

16.2.10.4 Configuring the High-Resolution PWM Submodule

Once the ePWM has been configured to provide conventional PWM of a given frequency and polarity, the HRPWM is configured by programming the HRCNFG register located at offset address 1040h. This register provides configuration options for the following key operating modes:

- **Edge Mode:** The MEP can be programmed to provide precise position control on the rising edge (RE), falling edge (FE), or both edges (BE) at the same time. FE and RE are used for power topologies requiring duty cycle control, while BE is used for topologies requiring phase shifting, for example, phase shifted full bridge.
- **Control Mode:** The MEP is programmed to be controlled either from the CMPAHR register (duty cycle control) or the TBPHSHR register (phase control). RE or FE control mode should be used with CMPAHR register. BE control mode should be used with TBPHSHR register.
- **Shadow Mode:** This mode provides the same shadowing (double buffering) option as in regular PWM mode. This option is valid only when operating from the CMPAHR register and should be chosen to be the same as the regular load option for the CMPA register. If TBPHSHR is used, then this option has no effect.

16.2.10.5 Operational Highlights for the High-Resolution PWM Submodule

The MEP logic is capable of placing an edge in one of 255 (8 bits) discrete time steps, each of which has a time resolution on the order of 150 ps. The MEP works with the TBM and CCM registers to be certain that time steps are optimally applied and that edge placement accuracy is maintained over a wide range of PWM frequencies, system clock frequencies and other operating conditions. Table 16-33 shows the typical range of operating frequencies supported by the HRPWM.

Table 16-33. Relationship Between MEP Steps, PWM Frequency and Resolution

System (MHz)	MEP Steps Per SYSCLKOUT (1) (2) (3)	PWM Minimum (Hz) (4)	PWM Maximum (MHz)	Resolution at Maximum (Bits) (5)
50.0	111	763	2.50	11.1
60.0	93	916	3.00	10.9
70.0	79	1068	3.50	10.6
80.0	69	1221	4.00	10.4
90.0	62	1373	4.50	10.3
100.0	56	1526	5.00	10.1

(1) System frequency = SYSCLKOUT, that is, CPU clock. TBCLK = SYSCLKOUT
(2) Table data based on a MEP time resolution of 180 ps (this is an example value)
(3) MEP steps applied = $T_{SYSCLKOUT}$/180 ps in this example.
(4) PWM minimum frequency is based on a maximum period value, TBPRD = 65 535. PWM mode is asymmetrical up-count.
(5) Resolution in bits is given for the maximum PWM frequency stated.

16.2.10.5.1 Edge Positioning

In a typical power control loop (switch modes, digital motor control (DMC), uninterruptible power supply (UPS)), a digital controller (PID, 2pole/2zero, lag/lead, etc.) issues a duty command, usually expressed in a per unit or percentage terms.

In the following example, assume that for a particular operating point, the demanded duty cycle is 0.405 or 40.5% on-time and the required converter PWM frequency is 1.25 MHz. In conventional PWM generation with a system clock of 100 MHz, the duty cycle choices are in the vicinity of 40.5%. In Figure 16-46, a compare value of 32 counts (duty = 40%) is the closest to 40.5% that you can attain. This is equivalent to an edge position of 320 ns instead of the desired 324 ns. This data is shown in Table 16-34.

By utilizing the MEP, you can achieve an edge position much closer to the desired point of 324 ns. Table 16-34 shows that in addition to the CMPA value, 22 steps of the MEP (CMPAHR register) will position the edge at 323.96 ns, resulting in almost zero error. In this example, it is assumed that the MEP has a step resolution of 180 ns.

Figure 16-46. Required PWM Waveform for a Requested Duty = 40.5%

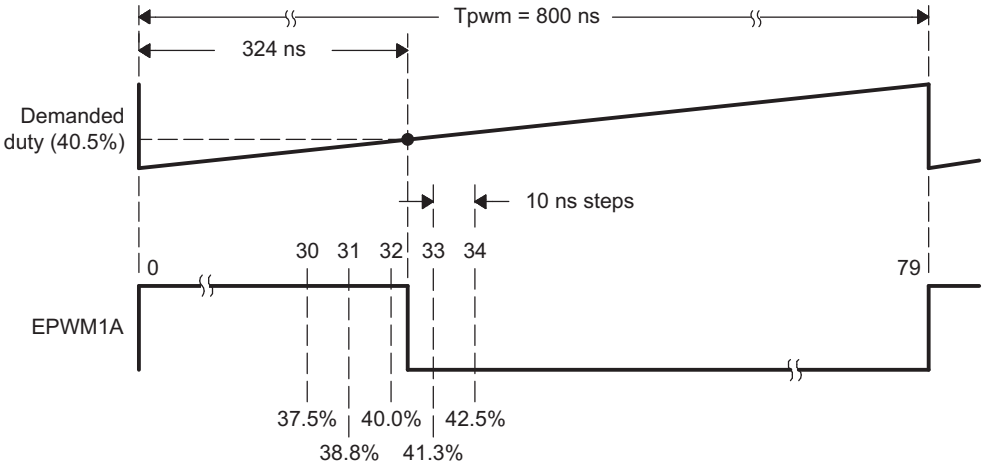


Table 16-34. CMPA vs Duty (left), and [CMPA:CMPAHR] vs Duty (right)

CMPA (count) (1) (2) (3)	DUTY (%)	High Time (ns)	CMPA (count)	CMPAHR (count)	Duty (%)	High Time (ns)
28	35.0	280	32	18	40.405	323.24
29	36.3	290	32	19	40.428	323.42
30	37.5	300	32	20	40.450	323.60
31	38.8	310	32	21	40.473	323.78
32	40.0	320	32	22	40.495	323.96
33	41.3	330	32	23	40.518	324.14
34	42.5	340	32	24	40.540	324.32
			32	25	40.563	324.50
Required			32	26	40.585	324.68
32.40	40.5	324	32	27	40.608	324.86

(1) System clock, SYSCLKOUT and TBCLK = 100 MHz, 10 ns
(2) For a PWM Period register value of 80 counts, PWM Period = 80 × 10 ns = 800 ns, PWM frequency = 1/800 ns = 1.25 MHz
(3) Assumed MEP step size for the above example = 180 ps

16.2.10.5.2 Scaling Considerations

The mechanics of how to position an edge precisely in time has been demonstrated using the resources of the standard (CMPA) and MEP (CMPAHR) registers. In a practical application, however, it is necessary to seamlessly provide the CPU a mapping function from a per-unit (fractional) duty cycle to a final integer (non-fractional) representation that is written to the [CMPA:CMPAHR] register combination.

To do this, first examine the scaling or mapping steps involved. It is common in control software to express duty cycle in a per-unit or percentage basis. This has the advantage of performing all needed math calculations without concern for the final absolute duty cycle, expressed in clock counts or high time in ns. Furthermore, it makes the code more transportable across multiple converter types running different PWM frequencies.

To implement the mapping scheme, a two-step scaling procedure is required.

Assumptions for this example:

System clock, SYSCLKOUT	=	10 ns (100 MHz)
PWM frequency	=	1.25 MHz (1/800 ns)
Required PWM duty cycle, **PWMDuty**	=	0.405 (40.5%)
PWM period in terms of coarse steps, **PWMperiod** (800 ns/10 ns)	=	80
Number of MEP steps per coarse step at 180 ps (10 ns/180 ps), **MEP_SF**	=	55
Value to keep CMPAHR within the range of 1-255 and fractional rounding constant (default value)	=	180h

Step 1: Percentage Integer Duty value conversion for CMPA register

CMPA register value	=	int(**PWMDuty** × **PWMperiod**); int means integer part
	=	int(0.405 × 80)
	=	int(32.4)
CMPA register value	=	32 (20h)

Step 2: Fractional value conversion for CMPAHR register

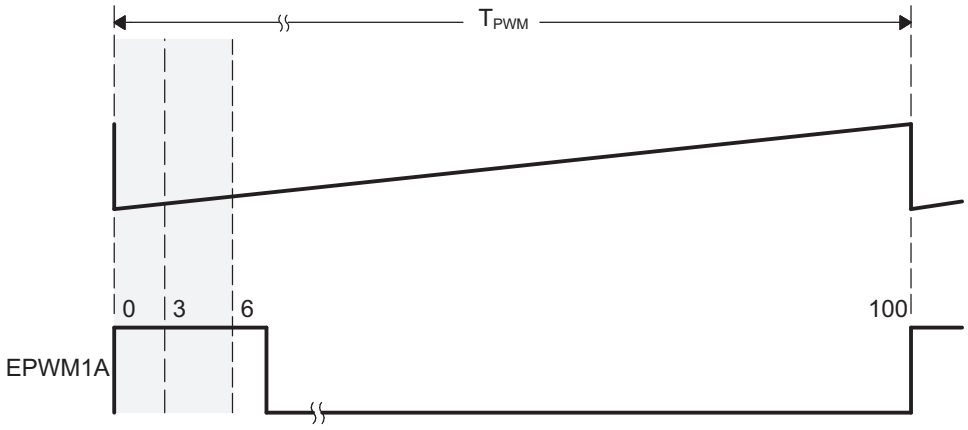
CMPAHR register value	=	(frac(**PWMDuty** × **PWMperiod**) × **MEP_SF**) << 8) + 180h; frac means fractional part
	=	(frac(32.4) × 55 <<8) + 180h; Shift is to move the value as CMPAHR high byte
	=	((0.4 × 55) <<8) + 180h
	=	(22 <<8) + 180h
	=	22 × 256 + 180h ; Shifting left by 8 is the same multiplying by 256.
	=	5632 + 180h
	=	1600h + 180h
CMPAHR value	=	1780h; CMPAHR value = 1700h, lower 8 bits will be ignored by hardware.

16.2.10.5.3 Duty Cycle Range Limitation

In high resolution mode, the MEP is not active for 100% of the PWM period. It becomes operational 3 SYSCLK cycles after the period starts.

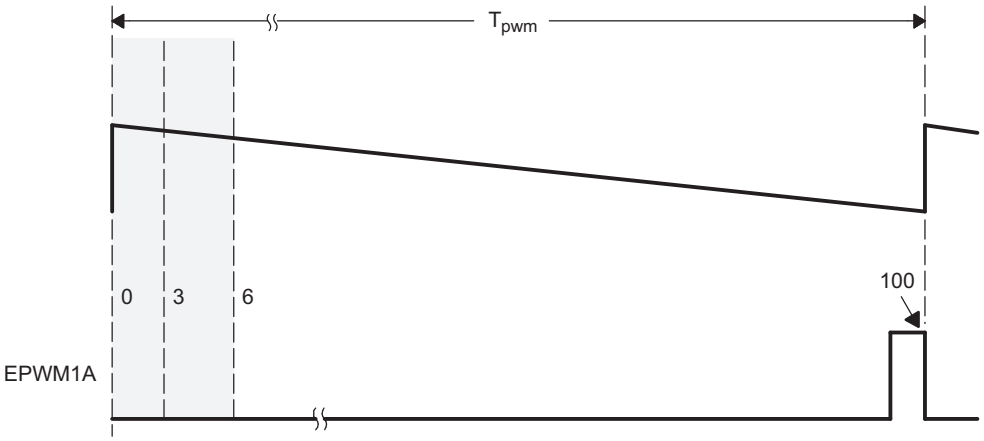
Duty cycle range limitations are illustrated in Figure 16-47. This limitation imposes a lower duty cycle limit on the MEP. For example, precision edge control is not available all the way down to 0% duty cycle. Although for the first 3 or 6 cycles, the HRPWM capabilities are not available, regular PWM duty control is still fully operational down to 0% duty. In most applications this should not be an issue as the controller regulation point is usually not designed to be close to 0% duty cycle.

Figure 16-47. Low % Duty Cycle Range Limitation Example When PWM Frequency = 1 MHz



If the application demands HRPWM operation in the low percent duty cycle region, then the HRPWM can be configured to operate in count-down mode with the rising edge position (REP) controlled by the MEP. This is illustrated in Figure 16-48. In this case low percent duty limitation is no longer an issue.

Figure 16-48. High % Duty Cycle Range Limitation Example when PWM Frequency = 1 MHz



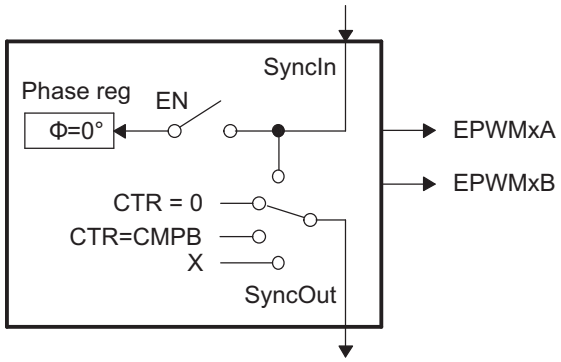
16.3 Applications to Power Topologies

An ePWM module has all the local resources necessary to operate completely as a standalone module or to operate in synchronization with other identical ePWM modules.

16.3.1 Overview of Multiple Modules

Previously in this user's guide, all discussions have described the operation of a single module. To facilitate the understanding of multiple modules working together in a system, the ePWM module described in reference is represented by the more simplified block diagram shown in Figure 16-49. This simplified ePWM block shows only the key resources needed to explain how a multiswitch power topology is controlled with multiple ePWM modules working together.

Figure 16-49. Simplified ePWM Module



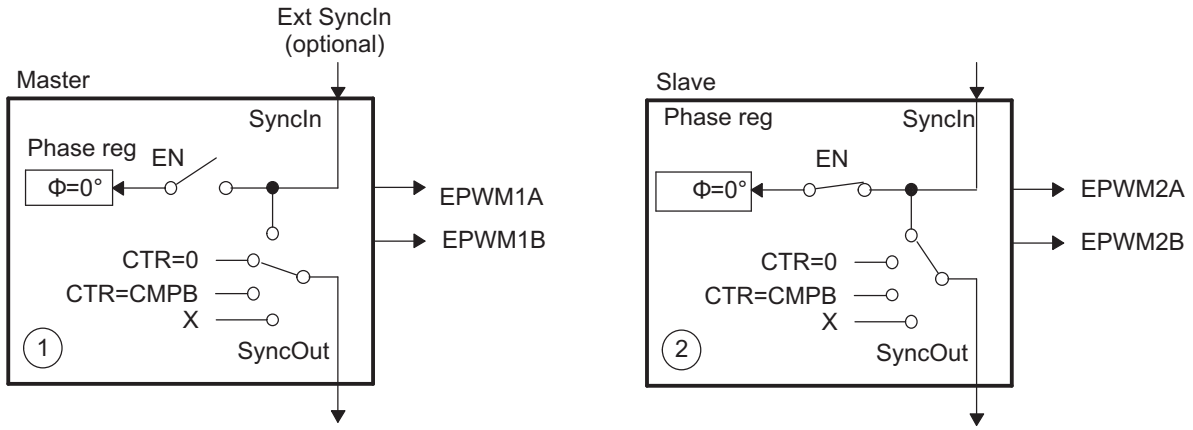
16.3.2 Key Configuration Capabilities

The key configuration choices available to each module are as follows:

- Options for SyncIn
  - Load own counter with phase register on an incoming sync strobe—enable (EN) switch closed
  - Do nothing or ignore incoming sync strobe—enable switch open
  - Sync flow-through - SyncOut connected to SyncIn
  - Master mode, provides a sync at PWM boundaries—SyncOut connected to CTR = PRD
  - Master mode, provides a sync at any programmable point in time—SyncOut connected to CTR = CMPB
  - Module is in standalone mode and provides No sync to other modules—SyncOut connected to X (disabled)
- Options for SyncOut
  - Sync flow-through - SyncOut connected to SyncIn
  - Master mode, provides a sync at PWM boundaries—SyncOut connected to CTR = PRD
  - Master mode, provides a sync at any programmable point in time—SyncOut connected to CTR = CMPB
  - Module is in standalone mode and provides No sync to other modules—SyncOut connected to X (disabled)

For each choice of SyncOut, a module may also choose to load its own counter with a new phase value on a SyncIn strobe input or choose to ignore it, i.e., via the enable switch. Although various combinations are possible, the two most common—master module and slave module modes—are shown in Figure 16-50.

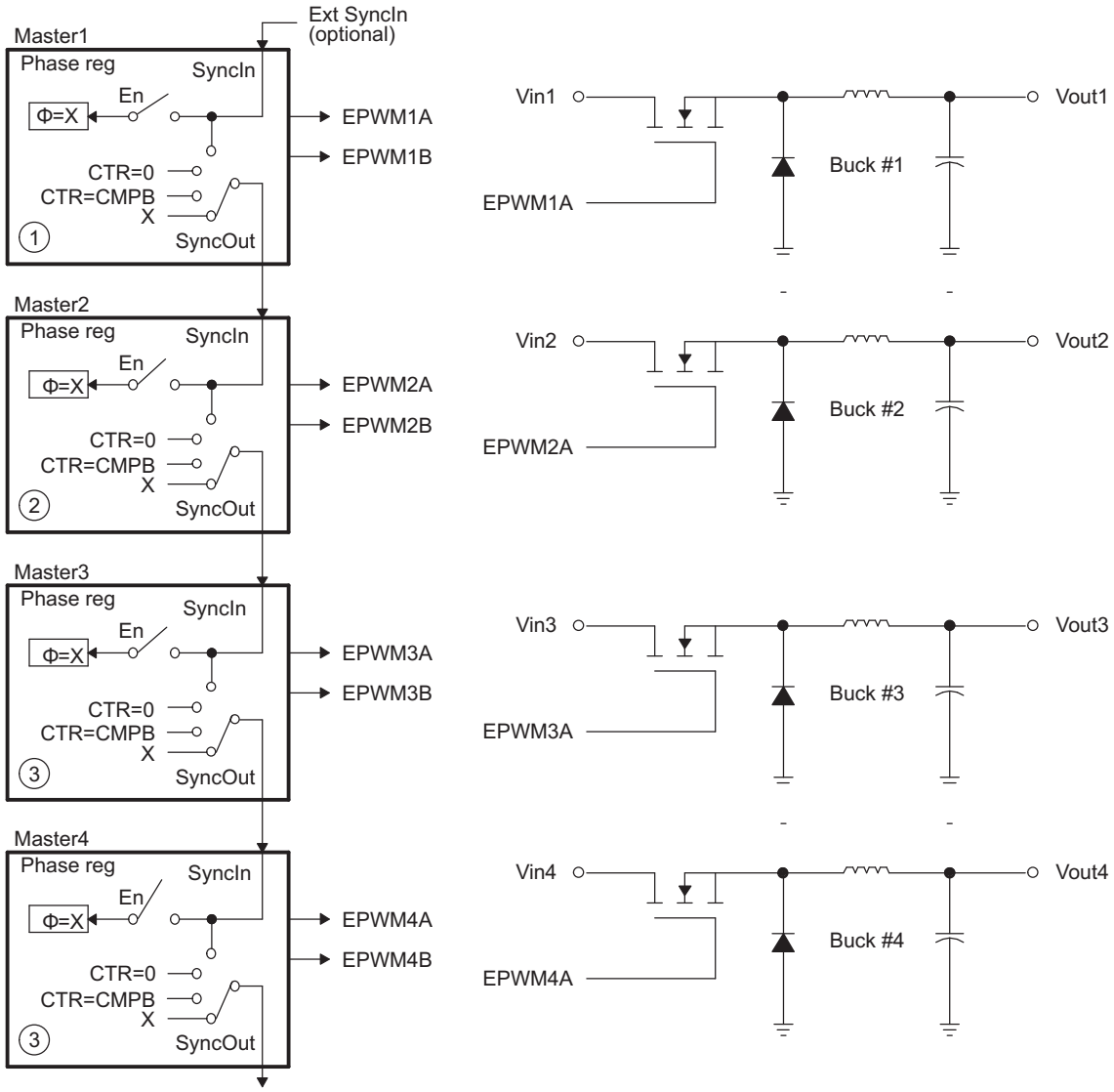
Figure 16-50. EPWM1 Configured as a Typical Master, EPWM2 Configured as a Slave



16.3.3 Controlling Multiple Buck Converters With Independent Frequencies

One of the simplest power converter topologies is the buck. A single ePWM module configured as a master can control two buck stages with the same PWM frequency. If independent frequency control is required for each buck converter, then one ePWM module must be allocated for each converter stage. Figure 16-51 shows four buck stages, each running at independent frequencies. In this case, all four ePWM modules are configured as Masters and no synchronization is used. Figure 16-52 shows the waveforms generated by the setup shown in Figure 16-51; note that only three waveforms are shown, although there are four stages.

Figure 16-51. Control of Four Buck Stages. (Note: $F_{PWM1} \neq F_{PWM2} \neq F_{PWM3} \neq F_{PWM4}$)



NOTE: Θ = X indicates value in phase register is a "don't care"

Figure 16-52. Buck Waveforms for Figure 16-51 (Note: Only three bucks shown here)

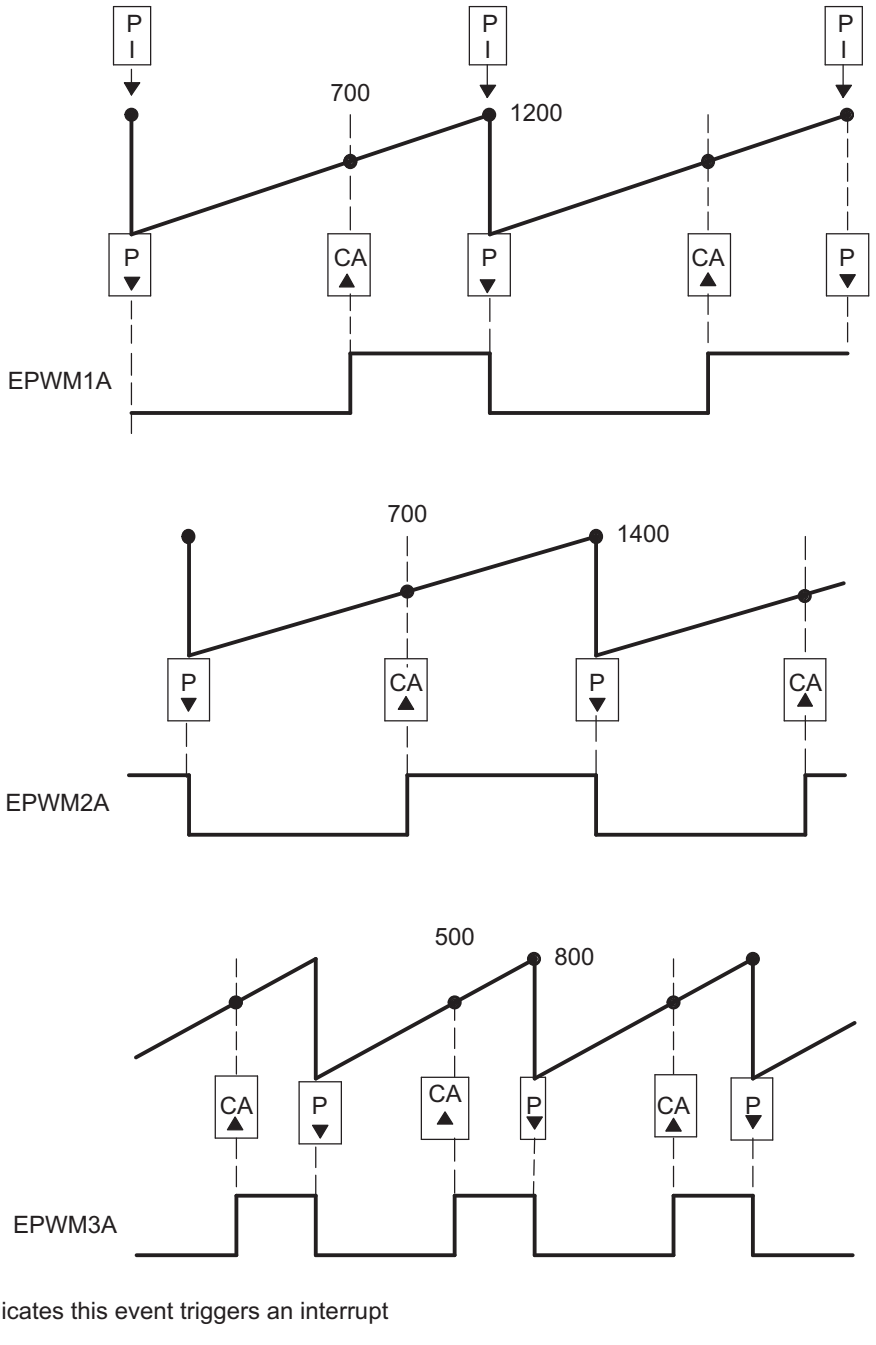


Table 16-35. EPWM1 Initialization for Figure 16-52

Register	Bit	Value	Comments
TBPRD	TBPRD	1200 (4B0h)	Period = 1201 TBCLK counts
TBPHS	TBPHS	0	Clear Phase Register to 0
TBCTL	CTRMODE	TB_UP	
	PHSEN	TB_DISABLE	Phase loading disabled
	PRDLD	TB_SHADOW	
	SYNCOSEL	TB_SYNC_DISABLE	
CMPCTL	SHDWAMODE	CC_SHADOW	
	SHDWBMODE	CC_SHADOW	
	LOADAMODE	CC_CTR_ZERO	Load on CTR = 0
	LOADBMODE	CC_CTR_ZERO	Load on CTR = 0
AQCTLA	PRD	AQ_CLEAR	
	CAU	AQ_SET	

Table 16-36. EPWM2 Initialization for Figure 16-52

Register	Bit	Value	Comments
TBPRD	TBPRD	1400 (578h)	Period = 1401 TBCLK counts
TBPHS	TBPHS	0	Clear Phase Register to 0
TBCTL	CTRMODE	TB_UP	
	PHSEN	TB_DISABLE	Phase loading disabled
	PRDLD	TB_SHADOW	
	SYNCOSEL	TB_SYNC_DISABLE	
CMPCTL	SHDWAMODE	CC_SHADOW	
	SHDWBMODE	CC_SHADOW	
	LOADAMODE	CC_CTR_ZERO	Load on CTR = 0
	LOADBMODE	CC_CTR_ZERO	Load on CTR = 0
AQCTLA	PRD	AQ_CLEAR	
	CAU	AQ_SET	

Table 16-37. EPWM3 Initialization for Figure 16-52

Register	Bit	Value	Comments
TBPRD	TBPRD	800 (320h)	Period = 801 TBCLK counts
TBPHS	TBPHS	0	Clear Phase Register to 0
TBCTL	CTRMODE	TB_UP	
	PHSEN	TB_DISABLE	Phase loading disabled
	PRDLD	TB_SHADOW	
	SYNCOSEL	TB_SYNC_DISABLE	
CMPCTL	SHDWAMODE	CC_SHADOW	
	SHDWBMODE	CC_SHADOW	
	LOADAMODE	CC_CTR_ZERO	Load on CTR = 0
	LOADBMODE	CC_CTR_ZERO	Load on CTR = 0
AQCTLA	PRD	AQ_CLEAR	
	CAU	AQ_SET	

Example 16-3. Configuration for Example in Figure 16-52

```
// Run Time (Note: Example execution of one run-time instance)
//=====================================================
    EPwm1Regs.CMPA.half.CMPA = 700;              // adjust duty for output EPWM1A
    EPwm2Regs.CMPA.half.CMPA = 700;              // adjust duty for output EPWM2A
    EPwm3Regs.CMPA.half.CMPA = 500;              // adjust duty for output EPWM3A
```

16.3.4 Controlling Multiple Buck Converters With Same Frequencies

If synchronization is a requirement, ePWM module 2 can be configured as a slave and can operate at integer multiple (N) frequencies of module 1. The sync signal from master to slave ensures these modules remain locked. Figure 16-53 shows such a configuration; Figure 16-54 shows the waveforms generated by the configuration.

Figure 16-53. Control of Four Buck Stages. (Note: $F_{PWM2} = N \times F_{PWM1}$)

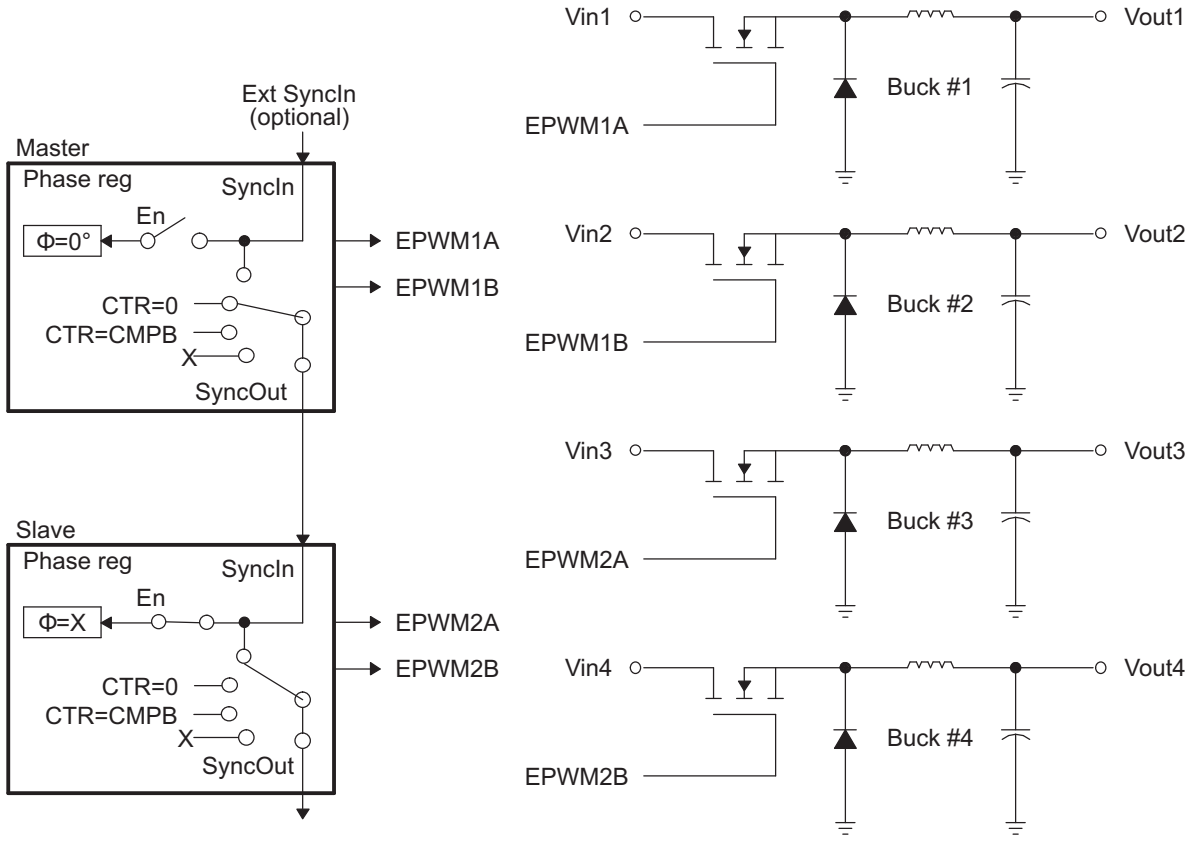


Figure 16-54. Buck Waveforms for Figure 16-53 (Note: $F_{PWM2} = F_{PWM1}$)

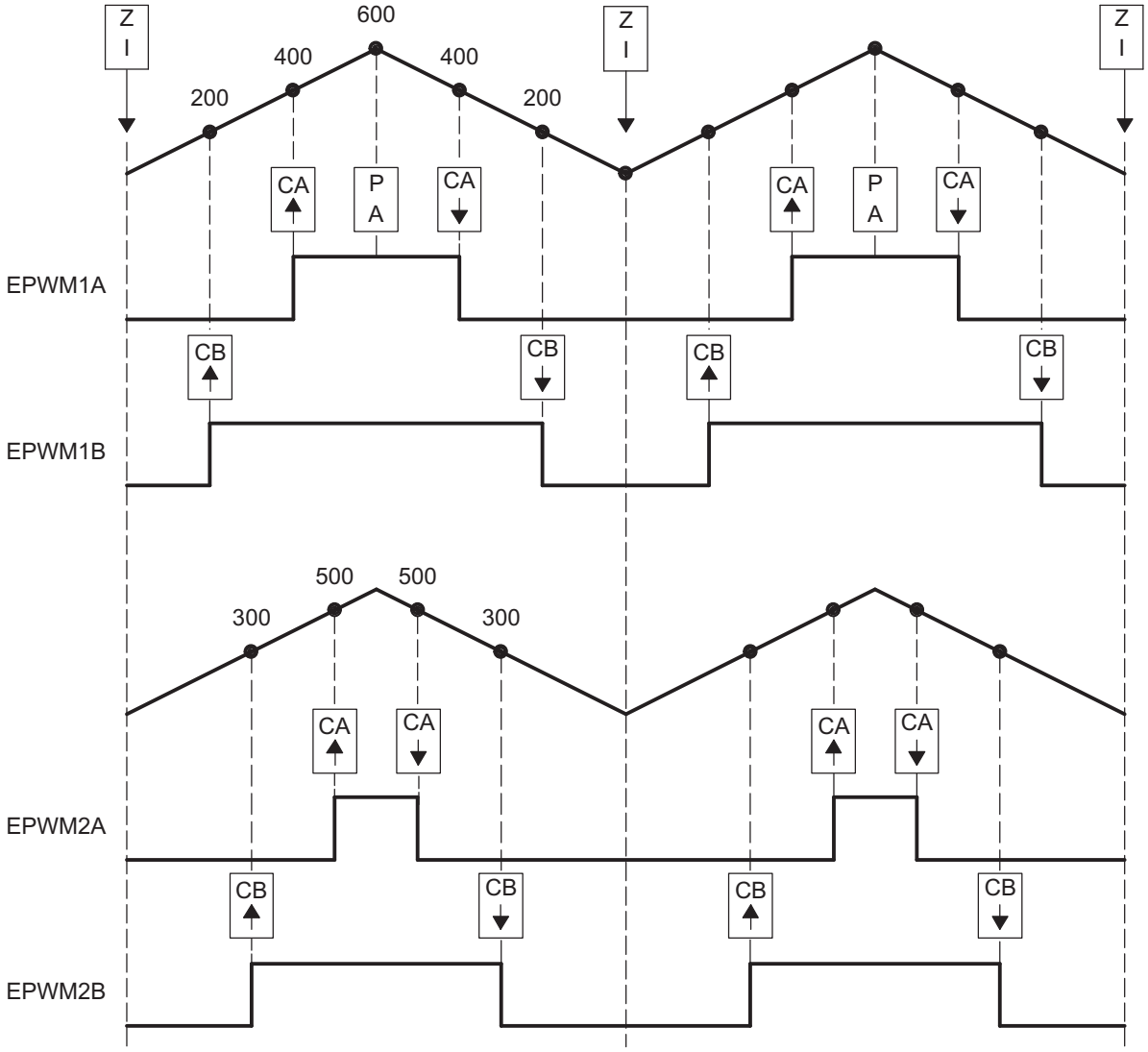


Table 16-38. EPWM1 Initialization for Figure 16-53

Register	Bit	Value	Comments
TBPRD	TBPRD	600 (258h)	Period = 1200 TBCLK counts
TBPHS	TBPHS	0	Clear Phase Register to 0
TBCTL	CTRMODE	TB_UPDOWN	
	PHSEN	TB_DISABLE	Phase loading disabled
	PRDLD	TB_SHADOW	
	SYNCOSEL	TB_CTR_ZERO	Sync down-stream module
CMPCTL	SHDWAMODE	CC_SHADOW	
	SHDWBMODE	CC_SHADOW	
	LOADAMODE	CC_CTR_ZERO	Load on CTR = 0
	LOADBMODE	CC_CTR_ZERO	Load on CTR = 0
AQCTLA	CAU	AQ_SET	Set actions for EPWM1A
	CAD	AQ_CLEAR	
AQCTLB	CBU	AQ_SET	Set actions for EPWM1B
	CBD	AQ_CLEAR	

Table 16-39. EPWM2 Initialization for Figure 16-53

Register	Bit	Value	Comments
TBPRD	TBPRD	600 (258h)	Period = 1200 TBCLK counts
TBPHS	TBPHS	0	Clear Phase Register to 0
TBCTL	CTRMODE	TB_UPDOWN	
	PHSEN	TB_ENABLE	Phase loading enabled
	PRDLD	TB_SHADOW	
	SYNCOSEL	TB_SYNC_IN	Sync flow-through
CMPCTL	SHDWAMODE	CC_SHADOW	
	SHDWBMODE	CC_SHADOW	
	LOADAMODE	CC_CTR_ZERO	Load on CTR = 0
	LOADBMODE	CC_CTR_ZERO	Load on CTR = 0
AQCTLA	CAU	AQ_SET	Set actions for EPWM2A
	CAD	AQ_CLEAR	
AQCTLB	CBU	AQ_SET	Set actions for EPWM2B
	CBD	AQ_CLEAR	

Example 16-4. Code Snippet for Configuration in Figure 16-53

```
// Run Time (Note: Example execution of one run-time instance)
//=========================================================
     EPwm1Regs.CMPA.half.CMPA = 400;       // adjust duty for output EPWM1A
     EPwm1Regs.CMPB = 200;                 // adjust duty for output EPWM1B
     EPwm2Regs.CMPA.half.CMPA = 500;       // adjust duty for output EPWM2A
     EPwm2Regs.CMPB = 300;                 // adjust duty for output EPWM2B
```

16.3.5 Controlling Multiple Half H-Bridge (HHB) Converters

Topologies that require control of multiple switching elements can also be addressed with these same ePWM modules. It is possible to control a Half-H bridge stage with a single ePWM module. This control can be extended to multiple stages. Figure 16-55 shows control of two synchronized Half-H bridge stages where stage 2 can operate at integer multiple (N) frequencies of stage 1. Figure 16-56 shows the waveforms generated by the configuration shown in Figure 16-55.

Module 2 (slave) is configured for Sync flow-through; if required, this configuration allows for a third Half-H bridge to be controlled by PWM module 3 and also, most importantly, to remain in synchronization with master module 1.

Figure 16-55. Control of Two Half-H Bridge Stages ($F_{PWM2} = N \times F_{PWM1}$)

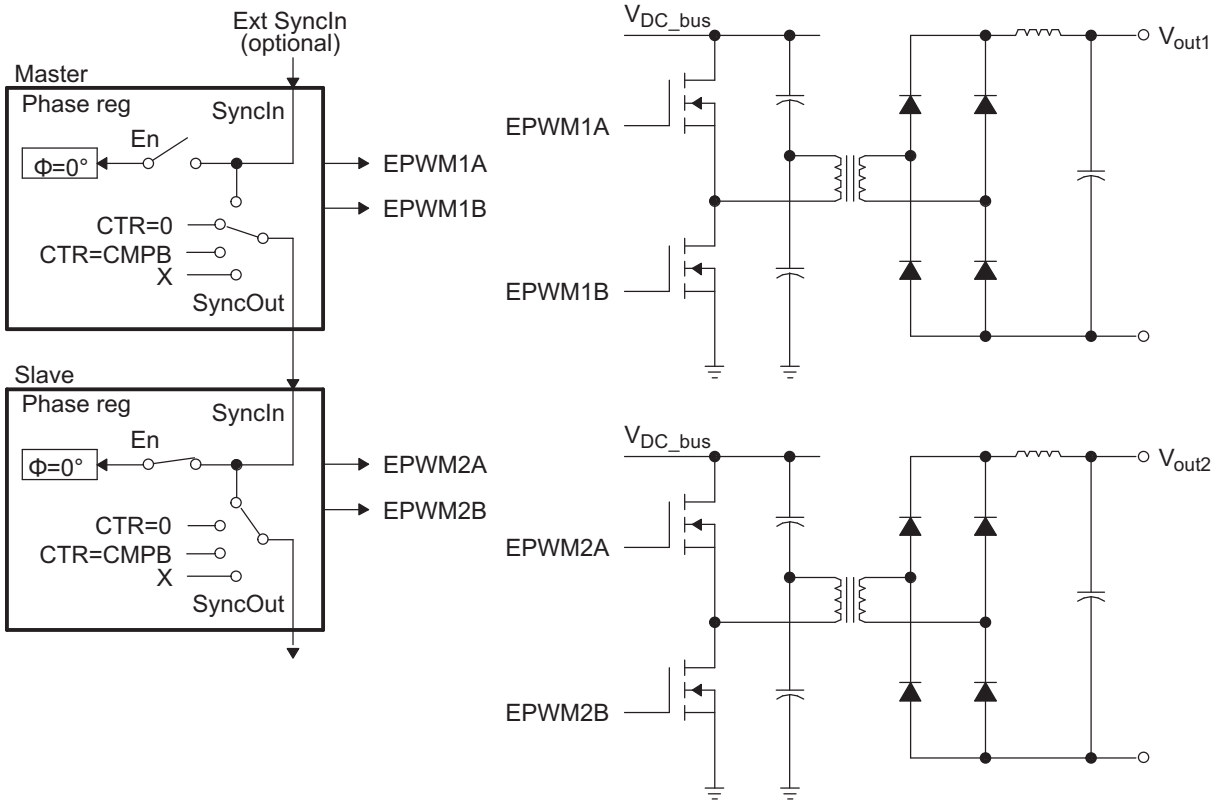


Figure 16-56. Half-H Bridge Waveforms for Figure 16-55 (Note: $F_{PWM2} = F_{PWM1}$)

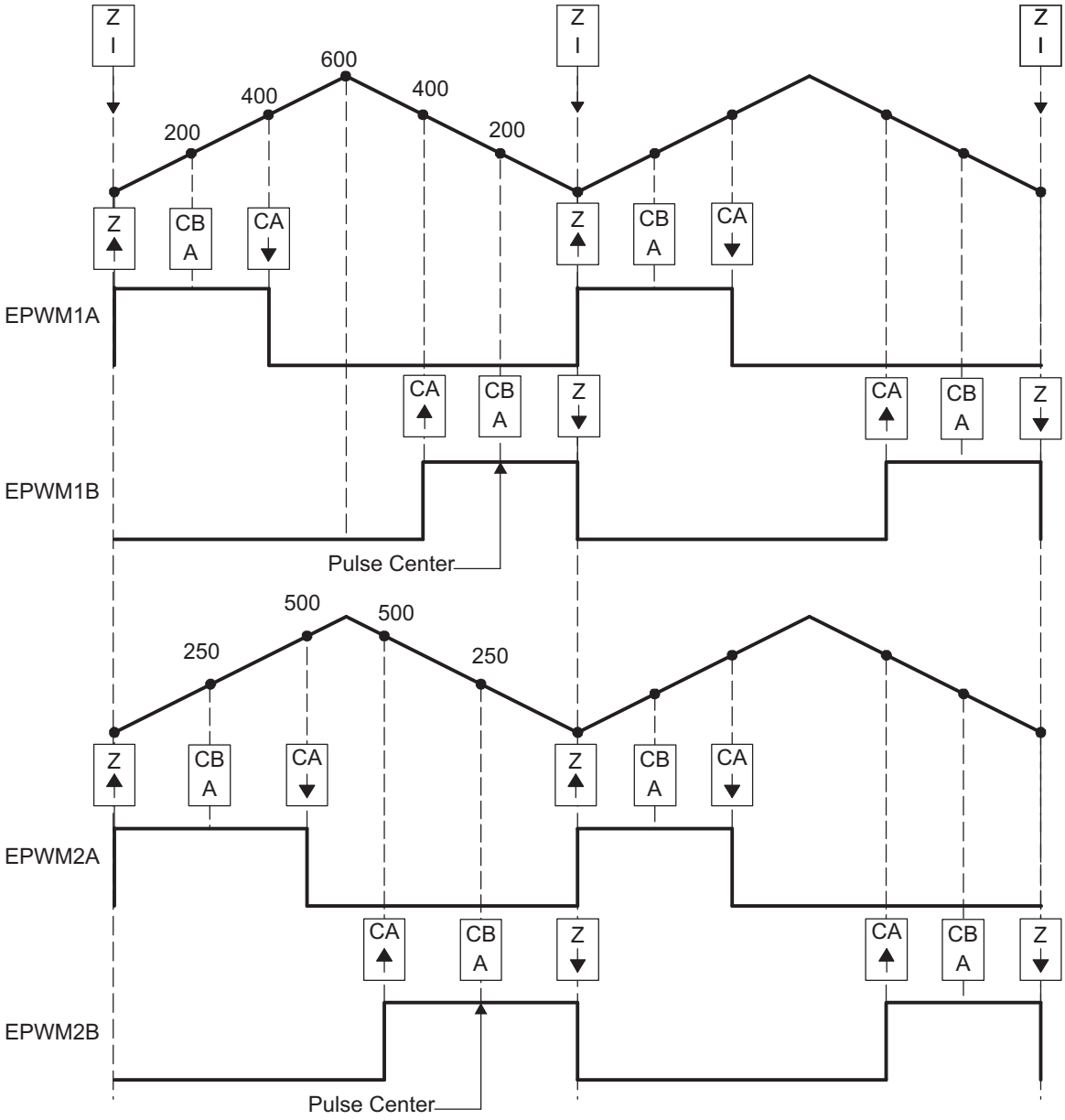


Table 16-40. EPWM1 Initialization for Figure 16-55

Register	Bit	Value	Comments
TBPRD	TBPRD	600 (258h)	Period = 1200 TBCLK counts
TBPHS	TBPHS	0	Clear Phase Register to 0
TBCTL	CTRMODE	TB_UPDOWN	
	PHSEN	TB_DISABLE	Phase loading disabled
	PRDLD	TB_SHADOW	
	SYNCOSEL	TB_CTR_ZERO	Sync down-stream module
CMPCTL	SHDWAMODE	CC_SHADOW	
	SHDWBMODE	CC_SHADOW	
	LOADAMODE	CC_CTR_ZERO	Load on CTR = 0
	LOADBMODE	CC_CTR_ZERO	Load on CTR = 0
AQCTLA	ZRO	AQ_SET	Set actions for EPWM1A
	CAU	AQ_CLEAR	
AQCTLB	ZRO	AQ_CLEAR	Set actions for EPWM1B
	CAD	AQ_SET	

Table 16-41. EPWM2 Initialization for Figure 16-55

Register	Bit	Value	Comments
TBPRD	TBPRD	600 (258h)	Period = 1200 TBCLK counts
TBPHS	TBPHS	0	Clear Phase Register to 0
TBCTL	CTRMODE	TB_UPDOWN	
	PHSEN	TB_ENABLE	Phase loading enabled
	PRDLD	TB_SHADOW	
	SYNCOSEL	TB_SYNC_IN	Sync flow-through
CMPCTL	SHDWAMODE	CC_SHADOW	
	SHDWBMODE	CC_SHADOW	
	LOADAMODE	CC_CTR_ZERO	Load on CTR = 0
	LOADBMODE	CC_CTR_ZERO	Load on CTR = 0
AQCTLA	ZRO	AQ_SET	Set actions for EPWM2A
	CAU	AQ_CLEAR	
AQCTLB	ZRO	AQ_CLEAR	Set actions for EPWM2B
	CAD	AQ_SET	

Example 16-5. Code Snippet for Configuration in Figure 16-55

```
// Run Time (Note: Example execution of one run-time instance)
//=========================================================
     EPwm1Regs.CMPA.half.CMPA = 400; // adjust duty for output EPWM1A
     EPwm1Regs.CMPB = 200;           // adjust duty for output EPWM1B
     EPwm2Regs.CMPA.half.CMPA = 500; // adjust duty for output EPWM2A
     EPwm2Regs.CMPB = 250;           // adjust duty for output EPWM2B
```

16.3.6 Controlling Dual 3-Phase Inverters for Motors (ACI and PMSM)

The idea of multiple modules controlling a single power stage can be extended to the 3-phase Inverter case. In such a case, six switching elements can be controlled using three PWM modules, one for each leg of the inverter. Each leg must switch at the same frequency and all legs must be synchronized. A master + two slaves configuration can easily address this requirement. Figure 16-57 shows how six PWM modules can control two independent 3-phase Inverters; each running a motor.

As in the cases shown in the previous sections, we have a choice of running each inverter at a different frequency (module 1 and module 4 are masters as in Figure 16-57), or both inverters can be synchronized by using one master (module 1) and five slaves. In this case, the frequency of modules 4, 5, and 6 (all equal) can be integer multiples of the frequency for modules 1, 2, 3 (also all equal).

Figure 16-57. Control of Dual 3-Phase Inverter Stages as Is Commonly Used in Motor Control

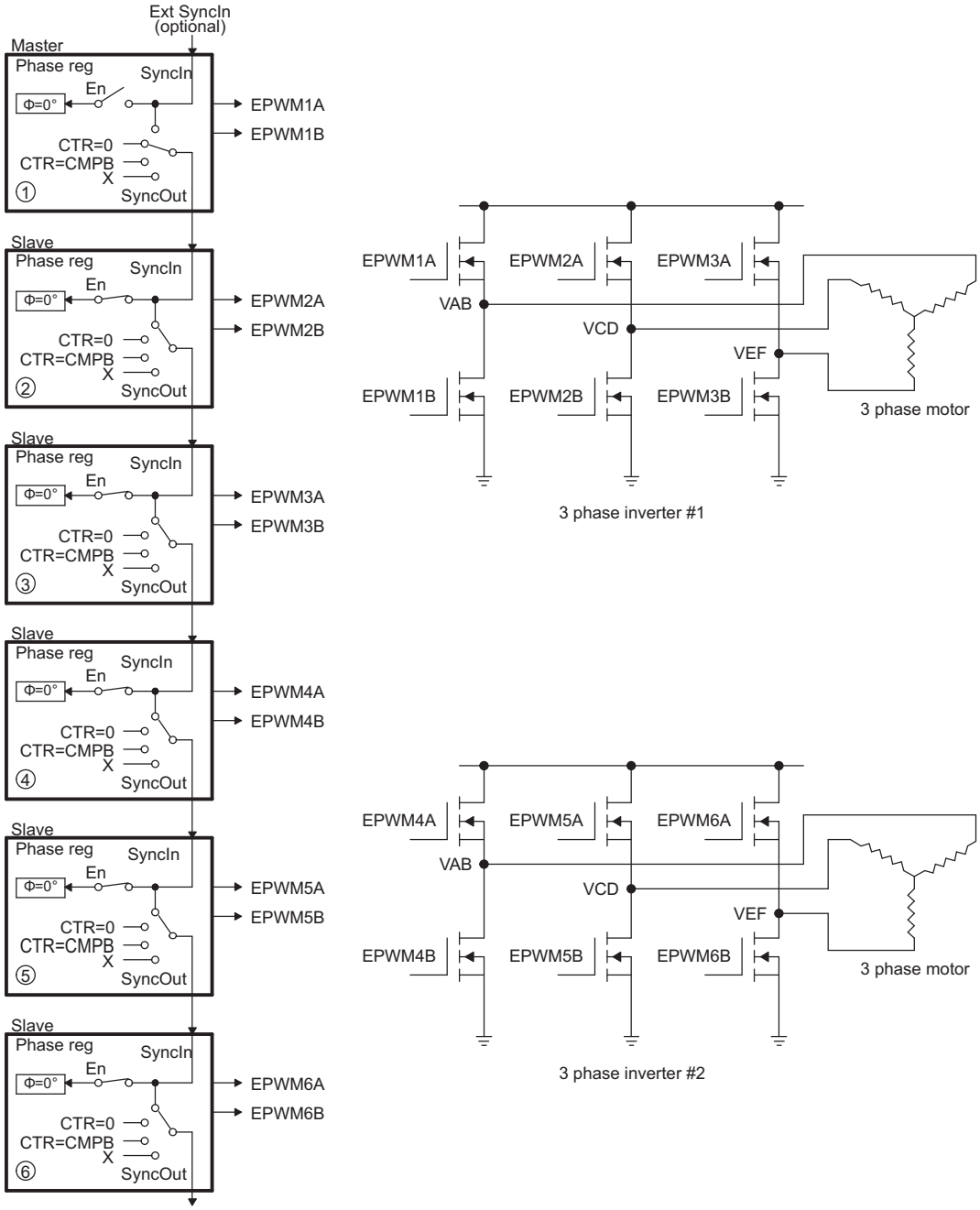


Figure 16-58. 3-Phase Inverter Waveforms for Figure 16-57 (Only One Inverter Shown)

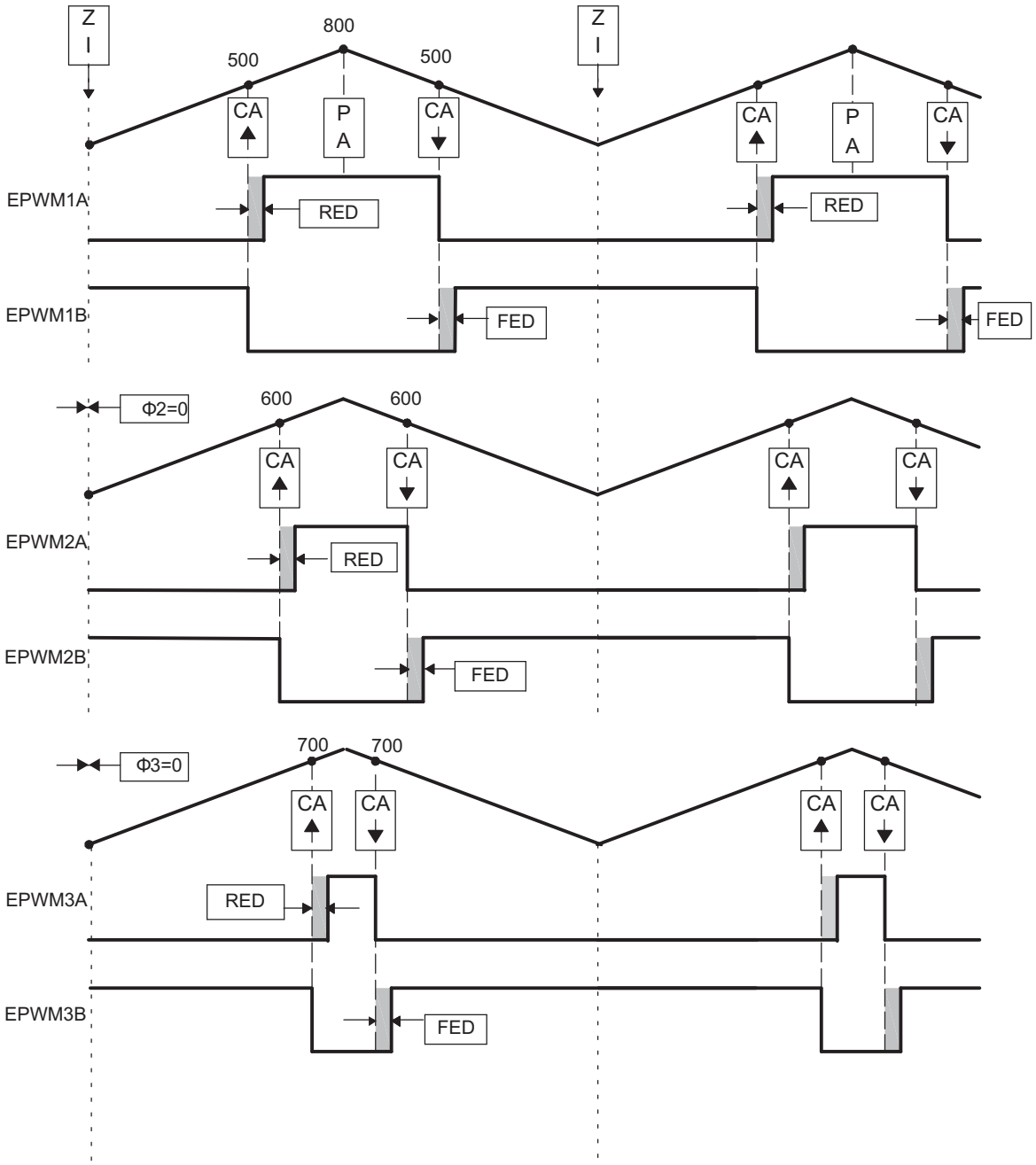


Table 16-42. EPWM1 Initialization for Figure 16-57

Register	Bit	Value	Comments
TBPRD	TBPRD	800 (320h)	Period = 1600 TBCLK counts
TBPHS	TBPHS	0	Clear Phase Register to 0
TBCTL	CTRMODE	TB_UPDOWN	
	PHSEN	TB_DISABLE	Phase loading disabled
	PRDLD	TB_SHADOW	
	SYNCOSEL	TB_CTR_ZERO	Sync down-stream module
CMPCTL	SHDWAMODE	CC_SHADOW	
	SHDWBMODE	CC_SHADOW	
	LOADAMODE	CC_CTR_ZERO	Load on CTR = 0
	LOADBMODE	CC_CTR_ZERO	Load on CTR = 0
AQCTLA	CAU	AQ_SET	Set actions for EPWM1A
	CAD	AQ_CLEAR	
DBCTL	MODE	DB_FULL_ENABLE	Enable Dead-band module
	POLSEL	DB_ACTV_HIC	Active Hi complementary
DBFED	DBFED	50	FED = 50 TBCLKs
	DBRED	50	RED = 50 TBCLKs

Table 16-43. EPWM2 Initialization for Figure 16-57

Register	Bit	Value	Comments
TBPRD	TBPRD	800 (320h)	Period = 1600 TBCLK counts
TBPHS	TBPHS	0	Clear Phase Register to 0
TBCTL	CTRMODE	TB_UPDOWN	
	PHSEN	TB_ENABLE	Slave module
	PRDLD	TB_SHADOW	
	SYNCOSEL	TB_SYNC_IN	Sync flow-through
CMPCTL	SHDWAMODE	CC_SHADOW	
	SHDWBMODE	CC_SHADOW	
	LOADAMODE	CC_CTR_ZERO	Load on CTR = 0
	LOADBMODE	CC_CTR_ZERO	Load on CTR = 0
AQCTLA	CAU	AQ_SET	Set actions for EPWM2A
	CAD	AQ_CLEAR	
DBCTL	MODE	DB_FULL_ENABLE	Enable Dead-band module
	POLSEL	DB_ACTV_HIC	Active Hi complementary
DBFED	DBFED	50	FED = 50 TBCLKs
	DBRED	50	RED = 50 TBCLKs

Table 16-44. EPWM3 Initialization for Figure 16-57

Register	Bit	Value	Comments
TBPRD	TBPRD	800 (320h)	Period = 1600 TBCLK counts
TBPHS	TBPHS	0	Clear Phase Register to 0
TBCTL	CTRMODE	TB_UPDOWN	
	PHSEN	TB_ENABLE	Slave module
	PRDLD	TB_SHADOW	
	SYNCOSEL	TB_SYNC_IN	Sync flow-through
CMPCTL	SHDWAMODE	CC_SHADOW	
	SHDWBMODE	CC_SHADOW	
	LOADAMODE	CC_CTR_ZERO	Load on CTR = 0
	LOADBMODE	CC_CTR_ZERO	Load on CTR = 0
AQCTLA	CAU	AQ_SET	Set actions for EPWM3A
	CAD	AQ_CLEAR	
DBCTL	MODE	DB_FULL_ENABLE	Enable Dead-band module
	POLSEL	DB_ACTV_HIC	Active Hi complementary
DBFED	DBFED	50	FED = 50 TBCLKs
	DBRED	50	RED = 50 TBCLKs

Example 16-6. Code Snippet for Configuration in Figure 16-57

```
// Run Time (Note: Example execution of one run-time instance)
//=====================================================
EPwm1Regs.CMPA.half.CMPA = 500; // adjust duty for output EPWM1A
EPwm2Regs.CMPA.half.CMPA = 600; // adjust duty for output EPWM2A
EPwm3Regs.CMPA.half.CMPA = 700; // adjust duty for output EPWM3A
```

16.3.7 Practical Applications Using Phase Control Between PWM Modules

So far, none of the examples have made use of the phase register (TBPHS). It has either been set to zero or its value has been a don't care. However, by programming appropriate values into TBPHS, multiple PWM modules can address another class of power topologies that rely on phase relationship between legs (or stages) for correct operation. As described in the TB module section, a PWM module can be configured to allow a SyncIn pulse to cause the TBPHS register to be loaded into the TBCNT register. To illustrate this concept, Figure 16-59 shows a master and slave module with a phase relationship of 120°, that is, the slave leads the master.

Figure 16-59. Configuring Two PWM Modules for Phase Control

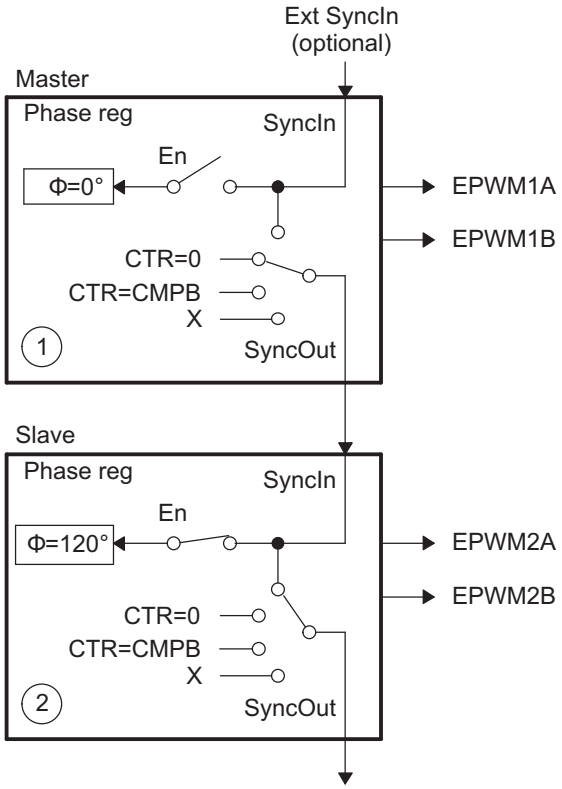
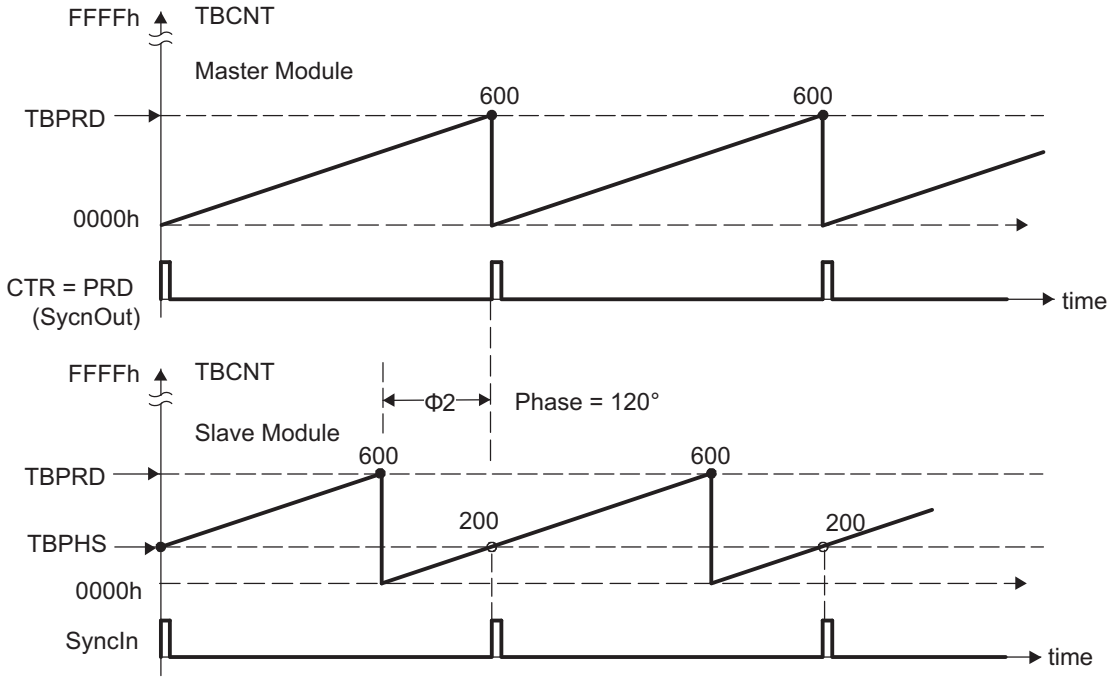


Figure 16-60 shows the associated timing waveforms for this configuration. Here, TBPRD = 600 for both master and slave. For the slave, TBPHS = 200 (200/600 × 360° = 120°). Whenever the master generates a SyncIn pulse (CTR = PRD), the value of TBPHS = 200 is loaded into the slave TBCNT register so the slave time-base is always leading the master's time-base by 120°.

Figure 16-60. Timing Waveforms Associated With Phase Control Between 2 Modules



16.3.8 Controlling a 3-Phase Interleaved DC/DC Converter

A popular power topology that makes use of phase-offset between modules is shown in Figure 16-61. This system uses three PWM modules, with module 1 configured as the master. To work, the phase relationship between adjacent modules must be F = 120°. This is achieved by setting the slave TBPHS registers 2 and 3 with values of 1/3 and 2/3 of the period value, respectively. For example, if the period register is loaded with a value of 600 counts, then TBPHS (slave 2) = 200 and TBPHS (slave 3) = 400. Both slave modules are synchronized to the master 1 module.

This concept can be extended to four or more phases, by setting the TBPHS values appropriately. The following formula gives the TBPHS values for N phases:

TBPHS(N,M) = (TBPRD/N) × (M - 1)

Where:

N = number of phases

M = PWM module number

For example, for the 3-phase case (N = 3), TBPRD = 600,

TBPHS(3,2) = (600/3) × (2 - 1) = 200 × 1 = 200 (Phase value for Slave module 2)

TBPHS(3,3) = (600/3) × (3 - 1) = 200 × 2 = 400 (Phase value for Slave module 3)

Figure 16-62 shows the waveforms for the configuration in Figure 16-61.

Figure 16-61. Control of a 3-Phase Interleaved DC/DC Converter

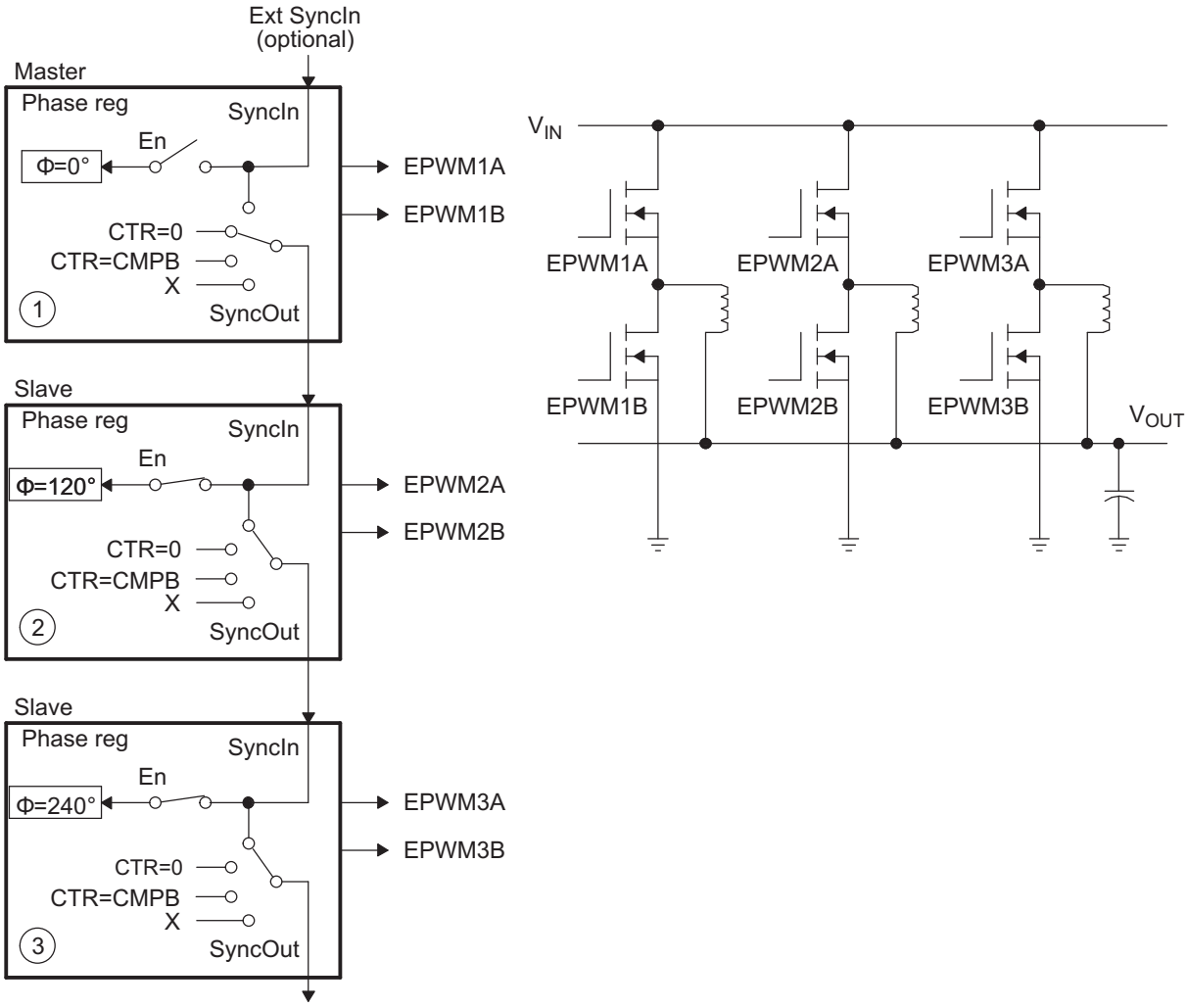


Figure 16-62. 3-Phase Interleaved DC/DC Converter Waveforms for Figure 16-61

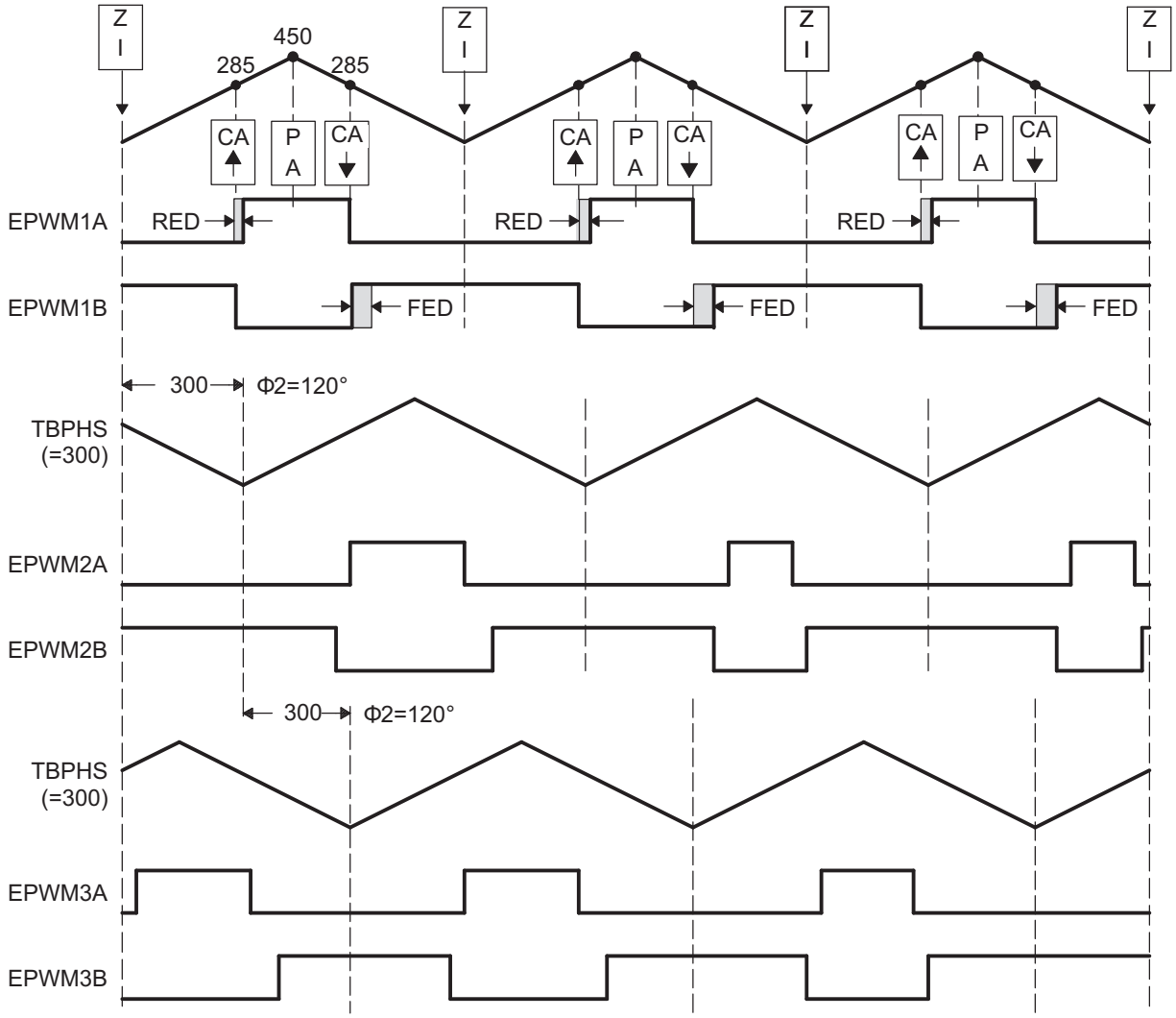


Table 16-45. EPWM1 Initialization for Figure 16-61

Register	Bit	Value	Comments
TBPRD	TBPRD	450 (1C2h)	Period = 900 TBCLK counts
TBPHS	TBPHS	0	Clear Phase Register to 0
TBCTL	CTRMODE	TB_UPDOWN	
	PHSEN	TB_DISABLE	Phase loading disabled
	PRDLD	TB_SHADOW	
	SYNCOSEL	TB_CTR_ZERO	Sync down-stream module
CMPCTL	SHDWAMODE	CC_SHADOW	
	SHDWBMODE	CC_SHADOW	
	LOADAMODE	CC_CTR_ZERO	Load on CTR = 0
	LOADBMODE	CC_CTR_ZERO	Load on CTR = 0
AQCTLA	CAU	AQ_SET	Set actions for EPWM1A
	CAD	AQ_CLEAR	
DBCTL	MODE	DB_FULL_ENABLE	Enable Dead-band module
	POLSEL	DB_ACTV_HIC	Active Hi complementary
DBFED	DBFED	20	FED = 20 TBCLKs
	DBRED	20	RED = 20 TBCLKs

Table 16-46. EPWM2 Initialization for Figure 16-61

Register	Bit	Value	Comments
TBPRD	TBPRD	450 (1C2h)	Period = 900 TBCLK counts
TBPHS	TBPHS	300	Phase = (300/900) × 360 = 120°
TBCTL	CTRMODE	TB_UPDOWN	
	PHSEN	TB_ENABLE	Slave module
	PRDLD	TB_SHADOW	
	SYNCOSEL	TB_SYNC_IN	Sync flow-through
	PHSDIR	TB_DOWN	Count DOWN on sync
CMPCTL	SHDWAMODE	CC_SHADOW	
	SHDWBMODE	CC_SHADOW	
	LOADAMODE	CC_CTR_ZERO	Load on CTR = 0
	LOADBMODE	CC_CTR_ZERO	Load on CTR = 0
AQCTLA	CAU	AQ_SET	Set actions for EPWM2A
	CAD	AQ_CLEAR	
DBCTL	MODE	DB_FULL_ENABLE	Enable Dead-band module
	POLSEL	DB_ACTV_HIC	Active Hi complementary
DBFED	DBFED	20	FED = 20 TBCLKs
	DBRED	20	RED = 20 TBCLKs

Table 16-47. EPWM3 Initialization for Figure 16-61

Register	Bit	Value	Comments
TBPRD	TBPRD	450 (1C2h)	Period = 900 TBCLK counts
TBPHS	TBPHS	300	Phase = (300/900) × 360 = 120°
TBCTL	CTRMODE	TB_UPDOWN	
	PHSEN	TB_ENABLE	Slave module
	PRDLD	TB_SHADOW	
	SYNCOSEL	TB_SYNC_IN	Sync flow-through
	PHSDIR	TB_UP	Count UP on sync
CMPCTL	SHDWAMODE	CC_SHADOW	
	SHDWBMODE	CC_SHADOW	
	LOADAMODE	CC_CTR_ZERO	Load on CTR = 0
	LOADBMODE	CC_CTR_ZERO	Load on CTR = 0
AQCTLA	CAU	AQ_SET	Set actions for EPWM3A
	CAD	AQ_CLEAR	
DBCTL	MODE	DB_FULL_ENABLE	Enable Dead-band module
	POLSEL	DB_ACTV_HIC	Active Hi complementary
DBFED	DBFED	20	FED = 20 TBCLKs
	DBRED	20	RED = 20 TBCLKs

Example 16-7. Code Snippet for Configuration in Figure 16-61

```
// Run Time (Note: Example execution of one run-time instance)
//=====================================================
EPwm1Regs.CMPA.half.CMPA = 285;         // adjust duty for output EPWM1A
EPwm2Regs.CMPA.half.CMPA = 285;         // adjust duty for output EPWM2A
EPwm3Regs.CMPA.half.CMPA = 285;         // adjust duty for output EPWM3A
```

16.3.9 Controlling Zero Voltage Switched Full Bridge (ZVSFB) Converter

The example given in Figure 16-63 assumes a static or constant phase relationship between legs (modules). In such a case, control is achieved by modulating the duty cycle. It is also possible to dynamically change the phase value on a cycle-by-cycle basis. This feature lends itself to controlling a class of power topologies known as *phase-shifted full bridge*, or *zero voltage switched full bridge.* Here the controlled parameter is not duty cycle (this is kept constant at approximately 50 percent); instead it is the phase relationship between legs. Such a system can be implemented by allocating the resources of two PWM modules to control a single power stage, which in turn requires control of four switching elements. Figure 16-64 shows a master/slave module combination synchronized together to control a full H-bridge. In this case, both master and slave modules are required to switch at the same PWM frequency. The phase is controlled by using the slave's phase register (TBPHS). The master's phase register is not used and therefore can be initialized to zero.

Figure 16-63. Controlling a Full-H Bridge Stage (F_{PWM2} = F_{PWM1})

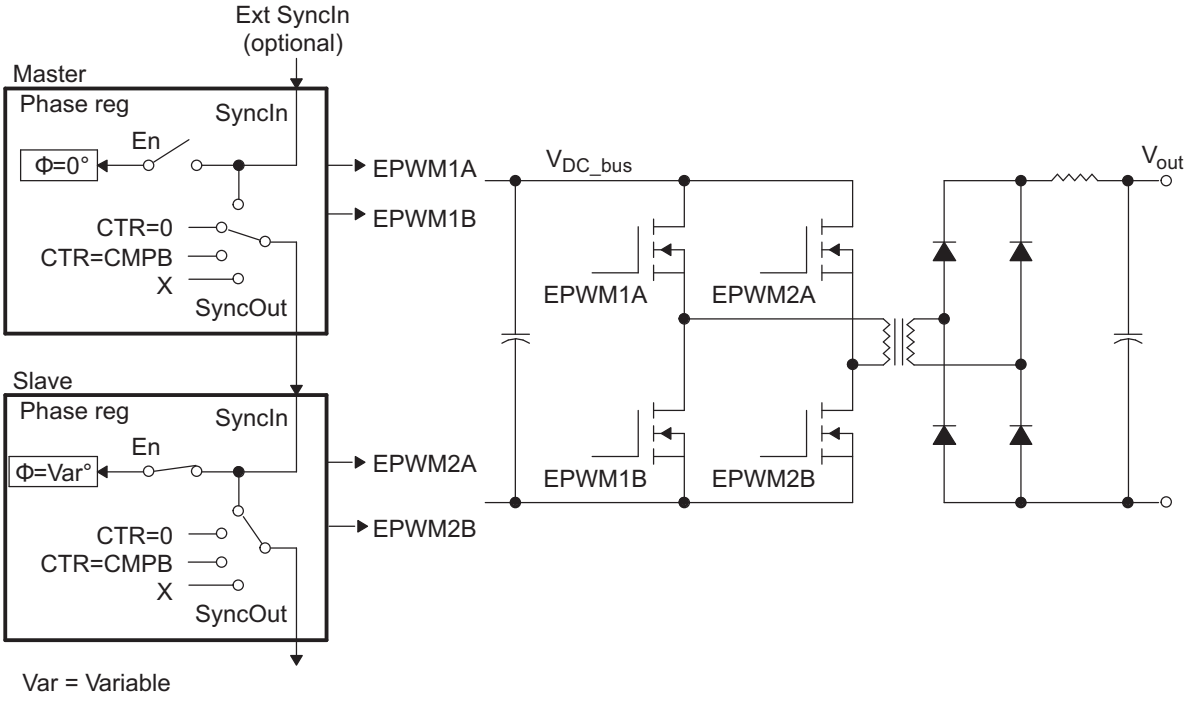


Figure 16-64. ZVS Full-H Bridge Waveforms

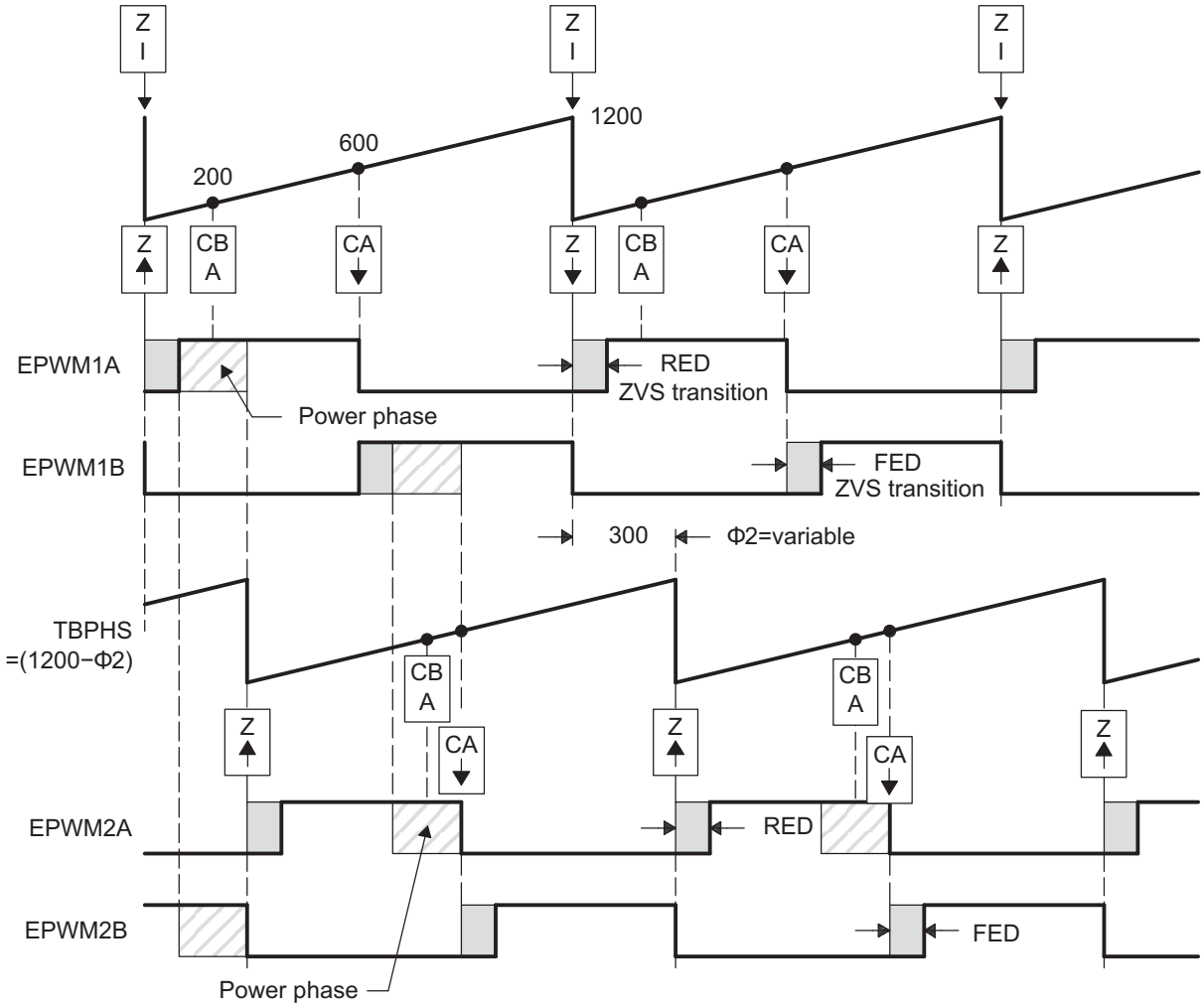


Table 16-48. EPWM1 Initialization for Figure 16-63

Register	Bit	Value	Comments
TBPRD	TBPRD	1200 (4B0h)	Period = 1201 TBCLK counts
TBPHS	TBPHS	0	Clear Phase Register to 0
TBCTL	CTRMODE	TB_UP	
	PHSEN	TB_DISABLE	Phase loading disabled
	PRDLD	TB_SHADOW	
	SYNCOSEL	TB_CTR_ZERO	Sync down-stream module
CMPA	CMPA	600 (258h)	Set 50% duty for EPWM1A
CMPCTL	SHDWAMODE	CC_SHADOW	
	SHDWBMODE	CC_SHADOW	
	LOADAMODE	CC_CTR_ZERO	Load on CTR = 0
	LOADBMODE	CC_CTR_ZERO	Load on CTR = 0
AQCTLA	ZRO	AQ_SET	Set actions for EPWM1A
	CAU	AQ_CLEAR	
DBCTL	MODE	DB_FULL_ENABLE	Enable Dead-band module
	POLSEL	DB_ACTV_HIC	Active Hi complementary
DBFED	DBFED	50	FED = 50 TBCLKs
	DBRED	70	RED = 70 TBCLKs

Table 16-49. EPWM2 Initialization for Figure 16-63

Register	Bit	Value	Comments
TBPRD	TBPRD	1200 (4B0h)	Period = 1201 TBCLK counts
TBPHS	TBPHS	0	Clear Phase Register to 0
TBCTL	CTRMODE	TB_UP	
	PHSEN	TB_ENABLE	Slave module
	PRDLD	TB_SHADOW	
	SYNCOSEL	TB_SYNC_IN	Sync flow-through
CMPA	CMPA	600 (258h)	Set 50% duty for EPWM2A
CMPCTL	SHDWAMODE	CC_SHADOW	
	SHDWBMODE	CC_SHADOW	
	LOADAMODE	CC_CTR_ZERO	Load on CTR = 0
	LOADBMODE	CC_CTR_ZERO	Load on CTR = 0
AQCTLA	ZRO	AQ_SET	Set actions for EPWM2A
	CAU	AQ_CLEAR	
DBCTL	MODE	DB_FULL_ENABLE	Enable Dead-band module
	POLSEL	DB_ACTV_HIC	Active Hi complementary
DBFED	DBFED	30	FED = 30 TBCLKs
	DBRED	40	RED = 40 TBCLKs

Example 16-8. Code Snippet for Configuration in Figure 16-63

```
// Run Time (Note: Example execution of one run-time instance)
//=========================================================
EPwm2Regs.TBPHS = 1200-300;                       // Set Phase reg to 300/1200 * 360 = 90 deg
EPwm1Regs.DBFED = FED1_NewValue;                  // Update ZVS transition interval
EPwm1Regs.DBRED = RED1_NewValue;                  // Update ZVS transition interval
EPwm2Regs.DBFED = FED2_NewValue;                  // Update ZVS transition interval
EPwm2Regs.DBRED = RED2_NewValue;                  // Update ZVS transition interval
```

16.4 Registers

This section includes the registers for the submodules.

Table 16-50. Submodule Registers

Submodule	Section
Time-Base Submodule Registers	Section 16.4.1
Counter-Compare Submodule Registers	Section 16.4.2
Action-Qualifier Submodule Registers	Section 16.4.3
Dead-Band Generator Submodule Registers	Section 16.4.4
PWM-Chopper Submodule Registers	Section 16.4.5
Trip-Zone Submodule Registers	Section 16.4.6
Event-Trigger Submodule Registers	Section 16.4.7
High-Resolution PWM Registers	Section 16.4.8

16.4.1 Time-Base Submodule Registers

Table 16-51 lists the memory-mapped registers for the time-base submodule. See your device-specific data manual for the memory address of these registers. All other register offset addresses not listed in Table 16-51 should be considered as reserved locations and the register contents should not be modified.

Table 16-51. Time-Base Submodule Registers

Offset	Acronym	Register Description	Section
0h	TBCTL	Time-Base Control Register	Section 16.4.1.1
2h	TBSTS	Time-Base Status Register	Section 16.4.1.2
4h	TBPHSHR	Time-Base Phase High-Resolution Register[(1)]	Section 16.4.8.1
6h	TBPHS	Time-Base Phase Register	Section 16.4.1.3
8h	TBCNT	Time-Base Counter Register	Section 16.4.1.4
Ah	TBPRD	Time-Base Period Register	Section 16.4.1.5

(1) This register is only available on ePWM instances that include the high-resolution PWM (HRPWM) extension; otherwise, this location is reserved. See your device-specific data manual to determine which instances include the HRPWM.

16.4.1.1 Time-Base Control Register (TBCTL)

The time-base control register (TBCTL) is shown in Figure 16-65 and described in Table 16-52.

Figure 16-65. Time-Base Control Register (TBCTL)

15	14	13	12	10	9	8
FREE, SOFT		PHSDIR	CLKDIV		HSPCLKDIV	
R/W-0		R/W-0	R/W-0		R/W-0	

7	6	5	4	3	2	1	0
HSPCLKDIV	SWFSYNC	SYNCOSEL		PRDLD	PHSEN	CTRMODE	
R/W-1	R/W-0	R/W-0		R/W-0	R/W-0	R/W-3h	

LEGEND: R/W = Read/Write; R = Read only; *-n* = value after reset

Table 16-52. Time-Base Control Register (TBCTL) Field Descriptions

Bit	Field	Value	Description
15-14	FREE, SOFT	0-3h	Emulation Mode Bits. These bits select the behavior of the ePWM time-base counter during emulation events:
		0	Stop after the next time-base counter increment or decrement
		1h	Stop when counter completes a whole cycle: • Up-count mode: stop when the time-base counter = period (TBCNT = TBPRD) • Down-count mode: stop when the time-base counter = 0000 (TBCNT = 0000h) • Up-down-count mode: stop when the time-base counter = 0000 (TBCNT = 0000h)
		2h-3h	Free run
13	PHSDIR		Phase Direction Bit. This bit is only used when the time-base counter is configured in the up-down-count mode. The PHSDIR bit indicates the direction the time-base counter (TBCNT) will count after a synchronization event occurs and a new phase value is loaded from the phase (TBPHS) register. This is irrespective of the direction of the counter before the synchronization event.. In the up-count and down-count modes this bit is ignored.
		0	Count down after the synchronization event.
		1	Count up after the synchronization event.
12:10	CLKDIV	0-7h	Time-base Clock Prescale Bits. These bits determine part of the time-base clock prescale value. TBCLK = SYSCLKOUT/(HSPCLKDIV × CLKDIV)
		0	/1 (default on reset)
		1h	/2
		2h	/4
		3h	/8
		4h	/16
		5h	/32
		6h	/64
		7h	/128
9-7	HSPCLKDIV	0-7h	High-Speed Time-base Clock Prescale Bits. These bits determine part of the time-base clock prescale value. TBCLK = SYSCLKOUT/(HSPCLKDIV × CLKDIV) This divisor emulates the HSPCLK in the TMS320x281x system as used on the Event Manager (EV) peripheral.
		0	/1
		1h	/2 (default on reset)
		2h	/4
		3h	/6
		4h	/8
		5h	/10
		6h	/12
		7h	/14
6	SWFSYNC		Software Forced Synchronization Pulse
		0	Writing a 0 has no effect and reads always return a 0.
		1	Writing a 1 forces a one-time synchronization pulse to be generated. This event is ORed with the EPWMxSYNCI input of the ePWM module. SWFSYNC is valid (operates) only when EPWMxSYNCI is selected by SYNCOSEL = 00.
5-4	SYNCOSEL	0-3h	Synchronization Output Select. These bits select the source of the EPWMxSYNCO signal.
		0	EPWMxSYNC:
		1h	CTR = 0: Time-base counter equal to zero (TBCNT = 0000h)
		2h	CTR = CMPB : Time-base counter equal to counter-compare B (TBCNT = CMPB)
		3h	Disable EPWMxSYNCO signal

Table 16-52. Time-Base Control Register (TBCTL) Field Descriptions (continued)

Bit	Field	Value	Description
3	PRDLD		Active Period Register Load From Shadow Register Select
		0	The period register (TBPRD) is loaded from its shadow register when the time-base counter, TBCNT, is equal to zero.
			A write or read to the TBPRD register accesses the shadow register.
		1	Load the TBPRD register immediately without using a shadow register.
			A write or read to the TBPRD register directly accesses the active register.
2	PHSEN		Counter Register Load From Phase Register Enable
		0	Do not load the time-base counter (TBCNT) from the time-base phase register (TBPHS)
		1	Load the time-base counter with the phase register when an EPWMxSYNCI input signal occurs or when a software synchronization is forced by the SWFSYNC bit.
1-0	CTRMODE	0-3h	Counter Mode. The time-base counter mode is normally configured once and not changed during normal operation. If you change the mode of the counter, the change will take effect at the next TBCLK edge and the current counter value shall increment or decrement from the value before the mode change.
			These bits set the time-base counter mode of operation as follows:
		0	Up-count mode
		1h	Down-count mode
		2h	Up-down-count mode
		3h	Stop-freeze counter operation (default on reset)

16.4.1.2 Time-Base Status Register (TBSTS)

The time-base status register (TBSTS) is shown in Figure 16-66 and described in Table 16-53.

Figure 16-66. Time-Base Status Register (TBSTS)

15	3	2	1	0
Reserved		CTRMAX	SYNCI	CTRDIR
R-0		R/W1C-0	R/W1C-0	R-1

LEGEND: R/W = Read/Write; R/W1C = Read/Write 1 to clear; *-n* = value after reset

Table 16-53. Time-Base Status Register (TBSTS) Field Descriptions

Bit	Field	Value	Description
15-3	Reserved	0	Reserved
2	CTRMAX		Time-Base Counter Max Latched Status Bit
		0	Reading a 0 indicates the time-base counter never reached its maximum value. Writing a 0 will have no effect.
		1	Reading a 1 on this bit indicates that the time-base counter reached the max value 0xFFFF. Writing a 1 to this bit will clear the latched event.
1	SYNCI		Input Synchronization Latched Status Bit
		0	Writing a 0 will have no effect. Reading a 0 indicates no external synchronization event has occurred.
		1	Reading a 1 on this bit indicates that an external synchronization event has occurred (EPWMxSYNCI). Writing a 1 to this bit will clear the latched event.
0	CTRDIR		Time-Base Counter Direction Status Bit. At reset, the counter is frozen; therefore, this bit has no meaning. To make this bit meaningful, you must first set the appropriate mode via TBCTL[CTRMODE].
		0	Time-Base Counter is currently counting down.
		1	Time-Base Counter is currently counting up.

16.4.1.3 Time-Base Phase Register (TBPHS)

The time-base phase register (TBPHS) is shown in Figure 16-67 and described in Table 16-54.

Figure 16-67. Time-Base Phase Register (TBPHS)

15	0
TBPHS	
R/W-0	

LEGEND: R/W = Read/Write; *-n* = value after reset

Table 16-54. Time-Base Phase Register (TBPHS) Field Descriptions

Bits	Name	Value	Description
15-0	TBPHS	0-FFFFh	These bits set time-base counter phase of the selected ePWM relative to the time-base that is supplying the synchronization input signal. • If TBCTL[PHSEN] = 0, then the synchronization event is ignored and the time-base counter is not loaded with the phase. • If TBCTL[PHSEN] = 1, then the time-base counter (TBCNT) will be loaded with the phase (TBPHS) when a synchronization event occurs. The synchronization event can be initiated by the input synchronization signal (EPWMxSYNCI) or by a software forced synchronization.

16.4.1.4 Time-Base Counter Register (TBCNT)

The time-base counter register (TBCNT) is shown in Figure 16-68 and described in Table 16-55.

Figure 16-68. Time-Base Counter Register (TBCNT)

15	0
TBCNT	
R/W-0	

LEGEND: R/W = Read/Write; *-n* = value after reset

Table 16-55. Time-Base Counter Register (TBCNT) Field Descriptions

Bits	Name	Value	Description
15-0	TBCNT	0-FFFFh	Reading these bits gives the current time-base counter value. Writing to these bits sets the current time-base counter value. The update happens as soon as the write occurs; the write is NOT synchronized to the time-base clock (TBCLK) and the register is not shadowed.

16.4.1.5 Time-Base Period Register (TBPRD)

The time-base period register (TBPRD) is shown in Figure 16-69 and described in Table 16-56.

Figure 16-69. Time-Base Period Register (TBPRD)

15	0
TBPRD	
R/W-0	

LEGEND: R/W = Read/Write; -*n* = value after reset

Table 16-56. Time-Base Period Register (TBPRD) Field Descriptions

Bits	Name	Value	Description
15-0	TBPRD	0-FFFFh	These bits determine the period of the time-base counter. This sets the PWM frequency. Shadowing of this register is enabled and disabled by the TBCTL[PRDLD] bit. By default this register is shadowed. • If TBCTL[PRDLD] = 0, then the shadow is enabled and any write or read will automatically go to the shadow register. In this case, the active register will be loaded from the shadow register when the time-base counter equals zero. • If TBCTL[PRDLD] = 1, then the shadow is disabled and any write or read will go directly to the active register, that is the register actively controlling the hardware. • The active and shadow registers share the same memory map address.

16.4.2 Counter-Compare Submodule Registers

Table 16-57 lists the memory-mapped registers for the counter-compare submodule. See your device-specific data manual for the memory address of these registers. All other register offset addresses not listed in Table 16-57 should be considered as reserved locations and the register contents should not be modified.

Table 16-57. Counter-Compare Submodule Registers

Offset	Acronym	Register Description	Section
Eh	CMPCTL	Counter-Compare Control Register	Section 16.4.2.1
10h	CMPAHR	Counter-Compare A High-Resolution Register(1)	Section 16.4.8.2
12h	CMPA	Counter-Compare A Register	Section 16.4.2.2
14h	CMPB	Counter-Compare B Register	Section 16.4.2.3

(1) This register is only available on ePWM instances that include the high-resolution PWM (HRPWM) extension; otherwise, this location is reserved. See your device-specific data manual to determine which instances include the HRPWM.

16.4.2.1 Counter-Compare Control Register (CMPCTL)

The counter-compare control register (CMPCTL) is shown in Figure 16-70 and described in Table 16-58.

Figure 16-70. Counter-Compare Control Register (CMPCTL)

15					10	9	8
Reserved						SHDWBFULL	SHDWAFULL
R-0						R-0	R-0
7	6	5	4	3	2	1	0
Reserved	SHDWBMODE	Reserved	SHDWAMODE	LOADBMODE		LOADAMODE	
R-0	R/W-0	R-0	R/W-0	R/W-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; *-n* = value after reset

Table 16-58. Counter-Compare Control Register (CMPCTL) Field Descriptions

Bits	Name	Value	Description
15-10	Reserved	0	Reserved
9	SHDWBFULL		Counter-compare B (CMPB) Shadow Register Full Status Flag. This bit self clears once a load-strobe occurs.
		0	CMPB shadow FIFO not full yet
		1	Indicates the CMPB shadow FIFO is full; a CPU write will overwrite current shadow value.
8	SHDWAFULL		Counter-compare A (CMPA) Shadow Register Full Status Flag. The flag bit is set when a 32-bit write to CMPA:CMPAHR register or a 16-bit write to CMPA register is made. A 16-bit write to CMPAHR register will not affect the flag. This bit self clears once a load-strobe occurs.
		0	CMPA shadow FIFO not full yet
		1	Indicates the CMPA shadow FIFO is full, a CPU write will overwrite the current shadow value.
7	Reserved	0	Reserved
6	SHDWBMODE		Counter-compare B (CMPB) Register Operating Mode
		0	Shadow mode. Operates as a double buffer. All writes via the CPU access the shadow register.
		1	Immediate mode. Only the active compare B register is used. All writes and reads directly access the active register for immediate compare action.
5	Reserved		Reserved
4	SHDWAMODE		Counter-compare A (CMPA) Register Operating Mode
		0	Shadow mode. Operates as a double buffer. All writes via the CPU access the shadow register.
		1	Immediate mode. Only the active compare register is used. All writes and reads directly access the active register for immediate compare action
3-2	LOADBMODE	0-3h	Active Counter-Compare B (CMPB) Load From Shadow Select Mode. This bit has no effect in immediate mode (CMPCTL[SHDWBMODE] = 1).
		0	Load on CTR = 0: Time-base counter equal to zero (TBCNT = 0000h)
		1h	Load on CTR = PRD: Time-base counter equal to period (TBCNT = TBPRD)
		2h	Load on either CTR = 0 or CTR = PRD
		3h	Freeze (no loads possible)
1-0	LOADAMODE	0-3h	Active Counter-Compare A (CMPA) Load From Shadow Select Mode. This bit has no effect in immediate mode (CMPCTL[SHDWAMODE] = 1).
		0	Load on CTR = 0: Time-base counter equal to zero (TBCNT = 0000h)
		1h	Load on CTR = PRD: Time-base counter equal to period (TBCNT = TBPRD)
		2h	Load on either CTR = 0 or CTR = PRD
		3h	Freeze (no loads possible)

16.4.2.2 Counter-Compare A Register (CMPA)

The counter-compare A register (CMPA) is shown in Figure 16-71 and described in Table 16-59.

Figure 16-71. Counter-Compare A Register (CMPA)

15	0
CMPA	
R/W-0	

LEGEND: R/W = Read/Write; -*n* = value after reset

Table 16-59. Counter-Compare A Register (CMPA) Field Descriptions

Bits	Name	Value	Description
15-0	CMPA	0-FFFFh	The value in the active CMPA register is continuously compared to the time-base counter (TBCNT). When the values are equal, the counter-compare module generates a "time-base counter equal to counter compare A" event. This event is sent to the action-qualifier where it is qualified and converted it into one or more actions. These actions can be applied to either the EPWMxA or the EPWMxB output depending on the configuration of the AQCTLA and AQCTLB registers. The actions that can be defined in the AQCTLA and AQCTLB registers include: • Do nothing; the event is ignored. • Clear: Pull the EPWMxA and/or EPWMxB signal low • Set: Pull the EPWMxA and/or EPWMxB signal high • Toggle the EPWMxA and/or EPWMxB signal Shadowing of this register is enabled and disabled by the CMPCTL[SHDWAMODE] bit. By default this register is shadowed. • If CMPCTL[SHDWAMODE] = 0, then the shadow is enabled and any write or read will automatically go to the shadow register. In this case, the CMPCTL[LOADAMODE] bit field determines which event will load the active register from the shadow register. • Before a write, the CMPCTL[SHDWAFULL] bit can be read to determine if the shadow register is currently full. • If CMPCTL[SHDWAMODE] = 1, then the shadow register is disabled and any write or read will go directly to the active register, that is the register actively controlling the hardware. • In either mode, the active and shadow registers share the same memory map address.

16.4.2.3 Counter-Compare B Register (CMPB)

The counter-compare B register (CMPB) is shown in Figure 16-72 and described in Table 16-60.

Figure 16-72. Counter-Compare B Register (CMPB)

15	0
CMPB	
R/W-0	

LEGEND: R/W = Read/Write; *-n* = value after reset

Table 16-60. Counter-Compare B Register (CMPB) Field Descriptions

Bits	Name	Value	Description
15-0	CMPB	0-FFFFh	The value in the active CMPB register is continuously compared to the time-base counter (TBCNT). When the values are equal, the counter-compare module generates a "time-base counter equal to counter compare B" event. This event is sent to the action-qualifier where it is qualified and converted it into one or more actions. These actions can be applied to either the EPWMxA or the EPWMxB output depending on the configuration of the AQCTLA and AQCTLB registers. The actions that can be defined in the AQCTLA and AQCTLB registers include: • Do nothing. event is ignored. • Clear: Pull the EPWMxA and/or EPWMxB signal low • Set: Pull the EPWMxA and/or EPWMxB signal high • Toggle the EPWMxA and/or EPWMxB signal Shadowing of this register is enabled and disabled by the CMPCTL[SHDWBMODE] bit. By default this register is shadowed. • If CMPCTL[SHDWBMODE] = 0, then the shadow is enabled and any write or read will automatically go to the shadow register. In this case, the CMPCTL[LOADBMODE] bit field determines which event will load the active register from the shadow register: • Before a write, the CMPCTL[SHDWBFULL] bit can be read to determine if the shadow register is currently full. • If CMPCTL[SHDWBMODE] = 1, then the shadow register is disabled and any write or read will go directly to the active register, that is the register actively controlling the hardware. • In either mode, the active and shadow registers share the same memory map address.

16.4.3 Action-Qualifier Submodule Registers

Table 16-61 lists the memory-mapped registers for the action-qualifier submodule. See your device-specific data manual for the memory address of these registers. All other register offset addresses not listed in Table 16-61 should be considered as reserved locations and the register contents should not be modified.

Table 16-61. Action-Qualifier Submodule Registers

Offset	Acronym	Register Description	Section
16h	AQCTLA	Action-Qualifier Output A Control Register	Section 16.4.3.1
18h	AQCTLB	Action-Qualifier Output B Control Register	Section 16.4.3.2
1Ah	AQSFRC	Action-Qualifier Software Force Register	Section 16.4.3.3
1Ch	AQCSFRC	Action-Qualifier Continuous Software Force Register	Section 16.4.3.4

16.4.3.1 Action-Qualifier Output A Control Register (AQCTLA)

The action-qualifier output A control register (AQCTLA) is shown in Figure 16-73 and described in Table 16-62.

Figure 16-73. Action-Qualifier Output A Control Register (AQCTLA)

15 12	11 10	9 8	7 6	5 4	3 2	1 0
Reserved	CBD	CBU	CAD	CAU	PRD	ZRO
R-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 16-62. Action-Qualifier Output A Control Register (AQCTLA) Field Descriptions

Bits	Name	Value	Description
15-12	Reserved	0	Reserved
11-10	CBD	0-3h	Action when the time-base counter equals the active CMPB register and the counter is decrementing.
		0	Do nothing (action disabled)
		1h	Clear: force EPWMxA output low.
		2h	Set: force EPWMxA output high.
		3h	Toggle EPWMxA output: low output signal will be forced high, and a high signal will be forced low.
9-8	CBU	0-3h	Action when the counter equals the active CMPB register and the counter is incrementing.
		0	Do nothing (action disabled)
		1h	Clear: force EPWMxA output low.
		2h	Set: force EPWMxA output high.
		3h	Toggle EPWMxA output: low output signal will be forced high, and a high signal will be forced low.
7-6	CAD	0-3h	Action when the counter equals the active CMPA register and the counter is decrementing.
		0	Do nothing (action disabled)
		1h	Clear: force EPWMxA output low.
		2h	Set: force EPWMxA output high.
		3h	Toggle EPWMxA output: low output signal will be forced high, and a high signal will be forced low.
5-4	CAU	0-3h	Action when the counter equals the active CMPA register and the counter is incrementing.
		0	Do nothing (action disabled)
		1h	Clear: force EPWMxA output low.
		2h	Set: force EPWMxA output high.
		3h	Toggle EPWMxA output: low output signal will be forced high, and a high signal will be forced low.
3-2	PRD	0-3h	Action when the counter equals the period. Note: By definition, in count up-down mode when the counter equals period the direction is defined as 0 or counting down.
		0	Do nothing (action disabled)
		1h	Clear: force EPWMxA output low.
		2h	Set: force EPWMxA output high.
		3h	Toggle EPWMxA output: low output signal will be forced high, and a high signal will be forced low.
1-0	ZRO	0-3h	Action when counter equals zero. Note: By definition, in count up-down mode when the counter equals 0 the direction is defined as 1 or counting up.
		0	Do nothing (action disabled)
		1h	Clear: force EPWMxA output low.
		2h	Set: force EPWMxA output high.
		3h	Toggle EPWMxA output: low output signal will be forced high, and a high signal will be forced low.

16.4.3.2 Action-Qualifier Output B Control Register (AQCTLB)

The action-qualifier output B control register (AQCTLB) is shown in Figure 16-74 and described in Table 16-63.

Figure 16-74. Action-Qualifier Output B Control Register (AQCTLB)

15 12	11 10	9 8	7 6	5 4	3 2	1 0
Reserved	CBD	CBU	CAD	CAU	PRD	ZRO
R-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 16-63. Action-Qualifier Output B Control Register (AQCTLB) Field Descriptions

Bits	Name	Value	Description
15-12	Reserved	0	Reserved
11-10	CBD	0-3h	Action when the counter equals the active CMPB register and the counter is decrementing.
		0	Do nothing (action disabled)
		1h	Clear: force EPWMxB output low.
		2h	Set: force EPWMxB output high.
		3h	Toggle EPWMxB output: low output signal will be forced high, and a high signal will be forced low.
9-8	CBU	0-3h	Action when the counter equals the active CMPB register and the counter is incrementing.
		0	Do nothing (action disabled)
		1h	Clear: force EPWMxB output low.
		2h	Set: force EPWMxB output high.
		3h	Toggle EPWMxB output: low output signal will be forced high, and a high signal will be forced low.
7-6	CAD	0-3h	Action when the counter equals the active CMPA register and the counter is decrementing.
		0	Do nothing (action disabled)
		1h	Clear: force EPWMxB output low.
		2h	Set: force EPWMxB output high.
		3h	Toggle EPWMxB output: low output signal will be forced high, and a high signal will be forced low.
5-4	CAU	0-3h	Action when the counter equals the active CMPA register and the counter is incrementing.
		0	Do nothing (action disabled)
		1h	Clear: force EPWMxB output low.
		2h	Set: force EPWMxB output high.
		3h	Toggle EPWMxB output: low output signal will be forced high, and a high signal will be forced low.
3-2	PRD	0-3h	Action when the counter equals the period. Note: By definition, in count up-down mode when the counter equals period the direction is defined as 0 or counting down.
		0	Do nothing (action disabled)
		1h	Clear: force EPWMxB output low.
		2h	Set: force EPWMxB output high.
		3h	Toggle EPWMxB output: low output signal will be forced high, and a high signal will be forced low.
1-0	ZRO	0-3h	Action when counter equals zero. Note: By definition, in count up-down mode when the counter equals 0 the direction is defined as 1 or counting up.
		0	Do nothing (action disabled)
		1h	Clear: force EPWMxB output low.
		2h	Set: force EPWMxB output high.
		3h	Toggle EPWMxB output: low output signal will be forced high, and a high signal will be forced low.

16.4.3.3 Action-Qualifier Software Force Register (AQSFRC)

The action-qualifier software force register (AQSFRC) is shown in Figure 16-75 and described in Table 16-64.

Figure 16-75. Action-Qualifier Software Force Register (AQSFRC)

15 8	7 6	5	4 3	2	1 0
Reserved	RLDCSF	OTSFB	ACTSFB	OTSFA	ACTSFA
R-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 16-64. Action-Qualifier Software Force Register (AQSFRC) Field Descriptions

Bit	Field	Value	Description
15-8	Reserved	0	Reserved
7-6	RLDCSF	0-3h	AQCSFRC Active Register Reload From Shadow Options
		0	Load on event counter equals zero
		1h	Load on event counter equals period
		2h	Load on event counter equals zero or counter equals period
		3h	Load immediately (the active register is directly accessed by the CPU and is not loaded from the shadow register).
5	OTSFB		One-Time Software Forced Event on Output B
		0	Writing a 0 (zero) has no effect. Always reads back a 0
			This bit is auto cleared once a write to this register is complete, that is, a forced event is initiated.)
			This is a one-shot forced event. It can be overridden by another subsequent event on output B.
		1	Initiates a single s/w forced event
4-3	ACTSFB	0-3h	Action when One-Time Software Force B Is invoked
		0	Does nothing (action disabled)
		1h	Clear (low)
		2h	Set (high)
		3h	Toggle (Low -> High, High -> Low)
			Note: This action is not qualified by counter direction (CNT_dir)
2	OTSFA		One-Time Software Forced Event on Output A
		0	Writing a 0 (zero) has no effect. Always reads back a 0.
			This bit is auto cleared once a write to this register is complete (that is, a forced event is initiated).
		1	Initiates a single software forced event
1-0	ACTSFA	0-3h	Action When One-Time Software Force A Is Invoked
		0	Does nothing (action disabled)
		1h	Clear (low)
		2h	Set (high)
		3h	Toggle (Low → High, High → Low)
			Note: This action is not qualified by counter direction (CNT_dir)

16.4.3.4 Action-Qualifier Continuous Software Force Register (AQCSFRC)

The action-qualifier continuous software force register (AQCSFRC) is shown in Figure 16-76 and described in Table 16-65.

Figure 16-76. Action-Qualifier Continuous Software Force Register (AQCSFRC)

15	4	3	2	1	0
Reserved		CSFB		CSFA	
R-0		R/W-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 16-65. Action-Qualifier Continuous Software Force Register (AQCSFRC) Field Descriptions

Bits	Name	Value	Description
15-4	Reserved	0	Reserved
3-2	CSFB	0-3h	Continuous Software Force on Output B
			In immediate mode, a continuous force takes effect on the next TBCLK edge.
			In shadow mode, a continuous force takes effect on the next TBCLK edge after a shadow load into the active register. To configure shadow mode, use AQSFRC[RLDCSF].
		0	Forcing disabled, that is, has no effect
		1h	Forces a continuous low on output B
		2h	Forces a continuous high on output B
		3h	Software forcing is disabled and has no effect
1-0	CSFA	0-3h	Continuous Software Force on Output A
			In immediate mode, a continuous force takes effect on the next TBCLK edge.
			In shadow mode, a continuous force takes effect on the next TBCLK edge after a shadow load into the active register.
		0	Forcing disabled, that is, has no effect
		1h	Forces a continuous low on output A
		2h	Forces a continuous high on output A
		3h	Software forcing is disabled and has no effect

16.4.4 Dead-Band Generator Submodule Registers

Table 16-66 lists the memory-mapped registers for the dead-band generator submodule. See your device-specific data manual for the memory address of these registers. All other register offset addresses not listed in Table 16-66 should be considered as reserved locations and the register contents should not be modified.

Table 16-66. Dead-Band Generator Submodule Registers

Offset	Acronym	Register Description	Section
1Eh	DBCTL	Dead-Band Generator Control Register	Section 16.4.4.1
20h	DBRED	Dead-Band Generator Rising Edge Delay Register	Section 16.4.4.2
22h	DBFED	Dead-Band Generator Falling Edge Delay Register	Section 16.4.4.3

16.4.4.1 Dead-Band Generator Control Register (DBCTL)

The dead-band generator control register (DBCTL) is shown in Figure 16-77 and described in Table 16-67.

Figure 16-77. Dead-Band Generator Control Register (DBCTL)

15 6	5 4	3 2	1 0
Reserved	IN_MODE	POLSEL	OUT_MODE
R-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 16-67. Dead-Band Generator Control Register (DBCTL) Field Descriptions

Bits	Name	Value	Description
15-6	Reserved	0	Reserved
5-4	IN_MODE	0-3h	Dead Band Input Mode Control. Bit 5 controls the S5 switch and bit 4 controls the S4 switch shown in Figure 16-29. This allows you to select the input source to the falling-edge and rising-edge delay. To produce classical dead-band waveforms, the default is EPWMxA In is the source for both falling and rising-edge delays.
		0	EPWMxA In (from the action-qualifier) is the source for both falling-edge and rising-edge delay.
		1h	EPWMxB In (from the action-qualifier) is the source for rising-edge delayed signal. EPWMxA In (from the action-qualifier) is the source for falling-edge delayed signal.
		2h	EPWMxA In (from the action-qualifier) is the source for rising-edge delayed signal. EPWMxB In (from the action-qualifier) is the source for falling-edge delayed signal.
		3h	EPWMxB In (from the action-qualifier) is the source for both rising-edge delay and falling-edge delayed signal.
3-2	POLSEL	0-3h	Polarity Select Control. Bit 3 controls the S3 switch and bit 2 controls the S2 switch shown in Figure 16-29. This allows you to selectively invert one of the delayed signals before it is sent out of the dead-band submodule. The following descriptions correspond to classical upper/lower switch control as found in one leg of a digital motor control inverter. These assume that DBCTL[OUT_MODE] = 1,1 and DBCTL[IN_MODE] = 0,0. Other enhanced modes are also possible, but not regarded as typical usage modes.
		0	Active high (AH) mode. Neither EPWMxA nor EPWMxB is inverted (default).
		1h	Active low complementary (ALC) mode. EPWMxA is inverted.
		2h	Active high complementary (AHC). EPWMxB is inverted.
		3h	Active low (AL) mode. Both EPWMxA and EPWMxB are inverted.
1-0	OUT_MODE	0-3h	Dead-band Output Mode Control. Bit 1 controls the S1 switch and bit 0 controls the S0 switch shown in Figure 16-29. This allows you to selectively enable or bypass the dead-band generation for the falling-edge and rising-edge delay.
		0	Dead-band generation is bypassed for both output signals. In this mode, both the EPWMxA and EPWMxB output signals from the action-qualifier are passed directly to the PWM-chopper submodule. In this mode, the POLSEL and IN_MODE bits have no effect.
		1h	Disable rising-edge delay. The EPWMxA signal from the action-qualifier is passed straight through to the EPWMxA input of the PWM-chopper submodule. The falling-edge delayed signal is seen on output EPWMxB. The input signal for the delay is determined by DBCTL[IN_MODE].
		2h	Disable falling-edge delay. The EPWMxB signal from the action-qualifier is passed straight through to the EPWMxB input of the PWM-chopper submodule. The rising-edge delayed signal is seen on output EPWMxA. The input signal for the delay is determined by DBCTL[IN_MODE].
		3h	Dead-band is fully enabled for both rising-edge delay on output EPWMxA and falling-edge delay on output EPWMxB. The input signal for the delay is determined by DBCTL[IN_MODE].

16.4.4.2 Dead-Band Generator Rising Edge Delay Register (DBRED)

The dead-band generator rising edge delay register (DBRED) is shown in Figure 16-78 and described in Table 16-68.

Figure 16-78. Dead-Band Generator Rising Edge Delay Register (DBRED)

15	10	9	0
Reserved		DEL	
R-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 16-68. Dead-Band Generator Rising Edge Delay Register (DBRED) Field Descriptions

Bits	Name	Value	Description
15-10	Reserved	0	Reserved
9-0	DEL	0-3FFh	Rising Edge Delay Count. 10-bit counter.

16.4.4.3 Dead-Band Generator Falling Edge Delay Register (DBFED)

The dead-band generator falling edge delay register (DBFED) is shown in Figure 16-79 and described in Table 16-69.

Figure 16-79. Dead-Band Generator Falling Edge Delay Register (DBFED)

15	10	9	0
Reserved		DEL	
R-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 16-69. Dead-Band Generator Falling Edge Delay Register (DBFED) Field Descriptions

Bits	Name	Value	Description
15-10	Reserved	0	Reserved
9-0	DEL	0-3FFh	Falling Edge Delay Count. 10-bit counter

16.4.5 PWM-Chopper Submodule Register

The PWM-chopper control register (PCCTL) is shown in Figure 16-80 and described in Table 16-70.

Figure 16-80. PWM-Chopper Control Register (PCCTL)

15 11	10 8	7 5	4 1	0
Reserved	CHPDUTY	CHPFREQ	OSHTWTH	CHPEN
R-0	R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; *-n* = value after reset

Table 16-70. PWM-Chopper Control Register (PCCTL) Bit Descriptions

Bits	Name	Value	Description
15-11	Reserved	0	Reserved
10-8	CHPDUTY	0-7h	Chopping Clock Duty Cycle
		0	Duty = 1/8 (12.5%)
		1h	Duty = 2/8 (25.0%)
		2h	Duty = 3/8 (37.5%)
		3h	Duty = 4/8 (50.0%)
		4h	Duty = 5/8 (62.5%)
		5h	Duty = 6/8 (75.0%)
		6h	Duty = 7/8 (87.5%)
		7h	Reserved
7-5	CHPFREQ	0-7h	Chopping Clock Frequency
		0	Divide by 1 (no prescale)
		1h	Divide by 2
		2h	Divide by 3
		3h-7h	Divide by 4 to divide by 8
4-1	OSHTWTH	0-Fh	One-Shot Pulse Width
		0	1 × SYSCLKOUT/8 wide
		1h	2 × SYSCLKOUT/8 wide
		2h	3 × SYSCLKOUT/8 wide
		3h-Fh	4 × SYSCLKOUT/8 wide to 16 × SYSCLKOUT/8 wide
0	CHPEN		PWM-chopping Enable
		0	Disable (bypass) PWM chopping function
		1	Enable chopping function

16.4.6 Trip-Zone Submodule Registers

Table 16-71 lists the memory-mapped registers for the trip-zone submodule. See your device-specific data manual for the memory address of these registers. All other register offset addresses not listed in Table 16-71 should be considered as reserved locations and the register contents should not be modified.

Table 16-71. Trip-Zone Submodule Registers

Offset	Acronym	Register Description	Section
24h	TZSEL	Trip-Zone Select Register	Section 16.4.6.1
28h	TZCTL	Trip-Zone Control Register	Section 16.4.6.2
2Ah	TZEINT	Trip-Zone Enable Interrupt Register	Section 16.4.6.3
2Ch	TZFLG	Trip-Zone Flag Register	Section 16.4.6.4
2Eh	TZCLR	Trip-Zone Clear Register	Section 16.4.6.5
30h	TZFRC	Trip-Zone Force Register	Section 16.4.6.6

16.4.6.1 Trip-Zone Select Register (TZSEL)

The trip-zone select register (TZSEL) is shown in Figure 16-81 and described in Table 16-72.

Figure 16-81. Trip-Zone Select Register (TZSEL)

15	9	8	7	1	0
Reserved/OSHT*n* (1)		OSHT1	Reserved/CBC*n* (1)		CBC1
R/W-0		R/W-0	R/W-0		R/W-0

LEGEND: R/W = Read/Write; -*n* = value after reset

(1) Number of register bits depends on how many trip-zone pins are available in the device. See your device-specific data manual.

Table 16-72. Trip-Zone Submodule Select Register (TZSEL) Field Descriptions

Bits	Name	Value	Description
15-8	OSHT*n*		Trip-zone *n* ($\overline{\text{TZn}}$) select. One-Shot (OSHT) trip-zone enable/disable. When any of the enabled pins go low, a one-shot trip event occurs for this ePWM module. When the event occurs, the action defined in the TZCTL register (Section 16.4.6.2) is taken on the EPWMxA and EPWMxB outputs. The one-shot trip condition remains latched until you clear the condition via the TZCLR register (Section 16.4.6.5).
		0	Disable $\overline{\text{TZn}}$ as a one-shot trip source for this ePWM module.
		1	Enable $\overline{\text{TZn}}$ as a one-shot trip source for this ePWM module.
7-0	CBC*n*		Trip-zone *n* ($\overline{\text{TZn}}$) select. Cycle-by-Cycle (CBC) trip-zone enable/disable. When any of the enabled pins go low, a cycle-by-cycle trip event occurs for this ePWM module. When the event occurs, the action defined in the TZCTL register (Section 16.4.6.2) is taken on the EPWMxA and EPWMxB outputs. A cycle-by-cycle trip condition is automatically cleared when the time-base counter reaches zero.
		0	Disable $\overline{\text{TZn}}$ as a CBC trip source for this ePWM module.
		1	Enable $\overline{\text{TZn}}$ as a CBC trip source for this ePWM module.

16.4.6.2 Trip-Zone Control Register (TZCTL)

The trip-zone control register (TZCTL) is shown in Figure 16-82 and described in Table 16-73.

Figure 16-82. Trip-Zone Control Register (TZCTL)

15	4	3	2	1	0
Reserved		TZB		TZA	
R-0		R/W-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 16-73. Trip-Zone Control Register (TZCTL) Field Descriptions

Bits	Name	Value	Description
15–4	Reserved	0	Reserved
3–2	TZB	0-3h	When a trip event occurs the following action is taken on output EPWMxB. Which trip-zone pins can cause an event is defined in the TZSEL register (Section 16.4.6.1).
		0	High impedance (EPWMxB = High-impedance state)
		1h	Force EPWMxB to a high state
		2h	Force EPWMxB to a low state
		3h	Do nothing, no action is taken on EPWMxB.
1–0	TZA	0-3h	When a trip event occurs the following action is taken on output EPWMxA. Which trip-zone pins can cause an event is defined in the TZSEL register (Section 16.4.6.1).
		0	High impedance (EPWMxA = High-impedance state)
		1h	Force EPWMxA to a high state
		2h	Force EPWMxA to a low state
		3h	Do nothing, no action is taken on EPWMxA.

16.4.6.3 Trip-Zone Enable Interrupt Register (TZEINT)

The trip-zone enable interrupt register (TZEINT) is shown in Figure 16-83 and described in Table 16-74.

Figure 16-83. Trip-Zone Enable Interrupt Register (TZEINT)

15	3	2	1	0
Reserved		OST	CBC	Rsvd
R-0		R/W-0	R/W-0	R-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 16-74. Trip-Zone Enable Interrupt Register (TZEINT) Field Descriptions

Bits	Name	Value	Description
15-3	Reserved	0	Reserved
2	OST		Trip-zone One-Shot Interrupt Enable
		0	Disable one-shot interrupt generation
		1	Enable Interrupt generation; a one-shot trip event will cause a EPWMxTZINT interrupt.
1	CBC		Trip-zone Cycle-by-Cycle Interrupt Enable
		0	Disable cycle-by-cycle interrupt generation.
		1	Enable interrupt generation; a cycle-by-cycle trip event will cause an EPWMxTZINT interrupt.
0	Reserved	0	Reserved

16.4.6.4 Trip-Zone Flag Register (TZFLG)

The trip-zone flag register (TZFLG) is shown in Figure 16-84 and described in Table 16-75.

Figure 16-84. Trip-Zone Flag Register (TZFLG)

15	3	2	1	0
Reserved		OST	CBC	INT
R-0		R-0	R-0	R-0

LEGEND: R/W = Read/Write; R = Read only; *-n* = value after reset

Table 16-75. Trip-Zone Flag Register (TZFLG) Field Descriptions

Bits	Name	Value	Description
15-3	Reserved	0	Reserved
2	OST		Latched Status Flag for A One-Shot Trip Event.
		0	No one-shot trip event has occurred.
		1	Indicates a trip event has occurred on a pin selected as a one-shot trip source. This bit is cleared by writing the appropriate value to the TZCLR register (Section 16.4.6.5).
1	CBC		Latched Status Flag for Cycle-By-Cycle Trip Event
		0	No cycle-by-cycle trip event has occurred.
		1	Indicates a trip event has occurred on a pin selected as a cycle-by-cycle trip source. The TZFLG[CBC] bit will remain set until it is manually cleared by the user. If the cycle-by-cycle trip event is still present when the CBC bit is cleared, then CBC will be immediately set again. The specified condition on the pins is automatically cleared when the ePWM time-base counter reaches zero (TBCNT = 0000h) if the trip condition is no longer present. The condition on the pins is only cleared when the TBCNT = 0000h no matter where in the cycle the CBC flag is cleared. This bit is cleared by writing the appropriate value to the TZCLR register (Section 16.4.6.5).
0	INT		Latched Trip Interrupt Status Flag
		0	Indicates no interrupt has been generated.
		1	Indicates an EPWMxTZINT interrupt was generated because of a trip condition. No further EPWMxTZINT interrupts will be generated until this flag is cleared. If the interrupt flag is cleared when either CBC or OST is set, then another interrupt pulse will be generated. Clearing all flag bits will prevent further interrupts. This bit is cleared by writing the appropriate value to the TZCLR register (Section 16.4.6.5).

16.4.6.5 Trip-Zone Clear Register (TZCLR)

The trip-zone clear register (TZCLR) is shown in Figure 16-85 and described in Table 16-76.

Figure 16-85. Trip-Zone Clear Register (TZCLR)

15	3	2	1	0
Reserved		OST	CBC	INT
R-0		R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 16-76. Trip-Zone Clear Register (TZCLR) Field Descriptions

Bits	Name	Value	Description
15-3	Reserved	0	Reserved
2	OST		Clear Flag for One-Shot Trip (OST) Latch
		0	Has no effect. Always reads back a 0.
		1	Clears this Trip (set) condition.
1	CBC		Clear Flag for Cycle-By-Cycle (CBC) Trip Latch
		0	Has no effect. Always reads back a 0.
		1	Clears this Trip (set) condition.
0	INT		Global Interrupt Clear Flag
		0	Has no effect. Always reads back a 0.
		1	Clears the trip-interrupt flag for this ePWM module (TZFLG[INT]).
			NOTE: No further EPWMxTZINT interrupts will be generated until the flag is cleared. If the TZFLG[INT] bit is cleared and any of the other flag bits are set, then another interrupt pulse will be generated. Clearing all flag bits will prevent further interrupts.

16.4.6.6 Trip-Zone Force Register (TZFRC)

The trip-zone force register (TZFRC) is shown in Figure 16-86 and described in Table 16-77.

Figure 16-86. Trip-Zone Force Register (TZFRC)

15	3	2	1	0
Reserved		OST	CBC	Rsvd
R-0		R/W-0	R/W-0	R-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 16-77. Trip-Zone Force Register (TZFRC) Field Descriptions

Bits	Name	Value	Description
15-3	Reserved	0	Reserved
2	OST		Force a One-Shot Trip Event via Software
		0	Writing of 0 is ignored. Always reads back a 0.
		1	Forces a one-shot trip event and sets the TZFLG[OST] bit.
1	CBC		Force a Cycle-by-Cycle Trip Event via Software
		0	Writing of 0 is ignored. Always reads back a 0.
		1	Forces a cycle-by-cycle trip event and sets the TZFLG[CBC] bit.
0	Reserved	0	Reserved

16.4.7 Event-Trigger Submodule Registers

Table 16-78 lists the memory-mapped registers for the event-trigger submodule. See your device-specific data manual for the memory address of these registers. All other register offset addresses not listed in Table 16-78 should be considered as reserved locations and the register contents should not be modified.

Table 16-78. Event-Trigger Submodule Registers

Offset	Acronym	Register Description	Section
32h	ETSEL	Event-Trigger Selection Register	Section 16.4.7.1
34h	ETPS	Event-Trigger Prescale Register	Section 16.4.7.2
36h	ETFLG	Event-Trigger Flag Register	Section 16.4.7.3
38h	ETCLR	Event-Trigger Clear Register	Section 16.4.7.4
3Ah	ETFRC	Event-Trigger Force Register	Section 16.4.7.5

16.4.7.1 Event-Trigger Selection Register (ETSEL)

The event-trigger selection register (ETSEL) is shown in Figure 16-87 and described in Table 16-79.

Figure 16-87. Event-Trigger Selection Register (ETSEL)

15	4	3	2	0
Reserved		INTEN	INTSEL	
R-0		R/W-0	R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 16-79. Event-Trigger Selection Register (ETSEL) Field Descriptions

Bits	Name	Value	Description
15-4	Reserved	0	Reserved
3	INTEN		Enable ePWM Interrupt (EPWMx_INT) Generation
		0	Disable EPWMx_INT generation
		1	Enable EPWMx_INT generation
2-0	INTSEL	0-7h	ePWM Interrupt (EPWMx_INT) Selection Options
		0	Reserved
		1h	Enable event time-base counter equal to zero. (TBCNT = 0000h)
		2h	Enable event time-base counter equal to period (TBCNT = TBPRD)
		3h	Reserved
		4h	Enable event time-base counter equal to CMPA when the timer is incrementing.
		5h	Enable event time-base counter equal to CMPA when the timer is decrementing.
		6h	Enable event: time-base counter equal to CMPB when the timer is incrementing.
		7h	Enable event: time-base counter equal to CMPB when the timer is decrementing.

16.4.7.2 Event-Trigger Prescale Register (ETPS)

The event-trigger prescale register (ETPS) is shown in Figure 16-88 and described in Table 16-80.

Figure 16-88. Event-Trigger Prescale Register (ETPS)

15	4	3	2	1	0
Reserved		INTCNT		INTPRD	
R-0		R-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; *-n* = value after reset

Table 16-80. Event-Trigger Prescale Register (ETPS) Field Descriptions

Bits	Name	Value	Description
15-4	Reserved	0	Reserved
3-2	INTCNT	0-3h	ePWM Interrupt Event (EPWMx_INT) Counter Register. These bits indicate how many selected ETSEL[INTSEL] events have occurred. These bits are automatically cleared when an interrupt pulse is generated. If interrupts are disabled, ETSEL[INT] = 0 or the interrupt flag is set, ETFLG[INT] = 1, the counter will stop counting events when it reaches the period value ETPS[INTCNT] = ETPS[INTPRD].
		0	No events have occurred.
		1h	1 event has occurred.
		2h	2 events have occurred.
		3h	3 events have occurred.
1-0	INTPRD	0-3h	ePWM Interrupt (EPWMx_INT) Period Select. These bits determine how many selected ETSEL[INTSEL] events need to occur before an interrupt is generated. To be generated, the interrupt must be enabled (ETSEL[INT] = 1). If the interrupt status flag is set from a previous interrupt (ETFLG[INT] = 1) then no interrupt will be generated until the flag is cleared via the ETCLR[INT] bit. This allows for one interrupt to be pending while another is still being serviced. Once the interrupt is generated, the ETPS[INTCNT] bits will automatically be cleared. Writing a INTPRD value that is the same as the current counter value will trigger an interrupt if it is enabled and the status flag is clear. Writing a INTPRD value that is less than the current counter value will result in an undefined state. If a counter event occurs at the same instant as a new zero or non-zero INTPRD value is written, the counter is incremented.
		0	Disable the interrupt event counter. No interrupt will be generated and ETFRC[INT] is ignored.
		1h	Generate an interrupt on the first event INTCNT = 01 (first event)
		2h	Generate interrupt on ETPS[INTCNT] = 1,0 (second event)
		3h	Generate interrupt on ETPS[INTCNT] = 1,1 (third event)

16.4.7.3 Event-Trigger Flag Register (ETFLG)

The event-trigger flag register (ETFLG) is shown in Figure 16-89 and described in Table 16-81.

Figure 16-89. Event-Trigger Flag Register (ETFLG)

15	1	0
Reserved		INT
R-0		R-0

LEGEND: R = Read only; -*n* = value after reset

Table 16-81. Event-Trigger Flag Register (ETFLG) Field Descriptions

Bits	Name	Value	Description
15-1	Reserved	0	Reserved
0	INT		Latched ePWM Interrupt (EPWMx_INT) Status Flag
		0	Indicates no event occurred
		1	Indicates that an ePWMx interrupt (EWPMx_INT) was generated. No further interrupts will be generated until the flag bit is cleared. Up to one interrupt can be pending while the ETFLG[INT] bit is still set. If an interrupt is pending, it will not be generated until after the ETFLG[INT] bit is cleared. Refer to Figure 16-42.

16.4.7.4 Event-Trigger Clear Register (ETCLR)

The event-trigger clear register (ETCLR) is shown in Figure 16-90 and described in Table 16-82.

Figure 16-90. Event-Trigger Clear Register (ETCLR)

15	1	0
Reserved		INT
R-0		R-0

LEGEND: R = Read only; -*n* = value after reset

Table 16-82. Event-Trigger Clear Register (ETCLR) Field Descriptions

Bits	Name	Value	Description
15-1	Reserved	0	Reserved
0	INT		ePWM Interrupt (EPWMx_INT) Flag Clear Bit
		0	Writing a 0 has no effect. Always reads back a 0.
		1	Clears the ETFLG[INT] flag bit and enable further interrupts pulses to be generated.

16.4.7.5 Event-Trigger Force Register (ETFRC)

The event-trigger force register (ETFRC) is shown in Figure 16-91 and described in Table 16-83.

Figure 16-91. Event-Trigger Force Register (ETFRC)

15	1	0
Reserved		INT
R-0		R-0

LEGEND: R = Read only; -*n* = value after reset

Table 16-83. Event-Trigger Force Register (ETFRC) Field Descriptions

Bits	Name	Value	Description
15-1	Reserved	0	Reserved
0	INT		INT Force Bit. The interrupt will only be generated if the event is enabled in the ETSEL register. The INT flag bit will be set regardless.
		0	Writing 0 to this bit will be ignored. Always reads back a 0.
		1	Generates an interrupt on $\overline{\text{EPWMxINT}}$ and set the INT flag bit. This bit is used for test purposes.

16.4.8 High-Resolution PWM Submodule Registers

Table 16-84 lists the memory-mapped registers for the high-resolution PWM submodule. See your device-specific data manual for the memory address of these registers. All other register offset addresses not listed in Table 16-84 should be considered as reserved locations and the register contents should not be modified.

Table 16-84. High-Resolution PWM Submodule Registers

Offset	Acronym	Register Description	Section
4h	TBPHSHR	Time-Base Phase High-Resolution Register	Section 16.4.8.1
10h	CMPAHR	Counter-Compare A High-Resolution Register	Section 16.4.8.2
1040h	HRCNFG	HRPWM Configuration Register	Section 16.4.8.3

16.4.8.1 Time-Base Phase High-Resolution Register (TBPHSHR)

The time-base phase high-resolution register (TBPHSHR) is shown in Figure 16-92 and described in Table 16-85.

Figure 16-92. Time-Base Phase High-Resolution Register (TBPHSHR)

15	8	7	0
TBPHSH		Reserved	
R/W-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 16-85. Time-Base Phase High-Resolution Register (TBPHSHR) Field Descriptions

Bit	Field	Value	Description
15-8	TBPHSH	0-FFh	Time-base phase high-resolution bits
7-0	Reserved	0	Reserved

16.4.8.2 Counter-Compare A High-Resolution Register (CMPAHR)

The counter-compare A high-resolution register (CMPAHR) is shown in Figure 16-93 and described in Table 16-86.

Figure 16-93. Counter-Compare A High-Resolution Register (CMPAHR)

15	8	7	0
CMPAHR		Reserved	
R/W-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 16-86. Counter-Compare A High-Resolution Register (CMPAHR) Field Descriptions

Bit	Field	Value	Description
15-8	CMPAHR	1-FFh	Compare A High-Resolution register bits for MEP step control. A minimum value of 1h is needed to enable HRPWM capabilities. Valid MEP range of operation 1-255h.
7-0	Reserved	0	Reserved

16.4.8.3 HRPWM Configuration Register (HRCNFG)

The HRPWM configuration register (HRCNFG) is shown in Figure 16-94 and described in Table 16-87.

Figure 16-94. HRPWM Configuration Register (HRCNFG)

15	4	3	2	1	0
Reserved		HRLOAD	CTLMODE	EDGMODE	
R-0		R/W-0	R/W-0	R/W-0	

LEGEND: R/W = Read/Write; R = Read only; *-n* = value after reset

Table 16-87. HRPWM Configuration Register (HRCNFG) Field Descriptions

Bit	Field	Value	Description
15-4	Reserved	0	ReserveD
3	HRLOAD		Shadow mode bit: Selects the time event that loads the CMPAHR shadow value into the active register:
		0	CTR = 0 (counter equals zero)
		1	CTR = PRD (counter equal period)
			Note: Load mode selection is valid only if CTLMODE = 0 has been selected. You should select this event to match the selection of the CMPA load mode (CMPCTL[LOADMODE] bits) in the EPWM module as follows:
			0 Load on CTR = 0: Time-base counter equal to zero (TBCNT = 0000h)
			1h Load on CTR = PRD: Time-base counter equal to period (TBCNT = TBPRD)
			2h Load on either CTR = 0 or CTR = PRD (should not be used with HRPWM)
			3h Freeze (no loads possible – should not be used with HRPWM)
2	CTLMODE		Control Mode Bits: Selects the register (CMP or TBPHS) that controls the MEP:
		0	CMPAHR(8) Register controls the edge position (this is duty control mode). (default on reset)
		1	TBPHSHR(8) Register controls the edge position (this is phase control mode).
1-0	EDGMODE	0-3h	Edge Mode Bits: Selects the edge of the PWM that is controlled by the micro-edge position (MEP) logic:
		0	HRPWM capability is disabled (default on reset)
		1h	MEP control of rising edge
		2h	MEP control of falling edge
		3h	MEP control of both edges

Enhanced Quadrature Encoder Pulse (eQEP) Module

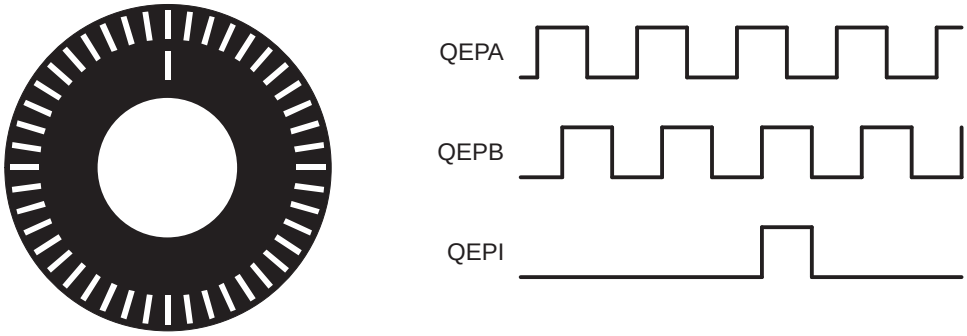
The enhanced quadrature encoder pulse (eQEP) module is used for direct interface with a linear or rotary incremental encoder to get position, direction, and speed information from a rotating machine for use in a high-performance motion and position-control system. This chapter describes the eQEP.

Topic **Page**

17.1 Introduction

A single track of slots patterns the periphery of an incremental encoder disk, as shown in Figure 17-1. These slots create an alternating pattern of dark and light lines. The disk count is defined as the number of dark/light line pairs that occur per revolution (lines per revolution). As a rule, a second track is added to generate a signal that occurs once per revolution (index signal: QEPI), which can be used to indicate an absolute position. Encoder manufacturers identify the index pulse using different terms such as index, marker, home position, and zero reference.

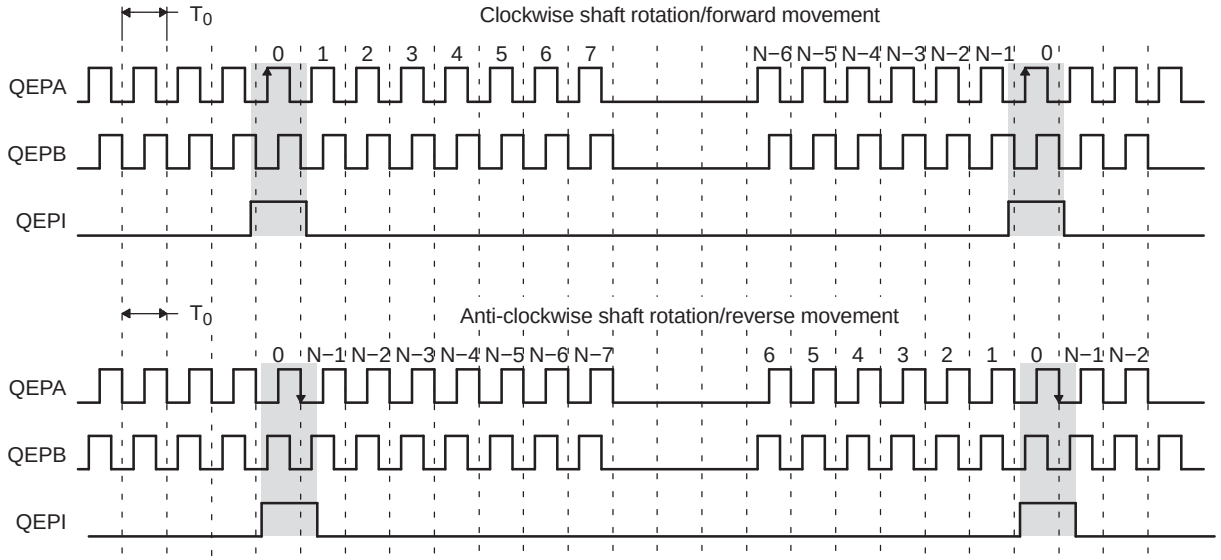
Figure 17-1. Optical Encoder Disk



To derive direction information, the lines on the disk are read out by two different photo-elements that "look" at the disk pattern with a mechanical shift of 1/4 the pitch of a line pair between them. This shift is realized with a reticle or mask that restricts the view of the photo-element to the desired part of the disk lines. As the disk rotates, the two photo-elements generate signals that are shifted 90 degrees out of phase from each other. These are commonly called the quadrature QEPA and QEPB signals. The clockwise direction for most encoders is defined as the QEPA channel going positive before the QEPB channel and vise versa as shown in Figure 17-2.

The encoder wheel typically makes one revolution for every revolution of the motor or the wheel may be at a geared rotation ratio with respect to the motor. Therefore, the frequency of the digital signal coming from the QEPA and QEPB outputs varies proportionally with the velocity of the motor. For example, a 2000-line encoder directly coupled to a motor running at 5000 revolutions per minute (rpm) results in a frequency of 166.6 KHz, so by measuring the frequency of either the QEPA or QEPB output, the processor can determine the velocity of the motor.

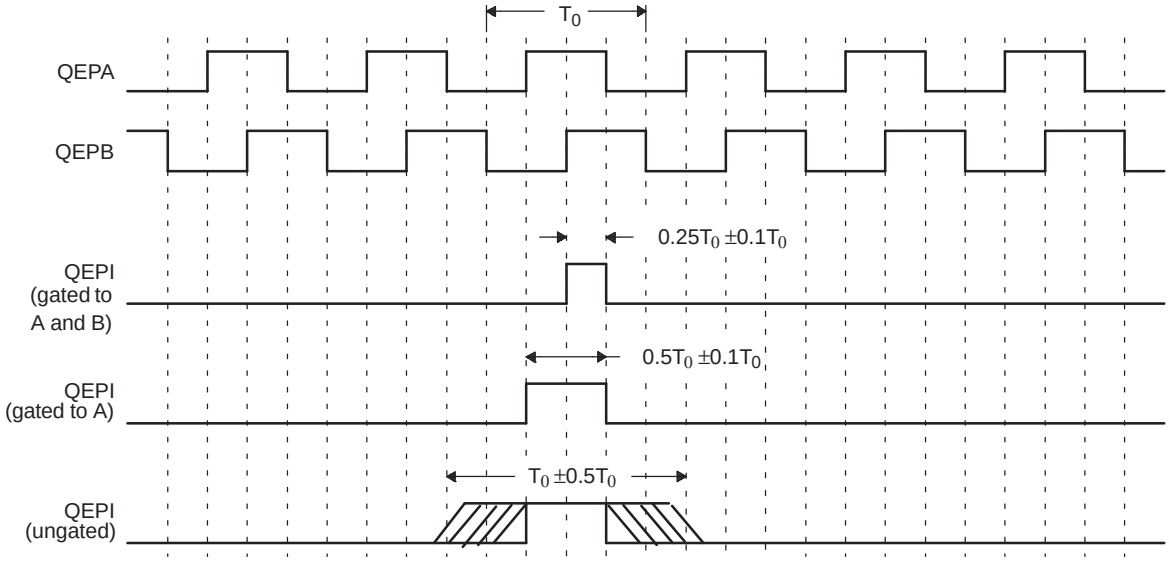
Figure 17-2. QEP Encoder Output Signal for Forward/Reverse Movement



Legend: N = lines per revolution

Quadrature encoders from different manufacturers come with two forms of index pulse (gated index pulse or ungated index pulse) as shown in Figure 17-3. A nonstandard form of index pulse is ungated. In the ungated configuration, the index edges are not necessarily coincident with A and B signals. The gated index pulse is aligned to any of the four quadrature edges and width of the index pulse and can be equal to a quarter, half, or full period of the quadrature signal.

Figure 17-3. Index Pulse Example



Some typical applications of shaft encoders include robotics and even computer input in the form of a mouse. Inside your mouse you can see where the mouse ball spins a pair of axles (a left/right, and an up/down axle). These axles are connected to optical shaft encoders that effectively tell the computer how fast and in what direction the mouse is moving.

General Issues: Estimating velocity from a digital position sensor is a cost-effective strategy in motor control. Two different first order approximations for velocity may be written as:

$$v(k) \approx \frac{x(k) - x(k-1)}{T} = \frac{\Delta X}{T} \quad (1)$$

$$v(k) \approx \frac{X}{t(k) - t(k-1)} = \frac{X}{\Delta T} \quad (2)$$

where

v(k): Velocity at time instant k

x(k): Position at time instant k

x(k-1): Position at time instant k - 1

T: Fixed unit time or inverse of velocity calculation rate

ΔX: Incremental position movement in unit time

t(k): Time instant "k"

t(k-1): Time instant "k - 1"

X: Fixed unit position

ΔT: Incremental time elapsed for unit position movement.

Equation 1 is the conventional approach to velocity estimation and it requires a time base to provide unit time event for velocity calculation. Unit time is basically the inverse of the velocity calculation rate.

The encoder count (position) is read once during each unit time event. The quantity [x(k) - x(k-1)] is formed by subtracting the previous reading from the current reading. Then the velocity estimate is computed by multiplying by the known constant 1/T (where T is the constant time between unit time events and is known in advance).

Estimation based on Equation 1 has an inherent accuracy limit directly related to the resolution of the position sensor and the unit time period T. For example, consider a 500-line per revolution quadrature encoder with a velocity calculation rate of 400 Hz. When used for position the quadrature encoder gives a four-fold increase in resolution, in this case, 2000 counts per revolution. The minimum rotation that can be detected is therefore 0.0005 revolutions, which gives a velocity resolution of 12 rpm when sampled at 400 Hz. While this resolution may be satisfactory at moderate or high speeds, for example, 1% error at 1200 rpm, it would clearly prove inadequate at low speeds. In fact, at speeds below 12 rpm, the speed estimate would erroneously be zero much of the time.

At low speed, Equation 2 provides a more accurate approach. It requires a position sensor that outputs a fixed interval pulse train, such as the aforementioned quadrature encoder. The width of each pulse is defined by motor speed for a given sensor resolution. Equation 2 can be used to calculate motor speed by measuring the elapsed time between successive quadrature pulse edges. However, this method suffers from the opposite limitation, as does Equation 1. A combination of relatively large motor speeds and high sensor resolution makes the time interval ΔT small, and thus more greatly influenced by the timer resolution. This can introduce considerable error into high-speed estimates.

For systems with a large speed range (that is, speed estimation is needed at both low and high speeds), one approach is to use Equation 2 at low speed and have the software switch over to Equation 1 when the motor speed rises above some specified threshold.

17.2 Architecture

This section provides the eQEP inputs and functional description.

NOTE: Multiple identical eQEP modules can be contained in a system. The number of modules is device-dependent and is based on target application needs. In this document, the letter x within a signal or module name is used to indicate a generic eQEP instance on a device.

17.2.1 EQEP Inputs

The eQEP inputs include two pins for quadrature-clock mode or direction-count mode, an index (or 0 marker), and a strobe input.

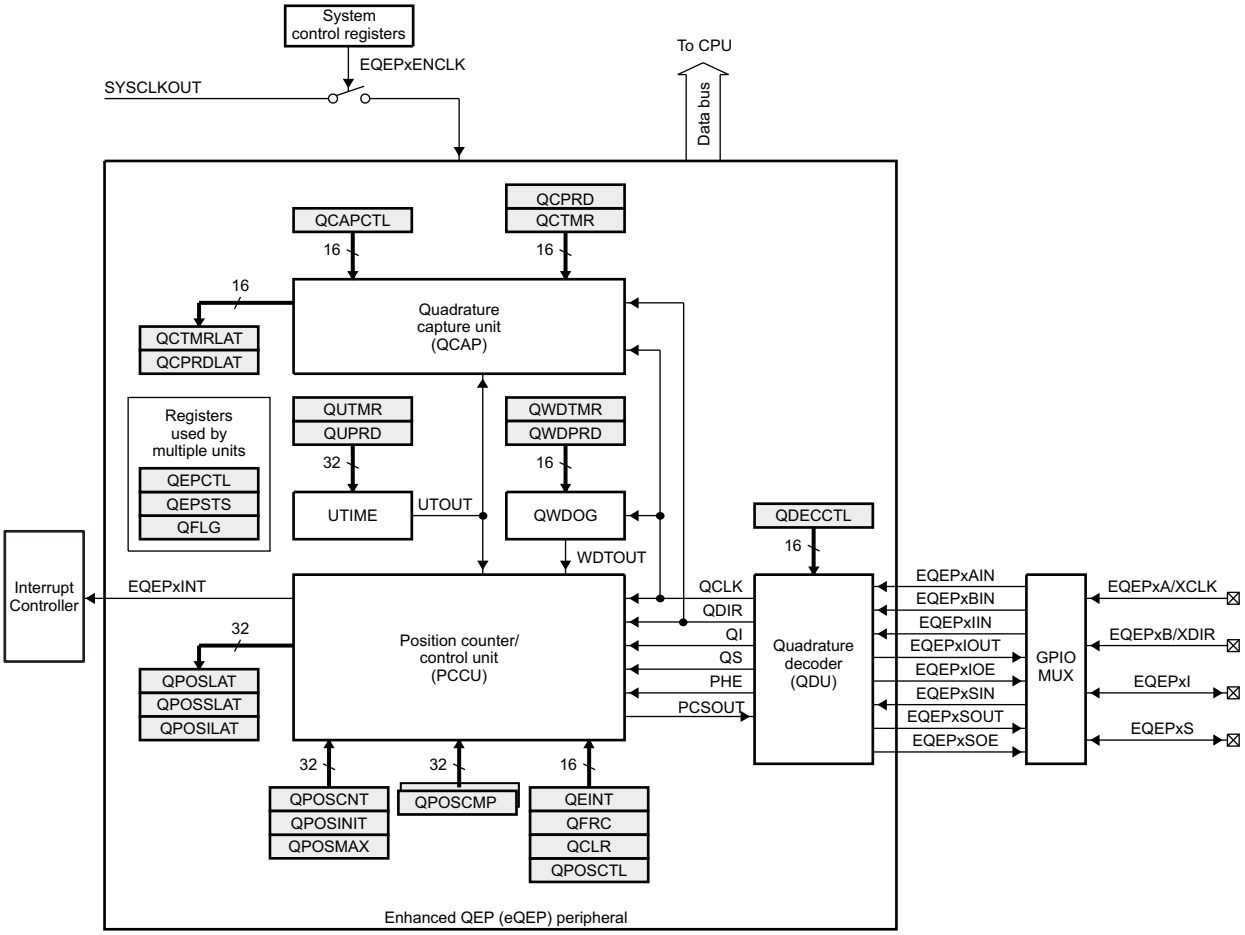
- QEPA/XCLK and QEPB/XDIR: These two pins can be used in quadrature-clock mode or direction-count mode.
  - Quadrature-clock Mode: The eQEP encoders provide two square wave signals (A and B) 90 electrical degrees out of phase whose phase relationship is used to determine the direction of rotation of the input shaft and number of eQEP pulses from the index position to derive the relative position information. For forward or clockwise rotation, QEPA signal leads QEPB signal and vice versa. The quadrature decoder uses these two inputs to generate quadrature-clock and direction signals.
  - Direction-count Mode: In direction-count mode, direction and clock signals are provided directly from the external source. Some position encoders have this type of output instead of quadrature output. The QEPA pin provides the clock input and the QEPB pin provides the direction input.
- QEPI: Index or Zero Marker: The eQEP encoder uses an index signal to assign an absolute start position from which position information is incrementally encoded using quadrature pulses. This pin is connected to the index output of the eQEP encoder to optionally reset the position counter for each revolution. This signal can be used to initialize or latch the position counter on the occurrence of a desired event on the index pin.
- QEPS: Strobe Input: This general-purpose strobe signal can initialize or latch the position counter on the occurrence of a desired event on the strobe pin. This signal is typically connected to a sensor or limit switch to notify that the motor has reached a defined position.

17.2.2 Functional Description

The eQEP peripheral contains the following major functional units (as shown in Figure 17-4):

- Programmable input qualification for each pin (part of the GPIO MUX)
- Quadrature decoder unit (QDU)
- Position counter and control unit for position measurement (PCCU)
- Quadrature edge-capture unit for low-speed measurement (QCAP)
- Unit time base for speed/frequency measurement (UTIME)
- Watchdog timer for detecting stalls (QWDOG)

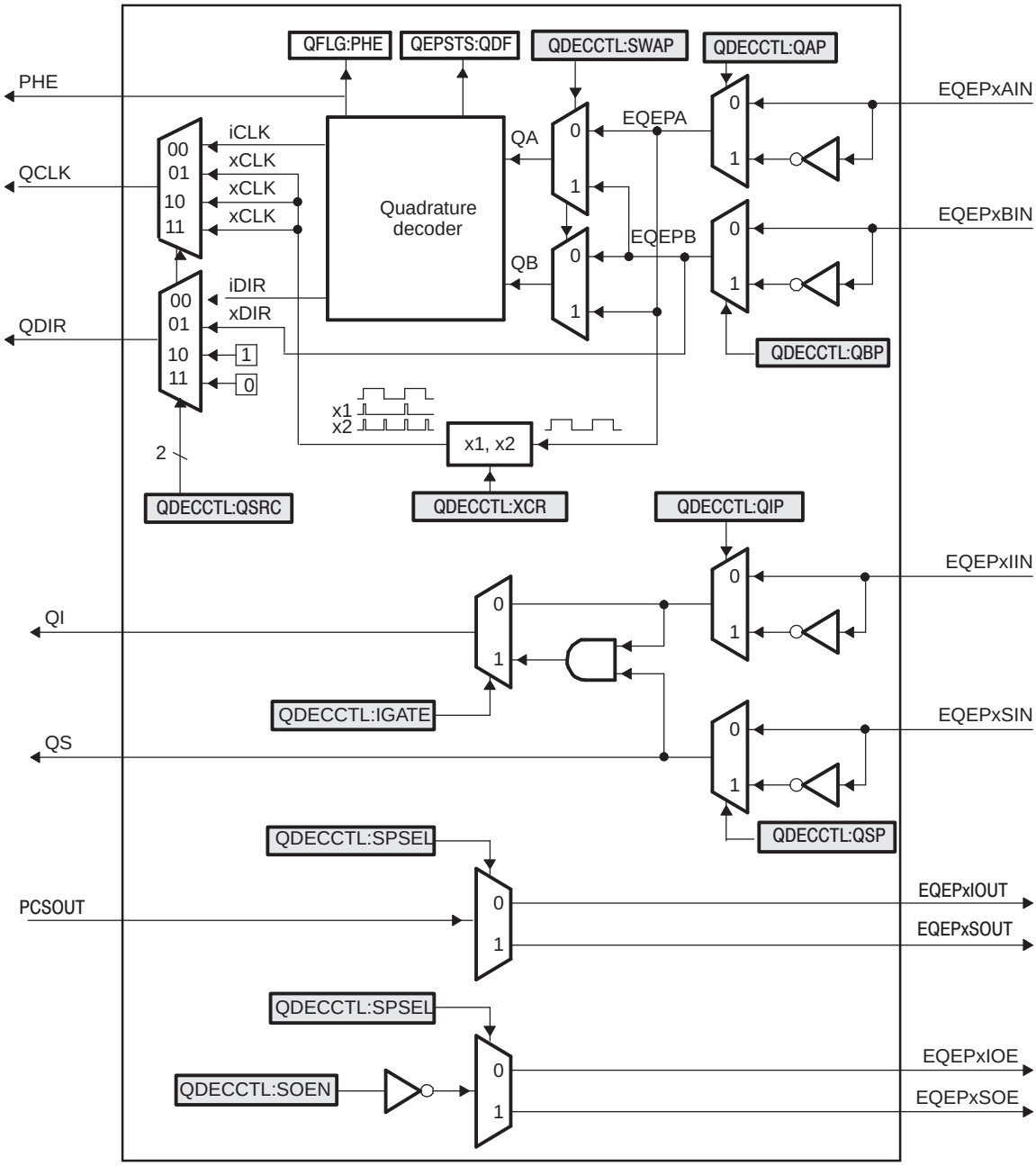
Figure 17-4. Functional Block Diagram of the eQEP Peripheral



17.2.3 Quadrature Decoder Unit (QDU)

Figure 17-5 shows a functional block diagram of the QDU.

Figure 17-5. Functional Block Diagram of Decoder Unit



17.2.3.1 Position Counter Input Modes

Clock and direction input to position counter is selected using the QSRC bit in the eQEP decoder control register (QDECCTL), based on interface input requirement as follows:

- Quadrature-count mode
- Direction-count mode
- UP-count mode
- DOWN-count mode

17.2.3.1.1 Quadrature Count Mode

The quadrature decoder generates the direction and clock to the position counter in quadrature count mode.

Direction Decoding— The direction decoding logic of the eQEP circuit determines which one of the sequences (QEPA, QEPB) is the leading sequence and accordingly updates the direction information in the QDF bit in the eQEP status register (QEPSTS). Table 17-1 and Figure 17-6 show the direction decoding logic in truth table and state machine form. Both edges of the QEPA and QEPB signals are sensed to generate count pulses for the position counter. Therefore, the frequency of the clock generated by the eQEP logic is four times that of each input sequence. Figure 17-7 shows the direction decoding and clock generation from the eQEP input signals.

Phase Error Flag— In normal operating conditions, quadrature inputs QEPA and QEPB will be 90 degrees out of phase. The phase error flag (PHE) is set in the QFLG register when edge transition is detected simultaneously on the QEPA and QEPB signals to optionally generate interrupts. State transitions marked by dashed lines in Figure 17-6 are invalid transitions that generate a phase error.

Count Multiplication— The eQEP position counter provides 4x times the resolution of an input clock by generating a quadrature-clock (QCLK) on the rising/falling edges of both eQEP input clocks (QEPA and QEPB) as shown in Figure 17-7.

Reverse Count— In normal quadrature count operation, QEPA input is fed to the QA input of the quadrature decoder and the QEPB input is fed to the QB input of the quadrature decoder. Reverse counting is enabled by setting the SWAP bit in the eQEP decoder control register (QDECCTL). This will swap the input to the quadrature decoder thereby reversing the counting direction.

Table 17-1. Quadrature Decoder Truth Table

Previous Edge	Present Edge	QDIR	QPOSCNT
QA↑	QB↑	UP	Increment
	QB↓	DOWN	Decrement
	QA↓	TOGGLE	Increment or Decrement
QA↓	QB↓	UP	Increment
	QB↑	DOWN	Decrement
	QA↑	TOGGLE	Increment or Decrement
QB↑	QA↑	DOWN	Increment
	QA↓	UP	Decrement
	QB↓	TOGGLE	Increment or Decrement
QB↓	QA↓	DOWN	Increment
	QA↑	UP	Decrement
	QB↑	TOGGLE	Increment or Decrement

Figure 17-6. Quadrature Decoder State Machine

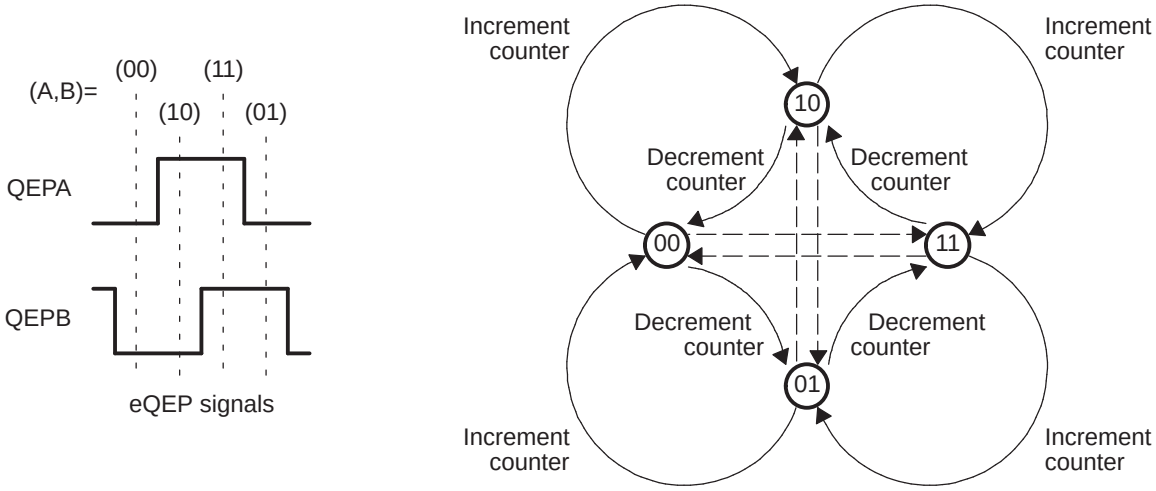
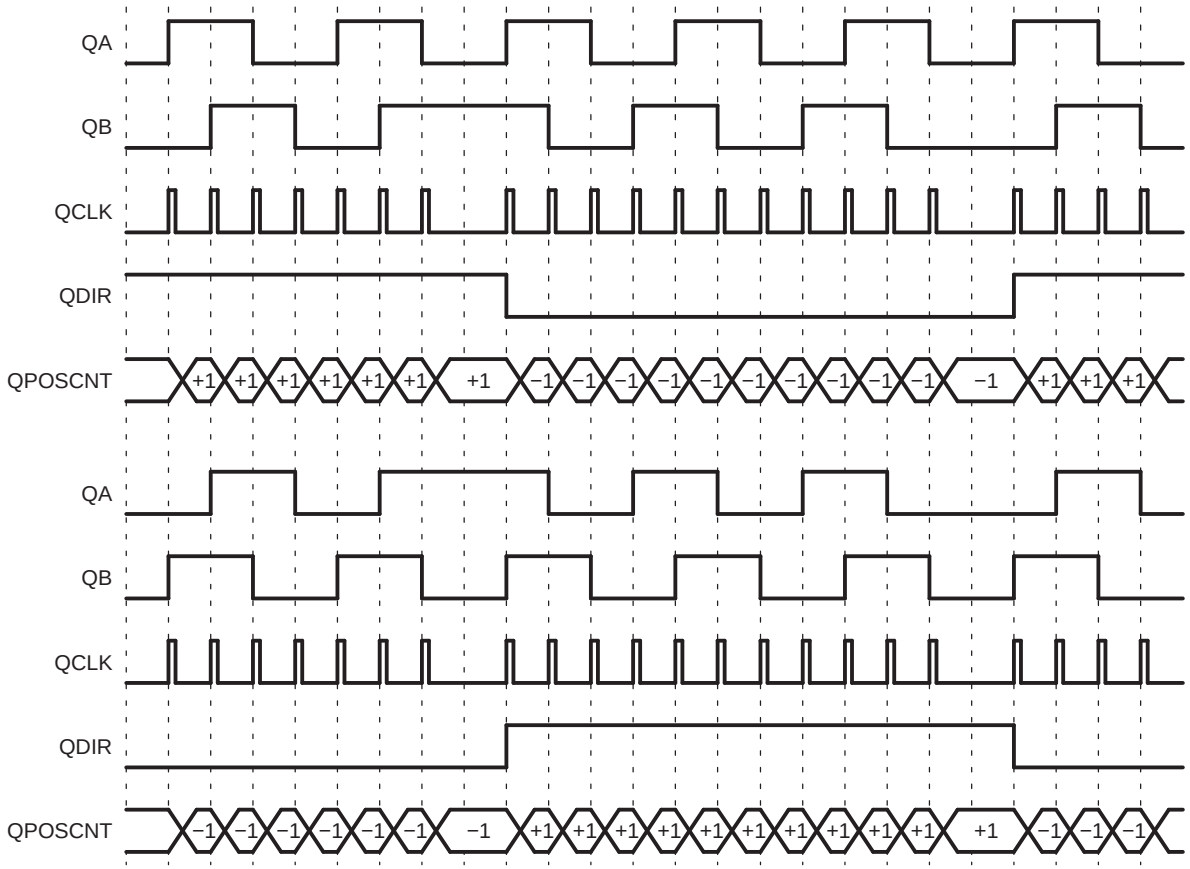


Figure 17-7. Quadrature-clock and Direction Decoding



17.2.3.1.2 Direction-count Mode

Some position encoders provide direction and clock outputs, instead of quadrature outputs. In such cases, direction-count mode can be used. QEPA input will provide the clock for position counter and the QEPB input will have the direction information. The position counter is incremented on every rising edge of a QEPA input when the direction input is high and decremented when the direction input is low.

17.2.3.1.3 Up-Count Mode

The counter direction signal is hard-wired for up count and the position counter is used to measure the frequency of the QEPA input. Setting of the XCR bit in the eQEP decoder control register (QDECCTL) enables clock generation to the position counter on both edges of the QEPA input, thereby increasing the measurement resolution by 2× factor.

17.2.3.1.4 Down-Count Mode

The counter direction signal is hardwired for a down count and the position counter is used to measure the frequency of the QEPA input. Setting of the XCR bit in the eQEP decoder control register (QDECCTL) enables clock generation to the position counter on both edges of a QEPA input, thereby increasing the measurement resolution by 2× factor.

17.2.3.2 eQEP Input Polarity Selection

Each eQEP input can be inverted using the in the eQEP decoder control register (QDECCTL[8:5]) control bits. As an example, setting of the QIP bit in QDECCTL inverts the index input.

17.2.3.3 Position-Compare Sync Output

The eQEP peripheral includes a position-compare unit that is used to generate the position-compare sync signal on compare match between the position counter register (QPOSCNT) and the position-compare register (QPOSCMP). This sync signal can be output using an index pin or strobe pin of the EQEP peripheral.

Setting the SOEN bit in the eQEP decoder control register (QDECCTL) enables the position-compare sync output and the SPSEL bit in QDECCTL selects either an eQEP index pin or an eQEP strobe pin.

17.2.4 Position Counter and Control Unit (PCCU)

The position counter and control unit provides two configuration registers (QEPCTL and QPOSCTL) for setting up position counter operational modes, position counter initialization/latch modes and position-compare logic for sync signal generation.

17.2.4.1 Position Counter Operating Modes

Position counter data may be captured in different manners. In some systems, the position counter is accumulated continuously for multiple revolutions and the position counter value provides the position information with respect to the known reference. An example of this is the quadrature encoder mounted on the motor controlling the print head in the printer. Here the position counter is reset by moving the print head to the home position and then position counter provides absolute position information with respect to home position.

In other systems, the position counter is reset on every revolution using index pulse and position counter provides rotor angle with respect to index pulse position.

Position counter can be configured to operate in following four modes

- Position Counter Reset on Index Event
- Position Counter Reset on Maximum Position
- Position Counter Reset on the first Index Event
- Position Counter Reset on Unit Time Out Event (Frequency Measurement)

In all the above operating modes, position counter is reset to 0 on overflow and to QPOSMAX register value on underflow. Overflow occurs when the position counter counts up after QPOSMAX value. Underflow occurs when position counter counts down after "0". Interrupt flag is set to indicate overflow/underflow in QFLG register.

17.2.4.1.1 Position Counter Reset on Index Event (QEPCTL[PCRM] = 00)

If the index event occurs during the forward movement, then position counter is reset to 0 on the next eQEP clock. If the index event occurs during the reverse movement, then the position counter is reset to the value in the QPOSMAX register on the next eQEP clock.

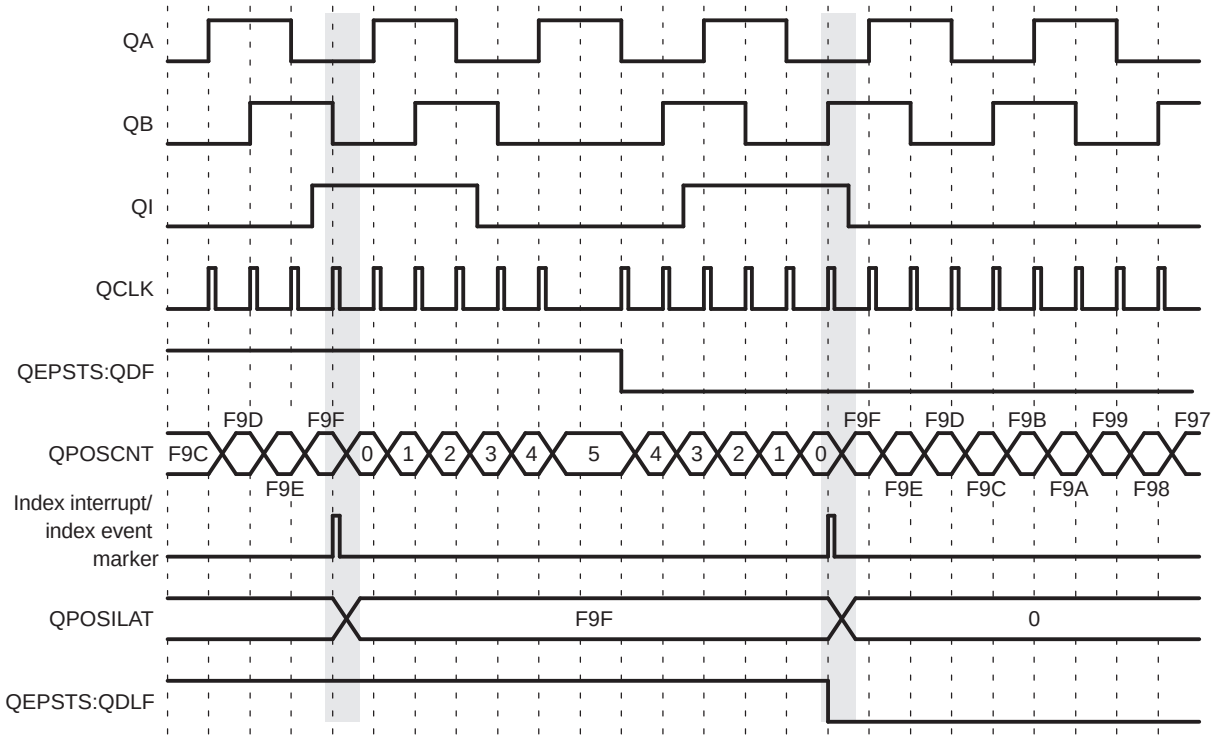
First index marker is defined as the quadrature edge following the first index edge. The eQEP peripheral records the occurrence of the first index marker (QEPSTS[FIMF]) and direction on the first index event marker (QEPSTS[FIDF]) in QEPSTS registers, it also remembers the quadrature edge on the first index marker so that same relative quadrature transition is used for index event reset operation.

For example, if the first reset operation occurs on the falling edge of QEPB during the forward direction, then all the subsequent reset must be aligned with the falling edge of QEPB for the forward rotation and on the rising edge of QEPB for the reverse rotation as shown in Figure 17-8.

The position-counter value is latched to the QPOSILAT register and direction information is recorded in the QEPSTS[QDLF] bit on every index event marker. The position-counter error flag (QEPSTS[PCEF]) and error interrupt flag (QFLG[PCE]) are set if the latched value is not equal to 0 or QPOSMAX. The position-counter error flag (QEPSTS[PCEF]) is updated on every index event marker and an interrupt flag (QFLG[PCE]) will be set on error that can be cleared only through software.

The index event latch configuration QEPCTL[IEL] bits are ignored in this mode and position counter error flag/interrupt flag are generated only in index event reset mode.

Figure 17-8. Position Counter Reset by Index Pulse for 1000 Line Encoder (QPOSMAX = 3999 or F9Fh)

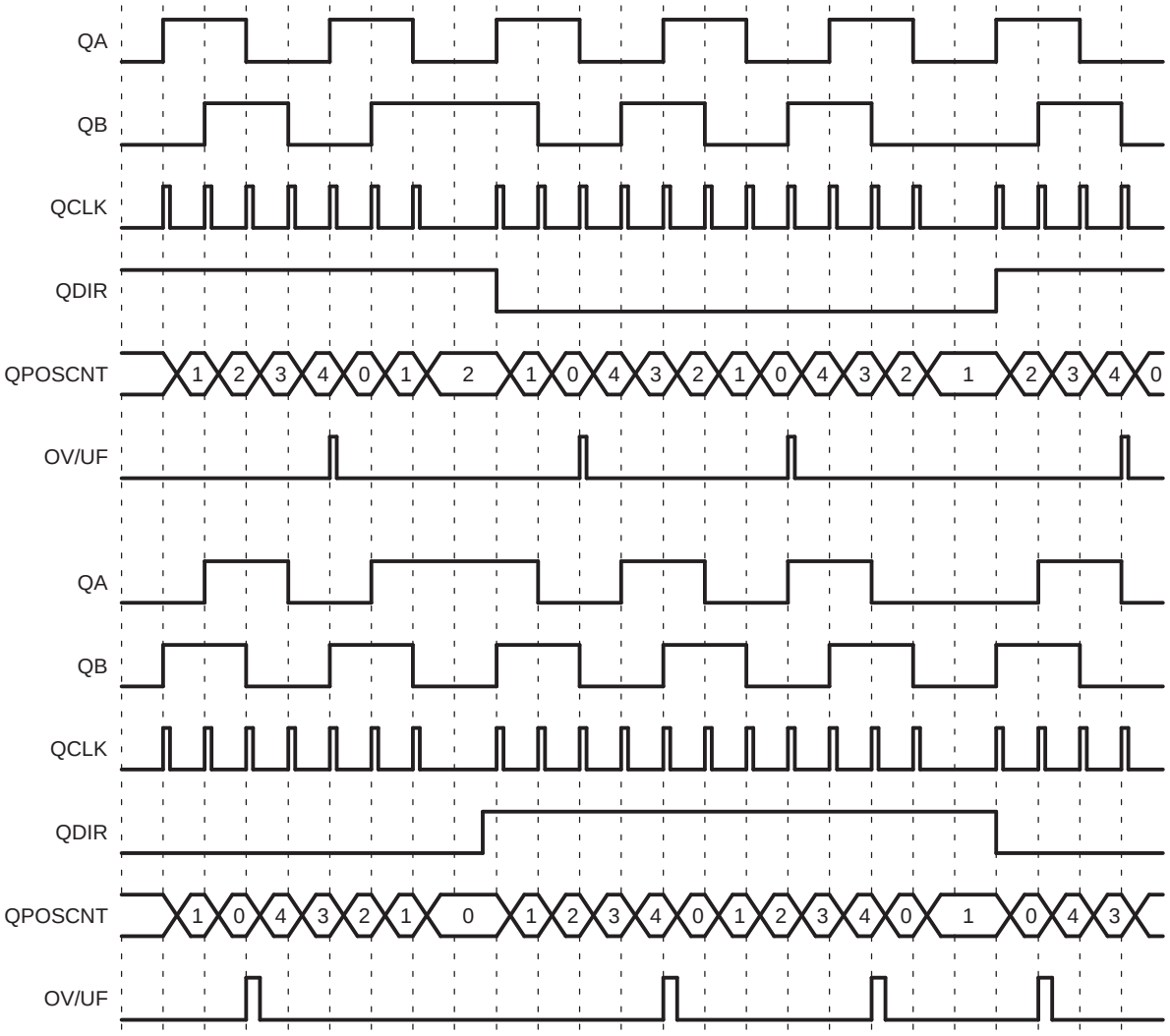


17.2.4.1.2 Position Counter Reset on Maximum Position (QEPCTL[PCRM]=01)

If the position counter is equal to QPOSMAX, then the position counter is reset to 0 on the next eQEP clock for forward movement and position counter overflow flag is set. If the position counter is equal to ZERO, then the position counter is reset to QPOSMAX on the next QEP clock for reverse movement and position counter underflow flag is set. Figure 17-9 shows the position counter reset operation in this mode.

First index marker is defined as the quadrature edge following the first index edge. The eQEP peripheral records the occurrence of the first index marker (QEPSTS[FIMF]) and direction on the first index event marker (QEPSTS[FIDF]) in the QEPSTS registers; it also remembers the quadrature edge on the first index marker so that the same relative quadrature transition is used for the software index marker (QEPCTL[IEL]=11).

Figure 17-9. Position Counter Underflow/Overflow (QPOSMAX = 4)



17.2.4.1.3 Position Counter Reset on the First Index Event (QEPCTL[PCRM] = 10)

If the index event occurs during forward movement, then the position counter is reset to 0 on the next eQEP clock. If the index event occurs during the reverse movement, then the position counter is reset to the value in the QPOSMAX register on the next eQEP clock. Note that this is done only on the first occurrence and subsequently the position counter value is not reset on an index event; rather, it is reset based on maximum position as described in Section 17.2.4.1.2.

First index marker is defined as the quadrature edge following the first index edge. The eQEP peripheral records the occurrence of the first index marker (QEPSTS[FIMF]) and direction on the first index event marker (QEPSTS[FIDF]) in QEPSTS registers. It also remembers the quadrature edge on the first index marker so that same relative quadrature transition is used for software index marker (QEPCTL[IEL]=11).

17.2.4.1.4 Position Counter Reset on Unit Time out Event (QEPCTL[PCRM] = 11)

In this mode, the QPOSCNT value is latched to the QPOSLAT register and then the QPOSCNT is reset (to 0 or QPOSMAX, depending on the direction mode selected by QDECCTL[QSRC] bits on a unit time event). This is useful for frequency measurement.

17.2.4.2 Position Counter Latch

The eQEP index and strobe input can be configured to latch the position counter (QPOSCNT) into QPOSILAT and QPOSSLAT, respectively, on occurrence of a definite event on these pins.

17.2.4.2.1 Index Event Latch

In some applications, it may not be desirable to reset the position counter on every index event and instead it may be required to operate the position counter in full 32-bit mode (QEPCTL[PCRM] = 01 and QEPCTL[PCRM] = 10 modes).

In such cases, the eQEP position counter can be configured to latch on the following events and direction information is recorded in the QEPSTS[QDLF] bit on every index event marker.

- Latch on Rising edge (QEPCTL[IEL] = 01)
- Latch on Falling edge (QEPCTL[IEL] = 10)
- Latch on Index Event Marker (QEPCTL[IEL] = 11)

This is particularly useful as an error checking mechanism to check if the position counter accumulated the correct number of counts between index events. As an example, the 1000-line encoder must count 4000 times when moving in the same direction between the index events.

The index event latch interrupt flag (QFLG[IEL]) is set when the position counter is latched to the QPOSILAT register. The index event latch configuration bits (QEPCTZ[IEL]) are ignored when QEPCTL[PCRM] = 00.

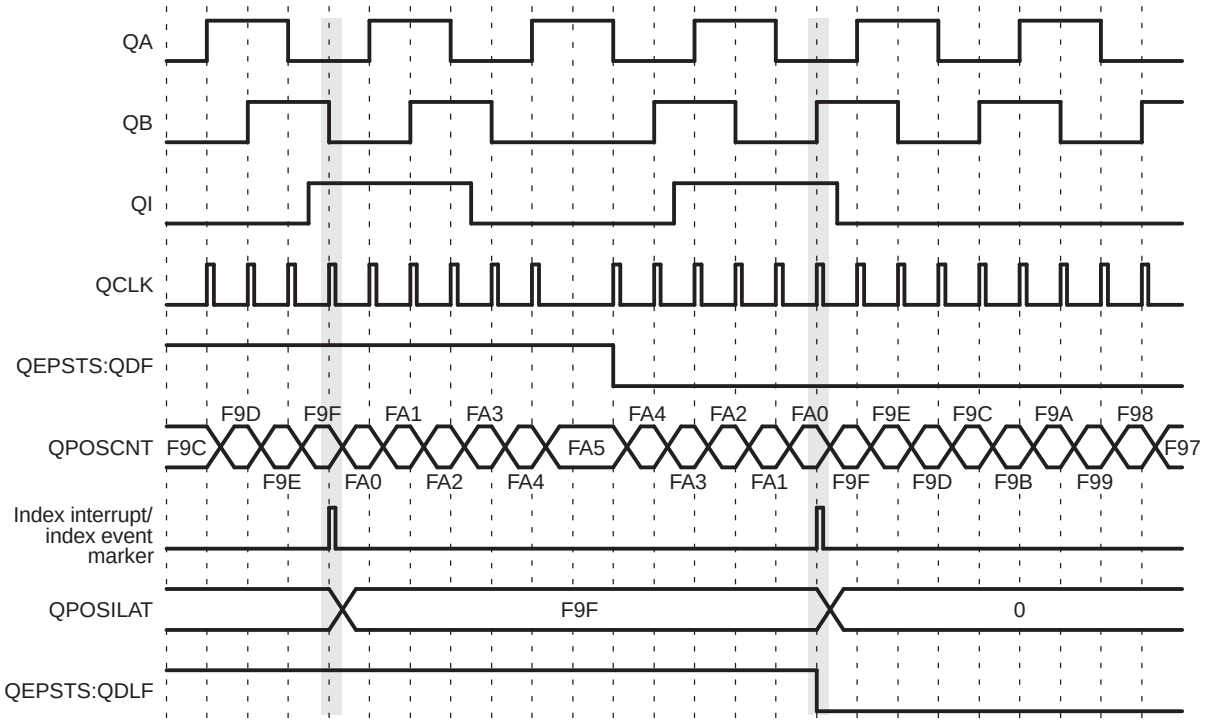
Latch on Rising Edge (QEPCTL[IEL] = 01)— The position counter value (QPOSCNT) is latched to the QPOSILAT register on every rising edge of an index input.

Latch on Falling Edge (QEPCTL[IEL] = 10)— The position counter value (QPOSCNT) is latched to the QPOSILAT register on every falling edge of index input.

Latch on Index Event Marker/Software Index Marker (QEPCTL[IEL] = 11)— The first index marker is defined as the quadrature edge following the first index edge. The eQEP peripheral records the occurrence of the first index marker (QEPSTS[FIMF]) and direction on the first index event marker (QEPSTS[FIDF]) in the QEPSTS registers. It also remembers the quadrature edge on the first index marker so that same relative quadrature transition is used for latching the position counter (QEPCTL[IEL] = 11).

Figure 17-10 shows the position counter latch using an index event marker.

Figure 17-10. Software Index Marker for 1000-line Encoder (QEPCTL[IEL] = 1)



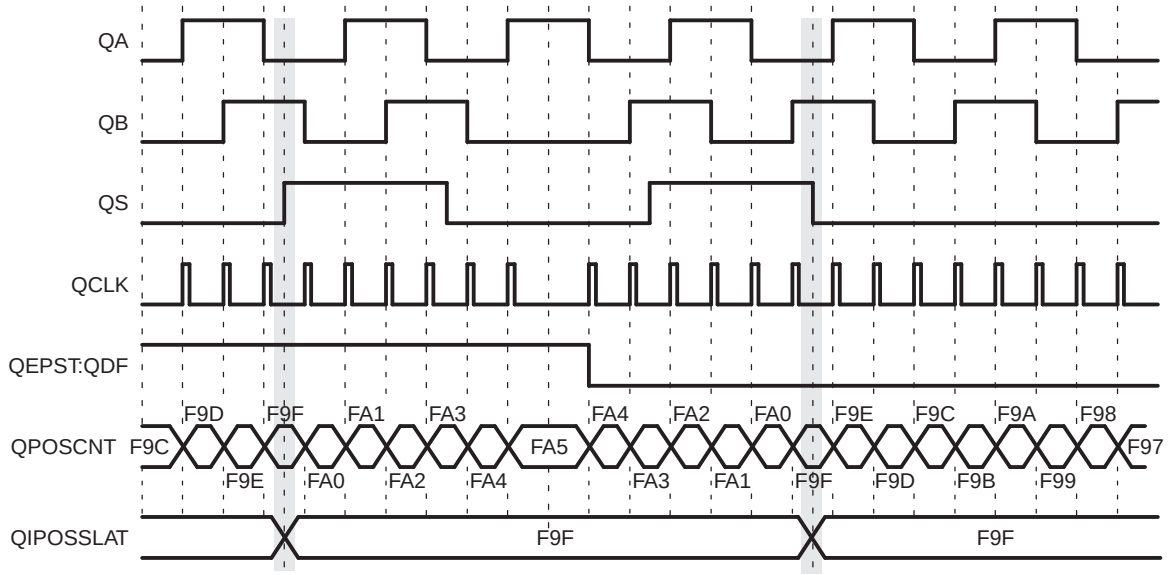
17.2.4.2.2 Strobe Event Latch

The position-counter value is latched to the QPOSSLAT register on the rising edge of the strobe input by clearing the QEPCTL[SEL] bit.

If the QEPCTL[SEL] bit is set, then the position counter value is latched to the QPOSSLAT register on the rising edge of the strobe input for forward direction and on the falling edge of the strobe input for reverse direction as shown in Figure 17-11.

The strobe event latch interrupt flag (QFLG[SEL]) is set when the position counter is latched to the QPOSSLAT register.

Figure 17-11. Strobe Event Latch (QEPCTL[SEL] = 1)



17.2.4.3 Position Counter Initialization

The position counter can be initialized using following events:

- Index event
- Strobe event
- Software initialization

Index Event Initialization (IEI)— The QEPI index input can be used to trigger the initialization of the position counter at the rising or falling edge of the index input.

If the QEPCTL[IEI] bits are 10, then the position counter (QPOSCNT) is initialized with a value in the QPOSINIT register on the rising edge of strobe input for forward direction and on the falling edge of strobe input for reverse direction.

The index event initialization interrupt flag (QFLG[IEI]) is set when the position counter is initialized with a value in the QPOSINIT register.

Strobe Event Initialization (SEI)— If the QEPCTL[SEI] bits are 10, then the position counter is initialized with a value in the QPOSINIT register on the rising edge of strobe input.

If the QEPCTL[SEL] bits are 11, then the position counter (QPOSCNT) is initialized with a value in the QPOSINIT register on the rising edge of strobe input for forward direction and on the falling edge of strobe input for reverse direction.

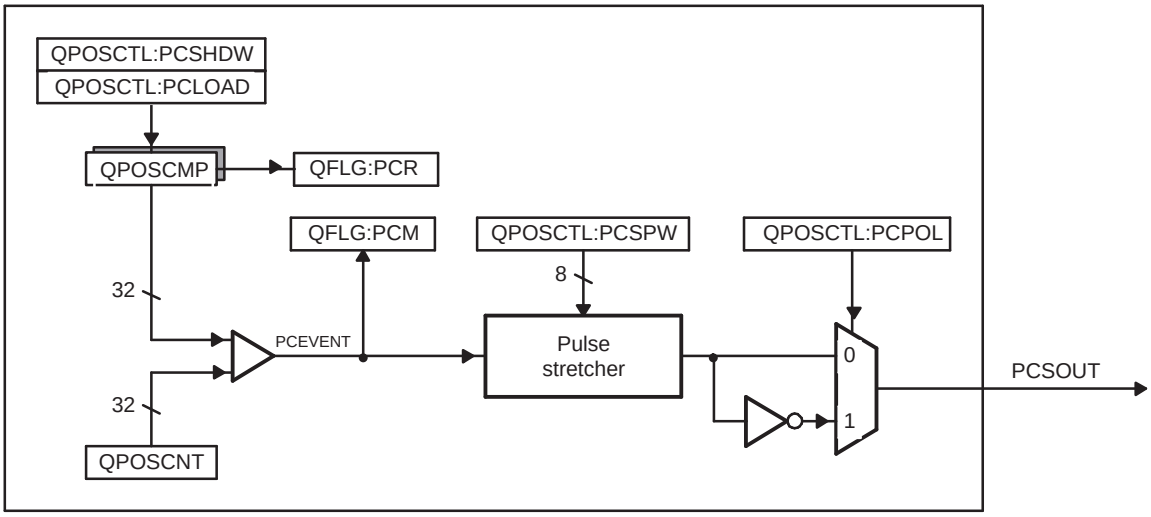
The strobe event initialization interrupt flag (QFLG[SEI]) is set when the position counter is initialized with a value in the QPOSINIT register.

Software Initialization (SWI)— The position counter can be initialized in software by writing a 1 to the QEPCTL[SWI] bit, which will automatically be cleared after initialization.

17.2.4.4 eQEP Position-compare Unit

The eQEP peripheral includes a position-compare unit that is used to generate a sync output and/or interrupt on a position-compare match. Figure 17-12 shows a diagram. The position-compare (QPOSCMP) register is shadowed and shadow mode can be enabled or disabled using the QPOSCTL[PSSHDW] bit. If the shadow mode is not enabled, the CPU writes directly to the active position compare register.

Figure 17-12. eQEP Position-compare Unit



In shadow mode, you can configure the position-compare unit (QPOSCTL[PCLOAD]) to load the shadow register value into the active register on the following events and to generate the position-compare ready (QFLG[PCR]) interrupt after loading.

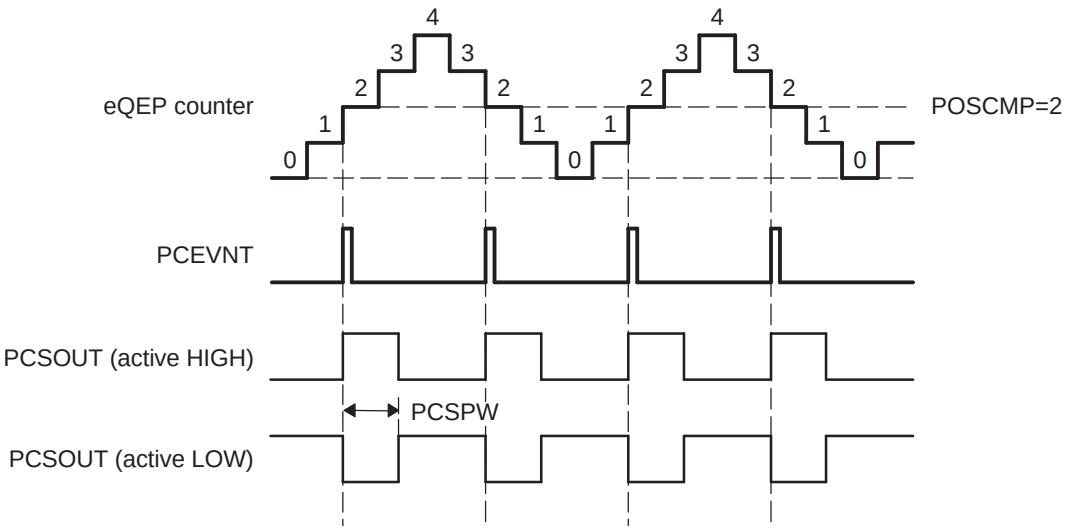
- Load on compare match
- Load on position-counter zero event

The position-compare match (QFLG[PCM]) is set when the position-counter value (QPOSCNT) matches with the active position-compare register (QPOSCMP) and the position-compare sync output of the programmable pulse width is generated on compare match to trigger an external device.

For example, if QPOSCMP = 2, the position-compare unit generates a position-compare event on 1 to 2 transitions of the eQEP position counter for forward counting direction and on 3 to 2 transitions of the eQEP position counter for reverse counting direction (see Figure 17-13).

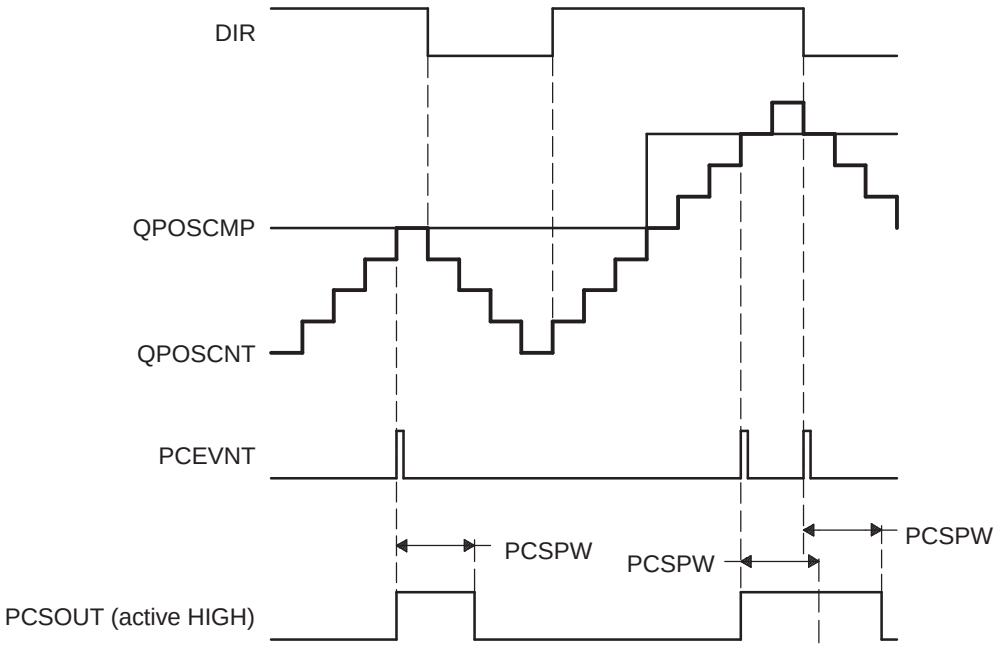
Figure 17-35 shows the layout of the eQEP Position-Compare Control Register (QPOSCTL) and Table 17-17 describes the QPOSCTL bit fields.

Figure 17-13. eQEP Position-compare Event Generation Points



The pulse stretcher logic in the position-compare unit generates a programmable position-compare sync pulse output on the position-compare match. In the event of a new position-compare match while a previous position-compare pulse is still active, then the pulse stretcher generates a pulse of specified duration from the new position-compare event as shown in Figure 17-14.

Figure 17-14. eQEP Position-compare Sync Output Pulse Stretcher



17.2.5 eQEP Edge Capture Unit

The eQEP peripheral includes an integrated edge capture unit to measure the elapsed time between the unit position events as shown in Figure 17-15. This feature is typically used for low speed measurement using the following equation:

$$v(k) = \frac{X}{t(k) - t(k-1)} = \frac{X}{\Delta T} \quad (3)$$

where,

- X - Unit position is defined by integer multiple of quadrature edges (see Figure 17-16)
- ΔT - Elapsed time between unit position events
- v(k) - Velocity at time instant "k"

The eQEP capture timer (QCTMR) runs from prescaled SYSCLKOUT and the prescaler is programmed by the QCAPCTL[CCPS] bits. The capture timer (QCTMR) value is latched into the capture period register (QCPRD) on every unit position event and then the capture timer is reset, a flag is set in QEPSTS[UPEVNT] to indicate that new value is latched into the QCPRD register. Software can check this status flag before reading the period register for low speed measurement and clear the flag by writing 1.

Time measurement (ΔT) between unit position events will be correct if the following conditions are met:

- No more than 65,535 counts have occurred between unit position events.
- No direction change between unit position events.

The capture unit sets the eQEP overflow error flag (QEPSTS[COEF]) in the event of capture timer overflow between unit position events. If a direction change occurs between the unit position events, then an error flag is set in the status register (QEPSTS[CDEF]).

Capture Timer (QCTMR) and Capture period register (QCPRD) can be configured to latch on following events.

- CPU read of QPOSCNT register
- Unit time-out event

If the QEPCTL[QCLM] bit is cleared, then the capture timer and capture period values are latched into the QCTMRLAT and QCPRDLAT registers, respectively, when the CPU reads the position counter (QPOSCNT).

If the QEPCTL[QCLM] bit is set, then the position counter, capture timer, and capture period values are latched into the QPOSLAT, QCTMRLAT and QCPRDLAT registers, respectively, on unit time out.

Figure 17-17 shows the capture unit operation along with the position counter.

NOTE: The QCAPCTL register should not be modified dynamically (such as switching CAPCLK prescaling mode from QCLK/4 to QCLK/8). The capture unit must be disabled before changing the prescaler.

Figure 17-15. eQEP Edge Capture Unit

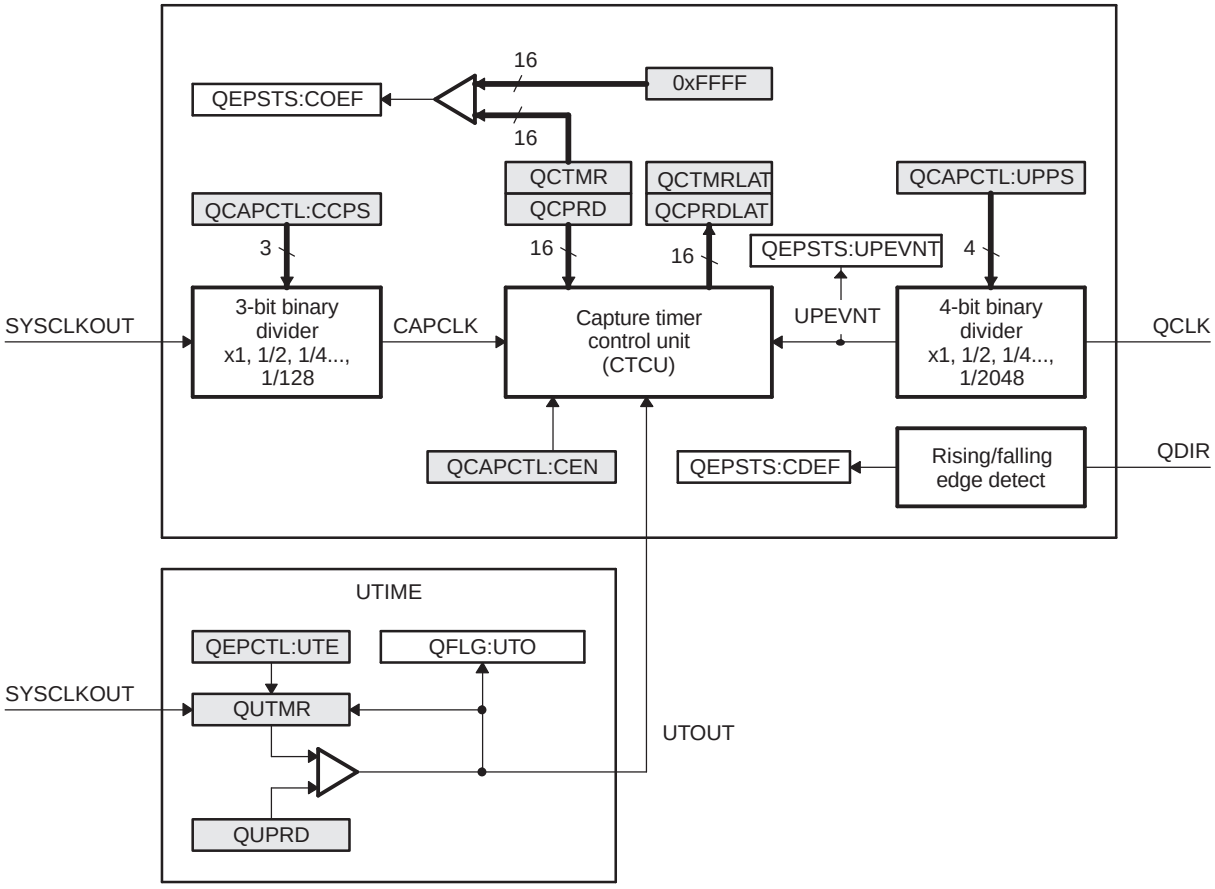
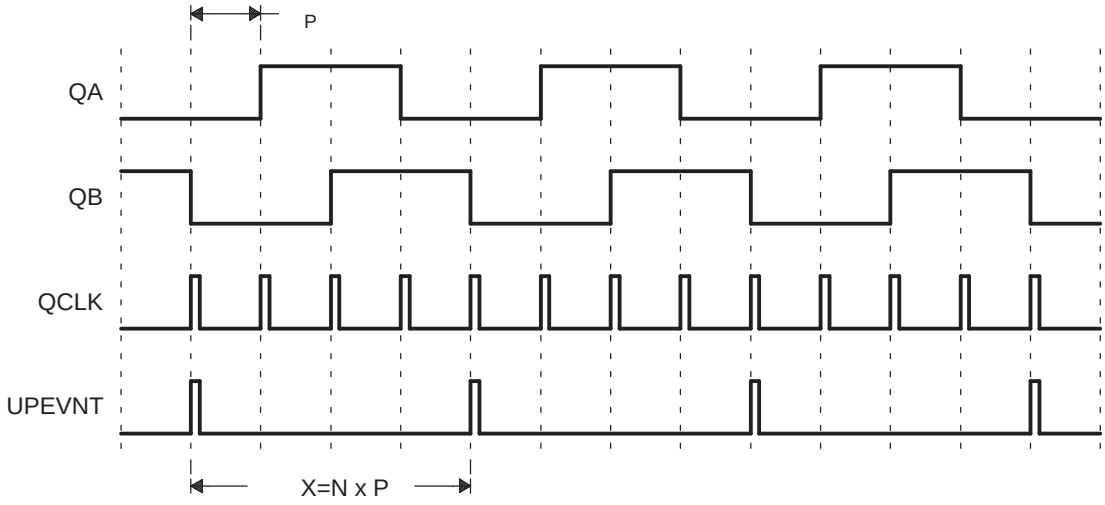
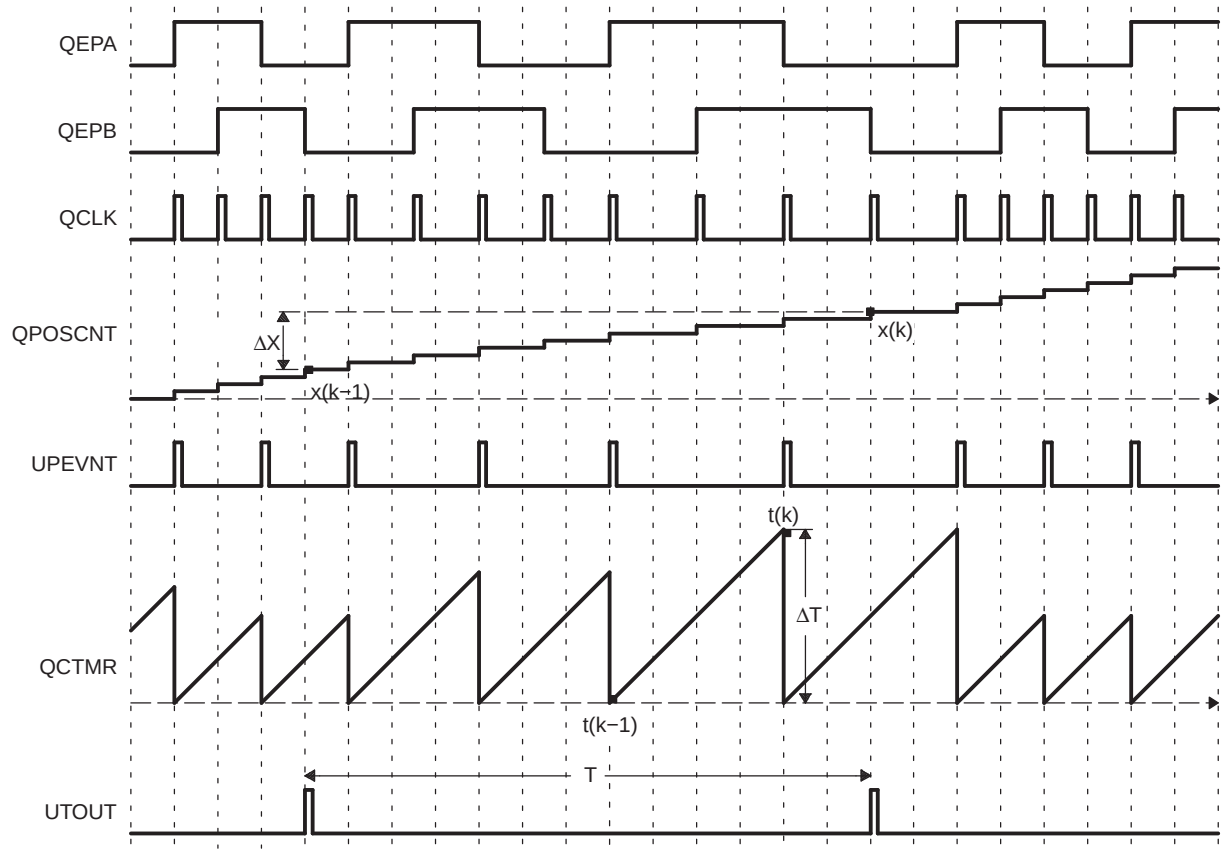


Figure 17-16. Unit Position Event for Low Speed Measurement (QCAPCTL[UPPS] = 0010)



N - Number of quadrature periods selected using QCAPCTL[UPPS] bits

Figure 17-17. eQEP Edge Capture Unit - Timing Details



Velocity Calculation Equations:

$$v(k) = \frac{x(k) - x(k-1)}{T} = \frac{\Delta X}{T} \quad (4)$$

where

v(k): Velocity at time instant k

x(k): Position at time instant k

x(k-1): Position at time instant k - 1

T: Fixed unit time or inverse of velocity calculation rate

ΔX: Incremental position movement in unit time

X: Fixed unit position

ΔT: Incremental time elapsed for unit position movement

t(k): Time instant "k"

t(k-1): Time instant "k - 1"

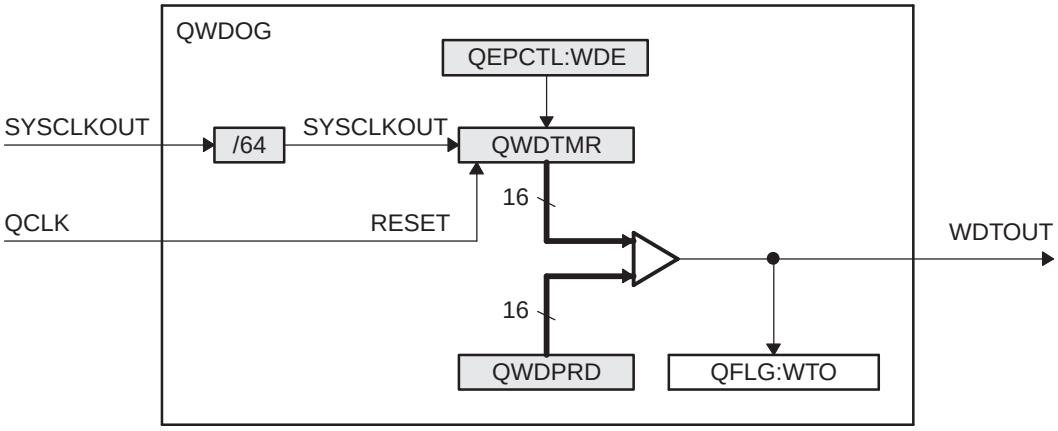
Unit time (T) and unit period (X) are configured using the QUPRD and QCAPCTL[UPPS] registers. Incremental position output and incremental time output is available in the QPOSLAT and QCPRDLAT registers.

Parameter	Relevant Register to Configure or Read the Information
T	Unit Period Register (QUPRD)
ΔX	Incremental Position = QPOSLAT(k) - QPOSLAT(K - 1)
X	Fixed unit position defined by sensor resolution and ZCAPCTL[UPPS] bits
ΔT	Capture Period Latch (QCPRDLAT)

17.2.6 eQEP Watchdog

The eQEP peripheral contains a 16-bit watchdog timer that monitors the quadrature-clock to indicate proper operation of the motion-control system. The eQEP watchdog timer is clocked from SYSCLKOUT/64 and the quadrate clock event (pulse) resets the watchdog timer. If no quadrature-clock event is detected until a period match (QWDPRD = QWDTMR), then the watchdog timer will time out and the watchdog interrupt flag will be set (QFLG[WTO]). The time-out value is programmable through the watchdog period register (QWDPRD).

Figure 17-18. eQEP Watchdog Timer

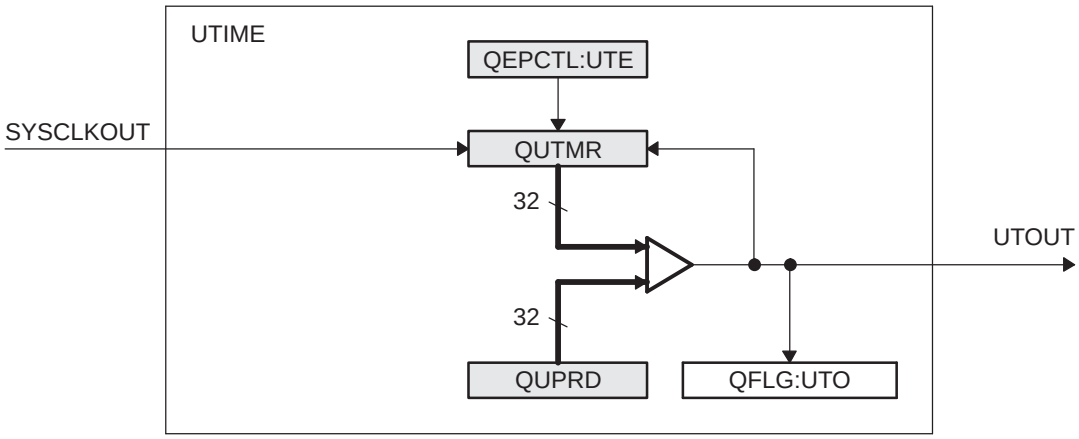


17.2.7 Unit Timer Base

The eQEP peripheral includes a 32-bit timer (QUTMR) that is clocked by SYSCLKOUT to generate periodic interrupts for velocity calculations. The unit time out interrupt is set (QFLG[UTO]) when the unit timer (QUTMR) matches the unit period register (QUPRD).

The eQEP peripheral can be configured to latch the position counter, capture timer, and capture period values on a unit time out event so that latched values are used for velocity calculation as described in Section Section 17.2.5.

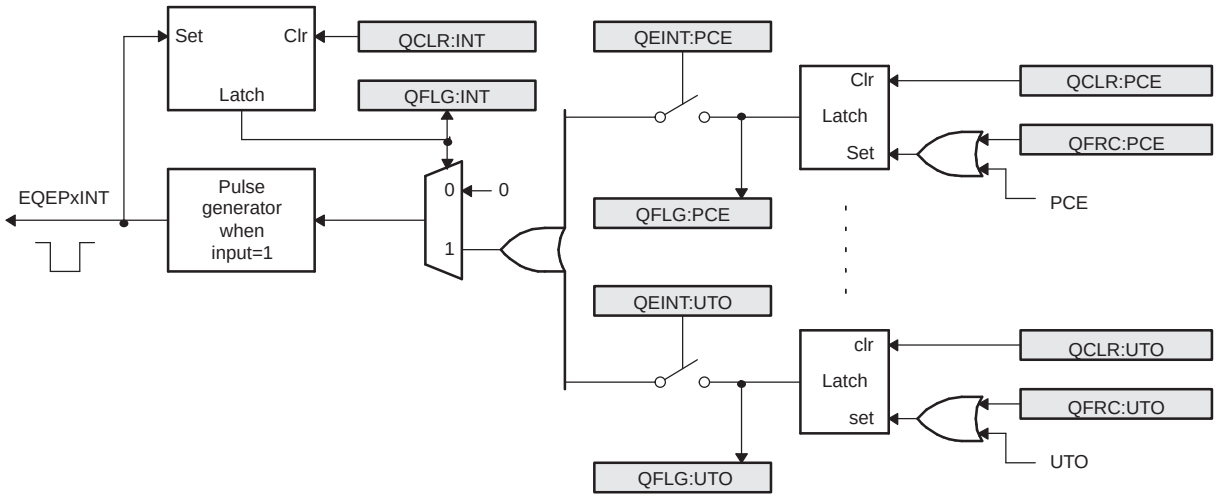
Figure 17-19. eQEP Unit Time Base



17.2.8 eQEP Interrupt Structure

Figure 17-20 shows how the interrupt mechanism works in the EQEP module.

Figure 17-20. EQEP Interrupt Generation



Eleven interrupt events (PCE, PHE, QDC, WTO, PCU, PCO, PCR, PCM, SEL, IEL, and UTO) can be generated. The interrupt control register (QEINT) is used to enable/disable individual interrupt event sources. The interrupt flag register (QFLG) indicates if any interrupt event has been latched and contains the global interrupt flag bit (INT). An interrupt pulse is generated only to the interrupt controller if any of the interrupt events is enabled, the flag bit is 1 and the INT flag bit is 0. The interrupt service routine will need to clear the global interrupt flag bit and the serviced event, via the interrupt clear register (QCLR), before any other interrupt pulses are generated. You can force an interrupt event by way of the interrupt force register (QFRC), which is useful for test purposes.

17.3 eQEP Registers

Table 17-2 lists the registers with their memory locations, sizes, and reset values.

Table 17-2. eQEP Registers

Offset	Acronym	Register Description	Size(×16)/ #shadow	Section
0h	QPOSCNT	eQEP Position Counter Register	2/0	Section 17.3.1
4h	QPOSINIT	eQEP Position Counter Initialization Register	2/0	Section 17.3.2
8h	QPOSMAX	eQEP Maximum Position Count Register	2/0	Section 17.3.3
Ch	QPOSCMP	eQEP Position-Compare Register	2/1	Section 17.3.4
10h	QPOSILAT	eQEP Index Position Latch Register	2/0	Section 17.3.5
14h	QPOSSLAT	eQEP Strobe Position Latch Register	2/0	Section 17.3.6
18h	QPOSLAT	eQEP Position Counter Latch Register	2/0	Section 17.3.7
1Ch	QUTMR	eQEP Unit Timer Register	2/0	Section 17.3.8
20h	QUPRD	eQEP Unit Period Register	2/0	Section 17.3.9
24h	QWDTMR	eQEP Watchdog Timer Register	1/0	Section 17.3.10
26h	QWDPRD	eQEP Watchdog Period Register	1/0	Section 17.3.11
28h	QDECCTL	eQEP Decoder Control Register	1/0	Section 17.3.12
2Ah	QEPCTL	eQEP Control Register	1/0	Section 17.3.13
2Ch	QCAPCTL	eQEP Capture Control Register	1/0	Section 17.3.14
2Eh	QPOSCTL	eQEP Position-Compare Control Register	1/0	Section 17.3.15
30h	QEINT	eQEP Interrupt Enable Register	1/0	Section 17.3.16
32h	QFLG	eQEP Interrupt Flag Register	1/0	Section 17.3.17
34h	QCLR	eQEP Interrupt Clear Register	1/0	Section 17.3.18
36h	QFRC	eQEP Interrupt Force Register	1/0	Section 17.3.19
38h	QEPSTS	eQEP Status Register	1/0	Section 17.3.20
3Ah	QCTMR	eQEP Capture Timer Register	1/0	Section 17.3.21
3Ch	QCPRD	eQEP Capture Period Register	1/0	Section 17.3.22
3Eh	QCTMRLAT	eQEP Capture Timer Latch Register	1/0	Section 17.3.23
40h	QCPRDLAT	eQEP Capture Period Latch Register	1/0	Section 17.3.24
5Ch	REVID	eQEP Revision ID Register	2/0	Section 17.3.25

17.3.1 eQEP Position Counter Register (QPOSCNT)

Figure 17-21. eQEP Position Counter Register (QPOSCNT)

31	0
QPOSCNT	
R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 17-3. eQEP Position Counter Register (QPOSCNT) Field Descriptions

Bits	Name	Value	Description
31-0	QPOSCNT	0-FFFF FFFFh	This 32-bit position counter register counts up/down on every eQEP pulse based on direction input. This counter acts as a position integrator whose count value is proportional to position from a give reference point.

17.3.2 eQEP Position Counter Initialization Register (QPOSINIT)

Figure 17-22. eQEP Position Counter Initialization Register (QPOSINIT)

31	0
QPOSINIT	
R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 17-4. eQEP Position Counter Initialization Register (QPOSINIT) Field Descriptions

Bits	Name	Value	Description
31-0	QPOSINIT	0-FFFF FFFFh	This register contains the position value that is used to initialize the position counter based on external strobe or index event. The position counter can be initialized through software.

17.3.3 eQEP Maximum Position Count Register (QPOSMAX)

Figure 17-23. eQEP Maximum Position Count Register (QPOSMAX)

31	0
QPOSMAX	
R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 17-5. eQEP Maximum Position Count Register (QPOSMAX) Field Descriptions

Bits	Name	Value	Description
31-0	QPOSMAX	0-FFFF FFFFh	This register contains the maximum position counter value.

17.3.4 eQEP Position-Compare Register (QPOSCMP)

Figure 17-24. eQEP Position-Compare Register (QPOSCMP)

31	0
QPOSCMP	
R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 17-6. eQEP Position-Compare Register (QPOSCMP) Field Descriptions

Bits	Name	Value	Description
31-0	QPOSCMP	0-FFFF FFFFh	The position-compare value in this register is compared with the position counter (QPOSCNT) to generate sync output and/or interrupt on compare match.

17.3.5 eQEP Index Position Latch Register (QPOSILAT)

Figure 17-25. eQEP Index Position Latch Register (QPOSILAT)

31	0
QPOSILAT	
R-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 17-7. eQEP Index Position Latch Register (QPOSILAT) Field Descriptions

Bits	Name	Value	Description
31-0	QPOSILAT	0-FFFF FFFFh	The position-counter value is latched into this register on an index event as defined by the QEPCTL[IEL] bits.

17.3.6 eQEP Strobe Position Latch Register (QPOSSLAT)

Figure 17-26. eQEP Strobe Position Latch Register (QPOSSLAT)

31	0
QPOSSLAT	
R-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 17-8. eQEP Strobe Position Latch Register (QPOSSLAT) Field Descriptions

Bits	Name	Value	Description
31-0	QPOSSLAT	0-FFFF FFFFh	The position-counter value is latched into this register on strobe event as defined by the QEPCTL[SEL] bits.

17.3.7 eQEP Position Counter Latch Register (QPOSLAT)

Figure 17-27. eQEP Position Counter Latch Register (QPOSLAT)

31	0
QPOSLAT	
R-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 17-9. eQEP Position Counter Latch Register (QPOSLAT) Field Descriptions

Bits	Name	Value	Description
31-0	QPOSLAT	0-FFFF FFFFh	The position-counter value is latched into this register on unit time out event.

17.3.8 eQEP Unit Timer Register (QUTMR)

Figure 17-28. eQEP Unit Timer Register (QUTMR)

31	0
QUTMR	
R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 17-10. eQEP Unit Timer Register (QUTMR) Field Descriptions

Bits	Name	Value	Description
31-0	QUTMR	0-FFFF FFFFh	This register acts as time base for unit time event generation. When this timer value matches with unit time period value, unit time event is generated.

17.3.9 eQEP Unit Period Register (QUPRD)

Figure 17-29. eQEP Unit Period Register (QUPRD)

31	0
QUPRD	
R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 17-11. eQEP Unit Period Register (QUPRD) Field Descriptions

Bits	Name	Value	Description
31-0	QUPRD	0-FFFF FFFFh	This register contains the period count for unit timer to generate periodic unit time events to latch the eQEP position information at periodic interval and optionally to generate interrupt.

17.3.10 eQEP Watchdog Timer Register (QWDTMR)

Figure 17-30. eQEP Watchdog Timer Register (QWDTMR)

15	0
QWDTMR	
R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 17-12. eQEP Watchdog Timer Register (QWDTMR) Field Descriptions

Bits	Name	Value	Description
15-0	QWDTMR	0-FFFF FFFFh	This register acts as time base for watch dog to detect motor stalls. When this timer value matches with watch dog period value, watch dog timeout interrupt is generated. This register is reset upon edge transition in quadrature-clock indicating the motion.

17.3.11 eQEP Watchdog Period Register (QWDPRD)

Figure 17-31. eQEP Watchdog Period Register (QWDPRD)

15	0
QWDPRD	
R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 17-13. eQEP Watchdog Period Register (QWDPRD) Field Description

Bits	Name	Value	Description
15-0	QWDPRD	0-FFFFh	This register contains the time-out count for the eQEP peripheral watch dog timer. When the watchdog timer value matches the watchdog period value, a watchdog timeout interrupt is generated.

17.3.12 QEP Decoder Control Register (QDECCTL)

Figure 17-32. QEP Decoder Control Register (QDECCTL)

15	14	13	12	11	10	9	8
QSRC		SOEN	SPSEL	XCR	SWAP	IGATE	QAP
R/W-0		R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

7	6	5	4	0
QBP	QIP	QSP	Reserved	
R/W-0	R/W-0	R/W-0	R-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 17-14. eQEP Decoder Control Register (QDECCTL) Field Descriptions

Bits	Name	Value	Description
15-14	QSRC	0-3h	Position-counter source selection
		0	Quadrature count mode (QCLK = iCLK, QDIR = iDIR)
		1h	Direction-count mode (QCLK = xCLK, QDIR = xDIR)
		2h	UP count mode for frequency measurement (QCLK = xCLK, QDIR = 1)
		3h	DOWN count mode for frequency measurement (QCLK = xCLK, QDIR = 0)
13	SOEN		Sync output-enable
		0	Disable position-compare sync output
		1	Enable position-compare sync output
12	SPSEL		Sync output pin selection
		0	Index pin is used for sync output
		1	Strobe pin is used for sync output
11	XCR		External clock rate
		0	2× resolution: Count the rising/falling edge
		1	1× resolution: Count the rising edge only
10	SWAP		Swap quadrature clock inputs. This swaps the input to the quadrature decoder, reversing the counting direction.
		0	Quadrature-clock inputs are not swapped
		1	Quadrature-clock inputs are swapped
9	IGATE		Index pulse gating option
		0	Disable gating of Index pulse
		1	Gate the index pin with strobe
8	QAP		QEPA input polarity
		0	No effect
		1	Negates QEPA input
7	QBP		QEPB input polarity
		0	No effect
		1	Negates QEPB input
6	QIP		QEPI input polarity
		0	No effect
		1	Negates QEPI input
5	QSP		QEPS input polarity
		0	No effect
		1	Negates QEPS input
4-0	Reserved	0	Always write as 0

17.3.13 eQEP Control Register (QEPCTL)

Figure 17-33. eQEP Control Register (QEPCTL)

15	14	13	12	11	10	9	8
FREE, SOFT		PCRM		SEI		IEI	
R/W-0		R/W-0		R/W-0		R/W-0	
7	6	5	4	3	2	1	0
SWI	SEL	IEL		PHEN	QCLM	UTE	WDE
R/W-0	R/W-0	R/W-0		R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; *-n* = value after reset

Table 17-15. eQEP Control Register (QEPCTL) Field Descriptions

Bits	Name	Value	Description
15-14	FREE, SOFT	0-3h	Emulation Control Bits
			QPOSCNT behavior:
		0	Position counter stops immediately on emulation suspend.
		1h	Position counter continues to count until the rollover.
		2h-3h	Position counter is unaffected by emulation suspend.
			QWDTMR behavior:
		0	Watchdog counter stops immediately.
		1	Watchdog counter counts until WD period match roll over.
		2h-3h	Watchdog counter is unaffected by emulation suspend.
			QUTMR behavior:
		0	Unit timer stops immediately.
		1h	Unit timer counts until period rollover.
		2h-3h	Unit timer is unaffected by emulation suspend.
			QCTMR behavior:
		0	Capture Timer stops immediately.
		1h	Capture Timer counts until next unit period event.
		2h-3h	Capture Timer is unaffected by emulation suspend.
13-12	PCRM	0-3h	Position counter reset mode
		0	Position counter reset on an index event
		1h	Position counter reset on the maximum position
		2h	Position counter reset on the first index event
		3h	Position counter reset on a unit time event
11-10	SEI	0-3h	Strobe event initialization of position counter
		0	Does nothing (action disabled)
		1h	Does nothing (action disabled)
		2h	Initializes the position counter on rising edge of the QEPS signal
		3h	**Clockwise Direction:** Initializes the position counter on the rising edge of QEPS strobe
			Counter Clockwise Direction: Initializes the position counter on the falling edge of QEPS strobe
9-8	IEI	0-3h	Index event initialization of position counter
		0	Do nothing (action disabled)
		1h	Do nothing (action disabled)
		2h	Initializes the position counter on the rising edge of the QEPI signal (QPOSCNT = QPOSINIT)
		3h	Initializes the position counter on the falling edge of QEPI signal (QPOSCNT = QPOSINIT)
7	SWI		Software initialization of position counter
		0	Do nothing (action disabled)
		1	Initialize position counter, this bit is cleared automatically

Table 17-15. eQEP Control Register (QEPCTL) Field Descriptions (continued)

Bits	Name	Value	Description
6	SEL		Strobe event latch of position counter
		0	The position counter is latched on the rising edge of QEPS strobe (QPOSSLAT = POSCCNT). Latching on the falling edge can be done by inverting the strobe input using the QSP bit in the QDECCTL register.
		1	**Clockwise Direction:** Position counter is latched on rising edge of QEPS strobe
			Counter Clockwise Direction: Position counter is latched on falling edge of QEPS strobe
5-4	IEL	0-3h	Index event latch of position counter (software index marker)
		0	Reserved
		1h	Latches position counter on rising edge of the index signal
		2h	Latches position counter on falling edge of the index signal
		3h	Software index marker. Latches the position counter and quadrature direction flag on index event marker. The position counter is latched to the QPOSILAT register and the direction flag is latched in the QEPSTS[QDLF] bit. This mode is useful for software index marking.
3	PHEN		Quadrature position counter enable/software reset
		0	Reset the eQEP peripheral internal operating flags/read-only registers. Control/configuration registers are not disturbed by a software reset.
		1	eQEP position counter is enabled
2	QCLM		eQEP capture latch mode
		0	Latch on position counter read by CPU. Capture timer and capture period values are latched into QCTMRLAT and QCPRDLAT registers when CPU reads the QPOSCNT register.
		1	Latch on unit time out. Position counter, capture timer and capture period values are latched into QPOSLAT, QCTMRLAT and QCPRDLAT registers on unit time out.
1	UTE		eQEP unit timer enable
		0	Disable eQEP unit timer
		1	Enable unit timer
0	WDE		eQEP watchdog enable
		0	Disable the eQEP watchdog timer
		1	Enable the eQEP watchdog timer

17.3.14 eQEP Capture Control Register (QCAPCTL)

Figure 17-34. eQEP Capture Control Register (QCAPCTL)

15	14	8
CEN	Reserved	
R/W-0	R-0	

7	6	4	3	0
Reserved	CCPS		UPPS	
R-0	R/W-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 17-16. eQEP Capture Control Register (QCAPCTL) Field Descriptions

Bits	Name	Value	Description
15	CEN		Enable eQEP capture
		0	eQEP capture unit is disabled
		1	eQEP capture unit is enabled
14-7	Reserved	0	Always write as 0
6-4	CCPS	0-7h	eQEP capture timer clock prescaler
		0	CAPCLK = SYSCLKOUT/1
		1h	CAPCLK = SYSCLKOUT/2
		2h	CAPCLK = SYSCLKOUT/4
		3h	CAPCLK = SYSCLKOUT/8
		4h	CAPCLK = SYSCLKOUT/16
		5h	CAPCLK = SYSCLKOUT/32
		6h	CAPCLK = SYSCLKOUT/64
		7h	CAPCLK = SYSCLKOUT/128
3-0	UPPS	0-Fh	Unit position event prescaler
		0	UPEVNT = QCLK/1
		1h	UPEVNT = QCLK/2
		2h	UPEVNT = QCLK/4
		3h	UPEVNT = QCLK/8
		4h	UPEVNT = QCLK/16
		5h	UPEVNT = QCLK/32
		6h	UPEVNT = QCLK/64
		7h	UPEVNT = QCLK/128
		8h	UPEVNT = QCLK/256
		9h	UPEVNT = QCLK/512
		Ah	UPEVNT = QCLK/1024
		Bh	UPEVNT = QCLK/2048
		Ch-Fh	Reserved

17.3.15 eQEP Position-Compare Control Register (QPOSCTL)

Figure 17-35. eQEP Position-Compare Control Register (QPOSCTL)

15	14	13	12	11	8
PCSHDW	PCLOAD	PCPOL	PCE	PCSPW	
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	

7	0
PCSPW	
R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 17-17. eQEP Position-Compare Control Register (QPOSCTL) Field Descriptions

Bit	Name	Value	Description
15	PCSHDW		Position-compare shadow enable
		0	Shadow disabled, load Immediate
		1	Shadow enabled
14	PCLOAD		Position-compare shadow load mode
		0	Load on QPOSCNT = 0
		1	Load when QPOSCNT = QPOSCMP
13	PCPOL		Polarity of sync output
		0	Active HIGH pulse output
		1	Active LOW pulse output
12	PCE		Position-compare enable/disable
		0	Disable position compare unit
		1	Enable position compare unit
11-0	PCSPW	0-FFFh	Select-position-compare sync output pulse width
		0	1 × 4 × SYSCLKOUT cycles
		1h	2 × 4 × SYSCLKOUT cycles
		2h-FFFh	3 × 4 × SYSCLKOUT cycles to 4096 × 4 × SYSCLKOUT cycles

17.3.16 eQEP Interrupt Enable Register (QEINT)

Figure 17-36. eQEP Interrupt Enable Register (QEINT)

15			12	11	10	9	8
Reserved				UTO	IEL	SEL	PCM
R-0				R/W-0	R/W-0	R/W-0	R/W-0
7	6	5	4	3	2	1	0
PCR	PCO	PCU	WTO	QDC	PHE	PCE	Reserved
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 17-18. eQEP Interrupt Enable Register (QEINT) Field Descriptions

Bits	Name	Value	Description
15-12	Reserved	0	Always write as 0
11	UTO		Unit time out interrupt enable
		0	Interrupt is disabled
		1	Interrupt is enabled
10	IEL		Index event latch interrupt enable
		0	Interrupt is disabled
		1	Interrupt is enabled
9	SEL		Strobe event latch interrupt enable
		0	Interrupt is disabled
		1	Interrupt is enabled
8	PCM		Position-compare match interrupt enable
		0	Interrupt is disabled
		1	Interrupt is enabled
7	PCR		Position-compare ready interrupt enable
		0	Interrupt is disabled
		1	Interrupt is enabled
6	PCO		Position counter overflow interrupt enable
		0	Interrupt is disabled
		1	Interrupt is enabled
5	PCU		Position counter underflow interrupt enable
		0	Interrupt is disabled
		1	Interrupt is enabled
4	WTO		Watchdog time out interrupt enable
		0	Interrupt is disabled
		1	Interrupt is enabled
3	QDC		Quadrature direction change interrupt enable
		0	Interrupt is disabled
		1	Interrupt is enabled
2	PHE		Quadrature phase error interrupt enable
		0	Interrupt is disabled
		1	Interrupt is enabled
1	PCE		Position counter error interrupt enable
		0	Interrupt is disabled
		1	Interrupt is enabled
0	Reserved	0	Reserved

17.3.17 eQEP Interrupt Flag Register (QFLG)

Figure 17-37. eQEP Interrupt Flag Register (QFLG)

15			12	11	10	9	8
Reserved				UTO	IEL	SEL	PCM
R-0				R-0	R-0	R-0	R-0
7	6	5	4	3	2	1	0
PCR	PCO	PCU	WTO	QDC	PHE	PCE	INT
R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0

LEGEND: R = Read only; -*n* = value after reset

Table 17-19. eQEP Interrupt Flag Register (QFLG) Field Descriptions

Bits	Name	Value	Description
15-12	Reserved	0	Always write as 0
11	UTO		Unit time out interrupt flag
		0	No interrupt generated
		1	Set by eQEP unit timer period match
10	IEL		Index event latch interrupt flag
		0	No interrupt generated
		1	This bit is set after latching the QPOSCNT to QPOSILAT
9	SEL		Strobe event latch interrupt flag
		0	No interrupt generated
		1	This bit is set after latching the QPOSCNT to QPOSSLAT
8	PCM		eQEP compare match event interrupt flag
		0	No interrupt generated
		1	This bit is set on position-compare match
7	PCR		Position-compare ready interrupt flag
		0	No interrupt generated
		1	This bit is set after transferring the shadow register value to the active position compare register.
6	PCO		Position counter overflow interrupt flag
		0	No interrupt generated
		1	This bit is set on position counter overflow.
5	PCU		Position counter underflow interrupt flag
		0	No interrupt generated
		1	This bit is set on position counter underflow.
4	WTO		Watchdog timeout interrupt flag
		0	No interrupt generated
		1	Set by watch dog timeout
3	QDC		Quadrature direction change interrupt flag
		0	No interrupt generated
		1	This bit is set during change of direction
2	PHE		Quadrature phase error interrupt flag
		0	No interrupt generated
		1	Set on simultaneous transition of QEPA and QEPB
1	PCE		Position counter error interrupt flag
		0	No interrupt generated
		1	Position counter error

Table 17-19. eQEP Interrupt Flag Register (QFLG) Field Descriptions (continued)

Bits	Name	Value	Description
0	INT		Global interrupt status flag
		0	No interrupt generated
		1	Interrupt was generated

17.3.18 eQEP Interrupt Clear Register (QCLR)

Figure 17-38. eQEP Interrupt Clear Register (QCLR)

15	14	13	12	11	10	9	8
Reserved				UTO	IEL	SEL	PCM
R-0				R/W-0	R/W-0	R/W-0	R/W-0
7	6	5	4	3	2	1	0
PCR	PCO	PCU	WTO	QDC	PHE	PCE	INT
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 17-20. eQEP Interrupt Clear Register (QCLR) Field Descriptions

Bit	Field	Value	Description
15-12	Reserved	0	Always write as 0s
11	UTO		Clear unit time out interrupt flag
		0	No effect
		1	Clears the interrupt flag
10	IEL		Clear index event latch interrupt flag
		0	No effect
		1	Clears the interrupt flag
9	SEL		Clear strobe event latch interrupt flag
		0	No effect
		1	Clears the interrupt flag
8	PCM		Clear eQEP compare match event interrupt flag
		0	No effect
		1	Clears the interrupt flag
7	PCR		Clear position-compare ready interrupt flag
		0	No effect
		1	Clears the interrupt flag
6	PCO		Clear position counter overflow interrupt flag
		0	No effect
		1	Clears the interrupt flag
5	PCU		Clear position counter underflow interrupt flag
		0	No effect
		1	Clears the interrupt flag
4	WTO		Clear watchdog timeout interrupt flag
		0	No effect
		1	Clears the interrupt flag
3	QDC		Clear quadrature direction change interrupt flag
		0	No effect
		1	Clears the interrupt flag

Table 17-20. eQEP Interrupt Clear Register (QCLR) Field Descriptions (continued)

Bit	Field	Value	Description
2	PHE		Clear quadrature phase error interrupt flag
		0	No effect
		1	Clears the interrupt flag
1	PCE		Clear position counter error interrupt flag
		0	No effect
		1	Clears the interrupt flag
0	INT		Global interrupt clear flag
		0	No effect
		1	Clears the interrupt flag and enables further interrupts to be generated if an event flags is set to 1.

17.3.19 eQEP Interrupt Force Register (QFRC)

Figure 17-39. eQEP Interrupt Force Register (QFRC)

15	12	11	10	9	8
Reserved		UTO	IEL	SEL	PCM
R-0		R/W-0	R/W-0	R/W-0	R/W-0

7	6	5	4	3	2	1	0
PCR	PCO	PCU	WTO	QDC	PHE	PCE	Reserved
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 17-21. eQEP Interrupt Force Register (QFRC) Field Descriptions

Bit	Field	Value	Description
15-12	Reserved	0	Always write as 0s
11	UTO		Force unit time out interrupt
		0	No effect
		1	Force the interrupt
10	IEL		Force index event latch interrupt
		0	No effect
		1	Force the interrupt
9	SEL		Force strobe event latch interrupt
		0	No effect
		1	Force the interrupt
8	PCM		Force position-compare match interrupt
		0	No effect
		1	Force the interrupt
7	PCR		Force position-compare ready interrupt
		0	No effect
		1	Force the interrupt
6	PCO		Force position counter overflow interrupt
		0	No effect
		1	Force the interrupt
5	PCU		Force position counter underflow interrupt
		0	No effect
		1	Force the interrupt
4	WTO		Force watchdog time out interrupt
		0	No effect
		1	Force the interrupt
3	QDC		Force quadrature direction change interrupt
		0	No effect
		1	Force the interrupt
2	PHE		Force quadrature phase error interrupt
		0	No effect
		1	Force the interrupt
1	PCE		Force position counter error interrupt
		0	No effect
		1	Force the interrupt
0	Reserved	0	Always write as 0

17.3.20 eQEP Status Register (QEPSTS)

Figure 17-40. eQEP Status Register (QEPSTS)

15							8
Reserved							
R-0							
7	6	5	4	3	2	1	0
UPEVNT	FIDF	QDF	QDLF	COEF	CDEF	FIMF	PCEF
R-0	R-0	R-0	R-0	R/W-1	R/W-1	R/W-1	R-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 17-22. eQEP Status Register (QEPSTS) Field Descriptions

Bit	Field	Value	Description
15-8	Reserved	0	Always write as 0
7	UPEVNT		Unit position event flag
		0	No unit position event detected
		1	Unit position event detected. Write 1 to clear.
6	FDF		Direction on the first index marker. Status of the direction is latched on the first index event marker.
		0	Counter-clockwise rotation (or reverse movement) on the first index event
		1	Clockwise rotation (or forward movement) on the first index event
5	QDF		Quadrature direction flag
		0	Counter-clockwise rotation (or reverse movement)
		1	Clockwise rotation (or forward movement)
4	QDLF		eQEP direction latch flag. Status of direction is latched on every index event marker.
		0	Counter-clockwise rotation (or reverse movement) on index event marker
		1	Clockwise rotation (or forward movement) on index event marker
3	COEF		Capture overflow error flag
		0	Sticky bit, cleared by writing 1
		1	Overflow occurred in eQEP Capture timer (QEPCTMR)
2	CDEF		Capture direction error flag
		0	Sticky bit, cleared by writing 1
		1	Direction change occurred between the capture position event.
1	FIMF		First index marker flag
		0	Sticky bit, cleared by writing 1
		1	Set by first occurrence of index pulse
0	PCEF		Position counter error flag. This bit is not sticky and it is updated for every index event.
		0	No error occurred during the last index transition.
		1	Position counter error

17.3.21 eQEP Capture Timer Register (QCTMR)

Figure 17-41. eQEP Capture Timer Register (QCTMR)

15	0
QCTMR	
R/W	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 17-23. eQEP Capture Time Register (QCTMR) Field Descriptions

Bits	Name	Value	Description
15-0	QCTMR	0-FFFFh	This register provides time base for edge capture unit.

17.3.22 eQEP Capture Period Register (QCPRD)

Figure 17-42. eQEP Capture Period Register (QCPRD)

15	0
QCPRD	
R/W	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 17-24. eQEP Capture Period Register (QCPRD) Field Descriptions

Bits	Name	Value	Description
15-0	QCPRD	0-FFFFh	This register holds the period count value between the last successive eQEP position events

17.3.23 eQEP Capture Timer Latch Register (QCTMRLAT)

Figure 17-43. eQEP Capture Timer Latch Register (QCTMRLAT)

15	0
QCTMRLAT	
R	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 17-25. eQEP Capture Timer Latch Register (QCTMRLAT) Field Descriptions

Bits	Name	Value	Description
15-0	QCTMRLAT	0-FFFFh	The eQEP capture timer value can be latched into this register on two events viz., unit timeout event, reading the eQEP position counter.

17.3.24 eQEP Capture Period Latch Register (QCPRDLAT)

Figure 17-44. eQEP Capture Period Latch Register (QCPRDLAT)

15	0
QCPRDLAT	
R/W	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 17-26. eQEP Capture Period Latch Register (QCPRDLAT) Field Descriptions

Bits	Name	Value	Description
15-0	QCPRDLAT	0-FFFFh	eQEP capture period value can be latched into this register on two events viz., unit timeout event, reading the eQEP position counter.

17.3.25 eQEP Revision ID Register (REVID)

Figure 17-45. eQEP Revision ID Register (REVID)

31	0
REV	
R-44D3 1103h	

LEGEND: R = Read only; -*n* = value after reset

Table 17-27. eQEP Revision ID Register (REVID) Field Descriptions

Bits	Name	Value	Description
31-0	REV	44D3 1103h	eQEP revision ID

Enhanced Direct Memory Access (EDMA3) Controller

The enhanced direct memory access (EDMA3) controller is a high-performance, multichannel, multithreaded DMA controller that allows you to program a wide variety of transfer geometries and transfer sequences. This chapter describes the features and operations of the EDMA3 controller.

Section 18.1 provides a brief overview, features, and terminology. Section 18.2 provides the architecture details and common operations of the EDMA3 channel controller (EDMA3CC) and the EDMA3 transfer controller (EDMA3TC). Section 18.3 contains examples and common usage scenarios. Section 18.4 describes the memory-mapped registers associated with the EDMA3 controller.

Topic **Page**

18.1 Introduction

18.1.1 Overview

The enhanced direct memory access (EDMA3) controller's primary purpose is to service user-programmed data transfers between two memory-mapped slave endpoints on the device. Typical usage includes, but is not limited to:

- Servicing software driven paging transfers (for example, from external memory to internal device memory
- Servicing event driven peripherals, such as a serial port
- Performing sorting or subframe extraction of various data structures
- Offloading data transfers from the main device CPU(s) or DSP(s) (See your device-specific data manual for specific peripherals that are accessible via EDMA3. See the section on SCR connectivity in your device-specific data manual for EDMA3 connectivity.)

The EDMA3 has a different architecture from the previous EDMA2 controller on the TMS320C621x/C671x DSPs and TMS320C64x DSPs.

The EDMA3 controller consists of two principal blocks:

- EDMA3 channel controller: EDMA3CC
- EDMA3 transfer controller(s): EDMA3TC*n*

The EDMA3 channel controller serves as the user interface for the EDMA3 controller. The EDMA3CC includes parameter RAM (PaRAM), channel control registers, and interrupt control registers. The EDMA3CC serves to prioritize incoming software requests or events from peripherals, and submits transfer requests (TR) to the EDMA3 transfer controller.

The EDMA3 transfer controllers are responsible for data movement. The transfer request packets (TRP) submitted by the EDMA3CC contains the transfer context, based on which the transfer controller issues read/write commands to the source and destination addresses programmed for a given transfer.

18.1.2 Features

The EDMA3 channel controller (EDMA3CC) has the following features:

- Fully orthogonal transfer description
  - 3 transfer dimensions
  - A-synchronized transfers: 1 dimension serviced per event
  - AB-synchronized transfers: 2 dimensions serviced per event
  - Independent indexes on source and destination
  - Chaining feature allows 3-D transfer based on single event
- Flexible transfer definition
  - Increment or constant addressing modes
  - Linking mechanism allows automatic PaRAM set update. Useful for ping-pong type transfers, auto-reload transfers.
  - Chaining allows multiple transfers to execute with a single event
- Interrupt generation for:
  - Transfer completion
  - Error conditions (illegal addresses, illegal modes, exceeding queue threshold)
- Debug visibility
  - Queue watermarking
  - Error and status recording to facilitate debug
  - Missed event detection
- 128 parameter RAM (PaRAM) entries
- 4 shadow regions

- 32 DMA channels
  - Event triggered transfers (transfers initiated by system/peripheral events)
  - Manual transfers (CPU(s) initiated DMA transfers)
  - Chained transfers (completion of transfer on one channel triggers a transfer on a “chained” channel)
- 8 QDMA channels
  - QDMA channels are triggered automatically upon writing to a parameter RAM (PaRAM) set entry
  - Supports linking and chaining features (similar to DMA channels)
  - Support for programmable QDMA channel to PaRAM mapping (any PaRAM entry can be used as a QDMA channel)
  - Optimized for use in conjunction to the IDMA controller (internal DMA in DSP subsystem)
- 2 event queues
- 16 event entries per event queue

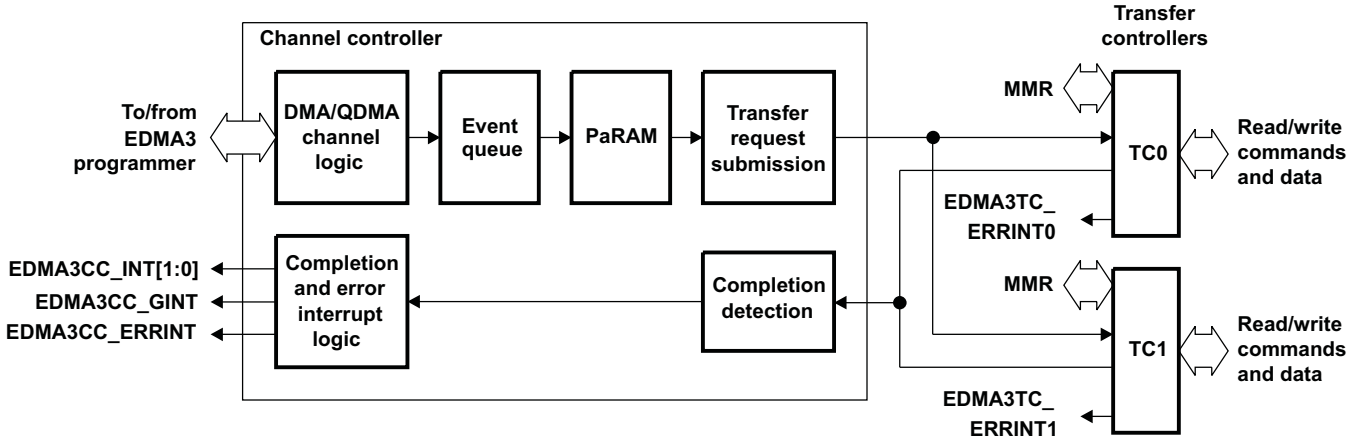
The EDMA3 transfer controller (EDMA3TC) has the following features:

- Supports 2-dimensional transfers with independent indexes on source and destination (EDMA3CC manages the 3rd dimension)
- More then one transfer controller allows concurrent transfers
- Programmable priority level for each transfer controller relative to each other and other masters in the system.
- Support for increment or constant addressing mode transfers
- Error conditions with interrupt support
- Supports more then one in-flight transfer requests
- Debug/status visibility
- 64-bit wide read and write ports
- Little-endian mode
- Transfer controller(s):
  - FIFIOSIZE = 128 bytes
  - BUSWIDTH (Read/Write Controllers) = 8 byte
  - DSTREGDEPTH = 4
  - DBS (default) = 16 bytes. The default burst size (DBS) is programmable, and can be configured for 16-, 32-, or 64-bytes burst size. See the Chip Configuration 0 Register (CFGCHIP0) in the *System Configuration (SYSCFG) Module* chapter for details to change the default burst size value.

18.1.3 Functional Block Diagram

Figure 18-1 shows a block diagram of the EDMA3 controller.

Figure 18-1. EDMA3 Controller Block Diagram



18.1.4 Terminology Used in This Document

The following are some terms used in this chapter.

Term	Meaning
A-synchronized transfer	A transfer type where 1 dimension is serviced per synchronization event.
AB-synchronized transfer	A transfer type where 2 dimensions are serviced per synchronization event.
Chaining	A trigger mechanism in which a transfer can be initiated at the completion of another transfer or subtransfer.
CPU(s)	The main processing engine or engines on a device. Typically a DSP or general-purpose processor. (See your device-specific data manual to learn more about the CPU on your system.)
DMA channel	A channel that can be triggered by external, manual, and chained events. All DMA channels exist in the EDMA3CC.
Dummy set or Dummy PaRAM set	A PaRAM set for which at least one of the count fields is equal to 0 and at least one of the count fields is nonzero. A null PaRAM set has all the count set fields cleared.
Dummy transfer	A dummy set results in the EDMA3CC performing a dummy transfer. This is not an error condition. A null set results in an error condition.
EDMA3 channel controller (EDMA3CC)	The user-programmable portion of the EDMA3. The EDMA3CC contains the parameter RAM (PaRAM) , event processing logic, DMA/QDMA channels, event queues, etc. The EDMA3CC services events (external, manual, chained, QDMA) and is responsible for submitting transfer requests to the transfer controllers (EDMA3TC), which perform the actual transfer.
EDMA3 programmer	Any entity on the chip that has read/write access to the EDMA3 registers and can program an EDMA3 transfer.
EDMA3 transfer controller(s) (EDMA3TC)	Transfer controllers are the transfer engine for the EDMA3. Performs the read/writes as dictated by the transfer requests submitted by the EDMA3CC.

Term	Meaning
Enhanced direct memory access (EDMA3) controller	Consists of the EDMA3 channel controller (EDMA3CC) and EDMA3 transfer controller(s) (EDMA3TC). Is referred to as EDMA3 in this document.
Link parameter set	A PaRAM set that is used for linking.
Linking	The mechanism of reloading a PaRAM set with new transfer characteristics on completion of the current transfer.
Memory-mapped slave	All on-chip memories, off-chip memories, and slave peripherals. These typically rely on the EDMA3 (or other master peripheral) to perform transfers to and from them.
Master peripherals	All peripherals that are capable of initiating read and write transfers to the peripherals system and may not solely rely on the EDMA3 for their data transfers.
Null set or Null PaRAM set	A PaRAM set that has all count fields cleared (except for the link field). A dummy PaRAM set has at least one of the count fields nonzero.
Null transfer	A trigger event for a null PaRAM set results in the EDMA3CC performing a null transfer. This is an error condition. A dummy transfer is not an error condition.
QDMA channel	One of the 8 channels that can be triggered when writing to the trigger word (TRWORD) of a PaRAM set. All QDMA channels exist in the EDMA3CC.
Parameter RAM (PaRAM)	Programmable RAM that stores PaRAM sets used by DMA channels, QDMA channels, and linking.
Parameter RAM (PaRAM) set	A 32-byte EDMA3 channel transfer definition. Each parameter set consists of 8 words (4-bytes each), which store the context for a DMA/QDMA/link transfer. A PaRAM set includes source address, destination address, counts, indexes, options, etc.
Parameter RAM (PaRAM) set entry	One of the 4-byte components of the parameter set.
Slave end points	All on-chip memories, off-chip memories, and slave peripherals. These rely on the EDMA3 to perform transfers to and from them.
Transfer request (TR)	A command for data movement that is issued from the EDMA3CC to the EDMA3TC. A TR includes source and destination addresses, counts, indexes, options, etc.
Trigger event	Action that causes the EDMA3CC to service the PaRAM set and submit a transfer request to the EDMA3TC. Trigger events for DMA channels include manual triggered (CPU triggered), external event triggered, and chain triggered. Trigger events for QDMA channels include autotriggered and link triggered.
Trigger word	For QDMA channels, the trigger word specifies the PaRAM set entry that when written results in a QDMA trigger event. The trigger word is programmed via the QDMA channel *n* mapping register (QCHMAP*n*) and can point to any PaRAM set entry.
TR synchronization (sync) event	See Trigger event.

18.2 Architecture

This section discusses the architecture of the EDMA3 controller.

18.2.1 Functional Overview

This section provides an overview of the EDMA3 channel controller (EDMA3CC) and EDMA3 transfer controller (EDMA3TC).

18.2.1.1 EDMA3 Channel Controller (EDMA3CC)

Figure 18-2 shows a functional block diagram of the EDMA3 channel controller (EDMA3CC).

The main blocks of the EDMA3CC are:

- DMA/QDMA Channel Logic: This block consists of logic that captures external system or peripheral events that can be used to initiate event triggered transfers, it also includes registers that allow configuring the DMA/QDMA channels (queue mapping, PaRAM entry mapping). It includes all the registers for different trigger type (manual, external events, chained and auto triggered) for enabling/disabling events, and monitor event status.
- Parameter RAM (PaRAM): Maintains parameter set entries for channel and reload parameter sets. The PaRAM needs to be written with the transfer context for the desired channels and link parameter sets.
- Event queues: These form the interface between the event detection logic and the transfer request submission logic.
- Transfer Request Submission Logic: This logic processes PaRAM sets based on a trigger event submitted to the event queue and submits a transfer request (TR) to the transfer controller associated with the event queue.
- Completion detection: The completion detect block detects completion of transfers by the EDMA3 transfer controller (EDMA3TC) and/or slave peripherals. Completion of transfers can optionally be used to chain trigger new transfers or to assert interrupts. The logic includes the interrupt processing registers for enabling/disabling interrupt (to be sent to the CPU), interrupt status/clearing registers.

Additionally there are:

- Region registers: Region registers allow DMA resources (DMA channels and interrupts) to be assigned to unique regions, which can be owned by unique EDMA programmers (a use model for hetero/multi core devices) or by unique tasks/threads (a use model for single core devices).
- Debug registers: Debug registers allow debug visibility by providing registers to read the queue status, channel controller status (what logic within the CC is active), and missed event status.

The EDMA3CC includes two channel types: DMA channels and QDMA channels.

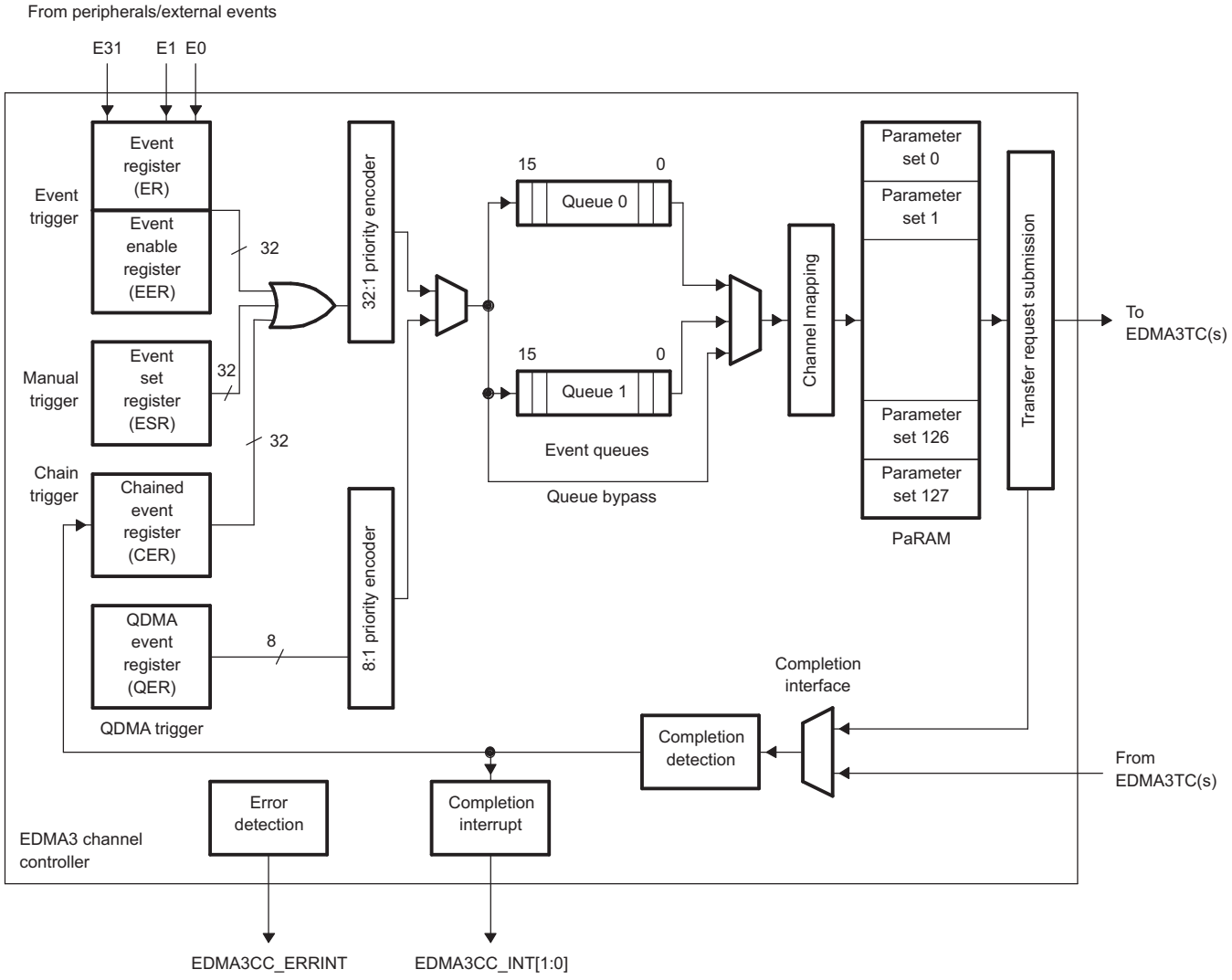
Each channel is associated with a given event queue/transfer controller and with a given PaRAM set. The main difference between a DMA channel and QDMA channel is how the transfers are triggered by the system. See Section 18.2.4.

A trigger event is needed to initiate a transfer. For DMA channels, a trigger event may be due to an external event, manual write to the event set register, or chained event. QDMA channels are autotriggered when a write is performed to the user-programmed trigger word. All such trigger events are logged into appropriate registers upon recognition. See DMA channel registers (Section 18.4.2.5) and QDMA channel registers (Section 18.4.2.7).

Once a trigger event is recognized, the event type/channel is queued in the appropriate EDMA3CC event queue. The assignment of each DMA/QDMA channel to event queue is programmable. Each queue is 16 deep, so up to 16 events may be queued (on a single queue) in the EDMA3CC at an instant in time. Additional pending events mapped to a full queue are queued when event queue space becomes available. See Section 18.2.10.

If events on different channels are detected simultaneously, the events are queued based on fixed priority arbitration scheme with the DMA channels being higher priority than the QDMA channels. Among the two groups of channels, the lowest-numbered channel is the highest priority.

Figure 18-2. EDMA3 Channel Controller (EDMA3CC) Block Diagram



Each event in the event queue is processed in the order it was queued. On reaching the head of the queue, the PaRAM associated with that channel is read to determine the transfer details. The TR submission logic evaluates the validity of the TR and is responsible for submitting a valid transfer request (TR) to the appropriate EDMA3TC (based on the event queue to EDMA3TC association, Q0 goes to TC0, and Q1 goes to TC1, etc.). For more details, see Section 18.2.3.

The EDMA3TC receives the request and is responsible for data movement as specified in the transfer request packet (TRP) and other necessary tasks like buffering, ensuring transfers are carried out in an optimal fashion wherever possible. For more details on EDMA3TC, see Section 18.2.1.2.

You may have chosen to receive an interrupt or chain to another channel on completion of the current transfer in which case the EDMA3TC signals completion to the EDMA3CC completion detection logic when the transfer is done. You can alternately choose to trigger completion when a TR leaves the EDMA3CC boundary rather than wait for all the data transfers to complete. Based on the setting of the EDMA3CC interrupt registers, the completion interrupt generation logic is responsible for generating EDMA3CC completion interrupts to the CPU. For more details, see Section 18.2.5.

Additionally, the EDMA3CC also has an error detection logic, which causes error interrupt generation on various error conditions (like missed events, exceeding event queue thresholds, etc.). For more details on error interrupts, see Section 18.2.9.4.

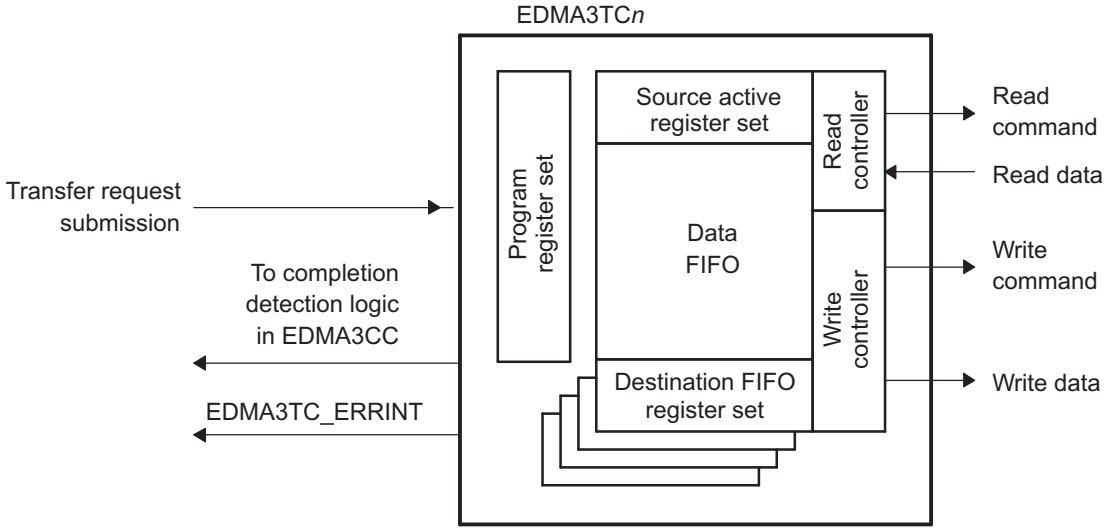
18.2.1.2 EDMA3 Transfer Controller (EDMA3TC)

Figure 18-3 shows a functional block diagram of the EDMA3 transfer controller (EDMA3TC).

The main blocks of the EDMA3TC are:

- DMA program register set: The DMA program register set stores the transfer requests received from the EDMA3 channel controller (EDMA3CC).
- DMA source active register set: The DMA source active register set stores the context for the DMA transfer request currently in progress in the read controller.
- Read controller: The read controller issues read commands to the source address.
- Destination FIFO register set: The destination (Dst) FIFO register set stores the context for the DMA transfer request(s) currently in progress or pending in the write controller.
- Write controller: The write controller issues write commands/write data to the destination address.
- Data FIFO: The data FIFO holds temporary in-flight data. The source peripheral's read data is stored in the data FIFO and subsequently written to the destination peripheral/end point by the write controller.
- Completion interface: The completion interface sends completion codes to the EDMA3CC when a transfer completes, and is used for generating interrupts and chained events (see Section 18.2.5 for details on transfer completion reporting).

Figure 18-3. EDMA3 Transfer Controller (EDMA3TC) Block Diagram



When the EDMA3TC is idle and receives its first TR, the TR is received in the DMA program register set, where it transitions to the DMA source active set and the destination FIFO register set immediately. The source active register set tracks the commands for the source side of the transfers, and the destination FIFO register set tracks commands for the destination side of the transfer. The second TR (if pending from EDMA3CC) is loaded into the DMA program set, ensuring it can start as soon as possible when the active transfer (the transfer in the source active set) is completed. As soon as the current active set is exhausted, the TR is loaded from the DMA program register set into the DMA source active register set as well as to the appropriate entry in the destination FIFO register set.

The read controller issues read commands governed by the rules of command fragmentation and optimization. These are issued only when the data FIFO has space available for the read data. The number of read commands issued depends on the TR transfer size. The TC write controller starts issuing write commands as soon as sufficient data is read in the data FIFO for the write controller to issue optimally sized write commands following the rules for command fragmentation and optimization. For details on command fragmentation and optimization, see Section 18.2.11.1.2.

The DSTREGDEPTH parameter (fixed for a given transfer controller) determines the number of entries in the Dst FIFO register set. The number of entries determines the amount of TR pipelining possible for a given TC. The write controller can manage the write context for the number of entries in the Dst FIFO register set. This allows the read controller to go ahead and issue read commands for the subsequent TRs while the Dst FIFO register set manages the write commands and data for the previous TR. In summary, if the DSTREGDEPTH is *n*, the read controller is able to process up to *n*TRs ahead of the write controller. However, the overall TR pipelining is also subject to the amount of free space in the data FIFO.

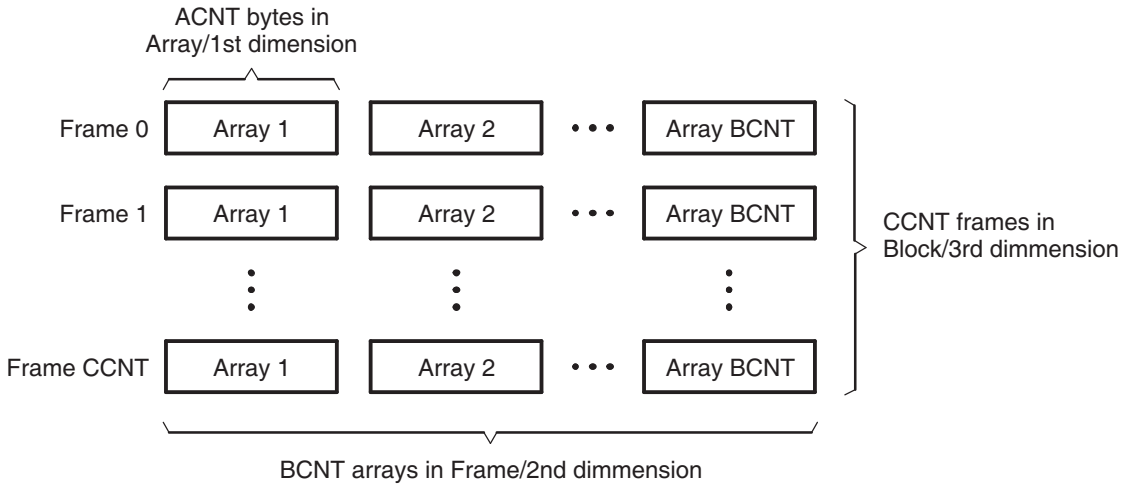
18.2.2 Types of EDMA3 Transfers

An EDMA3 transfer is always defined in terms of three dimensions. Figure 18-4 shows the three dimensions used by EDMA3 transfers. These three dimensions are defined as:

- 1st Dimension or Array (A): The 1st dimension in a transfer consists of ACNT contiguous bytes.
- 2nd Dimension or Frame (B): The 2nd dimension in a transfer consists of BCNT arrays of ACNT bytes. Each array transfer in the 2nd dimension is separated from each other by an index programmed using SRCBIDX or DSTBIDX.
- 3rd Dimension or Block (C): The 3rd dimension in a transfer consists of CCNT frames of BCNT arrays of ACNT bytes. Each transfer in the 3rd dimension is separated from the previous by an index programmed using SRCCIDX or DSTCIDX.

Note that the reference point for the index depends on the synchronization type. The amount of data transferred upon receipt of a trigger/synchronization event is controlled by the synchronization types (SYNCDIM bit in OPT). Of the three dimensions, only two synchronization types are supported: A-synchronized transfers and AB-synchronized transfers.

Figure 18-4. Definition of ACNT, BCNT, and CCNT



18.2.2.1 A-Synchronized Transfers

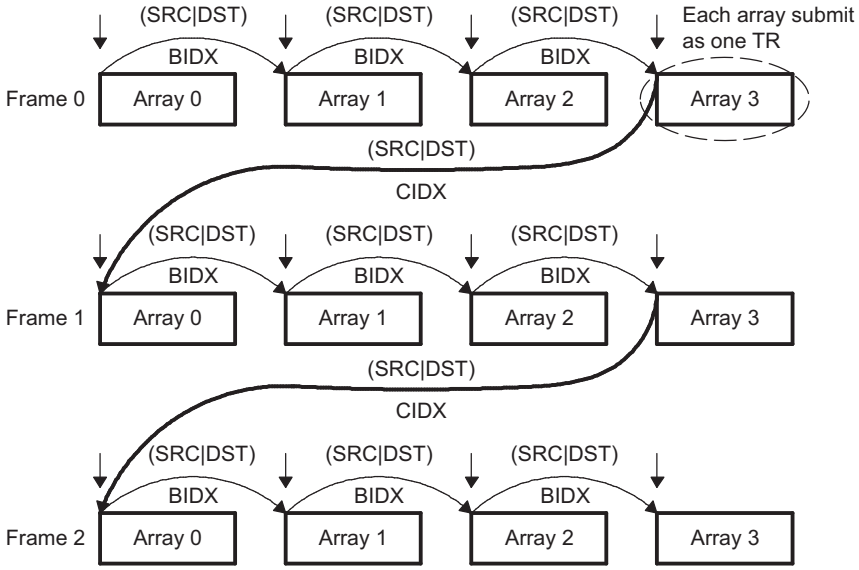
In an A-synchronized transfer, each EDMA3 sync event initiates the transfer of the 1st dimension of ACNT bytes, or one array of ACNT bytes. In other words, each event/TR packet conveys the transfer information for one array only. Thus, BCNT × CCNT events are needed to completely service a PaRAM set.

Arrays are always separated by SRCBIDX and DSTBIDX, as shown in Figure 18-5, where the start address of Array N is equal to the start address of Array N – 1 plus source (SRCBIDX) or destination (DSTBIDX).

Frames are always separated by SRCCIDX and DSTCIDX. For A-synchronized transfers, after the frame is exhausted, the address is updated by adding SRCCIDX/DSTCIDX to the beginning address of the last array in the frame. As in Figure 18-5, SRCCIDX/DSTCIDX is the difference between the start of Frame 0 Array 3 to the start of Frame 1 Array 0.

Figure 18-5 shows an A-synchronized transfer of 3 (CCNT) frames of 4 (BCNT) arrays of n (ACNT) bytes. In this example, a total of 12 sync events (BCNT × CCNT) exhaust a PaRAM set. See Section 18.2.3.6 for details on parameter set updates.

Figure 18-5. A-Synchronized Transfers (ACNT = n, BCNT = 4, CCNT = 3)



18.2.2.2 AB-Synchronized Transfers

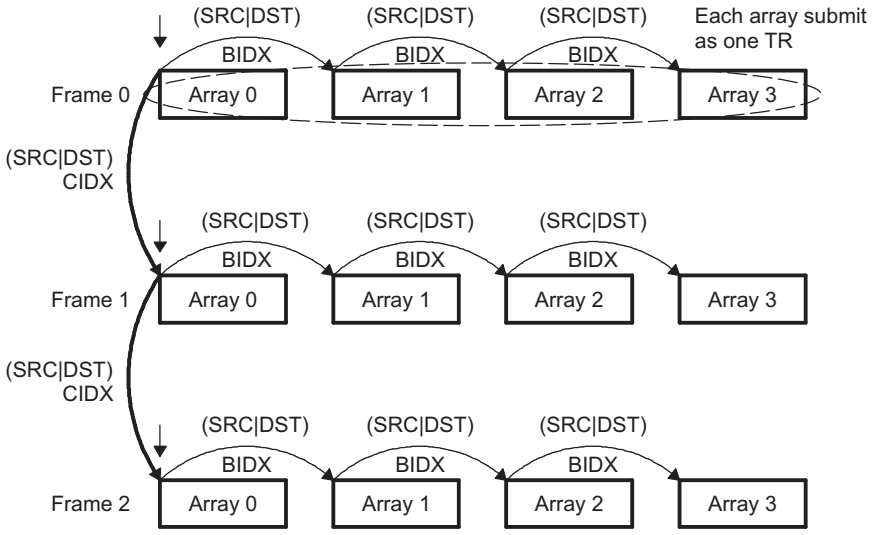
In a AB-synchronized transfer, each EDMA3 sync event initiates the transfer of 2 dimensions or one frame. In other words, each event/TR packet conveys information for one entire frame of BCNT arrays of ACNT bytes. Thus, CCNT events are needed to completely service a PaRAM set.

Arrays are always separated by SRCBIDX and DSTBIDX as shown in Figure 18-6. Frames are always separated by SRCCIDX and DSTCIDX.

Note that for AB-synchronized transfers, after a TR for the frame is submitted, the address update is to add SRCCIDX/DSTCIDX to the beginning address of the beginning array in the frame. This is different from A-synchronized transfers where the address is updated by adding SRCCIDX/DSTCIDX to the start address of the last array in the frame. See Section 18.2.3.6 for details on parameter set updates.

Figure 18-6 shows an AB-synchronized transfer of 3 (CCNT) frames of 4 (BCNT) arrays of *n* (ACNT) bytes. In this example, a total of 3 sync events (CCNT) exhaust a PaRAM set; that is, a total of 3 transfers of 4 arrays each completes the transfer.

Figure 18-6. AB-Synchronized Transfers (ACNT = n, BCNT = 4, CCNT = 3)



NOTE: ABC-synchronized transfers are not directly supported. But can be logically achieved by chaining between multiple AB-synchronized transfers.

18.2.3 Parameter RAM (PaRAM)

The EDMA3 controller is a RAM-based architecture. The transfer context (source/destination addresses, count, indexes, etc.) for DMA or QDMA channels is programmed in a parameter RAM table within the EDMA3CC, referred to as PaRAM. The PaRAM table is segmented into multiple PaRAM sets. Each PaRAM set includes eight 4-byte PaRAM set entries (32-bytes total per PaRAM set), which includes typical DMA transfer parameters such as source address, destination address, transfer counts, indexes, options, etc. See your device-specific data manual for the addresses of the PaRAM set entries.

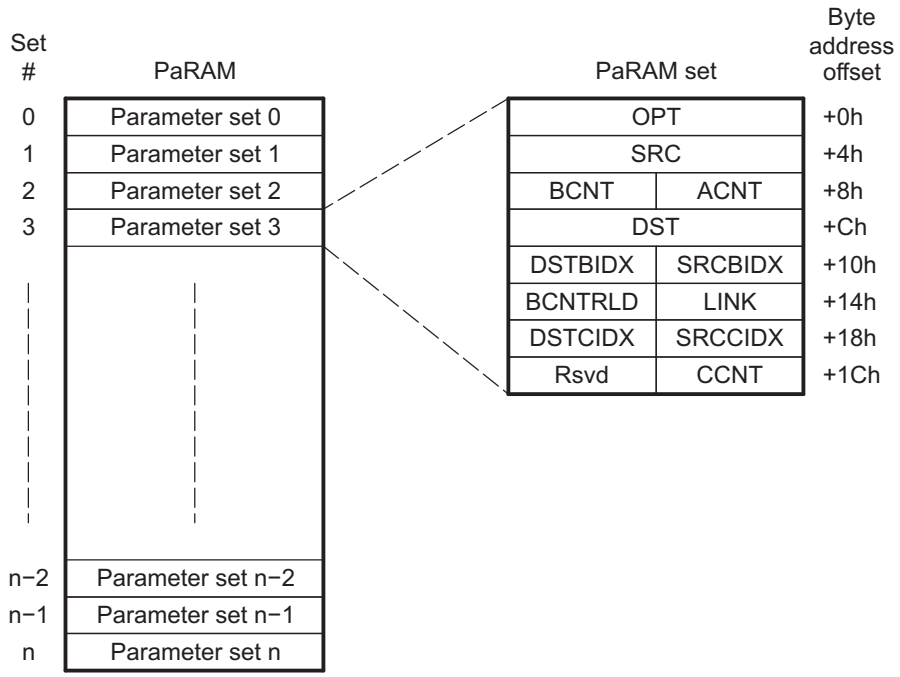
The PaRAM structure supports flexible ping-pong, circular buffering, channel chaining, and autoreloading (linking). The first *n* PaRAM sets are directly mapped to the DMA channels (where *n* is the number of DMA channels supported in the EDMA3CC for a specific device). The remaining PaRAM sets can be used for link entries or associated with QDMA channels. Additionally if the DMA channels are not used, the PaRAM sets associated with the unused DMA channels can also be used for link entries or QDMA channels.

NOTE: By default, QDMA channels are mapped to PaRAM set 0. These should be remapped before use, see Section 18.2.6.2.

18.2.3.1 PaRAM Set

Each parameter set of PaRAM is organized into eight 32-bit words or 32 bytes, as shown in Figure 18-7 and described in Table 18-1. Each PaRAM set consists of 16-bit and 32-bit parameters.

Figure 18-7. PaRAM Set



Note: *n* is the number of PaRAM sets supported in the EDMA3CC for a specific device.

Table 18-1. EDMA3 Channel Parameter Description

Offset Address (bytes)	Acronym	Parameter	Description
0h	OPT	Channel Options	Transfer Configuration Options
4h	SRC	Channel Source Address	The byte address from which data is transferred.
8h[(1)]	ACNT	Count for 1st Dimension	Unsigned value specifying the number of contiguous bytes within an array (first dimension of the transfer). Valid values range from 1 to 65 535.
	BCNT	Count for 2nd Dimension	Unsigned value specifying the number of arrays in a frame, where an array is ACNT bytes. Valid values range from 1 to 65 535.
Ch	DST	Channel Destination Address	The byte address to which data is transferred.
10h[(1)]	SRCBIDX	Source BCNT Index	Signed value specifying the byte address offset between source arrays within a frame (2nd dimension). Valid values range from –32 768 and 32 767.
	DSTBIDX	Destination BCNT Index	Signed value specifying the byte address offset between destination arrays within a frame (2nd dimension). Valid values range from –32 768 and 32 767.
14h[(1)]	LINK	Link Address	The PaRAM address containing the PaRAM set to be linked (copied from) when the current PaRAM set is exhausted. A value of FFFFh specifies a null link.
	BCNTRLD	BCNT Reload	The count value used to reload BCNT when BCNT decrements to 0 (TR submitted for the last array in 2nd dimension). Only relevant in A-synchronized transfers.
18h[(1)]	SRCCIDX	Source CCNT Index	Signed value specifying the byte address offset between frames within a block (3rd dimension). Valid values range from –32 768 and 32 767. A-synchronized transfers: The byte address offset from the beginning of the last source array in a frame to the beginning of the first source array in the next frame. AB-synchronized transfers: The byte address offset from the beginning of the first source array in a frame to the beginning of the first source array in the next frame.
	DSTCIDX	Destination CCNT index	Signed value specifying the byte address offset between frames within a block (3rd dimension). Valid values range from –32 768 and 32 767. A-synchronized transfers: The byte address offset from the beginning of the last destination array in a frame to the beginning of the first destination array in the next frame. AB-synchronized transfers: The byte address offset from the beginning of the first destination array in a frame to the beginning of the first destination array in the next frame.
1Ch	CCNT	Count for 3rd Dimension	Unsigned value specifying the number of frames in a block, where a frame is BCNT arrays of ACNT bytes. Valid values range from 1 to 65 535.
	RSVD	Reserved	Reserved

(1) If OPT, SRC, or DST is the trigger word for a QDMA transfer then it is required to do a 32-bit access to that field. Furthermore, it is recommended to perform only 32-bit accesses on the parameter RAM for best code compatibility. For example, switching the endianness of the processor swaps addresses of the 16-bit fields, but 32-bit accesses avoid the issue entirely.

18.2.3.2 EDMA3 Channel Parameter Set Fields

18.2.3.2.1 Channel Options Parameter (OPT)

The 32-bit channel options parameter (OPT) specifies the transfer configuration options. The channel options parameter (OPT) is described in Section 18.4.1.1.

18.2.3.2.2 Channel Source Address (SRC)

The 32-bit source address parameter specifies the starting byte address of the source. For SAM in increment mode, there are no alignment restrictions imposed by EDMA3. For SAM in constant addressing mode, you must program the source address to be aligned to a 256-bit aligned address (5 LSBs of address must be 0). The EDMA3TC will signal an error, if this rule is violated. See Section 18.2.11.2 for additional details.

18.2.3.2.3 Channel Destination Address (DST)

The 32-bit destination address parameter specifies the starting byte address of the destination. For DAM in increment mode, there are no alignment restrictions imposed by EDMA3. For DAM in constant addressing mode, you must program the destination address to be aligned to a 256-bit aligned address (5 LSBs of address must be 0). The EDMA3TC will signal an error, if this rule is violated. See Section 18.2.11.2 for additional details.

18.2.3.2.4 Count for 1st Dimension (ACNT)

ACNT represents the number of bytes within the 1st dimension of a transfer. ACNT is a 16-bit unsigned value with valid values between 0 and 65 535. Therefore, the maximum number of bytes in an array is 65 535 bytes (64K – 1 bytes). ACNT must be greater than or equal to 1 for a TR to be submitted to EDMA3TC. A transfer with ACNT equal to 0 is considered either a null or dummy transfer.

See Section 18.2.3.5 and Section 18.2.5.3 for details on dummy/null completion conditions.

18.2.3.2.5 Count for 2nd Dimension (BCNT)

BCNT is a 16-bit unsigned value that specifies the number of arrays of length ACNT. For normal operation, valid values for BCNT are between 1 and 65 535. Therefore, the maximum number of arrays in a frame is 65 535 (64K – 1 arrays). A transfer with BCNT equal to 0 is considered either a null or dummy transfer.

See Section 18.2.3.5 and Section 18.2.5.3 for details on dummy/null completion conditions.

18.2.3.2.6 Count for 3rd Dimension (CCNT)

CCNT is a 16-bit unsigned value that specifies the number of frames in a block. Valid values for CCNT are between 1 and 65 535. Therefore, the maximum number of frames in a block is 65 535 (64K – 1 frames). A transfer with CCNT equal to 0 is considered either a null or dummy transfer.

See Section 18.2.3.5 and Section 18.2.5.3 for details on dummy/null completion conditions.

18.2.3.2.7 BCNT Reload (BCNTRLD)

BCNTRLD is a 16-bit unsigned value used to reload the BCNT field once the last array in the 2nd dimension is transferred. This field is only used for A-synchronized transfers. In this case, the EDMA3CC decrements the BCNT value by 1 on each TR submission. When BCNT reaches 0, the EDMA3CC decrements CCNT and uses the BCNTRLD value to reinitialize the BCNT value.

For AB-synchronized transfers, the EDMA3CC submits the BCNT in the TR and the EDMA3TC decrements BCNT appropriately. For AB-synchronized transfers, BCNTRLD is not used.

18.2.3.2.8 Source B Index (SRCBIDX)

SRCBIDX is a 16-bit signed value (2s complement) used for source address modification between each array in the 2nd dimension. Valid values for SRCBIDX are between –32 768 and 32 767. It provides a byte address offset from the beginning of the source array to the beginning of the next source array. It applies to both A-synchronized and AB-synchronized transfers. Some examples:

- SRCBIDX = 0000h (0): no address offset from the beginning of an array to the beginning of the next array. All arrays are fixed to the same beginning address.
- SRCBIDX = 0003h (+3): the address offset from the beginning of an array to the beginning of the next array in a frame is 3 bytes. For example, if the current array begins at address 1000h, the next array begins at 1003h.
- SRCBIDX = FFFFh (–1): the address offset from the beginning of an array to the beginning of the next array in a frame is –1 byte. For example, if the current array begins at address 5054h, the next array begins at 5053h.

18.2.3.2.9 Destination B Index (DSTBIDX)

DSTBIDX is a 16-bit signed value (2s complement) used for destination address modification between each array in the 2nd dimension. Valid values for DSTBIDX are between –32 768 and 32 767. It provides a byte address offset from the beginning of the destination array to the beginning of the next destination array within the current frame. It applies to both A-synchronized and AB-synchronized transfers. See SRCBIDX (Section 18.2.3.2.8) for examples.

18.2.3.2.10 Source C Index (SRCCIDX)

SRCCIDX is a 16-bit signed value (2s complement) used for source address modification in the 3rd dimension. Valid values for SRCCIDX are between –32 768 and 32 767. It provides a byte address offset from the beginning of the current array (pointed to by SRC address) to the beginning of the first source array in the next frame. It applies to both A-synchronized and AB-synchronized transfers. Note that when SRCCIDX is applied, the current array in an A-synchronized transfer is the last array in the frame (Figure 18-5), while the current array in an AB-synchronized transfer is the first array in the frame (Figure 18-6).

18.2.3.2.11 Destination C Index (DSTCIDX)

DSTCIDX is a 16-bit signed value (2s complement) used for destination address modification in the 3rd dimension. Valid values are between –32 768 and 32 767. It provides a byte address offset from the beginning of the current array (pointed to by DST address) to the beginning of the first destination array TR in the next frame. It applies to both A-synchronized and AB-synchronized transfers. Note that when DSTCIDX is applied, the current array in an A-synchronized transfer is the last array in the frame (Figure 18-5), while the current array in a AB-synchronized transfer is the first array in the frame (Figure 18-6).

18.2.3.2.12 Link Address (LINK)

The EDMA3CC provides a mechanism, called linking, to reload the current PaRAM set upon its natural termination (that is, after the count fields are decremented to 0) with a new PaRAM set. The 16-bit parameter LINK specifies the byte address offset in the PaRAM from which the EDMA3CC loads/reloads the next PaRAM set during linking.

You must program the link address to point to a valid aligned 32-byte PaRAM set. The 5 LSBs of the LINK field should be cleared to 0.

The EDMA3CC ignores the upper 2 bits of the LINK entry, allowing the programmer the flexibility of programming the link address as either an absolute/literal byte address or use the PaRAM-base-relative offset address. Therefore, if you make use of the literal address with a range from 4000h to 7FFFh, it will be treated as a PaRAM-base-relative value of 0000h to 3FFFh.

You should make sure to program the LINK field correctly, so that link update is requested from a PaRAM address that falls in the range of the available PaRAM addresses on the device.

A LINK value of FFFFh is referred to as a NULL link that should cause the EDMA3CC to perform an internal write of 0 to all entries of the current PaRAM set, except for the LINK field that is set to FFFFh. Also, see Section 18.2.5 for details on terminating a transfer.

18.2.3.3 Null PaRAM Set

A null PaRAM set is defined as a PaRAM set where all count fields (ACNT, BCNT, and CCNT) are cleared to 0. If a PaRAM set associated with a channel is a NULL set, then when serviced by the EDMA3CC, the bit corresponding to the channel is set in the associated event missed register (EMR or QEMR). This bit remains set in the associated secondary event register (SER or QSER). *This implies that any future events on the same channel are ignored by the EDMA3CC and you are required to clear the bit in SER or QSER for the channel.* This is considered an error condition, since events are not expected on a channel that is configured as a null transfer. See Section 18.4.2.5.8 and Section 18.4.2.2.1 for more information on the SER and EMR registers, respectively.

18.2.3.4 Dummy PaRAM Set

A dummy PaRAM set is defined as a PaRAM set where at least one of the count fields (ACNT, BCNT, or CCNT) is cleared to 0 and at least one of the count fields is nonzero.

If a PaRAM set associated with a channel is a dummy set, then when serviced by the EDMA3CC, it will not set the bit corresponding to the channel (DMA/QDMA) in the event missed register (EMR or QEMR) and the secondary event register (SER or QSER) bit gets cleared similar to a normal transfer. Future events on that channel are serviced. A dummy transfer is a legal transfer of 0 bytes. See Section 18.4.2.5.8 and Section 18.4.2.2.1 for more information on the SER and EMR registers, respectively.

18.2.3.5 Dummy Versus Null Transfer Comparison

There are some differences in the way the EDMA3CC logic treats a dummy versus a null transfer request. A null transfer request is an error condition, but a dummy transfer is a legal transfer of 0 bytes. A null transfer causes an error bit (E*n*) in EMR to get set and the E*n* bit in SER remains set, essentially preventing any further transfers on that channel without clearing the associated error registers.

Table 18-2 summarizes the conditions and effects of null and dummy transfer requests.

Table 18-2. Dummy and Null Transfer Request

Feature	Null TR	Dummy TR
EMR/QEMR is set	Yes	No
SER/QSER remains set	Yes	No
Link update (STATIC = 0 in OPT)	Yes	Yes
QER is set	Yes	Yes
IPR and CER is set using early completion	Yes	Yes

18.2.3.6 Parameter Set Updates

When a TR is submitted for a given DMA/QDMA channel and its corresponding PaRAM set, the EDMA3CC is responsible for updating the PaRAM set in anticipation of the next trigger event. For nonfinal events, this includes address and count updates; for final events, this includes the link update.

The specific PaRAM set entries that are updated depend on the channel's synchronization type (A-synchronized or B-synchronized) and the current state of the PaRAM set. A B-update refers to the decrementing of BCNT in the case of A-synchronized transfers after the submission of successive TRs. A C-update refers to the decrementing of CCNT in the case of A-synchronized transfers after BCNT TRs for ACNT byte transfers have submitted. For AB-synchronized transfers, a C-update refers to the decrementing of CCNT after submission of every transfer request.

See Table 18-3 for details and conditions on the parameter updates. A link update occurs when the PaRAM set is exhausted, as described in Section 18.2.3.7.

After the TR is read from the PaRAM (and is in process of being submitted to EDMA3TC), the following fields are updated if needed:

- A-synchronized: BCNT, CCNT, SRC, DST
- AB-synchronized: CCNT, SRC, DST

The following fields are not updated (except for during linking, where all fields are overwritten by the link PaRAM set):

- A-synchronized: ACNT, BCNTRLD, SRCBIDX, DSTBIDX, SRCCIDX, DSTCIDX, OPT, LINK
- AB-synchronized: ACNT, BCNT, BCNTRLD, SRCBIDX, DSTBIDX, SRCCIDX, DSTCIDX, OPT, LINK

Note that PaRAM updates only pertain to the information that is needed to properly submit the next transfer request to the EDMA3TC. Updates that occur while data is moved within a transfer request are tracked within the transfer controller, and is detailed in Section 18.2.11. For A-synchronized transfers, the EDMA3CC always submits a TRP for ACNT bytes (BCNT = 1 and CCNT = 1). For AB-synchronized transfers, the EDMA3CC always submits a TRP for ACNT bytes of BCNT arrays (CCNT = 1). The EDMA3TC is responsible for updating source and destination addresses within the array based on ACNT and FWID (in OPT). For AB-synchronized transfers, the EDMA3TC is also responsible to update source and destination addresses between arrays based on SRCBIDX and DSTBIDX.

Table 18-3 shows the details of parameter updates that occur within EDMA3CC for A-synchronized and AB-synchronized transfers.

Table 18-3. Parameter Updates in EDMA3CC (for Non-Null, Non-Dummy PaRAM Set)

	A-Synchronized Transfer			AB-Synchronized Transfer		
	B-Update	**C-Update**	**Link Update**	**B-Update**	**C-Update**	**Link Update**
Condition:	**BCNT > 1**	**BCNT == 1 && CCNT > 1**	**BCNT == 1 && CCNT == 1**	**N/A**	**CCNT > 1**	**CCNT == 1**
SRC	+= SRCBIDX	+= SRCCIDX	= Link.SRC	in EDMA3TC	+= SRCCIDX	= Link.SRC
DST	+= DSTBIDX	+= DSTCIDX	= Link.DST	in EDMA3TC	+= DSTCIDX	= Link.DST
ACNT	None	None	= Link.ACNT	None	None	= Link.ACNT
BCNT	–= 1	= BCNTRLD	= Link.BCNT	in EDMA3TC	N/A	= Link.BCNT
CCNT	None	–= 1	= Link.CCNT	in EDMA3TC	–=1	= Link.CCNT
SRCBIDX	None	None	= Link.SRCBIDX	in EDMA3TC	None	= Link.SRCBIDX
DSTBIDX	None	None	= Link.DSTBIDX	None	None	= Link.DSTBIDX
SRCCIDX	None	None	= Link.SRCBIDX	in EDMA3TC	None	= Link.SRCBIDX
DSTCIDX	None	None	= Link.DSTBIDX	None	None	= Link.DSTBIDX
LINK	None	None	= Link.LINK	None	None	= Link.LINK
BCNTRLD	None	None	= Link.BCNTRLD	None	None	= Link.BCNTRLD
OPT[1]	None	None	= LINK.OPT	None	None	= LINK.OPT

(1) In all cases, no updates occur if OPT.STATIC == 1 for the current PaRAM set.

NOTE: The EDMA3CC includes no special hardware to detect when an indexed address update calculation overflows/underflows. The address update will wrap across boundaries as programmed by the user. You should ensure that no transfer is allowed to cross internal port boundaries between peripherals. A single TR must target a single source/destination slave endpoint.

18.2.3.7 Linking Transfers

The EDMA3CC provides a mechanism known as linking, which allows the entire PaRAM set to be reloaded from a location within the PaRAM memory map (for both DMA and QDMA channels). Linking is especially useful for maintaining ping-pong buffers, circular buffering, and repetitive/continuous transfers all with no CPU intervention. Upon completion of a transfer, the current transfer parameters are reloaded with the parameter set pointed to by the 16-bit link address field (of the current parameter set). Linking only occurs when the STATIC bit in OPT is cleared to 0.

NOTE: A transfer (DMA or QDMA) should always be linked to another useful transfer. If it is required to terminate a transfer, the transfer should be linked to a NULL set.

The link update occurs after the current PaRAM set event parameters have been exhausted. An event's parameters are exhausted when the EDMA3 channel controller has submitted all the transfers associated with the PaRAM set.

A link update occurs for null and dummy transfers depending on the state of the STATIC bit in OPT and the LINK field. In both cases (null or dummy), if the value of LINK is FFFFh then a null PaRAM set (with all 0s and LINK set to FFFFh) is written to the current PaRAM set. Similarly, if LINK is set to a value other than FFFFh then the appropriate PaRAM location pointed to by LINK is copied to the current PaRAM set.

Once the channel completion conditions are met for an event, the transfer parameters located at the link address are loaded into the current DMA or QDMA channel's associated parameter set. The EDMA3CC reads the entire PaRAM set (8 words) from the PaRAM set specified by LINK and writes all 8 words to the PaRAM set associated with the current channel. Figure 18-8 shows an example of a linked transfer.

Any PaRAM set in the PaRAM can be used as a link/reload parameter set; however, it is recommended that the PaRAM sets associated with peripheral synchronization events (see Section 18.2.6) should only be used for linking if the synchronization event isolated with the channel mapped to that PaRAM set is disabled.

If a PaRAM set location is mapped to a QDMA channel (by QCHMAP*n*), then copying the link PaRAM set onto the current QDMA channel PaRAM set is recognized as a trigger event and is latched in QER since a write to the trigger word was performed. This feature can be used to create a linked list of transfers using a single QDMA channel and multiple PaRAM sets.

Link-to-self transfers replicate the behavior of autoinitialization, which facilitates the use of circular buffering and repetitive transfers. After an EDMA3 channel exhausts its current PaRAM set, it reloads all the parameter set entries from another PaRAM set, which is initialized with values identical to the original PaRAM set. Figure 18-9 shows an example of a linked-to-self transfer. In Figure 18-9, parameter set 127 has the LINK field address pointing to the address of parameter set 127, that is, linked-to-self.

NOTE: If the STATIC bit in OPT is set for a PaRAM set, then link updates are not performed. The link updates performed internally by the EDMA3CC are atomic. This implies that when the EDMA3CC is updating a PaRAM set, accesses to PaRAM by other EDMA3 programmer's (for example, CPU configuration accesses) are not allowed. Also for QDMA, for example, if the first word of the PaRAM entry is defined as a trigger word, EDMA3CC logic assures that all 8 PaRAM words are updated before the new QDMA event can trigger the transfer for that PaRAM entry.

18.2.3.7.1 Constant Addressing Mode Transfers/Alignment Issues

If either SAM or DAM is set to 1 (constant addressing mode), then the source or destination address must be aligned to a 256-bit aligned address, respectively, and the corresponding BIDX should be an even multiple of 32 bytes (256 bit). The EDMA3CC does not recognize errors here but the EDMA3TC asserts an error, if this is not true. See Section 18.2.11.2.

NOTE: The constant addressing (CONST) mode has limited applicability. The EDMA3 should be configured for the constant addressing mode (SAM/DAM = 1) only if the transfer source or destination (on-chip memory, off-chip memory controllers, slave peripherals) support the constant addressing mode. On the C674x/OMAP-L1x processors, no peripherals, memory, or memory controller support constant addressing mode. If the constant addressing mode is not supported, the similar logical transfer can be achieved using the increment (INCR) mode (SAM/DAM = 0) by appropriately programming the count and indices values.

18.2.3.7.2 Element Size

The EDMA3 controller does not use the concept of element-size and element-indexing. Instead, all transfers are defined in terms of all three dimensions: ACNT, BCNT, and CCNT. An element-indexed transfer is logically achieved by programming ACNT to the size of the element and BCNT to the number of elements that need to be transferred. For example, if you have 16-bit audio data and 256 audio samples that needed to be transferred to a serial port, this can be done by programming the ACNT = 2 (2 bytes) and BCNT = 256.

Figure 18-8. Linked Transfer Example

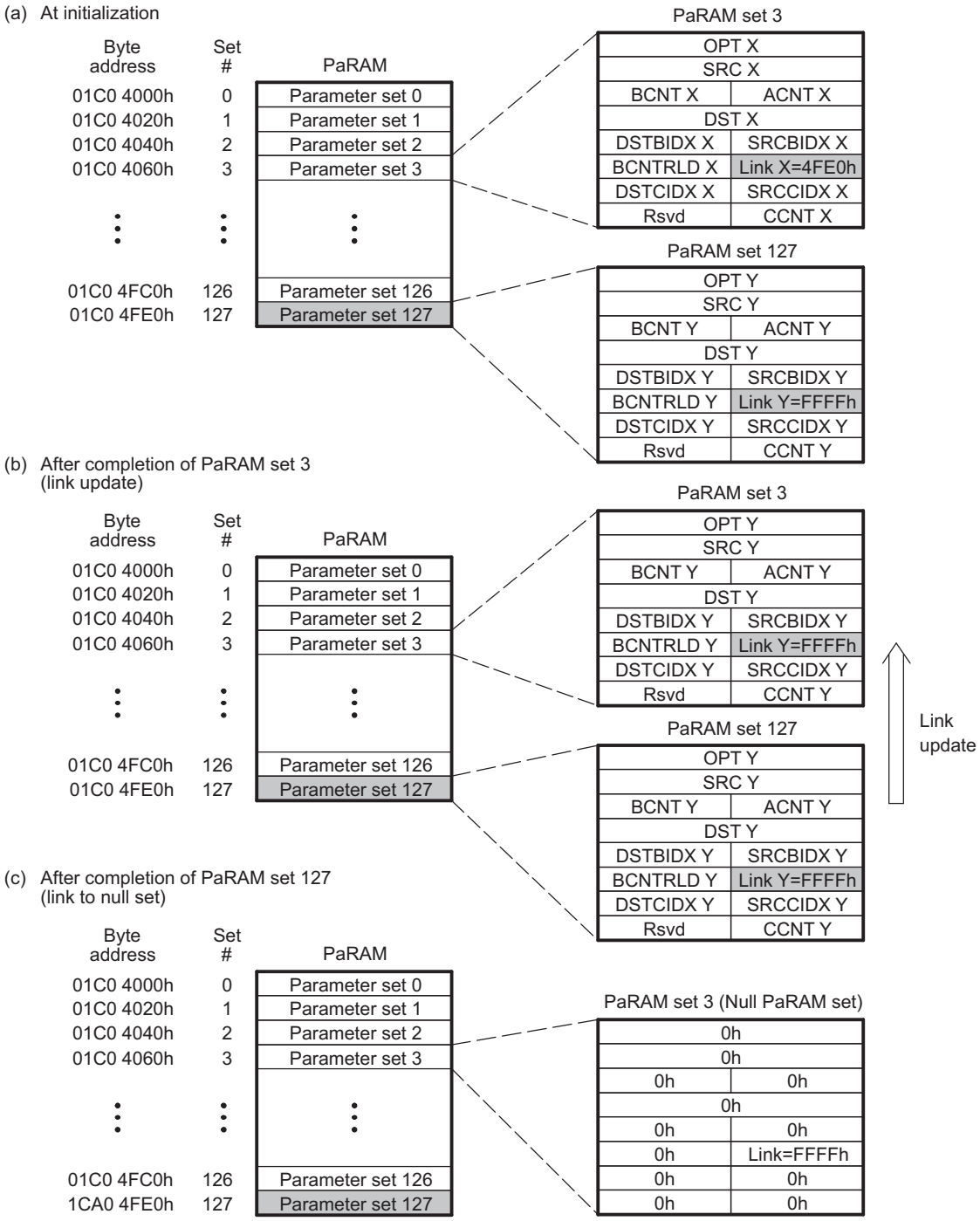
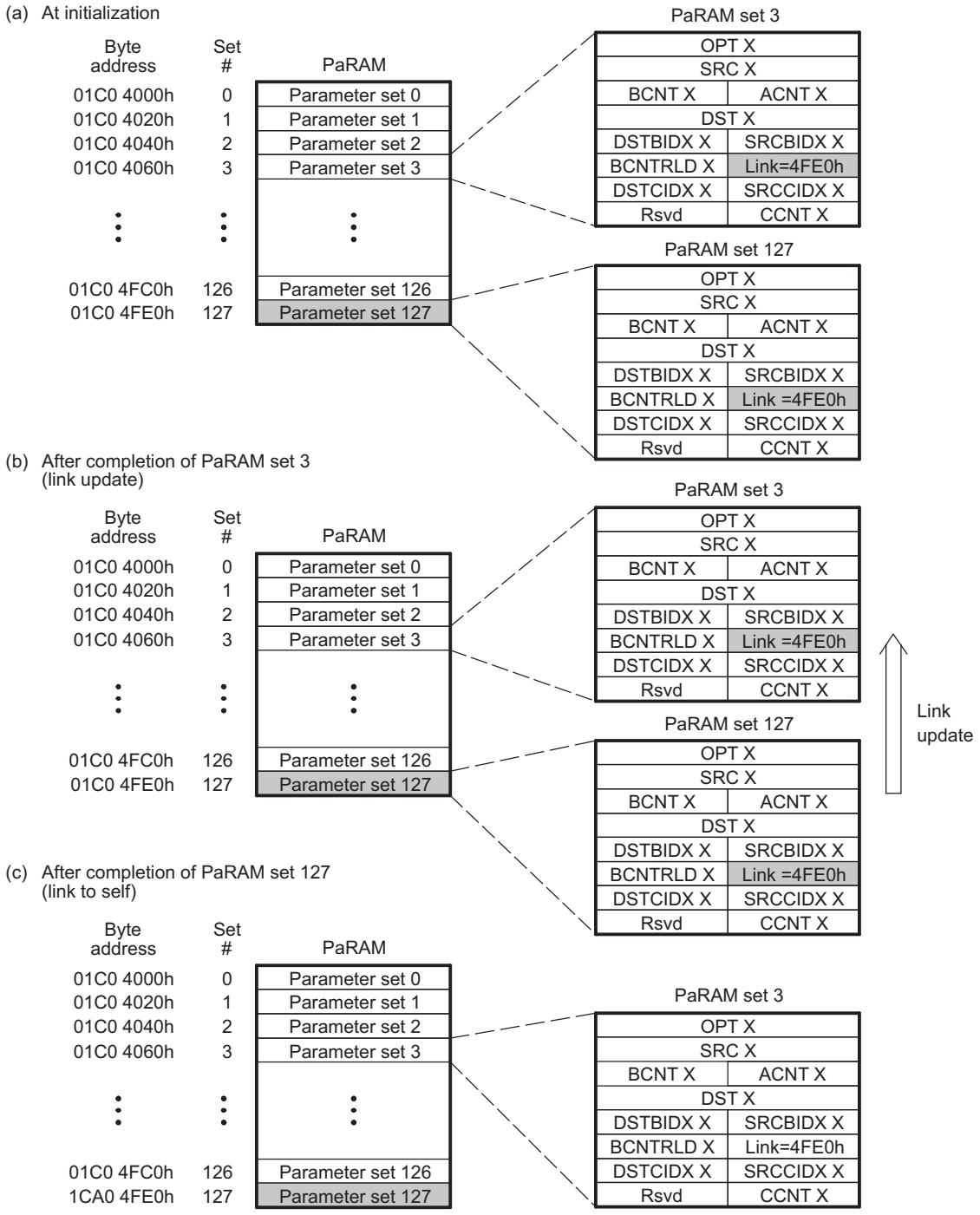


Figure 18-9. Link-to-Self Transfer Example



18.2.4 Initiating a DMA Transfer

There are multiple ways to initiate a programmed data transfer using the EDMA3 channel controller. Transfers on DMA channels are initiated by three sources:

- **Event-triggered transfer request** (this is the more typical usage of EDMA3): Allows for a peripheral, system, or externally-generated event to trigger a transfer request.
- **Manually-triggered transfer request:** The CPU manually triggers a transfer by writing a 1 to the corresponding bit in the event set register (ESR).
- **Chain-triggered transfer request:** A transfer is triggered on the completion of another transfer or subtransfer.

Transfers on QDMA channels are initiated by two sources:

- **Autotriggered transfer request:** A transfer is triggered when the PaRAM set entry programmed trigger word is written to.
- **Link-triggered transfer requests:** When linking occurs, the transfer is triggered when the PaRAM set entry programmed trigger word is written to.

18.2.4.1 DMA Channel

18.2.4.1.1 Event-Triggered Transfer Request

When an event is asserted from a peripheral or device pins, it gets latched in the corresponding bit of the event register (ER.E*n* = 1). If the corresponding event in the event enable register (EER) is enabled (EER.E*n* = 1), then the EDMA3CC prioritizes and queues the event in the appropriate event queue. When the event reaches the head of the queue, it is evaluated for submission as a transfer request to the transfer controller.

If the PaRAM set is valid (not a NULL set), then a transfer request packet (TRP) is submitted to the EDMA3TC and the E*n* bit in ER is cleared. At this point, a new event can be safely received by the EDMA3CC.

If the PaRAM set associated with the channel is a NULL set (see Section 18.2.3.3), then no transfer request (TR) is submitted and the corresponding E*n* bit in ER is cleared and simultaneously the corresponding channel bit is set in the event miss register (EMR.E*n* = 1) to indicate that the event was discarded due to a null TR being serviced. Good programming practices should include cleaning the event missed error before retriggering the DMA channel.

When an event is received, the corresponding event bit in the event register is set (ER.E*n* = 1), regardless of the state of EER.E*n*. If the event is disabled when an external event is received (ER.E*n* = 1 and EER.E*n* = 0), the ER.E*n* bit remains set. If the event is subsequently enabled (EER.E*n* = 1), then the pending event is processed by the EDMA3CC and the TR is processed/submitted, after which the ER.E*n* bit is cleared.

If an event is being processed (prioritized or is in the event queue) and another sync event is received for the same channel prior to the original being cleared (ER.E*n* != 0), then the second event is registered as a missed event in the corresponding bit of the event missed register (EMR.E*n* = 1).

For the synchronization events associated with each of the programmable DMA channels, see your device-specific data manual to determine the event to channel mapping.

18.2.4.1.2 Manually-Triggered Transfer Request

A DMA transfer is initiated by a write to the event set register (ESR) by the CPU (or any EDMA programmer). Writing a 1 to an event bit in the ESR results in the event being prioritized/queued in the appropriate event queue, regardless of the state of the EER.E*n* bit. When the event reaches the head of the queue, it is evaluated for submission as a transfer request to the transfer controller.

As in the event-triggered transfers, if the PaRAM set associated with the channel is valid (it is not a null set) then the TR is submitted to the associated EDMA3TC and the channel can be triggered again.

If the PaRAM set associated with the channel is a NULL set (see Section 18.2.3.3), then no transfer request (TR) is submitted and the corresponding E*n* bit in ER is cleared and simultaneously the corresponding channel bit is set in the event miss register (EMR.E*n* = 1) to indicate that the event was discarded due to a null TR being serviced. Good programming practices should include clearing the event missed error before retriggering the DMA channel.

If an event is being processed (prioritized or is in the event queue) and the same channel is manually set by a write to the corresponding channel bit of the event set register (ESR.E*n* = 1) prior to the original being cleared (ESR.E*n* = 0), then the second event is registered as a missed event in the corresponding bit of the event missed register (EMR.E*n* = 1).

18.2.4.1.3 Chain-Triggered Transfer Request

Chaining is a mechanism by which the completion of one transfer automatically sets the event for another channel. When a chained completion code is detected, the value of which is dictated by the transfer completion code (TCC[5:0] in OPT of the PaRAM set associated with the channel), it results in the corresponding bit in the chained event register (CER) to be set (CER.E[TCC] = 1).

Once a bit is set in CER, the EDMA3CC prioritizes and queues the event in the appropriate event queue. When the event reaches the head of the queue, it is evaluated for submission as a transfer request to the transfer controller.

As in the event-triggered transfers, if the PaRAM set associated with the channel is valid (it is not a null set) then the TR is submitted to the associated EDMA3TC and the channel can be triggered again.

If the PaRAM set associated with the channel is a NULL set (see Section 18.2.3.3), then no transfer request (TR) is submitted and the corresponding E*n* bit in CER is cleared and simultaneously the corresponding channel bit is set in the event miss register (EMR.E*n* = 1) to indicate that the event was discarded due to a null TR being serviced. In this case, the error condition must be cleared by you before the DMA channel can be retriggered. Good programming practices might include clearing the event missed error before retriggering the DMA channel.

If a chaining event is being processed (prioritized or queued) and another chained event is received for the same channel prior to the original being cleared (CER.E*n* != 0), then the second chained event is registered as a missed event in the corresponding channel bit of the event missed register (EMR.E*n* = 1).

NOTE: Chained event registers, event registers, and event set registers operate independently. An event (E*n*) can be triggered by any of the trigger sources (event-triggered, manually-triggered, or chain-triggered).

18.2.4.2 QDMA Channels

18.2.4.2.1 Autotriggered and Link-Triggered Transfer Request

NOTE: If OPT, SRC, or DST is the trigger word for a QDMA transfer then it is required to do a 32-bit access to that field.

QDMA-based transfer requests are issued when a QDMA event gets latched in the QDMA event register (QER.E*n* = 1). A bit corresponding to a QDMA channel is set in the QDMA event register (QER) when the following occurs:

- A CPU (or any EDMA3 programmer) write occurs to a PaRAM address that is defined as a QDMA channel trigger word (programmed in the QDMA channel *n* mapping register (QCHMAP*n*)) for the particular QDMA channel and the QDMA channel is enabled via the QDMA event enable register (QEER.E*n* = 1).
- EDMA3CC performs a link update on a PaRAM set address that is configured as a QDMA channel (matches QCHMAP*n* settings) and the corresponding channel is enabled via the QDMA event enable register (QEER.E*n* = 1).

Once a bit is set in QER, the EDMA3CC prioritizes and queues the event in the appropriate event queue. When the event reaches the head of the queue, it is evaluated for submission as a transfer request to the transfer controller.

As in the event-triggered transfers, if the PaRAM set associated with the channel is valid (it is not a null set) then the TR is submitted to the associated EDMA3TC and the channel can be triggered again.

If a bit is already set in QER (QER.E*n* = 1) and a second QDMA event for the same QDMA channel occurs prior to the original being cleared, the second QDMA event gets captured in the QDMA event miss register (QEMR.E*n* = 1).

18.2.4.3 Comparison Between DMA and QDMA Channels

The primary difference between DMA and QDMA channels is the event/channel synchronization. QDMA events are either autotriggered or link triggered. Autotriggering allows QDMA channels to be triggered by CPU(s) with a minimum number of linear writes to PaRAM. Link triggering allows a linked list of transfers to be executed, using a single QDMA PaRAM set and multiple link PaRAM sets.

A QDMA transfer is triggered when a CPU (or other EDMA3 programmer) writes to the trigger word of the QDMA channel parameter set (autotriggered) or when the EDMA3CC performs a link update on a PaRAM set that has been mapped to a QDMA channel (link triggered). Note that for CPU triggered (manually triggered) DMA channels, in addition to writing to the PaRAM set, it is required to write to the event set register (ESR) to kick-off the transfer.

QDMA channels are typically for cases where a single event will accomplish a complete transfer since the CPU (or EDMA3 programmer) must reprogram some portion of the QDMA PaRAM set in order to retrigger the channel. In other words, QDMA transfers are programmed with BCNT = CCNT = 1 for A-synchronized transfers, and CCNT = 1 for AB-synchronized transfers.

Additionally, since linking is also supported (if STATIC = 0 in OPT) for QDMA transfers, it allows you to initiate a linked list of QDMAs, so when EDMA3CC copies over a link PaRAM set (including the write to the trigger word), the current PaRAM set mapped to the QDMA channel will automatically be recognized as a valid QDMA event and initiate another set of transfers as specified by the linked set.

18.2.5 Completion of a DMA Transfer

A parameter set for a given channel is complete when the required number of transfer requests is submitted (based on receiving the number of synchronization events). The expected number of TRs for a non-null/non-dummy transfer is shown in Table 18-4 for both synchronization types along with state of the PaRAM set prior to the final TR being submitted. When the counts (BCNT and/or CCNT) are this value, the next TR results in a:

- Final chaining or interrupt codes to be sent by the transfer controllers (instead of intermediate).
- Link updates (linking to either null or another valid link set).

Table 18-4. Expected Number of Transfers for Non-Null Transfer

Sync Mode	Counts at time 0	Total # Transfers	Counts prior to final TR
A-synchronized	ACNT BCNT CCNT	(BCNT × CCNT) TRs of ACNT bytes each	BCNT == 1 && CCNT == 1
AB-synchronized	ACNT BCNT CCNT	CCNT TRs for ACNT × BCNT bytes each	CCNT == 1

You must program the PaRAM OPT field with a specific transfer completion code (TCC) along with the other OPT fields (TCCHEN, TCINTEN, ITCCHEN, and ITCINTEN bits) to indicate whether the completion code is to be used for generating a chained event or/and for generating an interrupt upon completion of a transfer.

The specific TCC value (6-bit binary value) programmed dictates which of the 64-bits in the chain event register (CER[TCC]) and/or interrupt pending register (IPR[TCC]) is set.

See Section 18.2.9 for details on interrupts and Section 18.2.8 for details on chaining.

You can also selectively program whether the transfer controller sends back completion codes on completion of the final transfer request (TR) of a parameter set (TCCHEN or TCINTEN), for all but the final transfer request (TR) of a parameter set (ITCCHEN or ITCINTEN), or for all TRs of a parameter set (both). See Section 18.2.8 for details on chaining (intermediate/final chaining) and Section 18.2.9 for details on intermediate/final interrupt completion.

A completion detection interface exists between the EDMA3 channel controller and transfer controller(s). This interface sends back information from the transfer controller to the channel controller to indicate that a specific transfer is completed.

All DMA/QDMA PaRAM sets must also specify a link address value. For repetitive transfers such as ping-pong buffers, the link address value should point to another predefined PaRAM set. Alternatively, a nonrepetitive transfer should set the link address value to the null link value. The null link value is defined as FFFFh. See Section 18.2.3.7 for more details.

NOTE: Any incoming events that are mapped to a null PaRAM set results in an error condition. The error condition should be cleared before the corresponding channel is used again. See Section 18.2.3.5.

There are three ways the EDMA3CC gets updated/informed about a transfer completion: normal completion, early completion, and dummy/null completion. This applies to both chained events and completion interrupt generation.

18.2.5.1 Normal Completion

In normal completion mode (TCCMODE = 0 in OPT), the transfer or sub-transfer is considered to be complete when the EDMA3 channel controller receives the completion codes from the EDMA3 transfer controller. In this mode, the completion code to the channel controller is posted by the transfer controller after it receives a signal from the destination peripheral. Normal completion is typically used to generate an interrupt to inform the CPU that a set of data is ready for processing.

18.2.5.2 Early Completion

In early completion mode (TCCMODE = 1 in OPT), the transfer is considered to be complete when the EDMA3 channel controller submits the transfer request (TR) to the EDMA3 transfer controller. In this mode, the channel controller generates the completion code internally. Early completion is typically useful for chaining, as it allows subsequent transfers to be chained-triggered while the previous transfer is still in progress within the transfer controller, maximizing the overall throughput of the set of the transfers.

18.2.5.3 Dummy or Null Completion

This is a variation of early completion. Dummy or null completion is associated with a dummy set (Section 18.2.3.4) or null set (Section 18.2.3.3). In both cases, the EDMA3 channel controller does not submit the associated transfer request to the EDMA3 transfer controller(s). However, if the set (dummy/null) has the OPT field programmed to return completion code (intermediate/final interrupt/chaining completion), then it will set the appropriate bits in the interrupt pending register (IPR) or chained event register (CER). The internal early completion path is used by the channel controller to return the completion codes internally (that is, EDMA3CC generates the completion code).

18.2.6 Event, Channel, and PaRAM Mapping

Most of the DMA channels are tied to a specific hardware peripheral event, thus allowing transfers to be triggered by events from device peripherals or external hardware. A DMA channel typically requests a data transfer when it receives its event (apart from manually-triggered, chain-triggered, and other transfers). The amount of data transferred per synchronization event depends on the channel's configuration (ACNT, BCNT, CCNT, etc.) and the synchronization type (A-synchronized or AB-synchronized).

The association of an event to a channel is fixed. Each of the DMA channels has one specific event associated with it. For the synchronization events associated with each of the programmable DMA channels, see your device-specific data manual to determine the event to channel mapping.

If in an application, a channel does not make use of the associated synchronization event or does not have an associated synchronization event (unused), that channel can be used for manually-triggered or chained-triggered transfers, for linking/reloading, or as a QDMA channel.

18.2.6.1 DMA Channel to PaRAM Mapping

The mapping between the DMA channel numbers and the PaRAM sets is a fixed, one-to-one mapping (see Table 18-5). In other words, channel (event) 0 is mapped to PaRAM set 0, channel (event 1) is mapped to PaRAM set 1, etc. So, for example, in order to program a transfer for event number 3, DMA channel 3 is associated with PaRAM set number 3 and you need to program this PaRAM set for configuring transfers associated with event number 3. See your device-specific data manual for the addresses of the PaRAM set entries.

Table 18-5. EDMA3 DMA Channel to PaRAM Mapping

PaRAM Set Number	Mapping
PaRAM Set 0	DMA Channel 0/Reload/QDMA
PaRAM Set 1	DMA Channel 1/Reload/QDMA
PaRAM Set 2	DMA Channel 2/Reload/QDMA
PaRAM Set 3	DMA Channel 3/Reload/QDMA
PaRAM Set 4	DMA Channel 4/Reload/QDMA
PaRAM Set 5	DMA Channel 5/Reload/QDMA
PaRAM Set 6	DMA Channel 6/Reload/QDMA
PaRAM Set 7	DMA Channel 7/Reload/QDMA
PaRAM Set 8	DMA Channel 8/Reload/QDMA
PaRAM Set 9	DMA Channel 9/Reload/QDMA
PaRAM Set 10	DMA Channel 10/Reload/QDMA
PaRAM Set 11	DMA Channel 11/Reload/QDMA
PaRAM Set 12	DMA Channel 12/Reload/QDMA
PaRAM Set 13	DMA Channel 13/Reload/QDMA
PaRAM Set 14	DMA Channel 14/Reload/QDMA
PaRAM Set 15	DMA Channel 15/Reload/QDMA
PaRAM Set 16	DMA Channel 16/Reload/QDMA
...	...
PaRAM Set 30	DMA Channel 30/Reload/QDMA
PaRAM Set 31	DMA Channel 31/Reload/QDMA
PaRAM Set 32	Reload/QDMA
PaRAM Set 33	Reload/QDMA
...	...
PaRAM Set *n* - 2	Reload/QDMA
PaRAM Set *n* - 1	Reload/QDMA
PaRAM Set *n*	Reload/QDMA

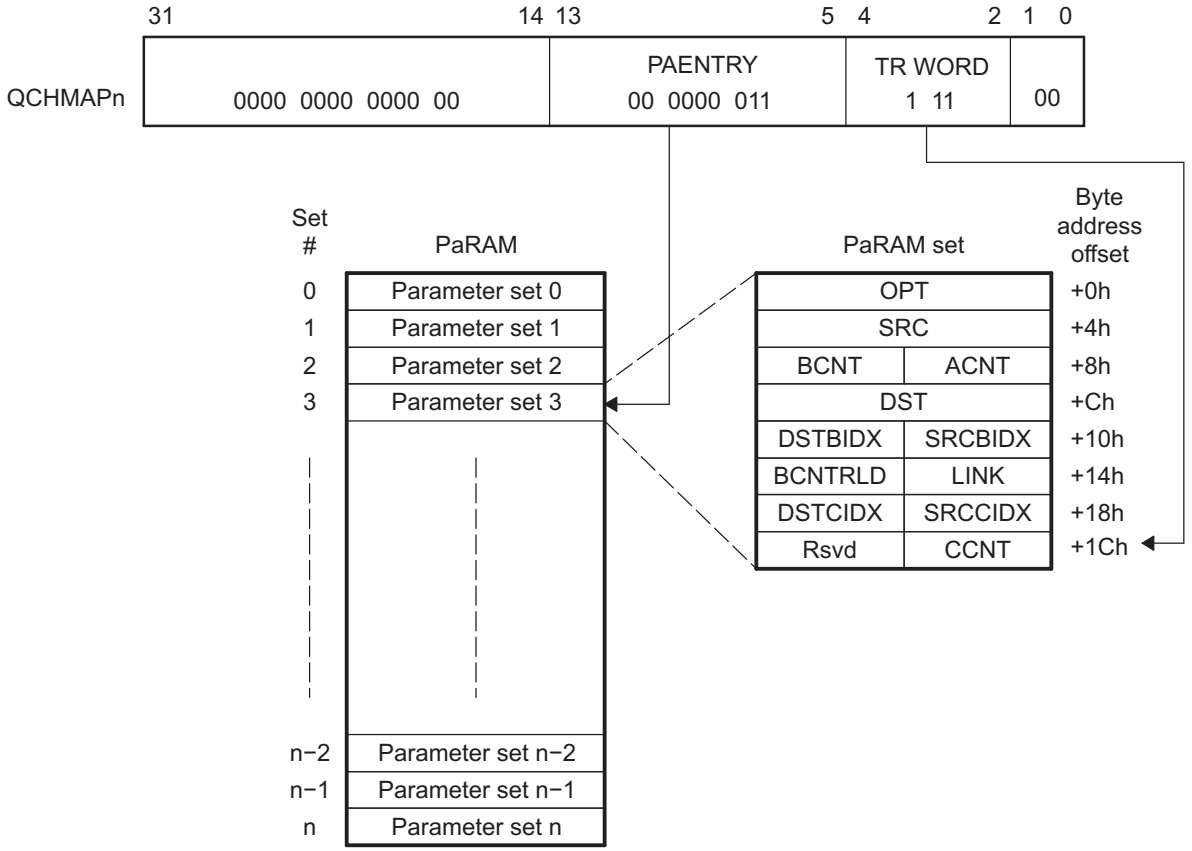
18.2.6.2 QDMA Channel to PaRAM Mapping

The mapping between the QDMA channels and the PaRAM sets is programmable .The QDMA channel *n* mapping register (QCHMAP*n*) in the EDMA3CC provides programmability for the QDMA channels to be mapped to any of the PaRAM sets in the PaRAM memory map. Figure 18-10 illustrates the use of QCHMAP.

Additionally, QCHMAP allows you to program the trigger word in the PaRAM set for the QDMA channel. A trigger word is one of the 8 words in the PaRAM set. For a QDMA transfer to occur, a valid TR synchronization event for EDMA3CC is a write to the trigger word in the PaRAM set pointed to by QCHMAP for a particular QDMA channel.

NOTE: By default, QDMA channels are mapped to PaRAM set 0. Care must be taken to appropriately remap PaRAM set 0 before it is used.

Figure 18-10. QDMA Channel to PaRAM Mapping



Note: *n* is the number of PaRAM sets supported in the EDMA3CC for a specific device.

18.2.7 EDMA3 Channel Controller Regions

The EDMA3 channel controller (EDMA3CC) divides its address space into multiple regions. Individual channel resources can be exclusively assigned to a specific region, where each region is typically assigned to a specific EDMA programmer. This allows partitioning of EDMA channel (DMA/QDMA) resources in hetero- or multi-core devices, and devices where certain additional masters (for example, coprocessors) can also program/initiate EDMA3 transfers. The application software running on these cores/coprocessors can operate in these exclusive shadow region memory-maps, minimizing possibilities of resource conflicts.

18.2.7.1 Region Overview

The EDMA3CC memory-mapped registers are divided in three main categories:

1. Global registers
2. Global region channel registers
3. Shadow region channel registers

The global registers are located at a single/fixed location in the EDMA3CC memory map. These registers control EDMA3 resource mapping and provide debug visibility and error tracking information. See your device-specific data manual for the EDMA3CC memory map.

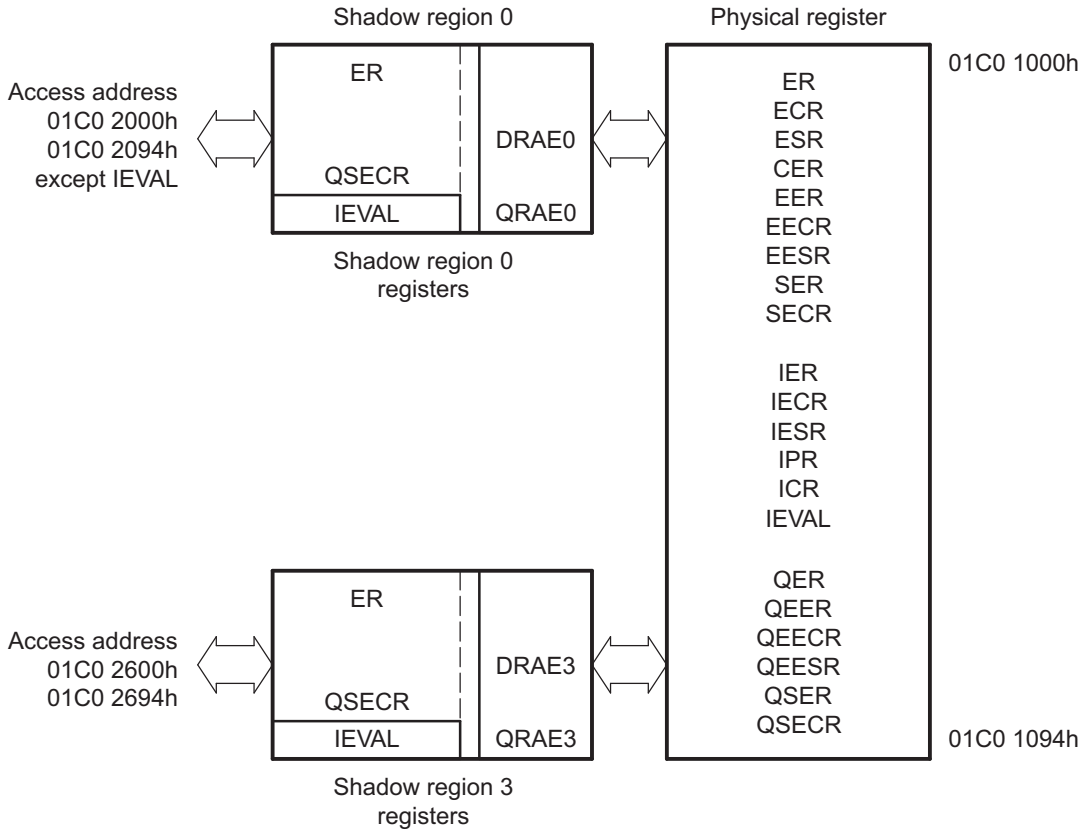
The channel registers (including DMA, QDMA, and interrupt registers) are accessible via the global channel region address range, or in the shadow *n* channel region address range(s). For example, the event enable register (EER) is visible in the global region register space at offset 1020h, or region addresses at offset 2020h for region 0 and at offset 2220h for region 1.

The underlying control register bits that are accessible via the shadow region address space (except for IEVAL*n*) are controlled by the DMA region access enable registers (DRAE*m*) and QDMA region access enable registers (QRAE*m*). Table 18-6 lists the registers in the shadow region memory-map. (See EDMA3CC memory-map figure for the complete global and shadow region memory-maps.) Figure 18-11 illustrates the conceptual view of the regions (where *n* is the number of shadow regions supported in the EDMA3CC for a specific device).

Table 18-6. Shadow Region Registers

DRAE*m*	**QRAE*m***
ER	QER
ECR	QEER
ESR	QEECR
CER	QEESR
EER	
EECR	
EESR	
SER	
SECR	
IER	
IECR	
IESR	
IPR	
ICR	
Register not affected by DRAE	
IEVAL	

Figure 18-11. Shadow Region Registers



18.2.7.2 Channel Controller Shadow Regions

For each EDMA3 shadow region (and associated memory-maps) there is a set of registers associated with the shadow region that allows association of the DMA/QDMA channels and interrupt completion codes to the region. These registers are user-programmed per region to assign ownership of the DMA/QDMA channels and TCC values to a region.

- DRAE*m*: One register exists for each of the shadow regions. The number of bits in each register matches the number of DMA channels. These registers need to be programmed to assign ownership of DMA channels to the respective region. Accesses to DMA event registers and interrupt registers via the shadow region address map are filtered through DRAE. A value of 1 in the corresponding DRAE bit implies that the corresponding DMA/interrupt channel is accessible; a value of 0 in the corresponding DRAE bit forces writes to be discarded and returns a value of 0 for reads.
- QRAE*m*: One register exists for every region. The number of bits in each register matches the number of QDMA channels. These registers must be programmed to assign ownership of QDMA channels to the respective region. To enable a channel in a shadow region using shadow region 0 QEER, the respective bit in QRAE must be set or writing into QEESR will not have the desired effect.

It is typical for an application to have a unique assignment of QDMA/DMA channels (and, therefore, a given bit position) to a given region.

The use of shadow regions allows for restricted access to EDMA3 resources (DMA channels, QDMA channels, TCC, interrupts) by tasks/cores/EDMA3 programmers in a system by setting or clearing bits in the DRAE/QRAE registers. If exclusive access to any given channel/TCC code is required for a region, then only that region's DRAE/QRAE should have the associated bit set.

Additionally, with each shadow region, there is an associated shadow region completion interrupt (EDMA3CC_INT*n* where *n* denotes the shadow region number). For multi-core/hetero-core devices, the various shadow region interrupts might be tied to the interrupt controllers for different cores. For single core devices, all shadow region interrupts would be routed to the device interrupt controller. See your device-specific data manual for the shadow region interrupt hookup to the device interrupt controller(s). The DRAE associated with each shadow region acts as a secondary interrupt enable (along with the interrupt enable register) for the respective shadow region interrupts. See Section 18.2.9 for more information on interrupts.

Example 18-1. Resource Pool Division Across Two Regions

This example illustrates a resource pool division across two regions, assuming region 0 must be allocated 16 DMA channels (0-15) and 1 QDMA channel (0), and 16 TCC codes (0-15). Region 1 needs to be allocated 16 DMA channels (16-31) and 7 QDMA channels (1-7), and 16 TCC codes (16-31). DRAE should be equal to the OR of the bits that are required for the DMA channels and the TCC codes:

```
Region 0: DRAE = 0x0000FFFF QRAE = 0x00000001 Region 1: DRAE = 0xFFFF0000 QRAE = 0x000000FE
```

18.2.8 Chaining EDMA3 Channels

The channel chaining capability for the EDMA3 allows the completion of an EDMA3 channel transfer to trigger another EDMA3 channel transfer. The purpose is to allow you the ability to chain several events through one event occurrence.

Chaining is different from linking (Section 18.2.3.7). The EDMA3 link feature reloads the current channel parameter set with the linked parameter set. The EDMA3 chaining feature does not modify or update any channel parameter set; it provides a synchronization event to the chained channel (see Section 18.2.4.1.3 for chain-triggered transfer requests).

Chaining is achieved at either final transfer completion or intermediate transfer completion, or both, of the current channel. Consider a channel *m* (DMA/QDMA) required to chain to channel *n*. Channel number *n* (0-31) needs to be programmed into the TCC field of channel *m* channel options parameter (OPT) set.

- If final transfer completion chaining (TCCHEN = 1 and ITCCHEN = 0 in channel *m* OPT) is enabled, the chain-triggered event occurs after the *last* transfer request of channel *m* is submitted (early completion) or completed (normal completion).
- If intermediate transfer completion chaining (TCCHEN = 0 and ITCCHEN = 0 in channel *m* OPT) is enabled, the chain-triggered event occurs after every *intermediate* transfer request of channel *m* is submitted (early completion) or completed (normal completion).
- If both final and intermediate transfer completion chaining (TCCHEN = 1 and ITCCHEN = 1 in channel *m* OPT) are enabled, the chain-trigger event occurs after *every* transfer request of channel *m* is submitted (early completion) or completed (normal completion).

Table 18-7 shows the number of chain event triggers occurring in different synchronized scenarios. Consider channel 31 programmed with ACNT = 3, BCNT = 4, CCNT = 5, and TCC = 30.

Table 18-7. Chain Event Triggers

	(Number of chained event triggers on channel 30)	
Options	**A-Synchronized**	**AB-Synchronized**
TCCHEN = 1, ITCCHEN = 0	1 (Last TR)	1 (Last TR)
TCCHEN = 0, ITCCHEN = 1	19 (All but the last TR)	4 (All but the last TR)
TCCHEN = 1, ITCCHEN = 1	20 (All TRs)	5 (All TRs)

18.2.9 EDMA3 Interrupts

The EDMA3 interrupts are divided into 2 categories:

- Transfer completion interrupts

- Error interrupts

For information on the transfer completion interrupts and the error interrupts, see your device-specific data manual.

18.2.9.1 Transfer Completion Interrupts

The EDMA3CC is responsible for generating transfer completion interrupts to the CPU. The EDMA3 generates a single completion interrupt per shadow region on behalf of all DMA/QDMA channels. Various control registers and bit fields facilitate EDMA3 interrupt generation.

The transfer completion code (TCC) value is directly mapped to the bits of the interrupt pending register (IPR), as shown in Table 18-8. For example, if TCC = 00 0000b, IPR[0] is set after transfer completion, and results in an interrupt generation to the CPU if in the EDMA3CC and device interrupt controller are configured to allow a CPU interrupt. See Section 18.2.9.1.1 for details on enabling EDMA3 transfer completion interrupts.

When a completion code is returned (as a result of early or normal completion), the corresponding bit in IPR is set. For the completion code to be returned, the PaRAM set associated with the transfer must enable the transfer completion interrupt (final/intermediate) in the channel options parameter (OPT).

The transfer completion code (TCC) can be programmed to any value for a DMA/QDMA channel. There does not need to be a direct relation between the channel number and the transfer completion code value. This allows multiple channels having the same transfer completion code value to cause a CPU to execute the same interrupt service routine (ISR) for different channels.

NOTE: The TCC field in the channel options parameter (OPT) is a 6-bit field and can be programmed for any value between 0-64. For devices with 32 DMA channels, the TCC should have a value between 0 to 31 so that it sets the appropriate bits (0 to 31) in IPR (and can interrupt the CPU(s) on enabling the IER register bits (0-31)).

Table 18-8. Transfer Complete Code (TCC) to EDMA3CC Interrupt Mapping

TCC Bits in OPT (TCINTEN/ITCINTEN = 1)	IPR Bit Set
00 0000b	IPR0
00 0001b	IPR1
00 0010b	IPR2
00 0011b	IPR3
00 0100b	IPR4
…	…
…	…
01 1110b	IPR30
01 1111b	IPR31

You can enable interrupt generation at either final transfer completion or intermediate transfer completion, or both. Consider channel *m* as an example.

- If the final transfer interrupt (TCINTEN = 1 and ITCINTEN = 0 in OPT) is enabled, the interrupt occurs after the *last* transfer request of channel *m* is either submitted or completed (depending on early or normal completion).
- If the intermediate transfer interrupt (TCINTEN = 0 and ITCINTEN = 1 in OPT) is enabled, the interrupt occurs after every *intermediate* transfer request of channel *m* is either submitted or completed (depending on early or normal completion).
- If both final and intermediate transfer completion interrupts (TCINTEN = 1 and ITCINTEN = 1 in OPT) are enabled, the interrupt occurs after *every* transfer request of channel *m* is submitted or completed (depending on early or normal completion).

Table 18-9 shows the number of interrupts occurring in different synchronized scenarios. Consider channel 31 programmed with ACNT = 3, BCNT = 4, CCNT = 5, and TCC = 30.

Table 18-9. Number of Interrupts

Options	A-Synchronized	AB-Synchronized
TCINTEN = 1, ITCINTEN = 0	1 (Last TR)	1 (Last TR)
TCINTEN = 0, ITCINTEN = 1	19 (All but the last TR)	4 (All but the last TR)
TCINTEN = 1, ITCINTEN = 1	20 (All TRs)	5 (All TRs)

18.2.9.1.1 Enabling Transfer Completion Interrupts

For the EDMA3 channel controller to assert a transfer completion to the external world, the interrupts have to be enabled in the EDMA3CC. This is in addition to setting up the TCINTEN and ITCINTEN bits in OPT of the associated PaRAM set.

The EDMA3 channel controller has interrupt enable registers (IER) and each bit location in IER serves as a primary enable for the corresponding interrupt pending register (IPR).

All the interrupt registers (IER, IESR, IECR, and IPR) are either manipulated from the global DMA channel region or by way of the DMA channel shadow regions. The shadow regions provide a view to the same set of physical registers that are in the global region.

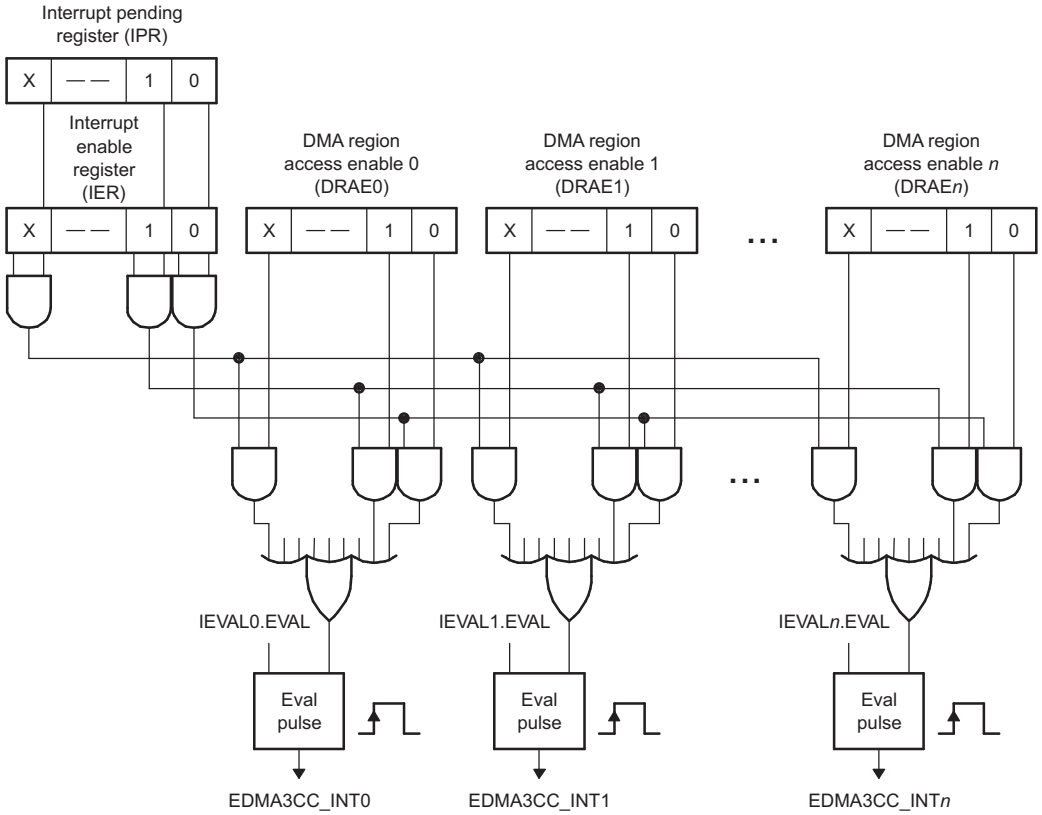
The EDMA3 channel controller has a hierarchical completion interrupt scheme that makes use of a single set of interrupt pending register (IPR) and single set of interrupt enable registers (IER). A second level of interrupt masking is provided by the programmable DMA region access enable registers (DRAE). See Figure 18-12.

For the EDMA3CC to generate the transfer completion interrupts that are associated with each shadow region, the following conditions must be true:

- EDMA3CC_INT0: (IPR.E0 & IER.E0 & DRAE0.E0) | (IPR.E1 & IER.E1 & DRAE0.E1) | …| (IPR.E*n* & IER.E*n* & DRAE0.E*n*)
- EDMA3CC_INT1: (IPR.E0 & IER.E0 & DRAE1.E0) | (IPR.E1 & IER.E1 & DRAE1.E1) | …| (IPR.E*n* & IER.E*n* & DRAE1.E*n*)

  where *n* is the number of shadow regions supported in the EDMA3CC for a specific device.

Figure 18-12. Interrupt Diagram



Note: *n* is the number of shadow regions supported in the EDMA3CC for a specific device.

NOTE: The DRAE for all regions is expected to be set up at system initialization and to remain static for an extended period of time. The interrupt enable registers should be used for dynamic enable/disable of individual interrupts.

Because there is no relation between the TCC value and the DMA/QDMA channel, it is possible, for example, for DMA channel 0 to have the OPT.TCC = 31 in its associated PaRAM set. This would mean that if a transfer completion interrupt is enabled (OPT.TCINTEN or OPT.ITCINTEN is set), then based on the TCC value, IPR.E31 is set up on completion. For proper channel operations and interrupt generation using the shadow region map, you must program the DRAE that is associated with the shadow region to have read/write access to both bit 0 (corresponding to channel 0) and bit 31 (corresponding to IPR.E31 bit that is set upon completion).

18.2.9.1.2 Clearing Transfer Completion Interrupts

Transfer completion interrupts that are latched to the interrupt pending register (IPR) is cleared by writing a 1 to the corresponding bit in the interrupt pending clear register (ICR). For example, a write of 1 to ICR.E0 clears a pending interrupt in IPR.E0.

If an incoming transfer completion code (TCC) gets latched to a bit in IPR, then additional bits that get set due to a subsequent transfer completion will not result in asserting the EDMA3CC completion interrupt. In order for the completion interrupt to be pulsed, the required transition is from a state where no enabled interrupts are set to a state where at least one enabled interrupt is set.

18.2.9.2 EDMA3 Interrupt Servicing

On completion of a transfer (early or normal completion), the EDMA3 channel controller sets the appropriate bit in the interrupt pending register (IPR) as specified by the transfer completion codes. If the completion interrupts are appropriately enabled, then the CPU enters the interrupt service routine (ISR) when the completion interrupt is asserted. Since there is a single completion interrupt for all DMA/QDMA channels.

After servicing the interrupt, the ISR should clear the corresponding bit in IPR; therefore, enabling recognition of future interrupts. Only when all IPR bits are cleared, the EDMA3CC will assert additional completion interrupts.

It is possible that when one interrupt is serviced; many other transfer completions result in additional bits being set in IPR, thereby resulting in additional interrupts. It is likely that each of these bits in IPR would need different types of service; therefore, the ISR must check all pending interrupts and continue until all the posted interrupts are appropriately serviced.

Following are examples (pseudo code) for a CPU interrupt service routine for an EDMA3CC completion interrupt.

The ISR routine in Example 18-2 is more exhaustive and incurs a higher latency.

Example 18-2. Interrupt Servicing

The pseudo code:

1. Read the interrupt pending register (IPR).
2. Perform the operations needed.
3. Write to the interrupt pending clear register (ICR) to clear the corresponding IPR bit.
4. Read IPR again:

   (a) If IPR is not equal to 0, repeat from step 2 (implies occurrence of new event between step 2 to step 4).

   (b) If IPR is equal to 0, this should assure you that all enabled interrupts are inactive.

NOTE: It is possible that during step 4, an event occurs while the IPR bits are read to be 0 and the application is still in the interrupt service routine. If this happens, a new interrupt is recorded in the device interrupt controller and a new interrupt is generated as soon as the application exits the interrupt service routine.

Example 18-3 is less rigorous, with less burden on the software in polling for set interrupt bits, but can occasionally cause a race condition, as mentioned above.

Example 18-3. Interrupt Servicing

If it is desired to leave any enabled and pending (possibly lower priority) interrupts, it is required to force the interrupt logic to reassert the interrupt pulse by setting the EVAL bit in the interrupt evaluation register (IEVAL).

The pseudo code:

1. Enter ISR.
2. Read IPR.
3. For the condition set in IPR that you desire to service:
   (a) Service interrupt as required by application.
   (b) Clear bit for serviced conditions (others may still be set, and other transfers may have resulted in returning the TCC to EDMA3CC after step 2).
4. Read IPR prior to exiting ISR:
   (a) If IPR is equal to 0, then exit ISR.
   (b) If IPR is not equal to 0, then set IEVAL so that upon exit of ISR, a new interrupt is triggered if any enabled interrupts are still pending.

The EVAL bit must not be set when IPR is read to be 0, to avoid generation of extra interrupt pulses.

NOTE: Since the DMA region access registers (DRAE) are required to enable the transfer completion region interrupts, it is assumed that there will be a unique and nonoverlapping (in most cases) assignment of the channels and interrupts among the different shadow regions. This allows the interrupt registers (IER, IESR, IECR, IPR, and ICR) in the different shadow regions to functionally operate in an independent manner and nonoverlapping. The above examples for the interrupt service routine is based on this assumption.

18.2.9.3 Interrupt Evaluation Operations

The EDMA3CC has interrupt evaluate registers (IEVAL) in each shadow region. These registers are the only registers in the DMA channel shadow region memory map that are not affected by the settings for the DMA region access enable registers (DRAE). A write of 1 to the EVAL bit in these registers associated with a particular shadow region results in pulsing the associated region interrupt, if any enabled interrupt (via IER) is still pending (IPR). This register can be used in order to assure that the interrupts are not missed by the CPU (or the EDMA3 master associated with the shadow region) if the software architecture chooses not to use all interrupts. See Example 18-3 for the use of IEVAL in the EDMA3 interrupt service routine (ISR).

Similarly an error evaluate register (EEVAL) exists in the global region. A write of 1 to the EVAL bit in EEVAL causes the pulsing of the error interrupt if any pending errors are in EMR, QEMR, or CCERR. See Section 18.2.9.4 for additional details on error interrupts.

NOTE: While using IEVAL for shadow region completion interrupts, you should make sure that the IEVAL operated upon is from that particular shadow region memory map.

18.2.9.4 Error Interrupts

The EDMA3CC error registers provide the capability to differentiate error conditions (event missed, threshold exceed, etc.). Additionally, if the error bits are set in these registers, it results in asserting the EDMA3CC error interrupt. If EDMA3CC error interrupt is enabled in the device interrupt controller, then it allows the CPU to handle the error conditions.

The EDMA3CC has a single error interrupt (EDMA3_CC0_ERRINT) that gets asserted for all EDMA3CC error conditions. There are four conditions that cause the error interrupt to be pulsed:

- DMA missed events: for all 32 DMA channels. These get latched in the event missed registers (EMR).
- QDMA missed events: for all QDMA channels. These get latched in the QDMA event missed register (QEMR).
- Threshold exceed: for all event queues. These get latched in EDMA3CC error register (CCERR).
- TCC error: for outstanding transfer requests expected to return completion code (TCCHEN or TCINTEN bit in OPT is set to 1) exceeding the maximum limit of 31. This also gets latched in the EDMA3CC error register (CCERR).

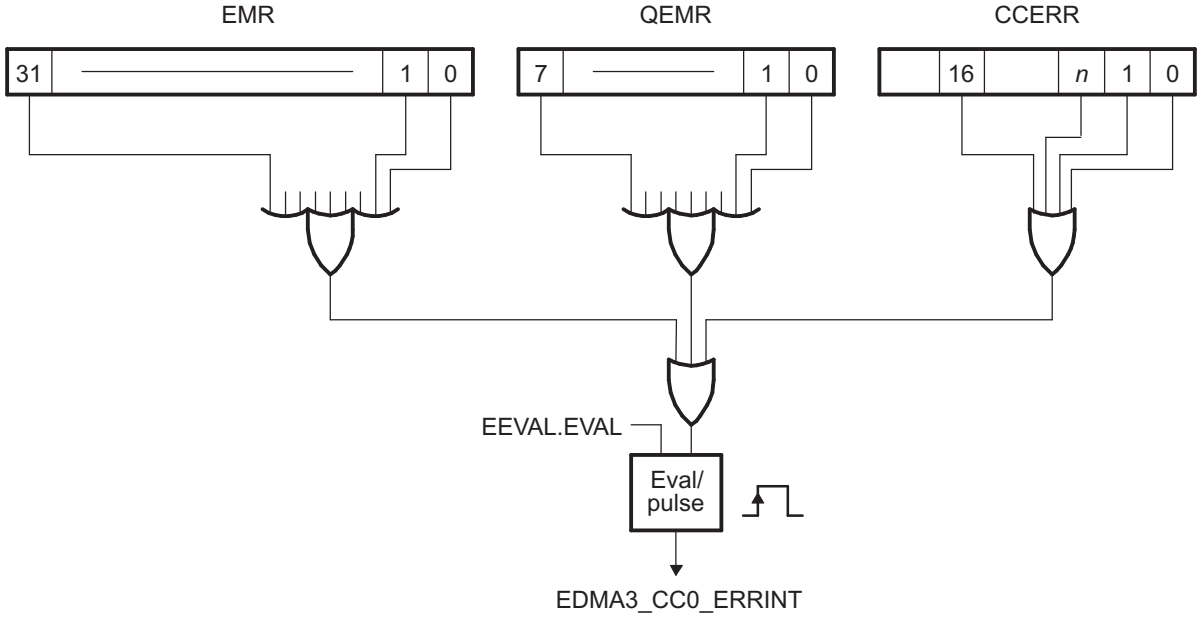
Figure 18-13 illustrates the EDMA3CC error interrupt generation operation.

If any of the bits are set in the error registers due to any error condition, the (EDMA3_CC0_ERRINT) always is asserted, as there are no enables for masking these error events. Similar to the transfer completion interrupts, the error interrupt also is pulsed only when the error interrupt condition transitions from a state where no errors are set to a state where at least one error bit is set. If additional error events are latched prior to the original error bits being cleared, the EDMA3CC does not generate additional interrupt pulses.

To reduce the burden on the software, similar to the interrupt evaluate register (IEVAL), there is an error evaluate register (EEVAL) that allows reevaluation of pending set error events/bits. This can be used so that the CPU(s) does not miss any error events.

NOTE: It is a good practice to have the error interrupt enabled in the device interrupt controller and associate an interrupt service routine with it to address the various error conditions appropriately. This puts less burden on software (polling for error status) and additionally provides a good debug mechanism for unexpected error conditions.

Figure 18-13. Error Interrupt Operation



Note: *n* is the number of queues supported in the EDMA3CC for a specific device.

18.2.10 Event Queue(s)

Event queues are a part of the EDMA3 channel controller. Event queues form the interface between the event detection logic in the EDMA3CC and the transfer request (TR) submission logic of the EDMA3CC. Each queue is 16 entries deep, that is, a maximum of 16 queued events per event queue. If there are more than 16 events, then the events that cannot find a place in the event queue remain set in the associated event register.

The number of event queues in the EDMA3CC determines the number of transfer controllers connected to the EDMA3CC. By default, there is a one-to-one mapping between the queues and transfer controllers. Therefore, the transfer requests (TRs) associated with events in Q0 get submitted to TC0. Similarly, transfer requests associated with events in Q1 get submitted to TC1, and so on.

An event that wins prioritization against other DMA and/or QDMA pending events is placed at the end of the appropriate event queue. Each event queue is serviced in a FIFO (first in–first out) order. Once the event reaches the head of its queue and the corresponding transfer controller is ready to receive another TR, the event is dequeued and the PaRAM set corresponding to the dequeued event is processed and submitted as a transfer request packet (TRP) to the associated EDMA3 transfer controller.

A lower numbered queue has a higher dequeuing priority then a higher numbered queue. For example, Q0 has higher priority than Q1, if Q0 and Q1 both have at least one event entry and if both TC0 and TC1 can accept transfer requests, then the event in Q0 is dequeued first and its associated PaRAM set is processed and submitted as a transfer request (TR) to TC0.

All the event entries in all the event queues are software readable (not writeable) by accessing the event queue entry registers (Q*x*E*y*). Each event entry register characterizes the queued event in terms of the type of event (manual, event, chained or autotriggered) and the event number. See Section 18.4.2.4.1 for a description of the bit fields in the queue event entry registers.

18.2.10.1 DMA/QDMA Channel to Event Queue Mapping

Each DMA channel and QDMA channel is independently programmed to map to a specific queue using the DMA queue number register *n* (DMAQNUM*n*) and the QDMA channel queue number register (QDMANUM). The mapping of DMA/QDMA channels is critical to achieving the desired performance level for the EDMA and most importantly in meeting real-time deadlines.

NOTE: If an event is ready to be queued and both the event queue and the EDMA3 transfer controller associated to the event queue are empty, then the event bypasses the event queue, and goes to the PaRAM processing logic and eventually to the transfer request submission logic for submission to the EDMA3TC. In this case, the event is not logged in the event queue status registers.

18.2.10.2 Queue RAM Debug Visibility

Each event queue has 16 entries. These 16 entries are managed in a circular FIFO manner. All event queue entries for all event queues are software readable by the event queue entry register (Q*x*E*x*). Additionally, for each queue there is a queue status register (QSTAT*n*).

These registers provide user visibility and may be helpful while debugging real-time issues (typically post-mortem), involving multiple events and event sources. The event queue entry register (Q*x*E*x*) uniquely identifies the specific event type (event-triggered, manually-triggered, chain-triggered, and QDMA events) along with the event number (for DMA/QDMA channels) that are in the queue or have been de-queued (passed through the queue). QSTAT*n* includes fields for the start pointer (STRTPTR) that provides the offset to the head entry of an event. It also includes a NUMVAL field that provides the total number of valid entries residing in the event queue at a given instance of time. The STRTPTR field may be used to index appropriately into the 16 event entries. The NUMVAL number of entries starting from STRTPTR are indicative of events still queued in the respective queue. The remaining entries may be read to determine which events have already been de-queued and submitted to the associated transfer controller.

18.2.10.3 Queue Resource Tracking

The EDMA3CC event queue includes watermarking/threshold logic that allows you to keep track of maximum usage of all event queues. This is useful for debugging real-time deadline violations that may result from head-of-line blocking on a given EDMA3 event queue.

You can program the maximum number of events that can queue up in an event queue by programming the threshold value (between 0 to 15) in the queue watermark threshold A register (QWMTHRA). The maximum queue usage is recorded actively in the watermark (WM) field of the queue status register (QSTAT*n*) that keeps getting updated based on a comparison of number of valid entries, which is also visible in the NUMVAL bit in QSTAT*n* and the maximum number of entries (WM bit in QSTAT*n*).

If the queue usage is exceeded, this status is visible in the EDMA3CC registers: the QTHRXCD*n* bit in the channel controller error register (CCERR) and the THRXCD bit in QSTAT*n*, where *n* stands for the event queue number. Any bits that are set in CCERR also generate an EDMA3CC error interrupt.

18.2.11 EDMA3 Transfer Controller (EDMA3TC)

The EDMA3 channel controller is the user-interface of the EDMA3 and the EDMA3 transfer controller (EDMA3TC) is the data movement engine of the EDMA3. The EDMA3CC submits transfer requests (TR) to the EDMA3TC and the EDMA3TC performs the data transfers dictated by the TR.

18.2.11.1 Architecture Details

18.2.11.1.1 EDMA3TC Configuration

Each transfer controller on a device is designed differently based on considerations like performance requirements, system topology (main SCR bus width, external memory bus width), gate count, etc. The parameters that determine the TC configurations are:

- FIFOSIZE: Determines the size in bytes for the Data FIFO that is the temporary buffer for the in-flight data. The data FIFO is where the read return data read by the TC read controller from the source endpoint is stored and subsequently written out to the destination endpoint by the TC write controller.
- Default Burst Size (DBS): The DBS is the maximum number of bytes per read/write command issued by a transfer controller.
- BUSWIDTH: The width of the read and write data buses in bytes, for the TC read and write controller, respectively. This is typically equal to the bus width of the main SCR interface.
- DSTREGDEPTH: This determines the number of Destination FIFO register set. The number of Destination FIFO register set for a transfer controller, determines the maximum number of outstanding transfer requests (TR pipelining).

Of the four parameters, the FIFOSIZE, BUSWIDTH, and DSTREGDEPTH values are fixed in design for a given device. The default burst size (DBS) for each transfer controller is configurable by the chip configuration 0 register (CFGCHIP0) in the System Configuration Module.

The burst size for each transfer controlled can be programmed to be 16-, 32-, or 64-bytes. The default values for DBS are typically chosen for optimal performance in most intended-use conditions; therefore, if you decide to use a value other then the default, you should evaluate the impact on performance. Depending on the FIFOSIZE and source/destination locations the performance for the transfer can vary significantly for different burst size values.

NOTE: It is expected that the DBS value for a transfer controller is static and should be based on the application requirement. It is not recommended that the DBS value be changed on-the-fly.

18.2.11.1.2 Command Fragmentation

The TC read and write controllers in conjunction with the source and destination register sets are responsible for issuing optimally-sized reads and writes to the slave endpoints. The transfer controller read/write transaction as specified by the transfer request packet is internally broken down into smaller bursts; this determines the default burst size (DBS) for the transfer controller. See Section 18.2.11.1.1 for the DBS value of each EDMA3TC.

The EDMA3TC attempts to issue the largest possible command size as limited by the DBS value or the ACNT/BCNT value of the TR. EDMA3TC obeys the following rules:

- The read/write controllers always issue commands less than or equal to the DBS value.
- The first command of a 1D transfer is always issued so that subsequent commands align to the DBS value.

Example 18-4 shows the command fragmentation for a DBS of 32 bytes. In summary, if the ACNT value is larger than the DBS value, then the EDMA3TC breaks the ACNT array into DBS-sized commands to the source/destination addresses. Each BCNT number of arrays are then serviced in succession.

Example 18-4. Command Fragmentation (DBS = 32)

The pseudo code:

1. ACNT = 8, BCNT = 8, SRCBIDX = 8, DSTBIDX = 10, SRCADDR = 64, DSTADDR = 191

   Read Controller: This is optimized from a 2D-transfer to a 1D-transfer such that the read side is equivalent to ACNT = 64, BCNT = 1.

   Cmd0 = 32 byte, Cmd0 = 32 byte

   Write Controller: Since DSTBIDX != ACNT, it is not optimized.

   Cmd0 = 8 byte, Cmd1 = 8 byte, Cmd2 = 8 byte, Cmd3 = 8 byte, Cmd4 = 8 byte, Cmd5 = 8 byte, Cmd6 = 8 byte, Cmd7 = 8 byte.

2. ACNT = 64, BCNT = 1, SRCADDR = 31, DSTADDR = 513

   Read Controller: Read address is not aligned.

   Cmd0 = 1 byte, (now the SRCADDR is aligned to 32 for the next command)

   Cmd1 = 32 bytes

   Cmd2 = 31 bytes

   Write Controller: The write address is also not aligned.

   Cmd0 = 31 bytes, (now the DSTADDR is aligned to 32 for the next command)

   Cmd1 = 32 bytes

   Cmd2 = 1 byte

18.2.11.1.3 TR Pipelining and Data Ordering

The transfer controller(s) can issue back-to-back transfer requests (TR). The number of outstanding TRs for a TC is limited by the number of destination FIFO register entries that is controlled by the DSTREGDEPTH parameter (fixed in design for a given transfer controller). TR pipelining refers to the ability of the TC read controller to issue read commands for a subsequent TR, while the TC write controller is still performing writes for the previous TR. Consider the case of 2 TRs (TR0 followed by TR1), because of TR pipelining, the TC read controller can start issuing the read commands for TR1 as soon as the last read command for TR0 has been issued, meanwhile the write commands and write data for TR0 are tracked by the destination FIFO registers. In summary, the TC read controller is able to process *n* TRs ahead of the write controller, where *n* is the number of destination FIFO register entries (typically 4).

TR pipelining is useful for maintaining throughput on back-to-back small TRs. It eliminates the read overhead because reads start in the background of a previous TR writes.

It should be noted that back-to-back TRs are targeted to different end points even though the read return data for the two TRs might get returned out of order (that is, read data for TR1 might come in before read data for TR0), the transfer controller issues that the write commands are issued in order (that is, write commands for TR0 will be issued before write commands for TR1).

18.2.11.2 Error Generation

Similar to the channel controller, the transfer controllers are capable of detecting and reporting several error conditions. The TC errors are generated, under three main conditions:

- BUSERR: The TC read or write controllers detect an error signaled by the source or destination address. The additional details on the type of error is also recorded in the ERRDET register, which indicates whether it is a read error (source address errors) or write error (destination address error).
- MMRAERR: CPU accesses illegal/reserved addresses in the EDMA3CC/TC memory-map.
- TRERR: A transfer request packet is detected to be violating the constant addressing mode transfer rules (the source/destination addresses and source/destination indexes must be aligned to 32 bytes).

You can poll for the errors, as the status of the errors can be read from the ERRSTAT registers, additionally if the error bits are enabled in the ERREN register, a bit set in the ERRSTAT will cause the error condition to interrupt the CPU(s). You can decide to enable/disable either or all error types.

18.2.11.3 Debug Features

The DMA program register set, DMA source active register set, and the destination FIFO register set are used to derive a brief history of TRs serviced through the transfer controller.

Additionally, the EDMA3TC status register (TCSTAT) has dedicated bit fields to indicate the ongoing activity within different parts of the transfer controller:

- The SRCACTV bit indicates whether the source active set is active.
- The DSTACTV bit indicates the number of TRs resident in the destination register active set at a given instance.
- The PROGBUSY bit indicates whether a valid TR is present in the DMA program set.

If the TRs are in progression, caution must be used and you must realize that there is a chance that the values read from the EDMA3TC status registers will be inconsistent since the EDMA3TC may change the values of these registers due to ongoing activities.

It is recommended that you ensure no additional submission of TRs to the EDMA3TC in order to facilitate ease of debug.

18.2.11.3.1 Destination FIFO Register Pointer

The destination FIFO register pointer is implemented as a circular buffer with the start pointer being DFSTRTPTR and a buffer depth of usually 2 or 4. The EDMA3TC maintains two important status details in TCSTAT that may be used during advanced debugging, if necessary. The DFSTRTPTR is a start pointer, that is, the index to the head of the destination FIFO register. The DSTACTV is a counter for the number of valid (occupied) entries. These registers may be used to get a brief history of transfers.

Examples of some register field values and their interpretation:

- DFSTRTPTR = 0 and DSTACTV = 0 implies that no TRs are stored in the destination FIFO register.
- DFSTRTPTR = 1 and DSTACTV = 2h implies that two TRs are present. The first pending TR is read from the destination FIFO register entry 1 and the second pending TR is read from the destination FIFO register entry 2.
- DFSTRTPTR = 3h and DSTACTV = 2h implies that two TRs are present. The first pending TR is read from the destination FIFO register entry 3 and the second pending TR is read from the destination FIFO register entry 0.

18.2.12 Event Dataflow

This section summarizes the data flow of a single event, from the time the event is latched to the channel controller to the time the transfer completion code is returned. The following steps list the sequence of EDMA3CC activity:

1. Event is asserted from an external source (peripheral or external interrupt). This also is similar for a manually-triggered, chained-triggered, or QDMA-triggered event. The event is latched into the ER.E*n* (or CER.E*n*, ESR.E*n*, QER.E*n*) bit.
2. Once an event is prioritized and queued into the appropriate event queue, the SER.E*n* (or QSER.E*n*) bit is set to inform the event prioritization/processing logic to disregard this event since it is already in the queue. Alternatively, if the transfer controller and the event queue are empty, then the event bypasses the queue.
3. The EDMA3CC processing and the submission logic evaluates the appropriate PaRAM set and determines whether it is a non-null and non-dummy transfer request (TR).
4. The EDMA3CC clears the ER.E*n* (or CER.E*n*, ESR.E*n*, QER.E*n*) bit and the SER.E*n* bit as soon as it determines the TR is non-null. In the case of a null set, the SER.E*n* bit remains set. It submits the non-null/non-dummy TR to the associated transfer controller. If the TR was programmed for early completion, the EDMA3CC immediately sets the interrupt pending register (IPR.I[TCC]).
5. If the TR was programmed for normal completion, the EDMA3CC sets the interrupt pending register (IPR.I[TCC]) when the EDMA3TC informs the EDMA3CC about completion of the transfer (returns transfer completion codes).
6. The EDMA3CC programs the associated EDMA3TC*n* Program Register Set with the TR.
7. The TR is then passed to the Source Active set and the Dst FIFO Register Set, if both the register sets are available.
8. The Read Controller processes the TR by issuing read commands to the source slave endpoint. The Read Data lands in the Data FIFO of the EDMA3TC*n*.
9. As soon as sufficient data is available, the Write Controller begins processing the TR by issuing write commands to the destination slave endpoint.
10. This continues until the TR completes and on receiving the acknowledgement signal from the destination slave end point, the EDMA3TC*n* then signals completion status to the EDMA3CC.

18.2.13 EDMA3 Prioritization

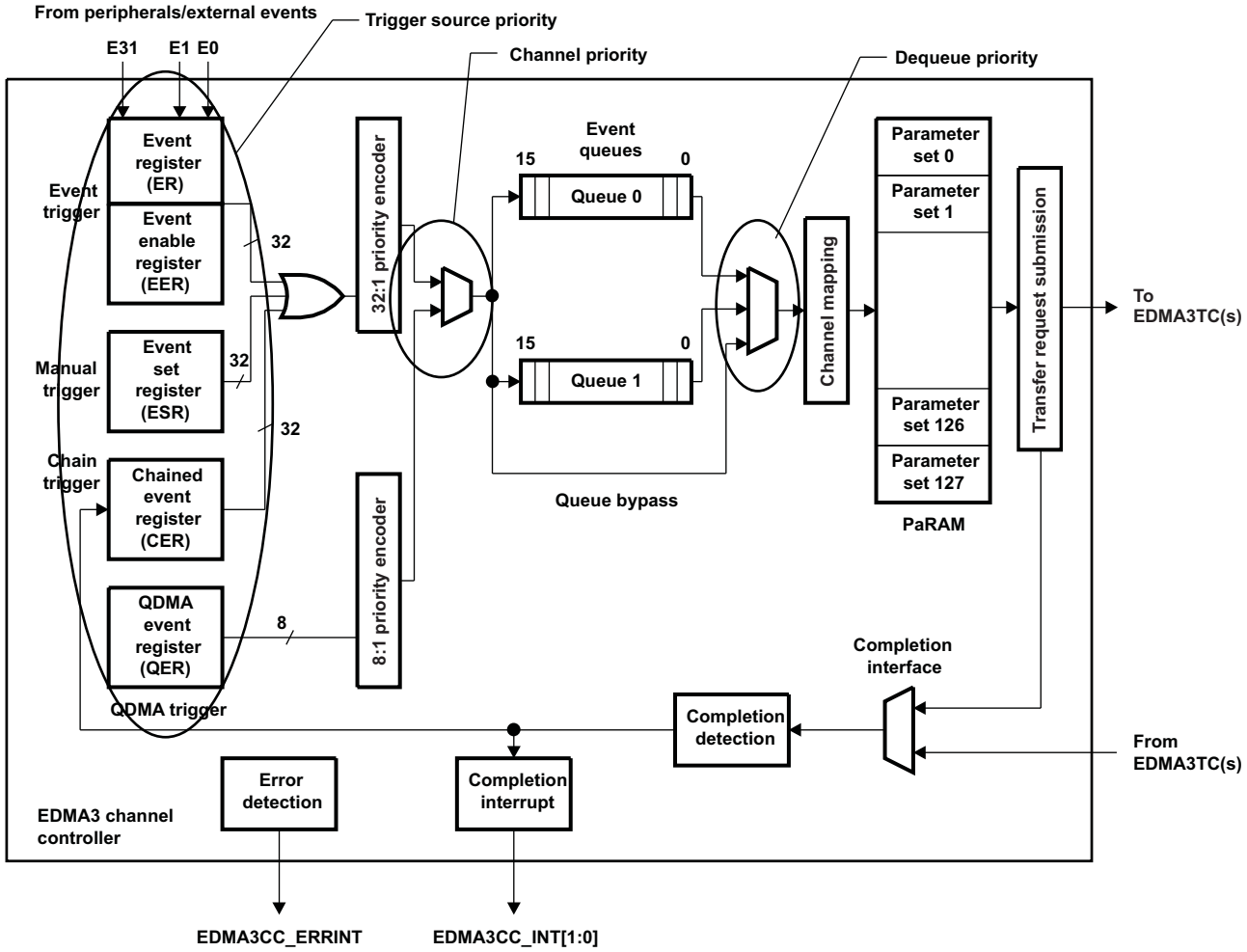
The EDMA3 controller has many implementation rules to deal with concurrent events/channels, transfers, etc. The following subsections detail various arbitration details whenever there might be occurrence of concurrent activity. Figure 18-14 shows the different places EDMA3 priorities come into play.

18.2.13.1 Channel Priority

The DMA event register (ER) captures all external/peripheral events connected to the EDMA3CC; likewise, the QDMA event register (QER) captures QDMA events for all QDMA channels; therefore, it is possible for events to occur simultaneously on the DMA/QDMA event inputs. For events arriving simultaneously, the event associated with the lowest channel number is prioritized for submission to the event queues (for DMA events, channel 0 has the highest priority and channel 31 has the lowest priority; similarly, for QDMA events, channel 0 has the highest priority and channel 7 has the lowest priority). This mechanism only sorts simultaneous events for submission to the event queues.

If a DMA and QDMA event occurs simultaneously, the DMA event always has prioritization against the QDMA event for submission to the event queues.

Figure 18-14. EDMA3 Prioritization



18.2.13.2 Trigger Source Priority

If a DMA channel is associated with more than one trigger source (event trigger, manual trigger, and chain trigger), and if multiple events are set simultaneously for the same channel (ER.E*n* = 1, ESR.E*n* = 1, CER.E*n* = 1), then the EDMA3CC always services these events in the following priority order: event trigger (via ER) is higher priority than chain trigger (via CER) and chain trigger is higher priority than manual trigger (via ESR).

This implies that if for channel 0, both ER.E0 = 1 and CER.E0 = 1 at the same time, then the ER.E0 event is always queued before the CER.E0 event.

18.2.13.3 Dequeue Priority

The priority of the associated transfer request (TR) is further mitigated by which event queue is being used for event submission (dictated by DMAQNUM*n* and QDMAQNUM). For submission of a TR to the transfer controller, events need to be dequeued from the event queues. A lower numbered queue has a higher dequeuing priority then a higher numbered queue. For example, if there are events in Q0 and Q1 and the respective transfer controllers (TC0 and TC1) are ready to receive the next TR from the EDMA3CC, then the transfer requests associated with events in Q0 will get submitted to TC0 prior to any transfer requests associated with events in Q1 getting submitted to TC1.

NOTE: At any given time, if there are outstanding events in multiple queues, when the transfer controller associated with the lower numbered (higher priority) queue is busy processing earlier transfer requests and the transfer controller associated with the higher numbered (lower priority) queue is idle, then the event in the higher numbered (lower priority) queue will dequeue first.

18.2.13.4 Master (Transfer Controller) Priority

All master peripherals on the device have a programmable priority level. When multiple masters are trying to access common shared resources (slave memory or peripherals), this priority value allows the system interconnect to arbitrate requests from different masters based on their priority. This priority assignment is determined in the Master Priority Registers (MSTPRI0-MSTPRI2) in the System Configuration Module (see the *System Configuration (SYSCFG) Module* chapter), where each master has an allocated priority value (power on reset default value), which can be re programmed based on the applications prioritization requirements. The priority value can be configured between 0 to 7, with 0 being the highest priority and 7 being the lowest priority.

Each transfer controller on the device is also a master peripheral. The priority of the transfer requests (read/write commands) issued by the individual EDMA3TC read/write ports in the system can be programmed via these registers.

The dequeue priority has a relatively secondary effect as compared to this Master priority; therefore, it is important to program the priority of each transfer controller with respect to each other and also with respect to other masters in the system.

NOTE: On previous architectures, the EDMA3TC priority was controlled by the QUEPRI register in the EDMA3CC memory-map. However for this device, the priority control for the transfer controllers is controlled by the chip-level registers in the System Configuration Module.

18.2.14 EDMA3CC and EDMA3TC Performance and System Considerations

18.2.14.1 System Priority Considerations

The main switched central resource (SCR) (see your device-specific data manual) arbitrates bus requests from all the masters (CPU, master peripherals, and the EDMA3 transfer controllers) to the shared slave resources (peripherals and memories). The priorities of transfer requests (read and write commands) from the EDMA3 transfer controllers with respect to each other and the other masters within the system is configured as explained in Section 18.2.13.4.

It is recommended that this priority be altered based on system level considerations. For example, peripherals servicing audio/video/display threads that typically have real-time deadlines should be programmed as highest priority requestors in the systems, where as, peripherals responsible for doing bulk/block/paging transfers with no real-time deadlines, should be programmed as a lower system priority.

The default priority for all transfer controllers is the same, 0 or highest priority relative to other masters; therefore, it is recommended that a TC servicing audio data requests from serial ports should be configured at a higher priority as compared to TC service memory to memory (paging/bulk) transfer requests.

18.2.14.2 TC Transfer Optimization Considerations

The transfer controller can internally optimize the way it issues read commands and write commands for a given transfer under certain conditions. For 2D transfers (that is, BCNT arrays of ACNT bytes), if the ACNT value is less than or equal to the DBS value, then the transfer controller will try to optimize the TR into a 1D transfer in order to maximize efficiency. The optimization only takes place if the EDMA3TC recognizes that the 2D transfer is organized as a single dimension (SAM/DAM = 0, increment mode), SRC/DST BIDX = ACNT, the ACNT value is a power of 2, and the BCNT value is less than or equal to 1023. If these conditions are met, then instead of issuing ACNT bytes worth read and/or write commands, the TC will try to optimize the bus usage by issuing commands as if ACNT' = ACNT × BCNT and BCNT = 1.

Table 18-10 summarizes the conditions in which the optimizations are performed.

Table 18-10. Read/Write Command Optimization Rules

ACNT ≤ DBS	ACNT is power of 2	BIDX = ACNT	BCNT ≤ 1023	SAM/DAM = 0 (Increment)	Description
Yes	Yes	Yes	Yes	Yes	Optimized
Yes	No	x	x	Yes	Not Optimized
Yes	x	No	x	Yes	Not Optimized
No	x	x	x	Yes	Not Optimized
x	x	x	x	No	Not Optimized

Consider a case in which it is needed to transfer 4096 bytes where the data is arranged linearly in both the source and destination locations (SAM/DAM = 0, SRC/DST BIDX = ACNT): Scenario A programs the ACNT = 4, BCNT = 1024 , AB-synchronized transfer; and Scenario B programs the ACNT = 64, BCNT = 64. Scenario B will yield a much optimized transfer and higher throughput, as the transfer meets all the optimization rules, which would result in TC internally treating it as a transfer with an ACNT' = 4096 (ACNT × BCNT). The TC will optimally size, default burst size worth read and write commands. In the case of Scenario B, since one of the optimization rules is not met (BCNT value is greater then 1023), the TC will end up issuing several ACNT byte (4 byte) size commands to complete the transfers, which will result in inefficient usage of the read/write buses.

18.2.14.3 Throttling the Read Command Rate in a Transfer Controller

By default, the transfer controller issues reads as fast as possible. In some cases, the reads issued by the EDMA3TCC could fill the available command buffering for a slave, delaying other (potentially higher priority) masters from successfully submitting commands to that slave. The rate at which read commands are issued by the EDMA3TC is controlled by the read command rate register (RDRATE), and this can be used to throttle the rate at which the commands are issued from the TC read interface. RDRATE defines the number of cycles that the EDMA3TC read controller waits before issuing subsequent commands for a given TR, thus minimizing the chance of the EDMA3TC consuming all available slave resources. The RDRATE value should be set to a relatively small value (or kept at default, which implies issuing read requests as fast as possible) if the transfer controller is targeted for high-priority transfers and set to a high value if the transfer controller is targeted for low-priority transfers. In contrast, the write Interface does not have any performance turning knobs because writes always have an interval between commands as write commands are submitted along with the associated write data.

18.2.15 EDMA3 Operating Frequency (Clock Control)

The EDMA3 channel controller and transfer controller are clocked from PLL controller 0 (PLLC0). For details, see the *Phase-Locked Loop Controller (PLLC)* chapter.

18.2.16 Reset Considerations

A hardware reset resets the EDMA3 (EDMA3CC and EDMA3TC) and the EDMA3 configuration registers. The PaRAM memory contents are undefined after device reset and you should not rely on parameters to be reset to a known state. The PaRAM set must be initialized to a desired value before it is used.

18.2.17 Power Management

The EDMA3 (EDMA3CC and EDMA3TC) can be placed in reduced-power modes to conserve power during periods of low activity. The power management of the peripheral is controlled by the device Power and Sleep Controller (PSC). The PSC acts as a master controller for power management for all peripherals on the device. For detailed information on power management procedures using the PSC, see the *Power and Sleep Controller (PSC)* chapter.

The EDMA3 controller can be idled on receiving a clock stop request from the PSC. The requests to EDMA3CC and EDMA3TC are separate. In general, you should verify that there are no pending activities in the EDMA3 controller before issuing a clock stop request via PSC.

The EDMA3CC checks for the following conditions:

- No pending DMA/QDMA events
- No outstanding events in the event queues
- Transfer request processing logic is not active
- No completion requests outstanding (early or normal completion)
- No configuration bus requests in progress

The first four conditions are software readable by the channel controller status register (CCSTAT) in the EDMA3CC.

Similarly, from the EDMA3TC perspective, you should check that there are no outstanding TRs that are getting processed and essentially the read/write controller is not busy processing a TR. The activity of EDMA3TC logic is read in TCSTAT for each EDMA3TC.

It is generally recommended to first disable the EDMA3CC and then the EDMA3TC(s) to put the EDMA3 controller in reduced-power modes.

Additionally, when EDMA3 is involved in servicing a peripheral and it is required to power-down both the peripheral and the EDMA, the recommended sequence is to first disable the peripheral, then disable the DMA channel associated with the peripheral (clearing the EER bit for the channel), then disable the EDMA3CC, and finally disable the EDMA3TC(s).

18.2.18 Emulation Considerations

During debug when using the emulator, the CPU(s) may be halted on an execute packet boundary for single-stepping, benchmarking, profiling, or other debug purposes. During an emulation halt, the EDMA3 channel controller and transfer controller operations continue. Events continue to be latched and processed and transfer requests continue to be submitted and serviced.

Since EDMA3 is involved in servicing multiple master and slave peripherals, it is not feasible to have an independent behavior of the EDMA3 for emulation halts. EDMA3 functionality would be coupled with the peripherals it is servicing, which might have different behavior during emulation halts. For example, if a multichannel buffered serial port (McBSP) is halted during an emulation access (FREE = 0 and SOFT = 0 or 1 in the McBSP registers), the McBSP stops generating the McBSP receive or transmit events (REVT or XEVT) to the EDMA. From the point of view of the McBSP, the EDMA3 is suspended, but other peripherals (for example, a timer) still assert events and will be serviced by the EDMA.

18.3 Transfer Examples

The EDMA3 channel controller performs a variety of transfers depending on the parameter configuration. The following sections provides a description and PaRAM configuration for some typical use case scenarios.

18.3.1 Block Move Example

The most basic transfer performed by the EDMA3 is a block move. During device operation it is often necessary to transfer a block of data from one location to another, usually between on-chip and off-chip memory.

In this example, a section of data is to be copied from external memory to internal L2 SRAM. A data block of 256 bytes residing at address 4000 0000h (external memory) needs to be transferred to internal address 1180 0000h (L2), as shown in Figure 18-15. Figure 18-16 shows the parameters for this transfer.

The source address for the transfer is set to the start of the data block in external memory, and the destination address is set to the start of the data block in L2. If the data block is less than 64K bytes, the PaRAM configuration in Figure 18-16 holds true with the synchronization type set to A-synchronized and indexes cleared to 0. If the amount of data is greater than 64K bytes, BCNT and the B-indexes need to be set appropriately with the synchronization type set to AB-synchronized. The STATIC bit in OPT is set to prevent linking.

This transfer example may also be set up using QDMA. For successive transfer submissions, of a similar nature, the number of cycles used to submit the transfer are fewer depending on the number of changing transfer parameters. You may program the QDMA trigger word to be the highest numbered offset in the PaRAM set that undergoes change.

Figure 18-15. Block Move Example

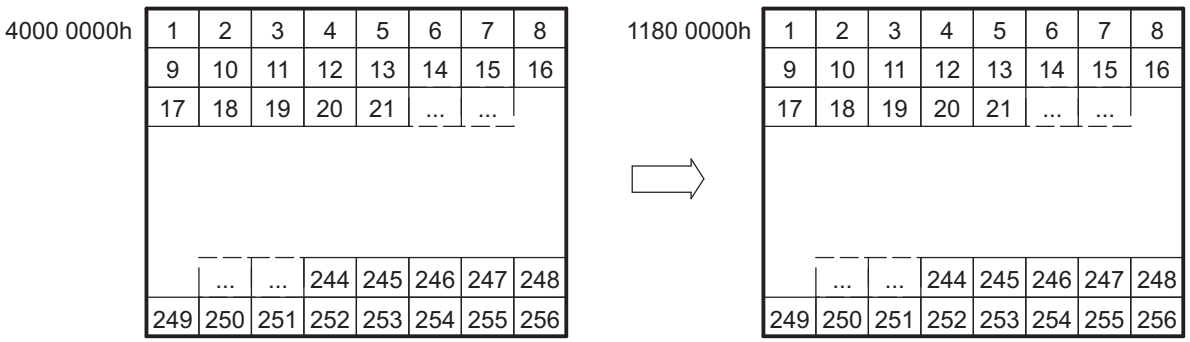


Figure 18-16. Block Move Example PaRAM Configuration

(a) EDMA Parameters

Parameter Contents	Parameter
0010 0008h	Channel Options Parameter (OPT)
4000 0000h	Channel Source Address (SRC)
0001h | 0100h	Count for 2nd Dimension (BCNT) | Count for 1st Dimension (ACNT)
1180 0000h	Channel Destination Address (DST)
0000h | 0000h	Destination BCNT Index (DSTBIDX) | Source BCNT Index (SRCBIDX)
0000h | FFFFh	BCNT Reload (BCNTRLD) | Link Address (LINK)
0000h | 0000h	Destination CCNT Index (DSTCIDX) | Source CCNT Index (SRCCIDX)
0000h | 0001h	Reserved | Count for 3rd Dimension (CCNT)

(b) Channel Options Parameter (OPT) Content

31	30 28	27 24	23	22	21	20	19 18	17 16
0	000	0000	0	0	0	1	00	00
PRIV	Reserved	PRIVID	ITCCHEN	TCCHEN	ITCINTEN	TCINTEN	Reserved	TCC

15 12	11	10 8	7 4	3	2	1	0
0000	0	000	0000	1	0	0	0
TCC	TCCMOD	FWID	Reserved	STATIC	SYNCDIM	DAM	SAM

18.3.2 Subframe Extraction Example

The EDMA3 can efficiently extract a small frame of data from a larger frame of data. By performing a 2D-to-1D transfer, the EDMA3 retrieves a portion of data for the CPU to process. In this example, a 640 × 480-pixel frame of video data is stored in external memory, SDRAM. Each pixel is represented by a 16-bit halfword. The CPU extracts a 16 × 12-pixel subframe of the image for processing. To facilitate more efficient processing time by the CPU, the EDMA3 places the subframe in internal L2 SRAM. Figure 18-17 shows the transfer of a subframe from external memory to L2. Figure 18-18 shows the parameters for this transfer.

The same PaRAM set options are used for QDMA channels, as well as DMA channels. The STATIC bit in OPT is set to 1 to prevent linking. For successive transfers, only changed parameters need to be programmed before triggering the channel.

Figure 18-17. Subframe Extraction Example

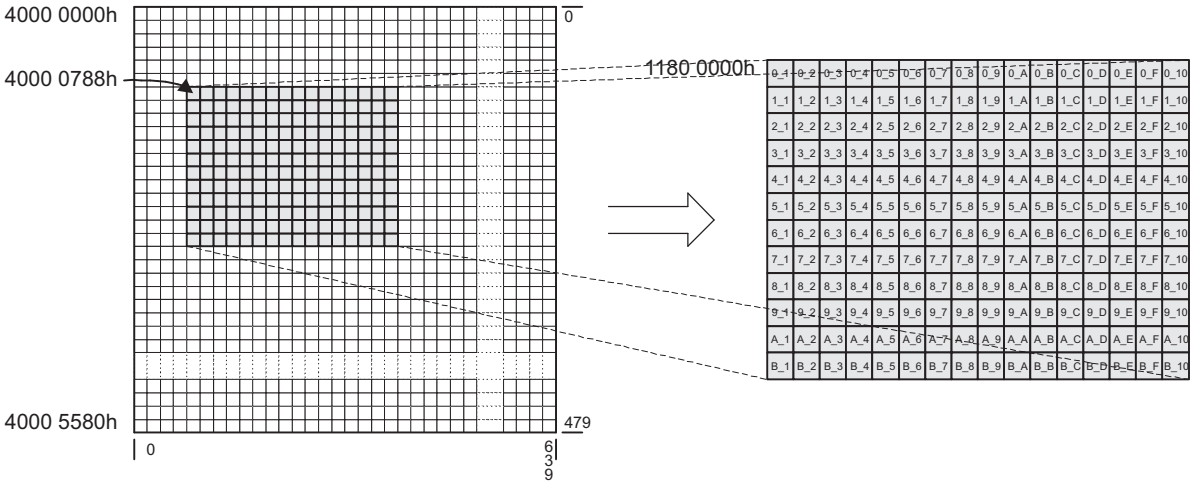


Figure 18-18. Subframe Extraction Example PaRAM Configuration

(a) EDMA Parameters

Parameter Contents	
0010 000Ch	
4000 0788h	
000Ch	0020h
1180 0000h	
0020h	0500h
0000h	FFFFh
0000h	0000h
0000h	0001h

Parameter	
Channel Options Parameter (OPT)	
Channel Source Address (SRC)	
Count for 2nd Dimension (BCNT)	Count for 1st Dimension (ACNT)
Channel Destination Address (DST)	
Destination BCNT Index (DSTBIDX)	Source BCNT Index (SRCBIDX)
BCNT Reload (BCNTRLD)	Link Address (LINK)
Destination CCNT Index (DSTCIDX)	Source CCNT Index (SRCCIDX)
Reserved	Count for 3rd Dimension (CCNT)

(b) Channel Options Parameter (OPT) Content

31	30 28	27 24	23	22	21	20	19 18	17 16
0	000	0000	0	0	0	1	00	00
PRIV	Reserved	PRIVID	ITCCHEN	TCCHEN	ITCINTEN	TCINTEN	Reserved	TCC

15 12	11	10 8	7 4	3	2	1	0
0000	0	000	0000	1	1	0	0
TCC	TCCMOD	FWID	Reserved	STATIC	SYNCDIM	DAM	SAM

18.3.3 Data Sorting Example

Many applications require the use of multiple data arrays; it is often desirable to have the arrays arranged such that the first elements of each array are adjacent, the second elements are adjacent, and so on. Often this is not how the data is presented to the device. Either data is transferred via a peripheral with the data arrays arriving one after the other or the arrays are located in memory with each array occupying a portion of contiguous memory spaces. For these instances, the EDMA3 can reorganize the data into the desired format. Figure 18-19 shows the data sorting.

In order to determine the parameter entry values, the following need to be considered:

- ACNT – Program this to be the size in bytes of an array.
- BCNT – Program this to be the number of arrays in a frame.
- CCNT – Program this to be the number of frames.
- SRCBIDX – Program this to be the size of the array or ACNT.
- DSTBIDX = CCNT × ACNT
- SRCCIDX = ACNT × BCNT
- DSTCIDX = ACNT

The synchronization type needs to be AB-synchronized and the STATIC bit is 0 to allow updates to the parameter set. It is advised to use normal DMA channels for sorting.

It is not possible to sort this with a single trigger event. Instead, the channel can be programmed to be chained to itself. After BCNT arrays get sorted, intermediate chaining could be used to trigger the channel again causing the transfer of the next BCNT arrays and so on. Figure 18-20 shows the parameter set programming for this transfer, assuming channel 0 and an array size of 4 bytes.

Figure 18-19. Data Sorting Example

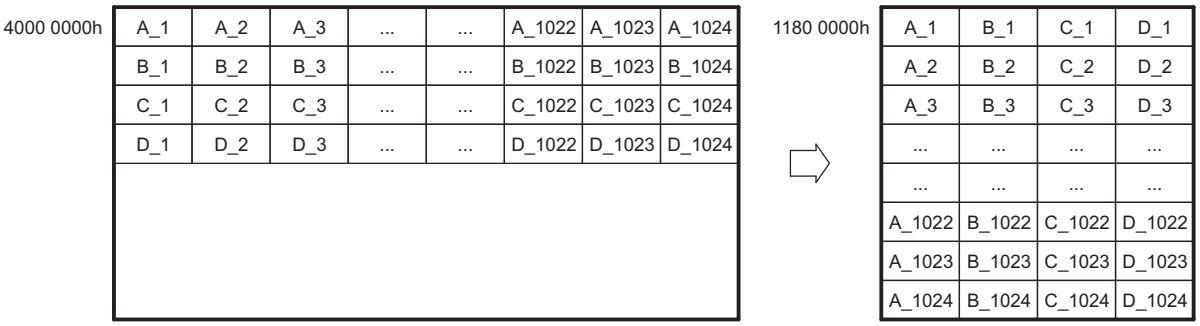


Figure 18-20. Data Sorting Example PaRAM Configuration

(a) EDMA Parameters

Parameter Contents	Parameter
0090 0004h	Channel Options Parameter (OPT)
4000 0000h	Channel Source Address (SRC)
0400h | 0004h	Count for 2nd Dimension (BCNT) | Count for 1st Dimension (ACNT)
1180 0000h	Channel Destination Address (DST)
0010h | 0004h	Destination BCNT Index (DSTBIDX) | Source BCNT Index (SRCBIDX)
0000h | FFFFh	BCNT Reload (BCNTRLD) | Link Address (LINK)
0004h | 1000h	Destination CCNT Index (DSTCIDX) | Source CCNT Index (SRCCIDX)
0000h | 0004h	Reserved | Count for 3rd Dimension (CCNT)

(b) Channel Options Parameter (OPT) Content

31	30–28	27–24	23	22	21	20	19–18	17–16
0	000	0000	1	0	0	1	00	00
PRIV	Reserved	PRIVID	ITCCHEN	TCCHEN	ITCINTEN	TCINTEN	Reserved	TCC

15–12	11	10–8	7–4	3	2	1	0
0000	0	000	0000	0	1	0	0
TCC	TCCMOD	FWID	Reserved	STATIC	SYNCDIM	DAM	SAM

18.3.4 Peripheral Servicing Example

NOTE: Examples in this section are sample examples. The peripherals, channels, and addresses used in these examples may not apply to your specific device. See your device-specific data manual for supported peripherals.

The EDMA3 channel controller also services peripherals in the background of CPU operation, without requiring any CPU intervention. Through proper initialization of the DMA channels, they can be configured to continuously service on-chip and off-chip peripherals throughout the device operation. Each event available to the EDMA3 has its own dedicated channel, and all channels operate simultaneously. The only requirements are to use the proper channel for a particular transfer and to enable the channel event in the event enable register (EER). When programming a DMA channel to service a peripheral, it is necessary to know how data is to be presented to the CPU. Data is always provided with some kind of synchronization event as either one element per event (nonbursting) or multiple elements per event (bursting).

18.3.4.1 Nonbursting Peripherals

Nonbursting peripherals include the on-chip multichannel buffered serial port (McBSP) and many external devices, such as codecs. Regardless of the peripheral, the DMA channel configuration is the same.

The McBSP transmit and receive data streams are treated independently by the EDMA3. The transmit and receive data streams can have completely different counts, data sizes, and formats. Figure 18-21 shows servicing incoming McBSP data.

To transfer the incoming data stream to its proper location in L2 memory, the DMA channel must be set up for a 1D-to-1D transfer with A-synchronization. Since an event (REVT) is generated for every word as it arrives, it is necessary to have the EDMA3 issue the transfer request for each element individually. Figure 18-22 shows the parameters for this transfer. The source address of the DMA channel is set to the data receive register (DRR) address for the McBSP, and the destination address is set to the start of the data block in L2. Since the address of DRR is fixed, the source B index is cleared to 0 (no modification) and the destination B index is set to 01b (increment).

Based on the premise that serial data is typically a high priority, the DMA channel should be programmed to be on queue 0.

Figure 18-21. Servicing Incoming McBSP Data Example

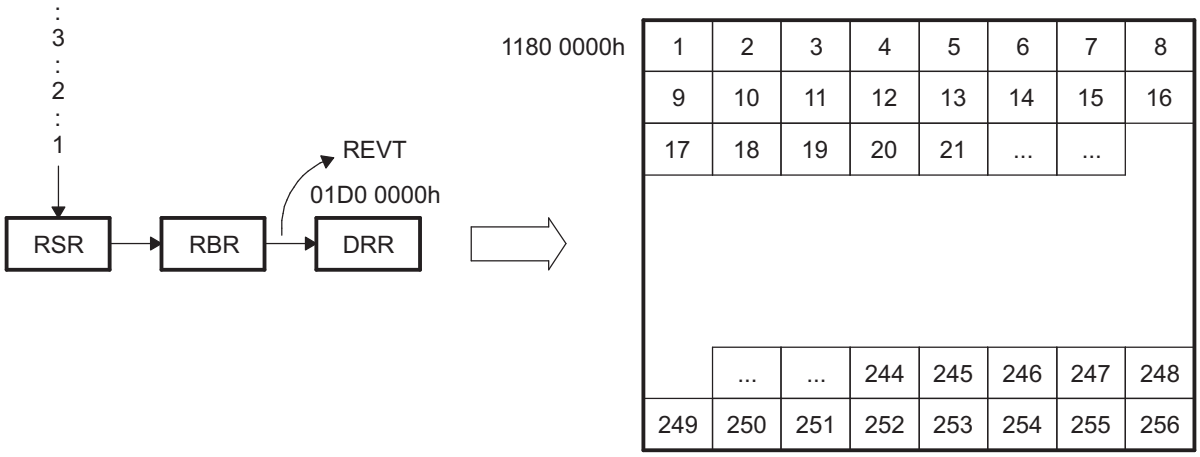


Figure 18-22. Servicing Incoming McBSP Data Example PaRAM

(a) EDMA Parameters

Parameter Contents		Parameter	
0010 0000h		Channel Options Parameter (OPT)	
01D0 0000h		Channel Source Address (SRC)	
0100h	0001h	Count for 2nd Dimension (BCNT)	Count for 1st Dimension (ACNT)
1180 0000h		Channel Destination Address (DST)	
0001h	0000h	Destination BCNT Index (DSTBIDX)	Source BCNT Index (SRCBIDX)
0000h	FFFFh	BCNT Reload (BCNTRLD)	Link Address (LINK)
0000h	0000h	Destination CCNT Index (DSTCIDX)	Source CCNT Index (SRCCIDX)
0000h	0004h	Reserved	Count for 3rd Dimension (CCNT)

(b) Channel Options Parameter (OPT) Content

31	30 28	27 24	23	22	21	20	19 18	17 16
0	000	0000	0	0	0	1	00	00
PRIV	Reserved	PRIVID	ITCCHEN	TCCHEN	ITCINTEN	TCINTEN	Reserved	TCC

15 12	11	10 8	7 4	3	2	1	0
0000	0	000	0000	0	0	0	0
TCC	TCCMOD	FWID	Reserved	STATIC	SYNCDIM	DAM	SAM

18.3.4.2 Bursting Peripherals

Higher bandwidth applications require that multiple data elements be presented to the CPU for every synchronization event. This frame of data can either be from multiple sources that are working simultaneously or from a single high-throughput peripheral that streams data to/from the CPU. In this example, a port is receiving a video frame from a camera and presenting it to the CPU one array at a time. The video image is 640 × 480 pixels, with each pixel represented by a 16-bit element. The image is to be stored in external memory. Figure 18-23 shows this example.

To transfer data from an external peripheral to an external buffer one array at a time based on EVT*n* , channel *n* must be configured. Due to the nature of the data (a video frame made up of arrays of pixels) the destination is essentially a 2D entity. Figure 18-24 shows the parameters to service the incoming data with a 1D-to-2D transfer using AB-synchronization. The source address is set to the location of the video framer peripheral, and the destination address is set to the start of the data buffer. Since the input address is static, the SRCBIDX is 0 (no modification to the source address). The destination is made up of arrays of contiguous, linear elements; therefore, the DSTBIDX is set to pixel size, 2 bytes. ANCT is equal to the pixel size, 2 bytes. BCNT is set to the number of pixels in an array, 640. CCNT is equal to the total number of arrays in the block, 480. SRCCIDX is 0 since the source address undergoes no increment. The DSTCIDX is equal to the difference between the starting addresses of each array. Since a pixel is 16 bits (2 bytes), DSTCIDX is equal to 640 × 2.

Figure 18-23. Servicing Peripheral Burst Example

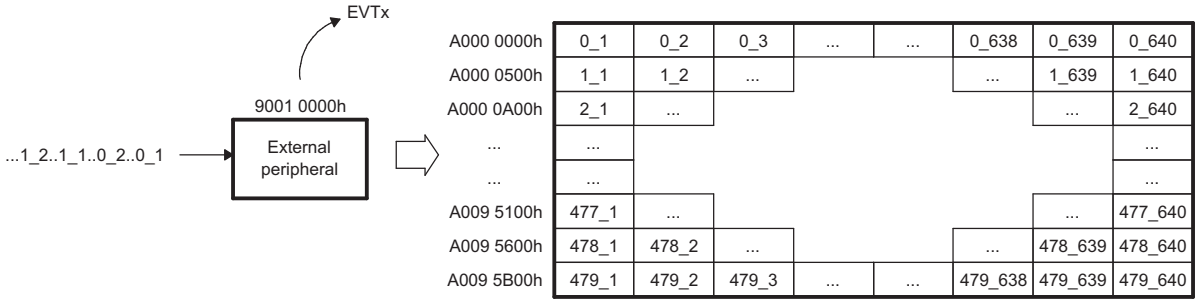


Figure 18-24. Servicing Peripheral Burst Example PaRAM

(a) EDMA Parameters

Parameter Contents	
0010 0004h	
Channel Source Address	
0280h	0002h
4000 0000h	
0002h	0000h
0000h	FFFFh
0500h	0000h
0000h	01E0h

Parameter	
Channel Options Parameter (OPT)	
Channel Source Address (SRC)	
Count for 2nd Dimension (BCNT)	Count for 1st Dimension (ACNT)
Channel Destination Address (DST)	
Destination BCNT Index (DSTBIDX)	Source BCNT Index (SRCBIDX)
BCNT Reload (BCNTRLD)	Link Address (LINK)
Destination CCNT Index (DSTCIDX)	Source CCNT Index (SRCCIDX)
Reserved	Count for 3rd Dimension (CCNT)

(b) Channel Options Parameter (OPT) Content

31	30 28	27 24	23	22	21	20	19 18	17 16
0	000	0000	0	0	0	1	00	00
PRIV	Reserved	PRIVID	ITCCHEN	TCCHEN	ITCINTEN	TCINTEN	Reserved	TCC

15 12	11	10 8	7 4	3	2	1	0
0000	0	000	0000	0	1	0	0
TCC	TCCMOD	FWID	Reserved	STATIC	SYNCDIM	DAM	SAM

18.3.4.3 Continuous Operation

Configuring a DMA channel to receive a single frame of data is useful, and is applicable to some systems. A majority of the time, however, data is going to be continuously transmitted and received throughout the entire operation of the CPU. In this case, it is necessary to implement some form of linking such that the DMA channels continuously reload the necessary parameter sets. In this example, the multichannel buffered serial port (McBSP) is configured to transmit and receive data on a array. To simplify the example, only two channels are active for both transmit and receive data streams. Each channel receives packets of 128 elements. The packets are transferred from the serial port to L2 memory and from L2 memory to the serial port, as shown in Figure 18-25.

The McBSP generates REVT for every element received and generates XEVT for every element transmitted. To service the data streams, the DMA channels associated with the McBSP must be set up for 1D-to-1D transfers with A-synchronization.

Figure 18-26 shows the parameters for the parameter entries for the channel for these transfers. In order to service the McBSP continuously throughout CPU operation, the channels must be linked to a duplicate PaRAM set in the PaRAM. After all frames have been transferred, the DMA channels reload and continue. Figure 18-27 shows the reload parameters for the channel.

18.3.4.3.1 Receive Channel

DMA channel 3 services the incoming data stream of the McBSP. The source address is set to that of the data receiver register (DRR), and the destination address is set to the first element of the data block. Since there are two data channels being serviced, A and B, they are to be located separately within the L2 SRAM.

In order to facilitate continuous operation, a copy of the PaRAM set for the channel is placed in PaRAM set 64. The LINK option is set and the link address is provided in the PaRAM set. Upon exhausting the channel 3 parameter set, the parameters located at the link address are loaded into the channel 3 parameter set and operation continues. This function continues throughout device operation until halted by the CPU.

18.3.4.3.2 Transmit Channel

DMA channel 2 services the outgoing data stream of the McBSP. In this case the destination address needs no update, hence, the parameter set changes accordingly. Linking is also used to allow continuous operation by the DMA channel, with duplicate PaRAM set entries at PaRAM set 65.

Figure 18-25. Servicing Continuous McBSP Data Example

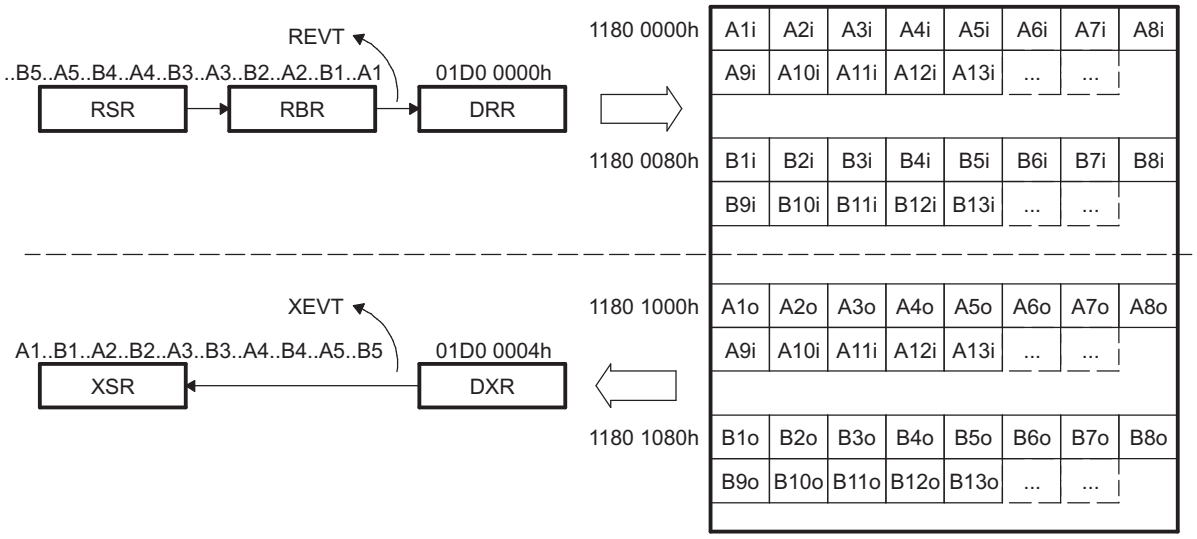


Figure 18-26. Servicing Continuous McBSP Data Example PaRAM

(a) EDMA Parameters for Receive Channel (PaRAM Set 3) being Linked to PaRAM Set 64

Parameter Contents	Parameter
0010 0000h	Channel Options Parameter (OPT)
01D0 0000h	Channel Source Address (SRC)
0080h / 0001h	Count for 2nd Dimension (BCNT) / Count for 1st Dimension (ACNT)
1180 0000h	Channel Destination Address (DST)
0001h / 0000h	Destination BCNT Index (DSTBIDX) / Source BCNT Index (SRCBIDX)
0080h / 4800h	BCNT Reload (BCNTRLD) / Link Address (LINK)
0000h / 0000h	Destination CCNT Index (DSTCIDX) / Source CCNT Index (SRCCIDX)
0000h / 0001h	Reserved / Count for 3rd Dimension (CCNT)

(b) Channel Options Parameter (OPT) Content for Receive Channel (PaRAM Set 3)

31	30–28	27–24	23	22	21	20	19–18	17–16
0	000	0000	0	0	0	1	00	00
PRIV	Reserved	PRIVID	ITCCHEN	TCCHEN	ITCINTEN	TCINTEN	Reserved	TCC

15–12	11	10–8	7–4	3	2	1	0
0000	0	000	0000	0	0	0	0
TCC	TCCMOD	FWID	Reserved	STATIC	SYNCDIM	DAM	SAM

(c) EDMA Parameters for Transmit Channel (PaRAM Set 2) being Linked to PaRAM Set 65

Parameter Contents	Parameter
0010 1000h	Channel Options Parameter (OPT)
1180 1000h	Channel Source Address (SRC)
0080h / 0001h	Count for 2nd Dimension (BCNT) / Count for 1st Dimension (ACNT)
01D0 0004h	Channel Destination Address (DST)
0000h / 0001h	Destination BCNT Index (DSTBIDX) / Source BCNT Index (SRCBIDX)
0080h / 4820h	BCNT Reload (BCNTRLD) / Link Address (LINK)
0000h / 0000h	Destination CCNT Index (DSTCIDX) / Source CCNT Index (SRCCIDX)
0000h / 0001h	Reserved / Count for 3rd Dimension (CCNT)

(d) Channel Options Parameter (OPT) Content for Transmit Channel (PaRAM Set 2)

31	30–28	27–24	23	22	21	20	19–18	17–16
0	000	0000	0	0	0	1	00	00
PRIV	Reserved	PRIVID	ITCCHEN	TCCHEN	ITCINTEN	TCINTEN	Reserved	TCC

15–12	11	10–8	7–4	3	2	1	0
0001	0	000	0000	0	0	0	0
TCC	TCCMOD	FWID	Reserved	STATIC	SYNCDIM	DAM	SAM

Figure 18-27. Servicing Continuous McBSP Data Example Reload PaRAM

(a) EDMA Reload Parameters (PaRAM Set 64) for Receive Channel

Parameter Contents	Parameter
0010 0000h	Channel Options Parameter (OPT)
01D0 0000h	Channel Source Address (SRC)
0080h / 0001h	Count for 2nd Dimension (BCNT) / Count for 1st Dimension (ACNT)
1180 0000h	Channel Destination Address (DST)
0001h / 0000h	Destination BCNT Index (DSTBIDX) / Source BCNT Index (SRCBIDX)
0080h / 4800h	BCNT Reload (BCNTRLD) / Link Address (LINK)
0000h / 0000h	Destination CCNT Index (DSTCIDX) / Source CCNT Index (SRCCIDX)
0000h / 0001h	Reserved / Count for 3rd Dimension (CCNT)

(b) Channel Options Parameter (OPT) Content for Receive Channel (PaRAM Set 64)

31	30 28	27 24	23	22	21	20	19 18	17 16
0	000	0000	0	0	0	1	00	00
PRIV	Reserved	PRIVID	ITCCHEN	TCCHEN	ITCINTEN	TCINTEN	Reserved	TCC

15 12	11	10 8	7 4	3	2	1	0
0000	0	000	0000	0	0	0	0
TCC	TCCMOD	FWID	Reserved	STATIC	SYNCDIM	DAM	SAM

(c) EDMA Reload Parameters (PaRAM Set 65) for Transmit Channel

Parameter Contents	Parameter
0010 1000h	Channel Options Parameter (OPT)
1180 1000h	Channel Source Address (SRC)
0080h / 0001h	Count for 2nd Dimension (BCNT) / Count for 1st Dimension (ACNT)
01D0 0004h	Channel Destination Address (DST)
0000h / 0001h	Destination BCNT Index (DSTBIDX) / Source BCNT Index (SRCBIDX)
0080h / 4820h	BCNT Reload (BCNTRLD) / Link Address (LINK)
0000h / 0000h	Destination CCNT Index (DSTCIDX) / Source CCNT Index (SRCCIDX)
0000h / 0001h	Reserved / Count for 3rd Dimension (CCNT)

(d) Channel Options Parameter (OPT) Content for Transmit Channel (PaRAM Set 65)

31	30 28	27 24	23	22	21	20	19 18	17 16
0	000	0000	0	0	0	1	00	00
PRIV	Reserved	PRIVID	ITCCHEN	TCCHEN	ITCINTEN	TCINTEN	Reserved	TCC

15 12	11	10 8	7 4	3	2	1	0
0001	0	000	0000	0	0	0	0
TCC	TCCMOD	FWID	Reserved	STATIC	SYNCDIM	DAM	SAM

18.3.4.4 Ping-Pong Buffering

Although the previous configuration allows the EDMA3 to service a peripheral continuously, it presents a number of restrictions to the CPU. Since the input and output buffers are continuously being filled/emptied, the CPU must match the pace of the EDMA3 very closely in order to process the data. The EDMA3 receive data must always be placed in memory before the CPU accesses it, and the CPU must provide the output data before the EDMA3 transfers it. Though not impossible, this is an unnecessary challenge. It is particularly difficult in a 2-level cache scheme.

Ping-pong buffering is a simple technique that allows the CPU activity to be distanced from the EDMA3 activity. This means that there are multiple (usually two) sets of data buffers for all incoming and outgoing data streams. While the EDMA3 transfers the data into and out of the ping buffers, the CPU manipulates the data in the pong buffers. When both CPU and EDMA3 activity completes, they switch. The EDMA3 then writes over the old input data and transfers the new output data. Figure 18-28 shows the ping-pong scheme for this example.

To change the continuous operation example, such that a ping-pong buffering scheme is used, the DMA channels need only a moderate change. Instead of one link parameter set, there are two; one for transferring data to/from the ping buffers and one for transferring data to/from the pong buffers. As soon as one transfer completes, the channel loads the PaRAM set for the other and the data transfers continue. Figure 18-29 shows the DMA channel configuration required.

Each channel has two link parameter sets, ping and pong. The DMA channel is initially loaded with the ping parameters (Figure 18-29). The link address for the ping set is set to the PaRAM offset of the pong parameter set (Figure 18-30). The link address for the pong set is set to the PaRAM offset of the ping parameter set (Figure 18-31). The channel options, count values, and index values are all identical between the ping and pong parameters for each channel. The only differences are the link address provided and the address of the data buffer.

18.3.4.4.1 Synchronization with the CPU

In order to utilize the ping-pong buffering technique, the system must signal the CPU when to begin to access the new data set. After the CPU finishes processing an input buffer (ping), it waits for the EDMA3 to complete before switching to the alternate (pong) buffer. In this example, both channels provide their channel numbers as their report word and set the TCINTEN bit to 1 to generate an interrupt after completion. When channel 3 fills an input buffer, the E3 bit in the interrupt pending register (IPR) is set to 1; when channel 2 empties an output buffer, the E2 bit in IPR is set to 1. The CPU must manually clear these bits. With the channel parameters set, the CPU polls IPR to determine when to switch. The EDMA3 and CPU could alternatively be configured such that the channel completion interrupts the CPU. By doing this, the CPU could service a background task while waiting for the EDMA3 to complete.

Figure 18-28. Ping-Pong Buffering for McBSP Data Example

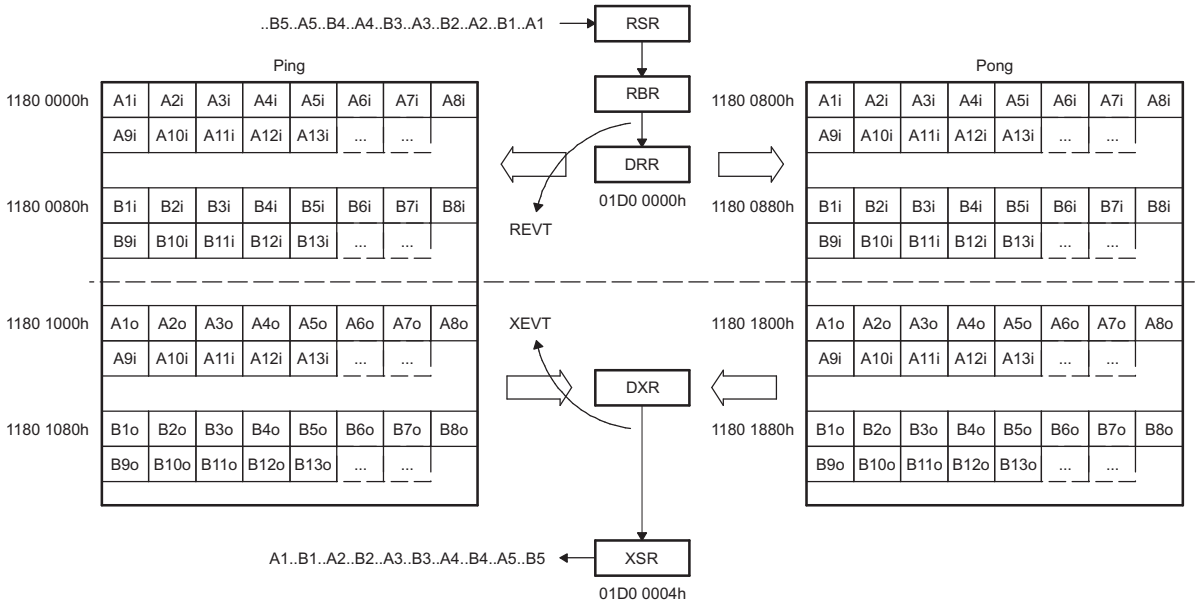


Figure 18-29. Ping-Pong Buffering for McBSP Example PaRAM

(a) EDMA Parameters for Channel 3 (Using PaRAM Set 3 Linked to Pong Set 64)

Parameter Contents		Parameter	
0010 3000h		Channel Options Parameter (OPT)	
01D0 0000h		Channel Source Address (SRC)	
0080h	0001h	Count for 2nd Dimension (BCNT)	Count for 1st Dimension (ACNT)
1180 0000h		Channel Destination Address (DST)	
0001h	0000h	Destination BCNT Index (DSTBIDX)	Source BCNT Index (SRCBIDX)
0080h	4800h	BCNT Reload (BCNTRLD)	Link Address (LINK)
0000h	0000h	Destination CCNT Index (DSTCIDX)	Source CCNT Index (SRCCIDX)
0000h	0001h	Reserved	Count for 3rd Dimension (CCNT)

(b) Channel Options Parameter (OPT) Content for Channel 3

31	30 28	27 24	23	22	21	20	19 18	17 16
0	000	0000	0	0	0	1	00	00
PRIV	Reserved	PRIVID	ITCCHEN	TCCHEN	ITCINTEN	TCINTEN	Reserved	TCC

15 12	11	10 8	7 4	3	2	1	0
0011	0	000	0000	0	0	0	0
TCC	TCCMOD	FWID	Reserved	STATIC	SYNCDIM	DAM	SAM

(c) EDMA Parameters for Channel 2 (Using PaRAM Set 2 Linked to Pong Set 65)

Parameter Contents		Parameter	
0010 2000h		Channel Options Parameter (OPT)	
1180 1000h		Channel Source Address (SRC)	
0080h	0001h	Count for 2nd Dimension (BCNT)	Count for 1st Dimension (ACNT)
01D0 0004h		Channel Destination Address (DST)	
0000h	0001h	Destination BCNT Index (DSTBIDX)	Source BCNT Index (SRCBIDX)
0080h	4840h	BCNT Reload (BCNTRLD)	Link Address (LINK)
0000h	0000h	Destination CCNT Index (DSTCIDX)	Source CCNT Index (SRCCIDX)
0000h	0001h	Reserved	Count for 3rd Dimension (CCNT)

(d) Channel Options Parameter (OPT) Content for Channel 2

31	30 28	27 24	23	22	21	20	19 18	17 16
0	000	0000	0	0	0	1	00	00
PRIV	Reserved	PRIVID	ITCCHEN	TCCHEN	ITCINTEN	TCINTEN	Reserved	TCC

15 12	11	10 8	7 4	3	2	1	0
0010	0	000	0000	0	0	0	0
TCC	TCCMOD	FWID	Reserved	STATIC	SYNCDIM	DAM	SAM

Figure 18-30. Ping-Pong Buffering for McBSP Example Pong PaRAM

(a) EDMA Pong Parameters for Channel 3 at Set 64 Linked to Set 65

Parameter Contents		Parameter	
0010 D000h		Channel Options Parameter (OPT)	
01D0 0000h		Channel Source Address (SRC)	
0080h	0001h	Count for 2nd Dimension (BCNT)	Count for 1st Dimension (ACNT)
1180 0800h		Channel Destination Address (DST)	
0001h	0000h	Destination BCNT Index (DSTBIDX)	Source BCNT Index (SRCBIDX)
0080h	4820h	BCNT Reload (BCNTRLD)	Link Address (LINK)
0000h	0000h	Destination CCNT Index (DSTCIDX)	Source CCNT Index (SRCCIDX)
0000h	0001h	Reserved	Count for 3rd Dimension (CCNT)

(b) EDMA Pong Parameters for Channel 2 at Set 66 Linked to Set 67

Parameter Contents		Parameter	
0010 C000h		Channel Options Parameter (OPT)	
1180 1800h		Channel Source Address (SRC)	
0080h	0001h	Count for 2nd Dimension (BCNT)	Count for 1st Dimension (ACNT)
01D0 0004h		Channel Destination Address (DST)	
0000h	0001h	Destination BCNT Index (DSTBIDX)	Source BCNT Index (SRCBIDX)
0080h	4860h	BCNT Reload (BCNTRLD)	Link Address (LINK)
0000h	0000h	Destination CCNT Index (DSTCIDX)	Source CCNT Index (SRCCIDX)
0000h	0001h	Reserved	Count for 3rd Dimension (CCNT)

Figure 18-31. Ping-Pong Buffering for McBSP Example Ping PaRAM

(a) EDMA Ping Parameters for Channel 3 at Set 65 Linked to Set 64

Parameter Contents		Parameter	
0010 D000h		Channel Options Parameter (OPT)	
01D0 0000h		Channel Source Address (SRC)	
0080h	0001h	Count for 2nd Dimension (BCNT)	Count for 1st Dimension (ACNT)
1180 0000h		Channel Destination Address (DST)	
0001h	0000h	Destination BCNT Index (DSTBIDX)	Source BCNT Index (SRCBIDX)
0080h	4800h	BCNT Reload (BCNTRLD)	Link Address (LINK)
0000h	0000h	Destination CCNT Index (DSTCIDX)	Source CCNT Index (SRCCIDX)
0000h	0001h	Reserved	Count for 3rd Dimension (CCNT)

(b) EDMA Ping Parameters for Channel 2 at Set 67 Linked to Set 66

Parameter Contents		Parameter	
0010 C000h		Channel Options Parameter (OPT)	
1180 1000h		Channel Source Address (SRC)	
0080h	0001h	Count for 2nd Dimension (BCNT)	Count for 1st Dimension (ACNT)
01D0 0004h		Channel Destination Address (DST)	
0000h	0001h	Destination BCNT Index (DSTBIDX)	Source BCNT Index (SRCBIDX)
0080h	4840h	BCNT Reload (BCNTRLD)	Link Address (LINK)
0000h	0000h	Destination CCNT Index (DSTCIDX)	Source CCNT Index (SRCCIDX)
0000h	0001h	Reserved	Count for 3rd Dimension (CCNT)

18.3.4.5 Transfer Chaining Examples

The following examples explain the intermediate transfer complete chaining function.

18.3.4.5.1 Servicing Input/Output FIFOs with a Single Event

Many systems require the use of a pair of external FIFOs that must be serviced at the same rate. One FIFO buffers data input, and the other buffers data output. The EDMA3 channels that service these FIFOs can be set up for AB-synchronized transfers. While each FIFO is serviced with a different set of parameters, both can be signaled from a single event. For example, an external interrupt pin can be tied to the status flags of one of the FIFOs. When this event arrives, the EDMA3 needs to perform servicing for both the input and output streams. Without the intermediate transfer complete chaining feature this would require two events, and thus two external interrupt pins. The intermediate transfer complete chaining feature allows the use of a single external event (for example, a GPIO event). Figure 18-32 shows the EDMA3 setup and illustration for this example.

A GPIO event (in this case, GPINT0) triggers an array transfer. Upon completion of each intermediate array transfer of channel 16, intermediate transfer complete chaining sets the E31 bit (specified by TCC of 31) in the chained event register (CER) and provides a synchronization event to channel 31. Upon completion of the last array transfer of channel 16, transfer complete chaining—not intermediate transfer complete chaining—sets the E31 bit in CER (specified by TCCMODE:TCC) and provides a synchronization event to channel 31. The completion of channel 31 sets the I31 bit (specified by TCCMODE:TCC) in the interrupt pending register (IPR), which can generate an interrupt to the CPU, if the I31 bit in the interrupt enable register (IER) is set to 1.

18.3.4.5.2 Breaking Up Large Transfers with Intermediate Chaining

Another feature of intermediate transfer chaining (ITCCHEN) is for breaking up large transfers. A large transfer may lock out other transfers of the same priority level for the duration of the transfer. For example, a large transfer on queue 0 from the internal memory to the external memory using the EMIF may starve other EDMA3 transfers on the same queue. In addition, this large high-priority transfer may prevent the EMIF for a long duration to service other lower priority transfers. When a large transfer is considered to be high priority, it should be split into multiple smaller transfers. Figure 18-33 shows the EDMA3 setup and illustration of an example single large block transfer.

The intermediate transfer chaining enable (ITCCHEN) provides a method to break up a large transfer into smaller transfers. For example, to move a single large block of memory (16K bytes), the EDMA3 performs an A-synchronized transfer. The element count is set to a reasonable value, where reasonable derives from the amount of time it would take to move this smaller amount of data. Assume 1K byte is a reasonable small transfer in this example. The EDMA3 is set up to transfer 16 arrays of 1K byte elements, for a total of 16K byte elements. The TCC field in the channel options parameter (OPT) is set to the same value as the channel number and ITCCHEN are set. In this example, DMA channel 25 is used and TCC is also set to 25. The TCINTEN may also be set to trigger interrupt 25 when the last 1K byte array is transferred. The CPU starts the EDMA3 transfer by writing to the appropriate bit of the event set register (ESR.E25). The EDMA3 transfers the first 1K byte array. Upon completion of the first array, intermediate transfer complete code chaining generates a synchronization event to channel 25, a value specified by the TCC field. This intermediate transfer completion chaining event causes DMA channel 25 to transfer the next 1K byte array. This process continues until the transfer parameters are exhausted, at which point the EDMA3 has completed the 16K byte transfer. This method breaks up a large transfer into smaller packets, thus providing natural time slices in the transfer such that other events may be processed. Figure 18-34 shows the EDMA3 setup and illustration of the broken up smaller packet transfers.

Figure 18-32. Intermediate Transfer Completion Chaining Example

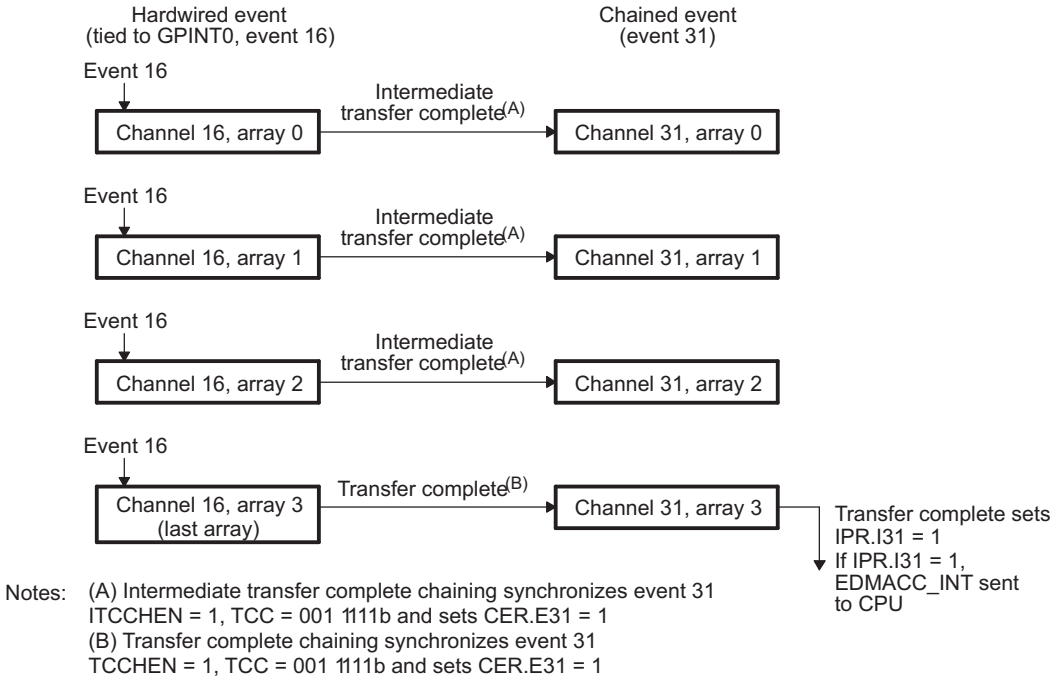


Figure 18-33. Single Large Block Transfer Example

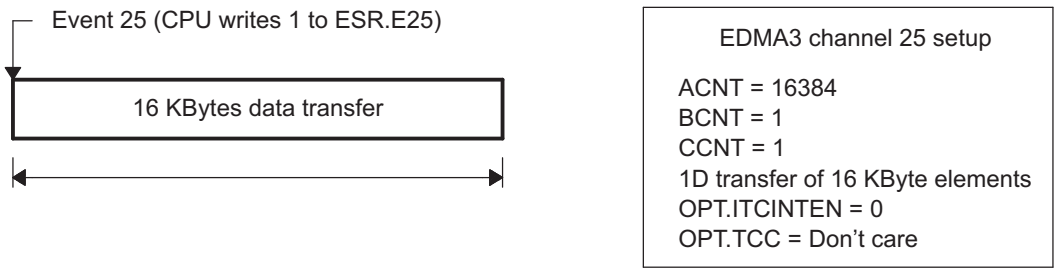
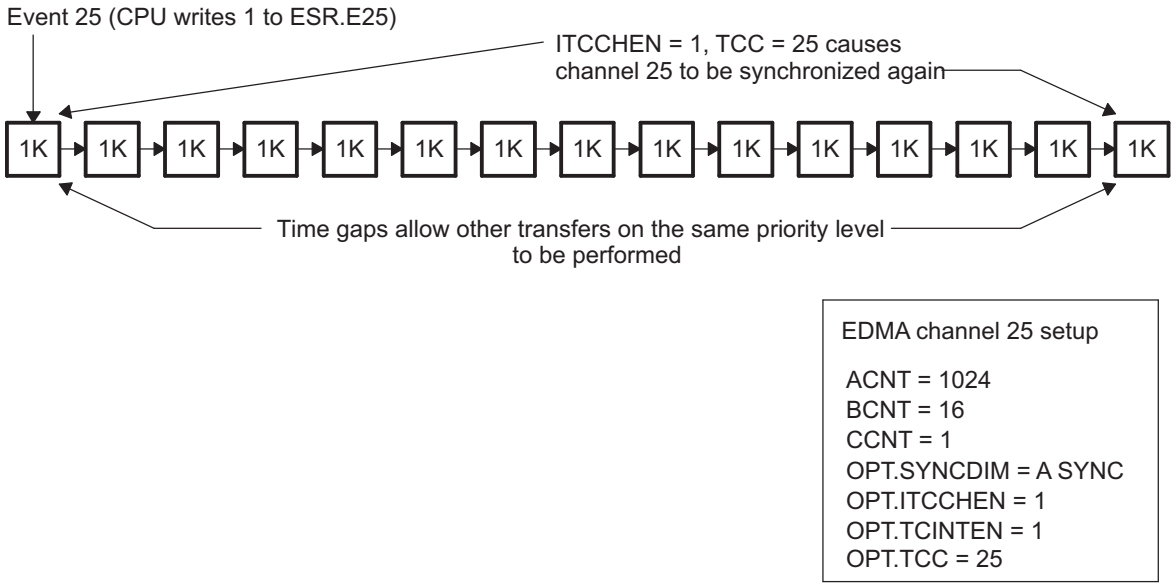


Figure 18-34. Smaller Packet Data Transfers Example



18.4 Registers

This section discusses the registers of the EDMA3 controller.

18.4.1 Parameter RAM (PaRAM) Entries

Table 18-11 lists the parameter RAM (PaRAM) entries for the EDMA3 channel controller (EDMA3CC). See your device-specific data manual for the memory address of these registers.

Table 18-11. EDMA3 Channel Controller (EDMA3CC) Parameter RAM (PaRAM) Entries

Offset	Acronym	Parameter	Section
0h	OPT	Channel Options	Section 18.4.1.1
4h	SRC	Channel Source Address	Section 18.4.1.2
8h	A_B_CNT	A Count/B Count	Section 18.4.1.3
Ch	DST	Channel Destination Address	Section 18.4.1.4
10h	SRC_DST_BIDX	Source B Index/Destination B Index	Section 18.4.1.5
14h	LINK_BCNTRLD	Link Address/B Count Reload	Section 18.4.1.6
18h	SRC_DST_CIDX	Source C Index/Destination C Index	Section 18.4.1.7
1Ch	CCNT	C Count	Section 18.4.1.8

18.4.1.1 Channel Options Parameter (OPT)

The channel options parameter (OPT) is shown in Figure 18-35 and described in Table 18-12.

NOTE: The TCC field in OPT is a 6-bit field and can be programmed for any value between 0-64. For devices with 32 DMA channels, the TCC field should have a value between 0 to 31 so that it sets the appropriate bits (0 to 31) in the interrupt pending register (IPR) (and can interrupt the CPU(s) on enabling the interrupt enable register (IER) bits (0-31)).

Figure 18-35. Channel Options Parameter (OPT)

31–28	27–24	23	22	21	20	19–18	17–16
Reserved	PRIVID	ITCCHEN	TCCHEN	ITCINTEN	TCINTEN	Reserved	TCC
R-0	R-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0 R-0	R/W-0

15–12	11	10–8	7–4	3	2	1	0
TCC	TCCMOD	FWID	Reserved	STATIC	SYNCDIM	DAM	SAM
R/W-0	R/W-0	R/W-0	R-0	R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 18-12. Channel Options Parameters (OPT) Field Descriptions

Bit	Field	Value	Description
31-28	Reserved	0	Reserved
27-24	PRIVID	0-Fh	Privilege identification for the external host/CPU/DMA that programmed this PaRAM set. This value is set with the EDMA3 master's privilege identification value when any part of the PaRAM set is written.
23	ITCCHEN		Intermediate transfer completion chaining enable.
		0	Intermediate transfer complete chaining is disabled.
		1	Intermediate transfer complete chaining is enabled.
			When enabled, the chained event register (CER) bit is set on every intermediate chained transfer completion (upon completion of every intermediate TR in the PaRAM set, except the final TR in the PaRAM set). The bit (position) set in CER is the TCC value specified.
22	TCCHEN		Transfer complete chaining enable.
		0	Transfer complete chaining is disabled.
		1	Transfer complete chaining is enabled.
			When enabled, the chained event register (CER) bit is set on final chained transfer completion (upon completion of the final TR in the PaRAM set). The bit (position) set in CER is the TCC value specified.
21	ITCINTEN		Intermediate transfer completion interrupt enable.
		0	Intermediate transfer complete interrupt is disabled.
		1	Intermediate transfer complete interrupt is enabled.
			When enabled, the interrupt pending register (IPR) bit is set on every intermediate transfer completion (upon completion of every intermediate TR in the PaRAM set, except the final TR in the PaRAM set). The bit (position) set in IPR is the TCC value specified. In order to generate a completion interrupt to the CPU, the corresponding IER[TCC] bit must be set to 1.
20	TCINTEN		Transfer complete interrupt enable.
		0	Transfer complete interrupt is disabled.
		1	Transfer complete interrupt is enabled.
			When enabled, the interrupt pending register (IPR) bit is set on transfer completion (upon completion of the final TR in the PaRAM set). The bit (position) set in IPR is the TCC value specified. In order to generate a completion interrupt to the CPU, the corresponding IER[TCC] bit must be set to 1.
19	Reserved	0	Reserved. Always write 0 to this bit.
18	Reserved	0	Reserved

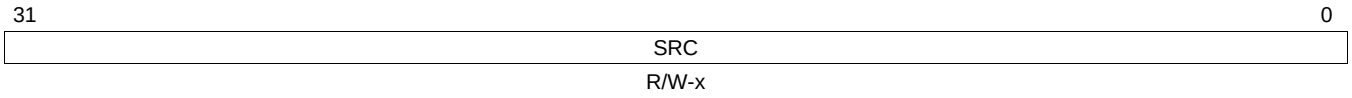
Table 18-12. Channel Options Parameters (OPT) Field Descriptions (continued)

Bit	Field	Value	Description
17-12	TCC	0-3Fh	Transfer complete code. This 6-bit code is used to set the relevant bit in chaining enable register (CER[TCC]) for chaining or in interrupt pending register (IPR[TCC]) for interrupts.
		0-1Fh	Valid values
		20h-3Fh	Reserved
11	TCCMODE		Transfer complete code mode. Indicates the point at which a transfer is considered completed for chaining and interrupt generation.
		0	Normal completion: A transfer is considered completed after the data has been transferred.
		1	Early completion: A transfer is considered completed after the EDMA3CC submits a TR to the EDMA3TC. TC may still be transferring data when interrupt/chain is triggered.
10-8	FWID	0-7h	FIFO Width. Applies if either SAM or DAM is set to constant addressing mode.
		0	FIFO width is 8-bit.
		1h	FIFO width is 16-bit.
		2h	FIFO width is 32-bit.
		3h	FIFO width is 64-bit.
		4h	FIFO width is 128-bit.
		5h	FIFO width is 256-bit.
		6h-7h	Reserved
7-4	Reserved	0	Reserved
3	STATIC		Static PaRAM set.
		0	PaRAM set is not static. PaRAM set is updated or linked after TR is submitted. A value of 0 should be used for DMA channels and for nonfinal transfers in a linked list of QDMA transfers.
		1	PaRAM set is static. PaRAM set is not updated or linked after TR is submitted. A value of 1 should be used for isolated QDMA transfers or for the final transfer in a linked list of QDMA transfers.
2	SYNCDIM		Transfer synchronization dimension.
		0	A-synchronized. Each event triggers the transfer of a single array of ACNT bytes.
		1	AB-synchronized. Each event triggers the transfer of BCNT arrays of ACNT bytes.
1	DAM		Destination address mode.
		0	Increment (INCR) mode. Destination addressing within an array increments. Destination is not a FIFO.
		1	Constant addressing (CONST) mode. Destination addressing within an array wraps around upon reaching FIFO width. Note: The constant addressing (CONST) mode has limited applicability. The EDMA3 should be configured for the constant addressing mode (SAM/DAM = 1) only if the transfer source or destination (on-chip memory, off-chip memory controllers, slave peripherals) support the constant addressing mode. On the C674x/OMAP-L1x processors, no peripherals, memory, or memory controller support constant addressing mode. If the constant addressing mode is not supported, the similar logical transfer can be achieved using the increment (INCR) mode (SAM/DAM = 0) by appropriately programming the count and indices values.
0	SAM		Source address mode.
		0	Increment (INCR) mode. Source addressing within an array increments. Source is not a FIFO.
		1	Constant addressing (CONST) mode. Source addressing within an array wraps around upon reaching FIFO width. Note: The constant addressing (CONST) mode has limited applicability. The EDMA3 should be configured for the constant addressing mode (SAM/DAM = 1) only if the transfer source or destination (on-chip memory, off-chip memory controllers, slave peripherals) support the constant addressing mode. On the C674x/OMAP-L1x processors, no peripherals, memory, or memory controller support constant addressing mode. If the constant addressing mode is not supported, the similar logical transfer can be achieved using the increment (INCR) mode (SAM/DAM = 0) by appropriately programming the count and indices values.

18.4.1.2 Channel Source Address Parameter (SRC)

The channel source address parameter (SRC) specifies the starting byte address of the source. The SRC is shown in Figure 18-36 and described in Table 18-13.

Figure 18-36. Channel Source Address Parameter (SRC)



LEGEND: R = Read only; -*n* = value after reset

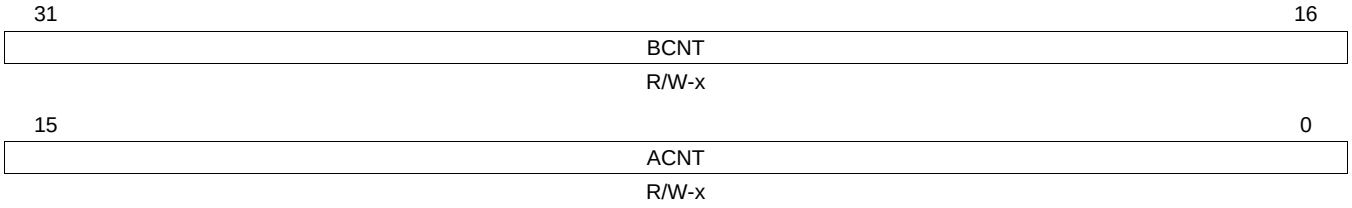
Table 18-13. Channel Source Address Parameter (SRC) Field Descriptions

Bit	Field	Value	Description
31-0	SRC	0-FFFF FFFFh	Source address. Specifies the starting byte address of the source.

18.4.1.3 A Count/B Count Parameter (A_B_CNT)

The A count/B count parameter (A_B_CNT) specifies the number of bytes within the 1st dimension of a transfer and the number of arrays of length ACNT. The A_B_CNT is shown in Figure 18-37 and described in Table 18-14.

Figure 18-37. A Count/B Count Parameter (A_B_CNT)



LEGEND: R/W = Read/Write; -*n* = value after reset; -x = value is indeterminate after reset

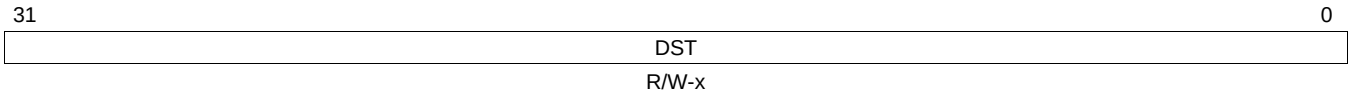
Table 18-14. A Count/B Count Parameter (A_B_CNT) Field Descriptions

Bit	Field	Value	Description
31-16	BCNT	0-FFFFh	B count. Unsigned value specifying the number of arrays in a frame, where an array is ACNT bytes. Valid values range from 1 to 65 535.
15-0	ACNT	0-FFFFh	A count for 1st Dimension. Unsigned value specifying the number of contiguous bytes within an array (first dimension of the transfer). Valid values range from 1 to 65 535.

18.4.1.4 Channel Destination Address Parameter (DST)

The channel destination address parameter (DST) specifies the starting byte address of the source. The DST is shown in Figure 18-38 and described in Table 18-15.

Figure 18-38. Channel Destination Address Parameter (DST)



LEGEND: R = Read only; -*n* = value after reset

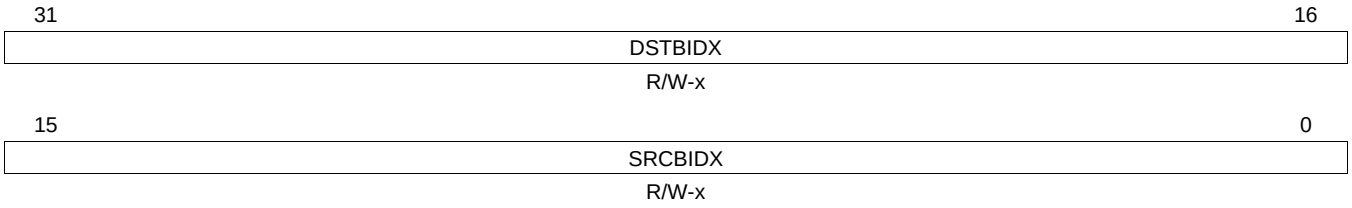
Table 18-15. Channel Destination Address Parameter (DST) Field Descriptions

Bit	Field	Value	Description
31-0	DST	0-FFFF FFFFh	Destination address. Specifies the starting byte address of the destination where data is transferred.

18.4.1.5 Source B Index/Destination B Index Parameter (SRC_DST_BIDX)

The source B index/destination B index parameter (SRC_DST_BIDX) specifies the value (2s complement) used for source address modification between each array in the 2nd dimension and the value (2s complement) used for destination address modification between each array in the 2nd dimension. The SRC_DST_BIDX is shown in Figure 18-39 and described in Table 18-16.

Figure 18-39. Source B Index/Destination B Index Parameter (SRC_DST_BIDX)



LEGEND: R/W = Read/Write; -*n* = value after reset; -x = value is indeterminate after reset

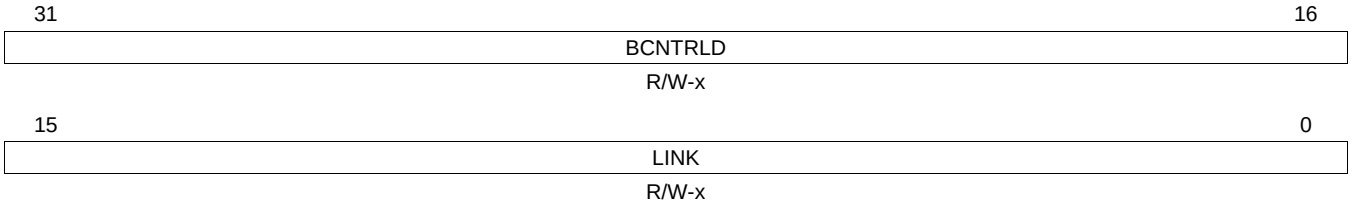
Table 18-16. Source B Index/Destination B Index Parameter (SRC_DST_BIDX) Field Descriptions

Bit	Field	Value	Description
31-16	DSTBIDX	0-FFFFh	Destination B index. Signed value specifying the byte address offset between destination arrays within a frame (2nd dimension). Valid values range from –32 768 and 32 767.
15-0	SRCBIDX	0-FFFFh	Source B index. Signed value specifying the byte address offset between source arrays within a frame (2nd dimension). Valid values range from –32 768 and 32 767.

18.4.1.6 Link Address/B Count Reload Parameter (LINK_BCNTRLD)

The link address/B count reload parameter (LINK_BCNTRLD) specifies the byte address offset in the PaRAM from which the EDMA3CC loads/reloads the next PaRAM set during linking and the value used to reload the BCNT field in the A count/B count parameter (A_B_CNT) once the last array in the 2nd dimension is transferred. The LINK_BCNTRLD is shown in Figure 18-40 and described in Table 18-17.

Figure 18-40. Link Address/B Count Reload Parameter (LINK_BCNTRLD)



LEGEND: R/W = Read/Write; -*n* = value after reset; -x = value is indeterminate after reset

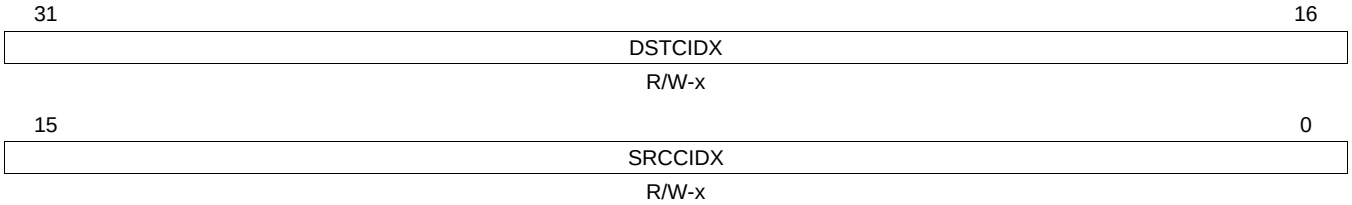
Table 18-17. Link Address/B Count Reload Parameter (LINK_BCNTRLD) Field Descriptions

Bit	Field	Value	Description
31-16	BCNTRLD	0-FFFFh	B count reload. The count value used to reload BCNT in the A count/B count parameter (A_B_CNT) when BCNT decrements to 0 (TR submitted for the last array in 2nd dimension). Only relevant in A-synchronized transfers.
15-0	LINK	0-FFFFh	Link address. The PaRAM address containing the PaRAM set to be linked (copied from) when the current PaRAM set is exhausted. You must program the link address to point to a valid aligned 32-byte PaRAM set. The 5 LSBs of the LINK field should be cleared to 0. A value of FFFFh specifies a null link.

18.4.1.7 Source C Index/Destination C Index Parameter (SRC_DST_CIDX)

The source C index/destination C index parameter (SRC_DST_CIDX) specifies the value (2s complement) used for source address modification between each array in the 3rd dimension and the value (2s complement) used for destination address modification between each array in the 3rd dimension. The SRC_DST_CIDX is shown in Figure 18-41 and described in Table 18-18.

Figure 18-41. Source C Index/Destination C Index Parameter (SRC_DST_CIDX)



LEGEND: R/W = Read/Write; -*n* = value after reset; -x = value is indeterminate after reset

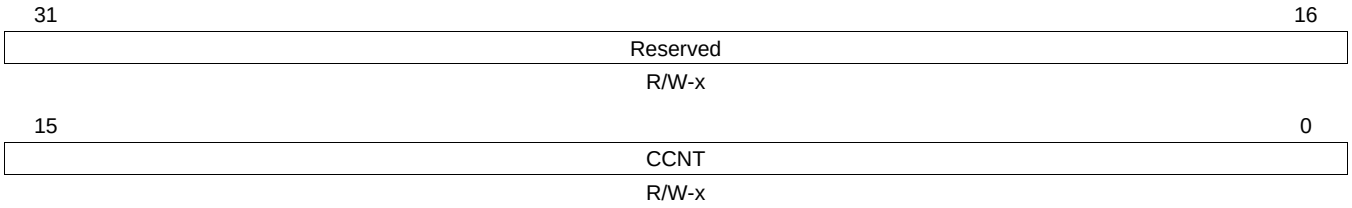
Table 18-18. Source C Index/Destination C Index Parameter (SRC_DST_CIDX) Field Descriptions

Bit	Field	Value	Description
31-16	DSTCIDX	0-FFFFh	Destination C index. Signed value specifying the byte address offset between frames within a block (3rd dimension). Valid values range from –32 768 and 32 767.
15-0	SRCCIDX	0-FFFFh	Source C index. Signed value specifying the byte address offset between frames within a block (3rd dimension). Valid values range from –32 768 and 32 767.

18.4.1.8 C Count Parameter (CCNT)

The C count parameter (CCNT) specifies the number of frames in a block. The CCNT is shown in Figure 18-42 and described in Table 18-19.

Figure 18-42. C Count Parameter (CCNT)



LEGEND: R/W = Read/Write; -*n* = value after reset; -x = value is indeterminate after reset

Table 18-19. C Count Parameter (CCNT) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	Reserved
15-0	CCNT	0-FFFFh	C counter. Unsigned value specifying the number of frames in a block, where a frame is BCNT arrays of ACNT bytes. Valid values range from 1 to 65 535.

18.4.2 EDMA3 Channel Controller (EDMA3CC) Registers

Table 18-20 lists the memory-mapped registers for the EDMA3 channel controller (EDMA3CC). See your device-specific data manual for the memory address of these registers and for the shadow region addresses. All other register offset addresses not listed in Table 18-20 should be considered as reserved locations and the register contents should not be modified.

Table 18-20. EDMA3 Channel Controller (EDMA3CC) Registers

Offset	Acronym	Register Description	Section
0h	REVID	Revision Identification Register	Section 18.4.2.1.1
4h	CCCFG	EDMA3CC Configuration Register	Section 18.4.2.1.2
		Global Registers	
200h	QCHMAP0	QDMA Channel 0 Mapping Register	Section 18.4.2.1.3
204h	QCHMAP1	QDMA Channel 1 Mapping Register	Section 18.4.2.1.3
208h	QCHMAP2	QDMA Channel 2 Mapping Register	Section 18.4.2.1.3
20Ch	QCHMAP3	QDMA Channel 3 Mapping Register	Section 18.4.2.1.3
210h	QCHMAP4	QDMA Channel 4 Mapping Register	Section 18.4.2.1.3
214h	QCHMAP5	QDMA Channel 5 Mapping Register	Section 18.4.2.1.3
218h	QCHMAP6	QDMA Channel 6 Mapping Register	Section 18.4.2.1.3
21Ch	QCHMAP7	QDMA Channel 7 Mapping Register	Section 18.4.2.1.3
240h	DMAQNUM0	DMA Channel Queue Number Register 0	Section 18.4.2.1.4
244h	DMAQNUM1	DMA Channel Queue Number Register 1	Section 18.4.2.1.4
248h	DMAQNUM2	DMA Channel Queue Number Register 2	Section 18.4.2.1.4
24Ch	DMAQNUM3	DMA Channel Queue Number Register 3	Section 18.4.2.1.4
260h	QDMAQNUM	QDMA Channel Queue Number Register	Section 18.4.2.1.5
284h	QUEPRI	Queue Priority Register(1)	Section 18.4.2.1.6
300h	EMR	Event Missed Register	Section 18.4.2.2.1
308h	EMCR	Event Missed Clear Register	Section 18.4.2.2.2
310h	QEMR	QDMA Event Missed Register	Section 18.4.2.2.3
314h	QEMCR	QDMA Event Missed Clear Register	Section 18.4.2.2.4
318h	CCERR	EDMA3CC Error Register	Section 18.4.2.2.5
31Ch	CCERRCLR	EDMA3CC Error Clear Register	Section 18.4.2.2.6
320h	EEVAL	Error Evaluate Register	Section 18.4.2.2.7
340h	DRAE0	DMA Region Access Enable Register for Region 0	Section 18.4.2.3.1
348h	DRAE1	DMA Region Access Enable Register for Region 1	Section 18.4.2.3.1
350h	DRAE2	DMA Region Access Enable Register for Region 2	Section 18.4.2.3.1
358h	DRAE3	DMA Region Access Enable Register for Region 3	Section 18.4.2.3.1
380h	QRAE0	QDMA Region Access Enable Register for Region 0	Section 18.4.2.3.2
384h	QRAE1	QDMA Region Access Enable Register for Region 1	Section 18.4.2.3.2
388h	QRAE2	QDMA Region Access Enable Register for Region 2	Section 18.4.2.3.2
38Ch	QRAE3	QDMA Region Access Enable Register for Region 3	Section 18.4.2.3.2
400h-43Ch	Q0E0-Q0E15	Event Queue Entry Registers Q0E0-Q0E15	Section 18.4.2.4.1
440h-47Ch	Q1E0-Q1E15	Event Queue Entry Registers Q1E0-Q1E15	Section 18.4.2.4.1
600h	QSTAT0	Queue 0 Status Register	Section 18.4.2.4.2
604h	QSTAT1	Queue 1 Status Register	Section 18.4.2.4.2
620h	QWMTHRA	Queue Watermark Threshold A Register	Section 18.4.2.4.3
640h	CCSTAT	EDMA3CC Status Register	Section 18.4.2.4.4

(1) On previous architectures, the EDMA3TC priority was controlled by the queue priority register (QUEPRI) in the EDMA3CC memory-map. However for this device, the priority control for the transfer controllers is controlled by the chip-level registers in the System Configuration Module. You should use the chip-level registers and not QUEPRI to configure the TC priority.

Table 18-20. EDMA3 Channel Controller (EDMA3CC) Registers (continued)

Offset	Acronym	Register Description	Section
		Global Channel Registers	
1000h	ER	Event Register	Section 18.4.2.5.1
1008h	ECR	Event Clear Register	Section 18.4.2.5.2
1010h	ESR	Event Set Register	Section 18.4.2.5.3
1018h	CER	Chained Event Register	Section 18.4.2.5.4
1020h	EER	Event Enable Register	Section 18.4.2.5.5
1028h	EECR	Event Enable Clear Register	Section 18.4.2.5.6
1030h	EESR	Event Enable Set Register	Section 18.4.2.5.7
1038h	SER	Secondary Event Register	Section 18.4.2.5.8
1040h	SECR	Secondary Event Clear Register	Section 18.4.2.5.9
1050h	IER	Interrupt Enable Register	Section 18.4.2.6.1
1058h	IECR	Interrupt Enable Clear Register	Section 18.4.2.6.2
1060h	IESR	Interrupt Enable Set Register	Section 18.4.2.6.3
1068h	IPR	Interrupt Pending Register	Section 18.4.2.6.4
1070h	ICR	Interrupt Clear Register	Section 18.4.2.6.5
1078h	IEVAL	Interrupt Evaluate Register	Section 18.4.2.6.6
1080h	QER	QDMA Event Register	Section 18.4.2.7.1
1084h	QEER	QDMA Event Enable Register	Section 18.4.2.7.2
1088h	QEECR	QDMA Event Enable Clear Register	Section 18.4.2.7.3
108Ch	QEESR	QDMA Event Enable Set Register	Section 18.4.2.7.4
1090h	QSER	QDMA Secondary Event Register	Section 18.4.2.7.5
1094h	QSECR	QDMA Secondary Event Clear Register	Section 18.4.2.7.6
		Shadow Region 0 Channel Registers	
2000h	ER	Event Register	—
2008h	ECR	Event Clear Register	—
2010h	ESR	Event Set Register	—
2018h	CER	Chained Event Register	—
2020h	EER	Event Enable Register	—
2028h	EECR	Event Enable Clear Register	—
2030h	EESR	Event Enable Set Register	—
2038h	SER	Secondary Event Register	—
2040h	SECR	Secondary Event Clear Register	—
2050h	IER	Interrupt Enable Register	—
2058h	IECR	Interrupt Enable Clear Register	—
2060h	IESR	Interrupt Enable Set Register	—
2068h	IPR	Interrupt Pending Register	—
2070h	ICR	Interrupt Clear Register	—
2078h	IEVAL	Interrupt Evaluate Register	—
2080h	QER	QDMA Event Register	—
2084h	QEER	QDMA Event Enable Register	—
2088h	QEECR	QDMA Event Enable Clear Register	—
208Ch	QEESR	QDMA Event Enable Set Register	—
2090h	QSER	QDMA Secondary Event Register	—
2094h	QSECR	QDMA Secondary Event Clear Register	—

Table 18-20. EDMA3 Channel Controller (EDMA3CC) Registers (continued)

Offset	Acronym	Register Description	Section
		Shadow Region 1 Channel Registers	
2200h	ER	Event Register	—
2208h	ECR	Event Clear Register	—
2210h	ESR	Event Set Register	—
2218h	CER	Chained Event Register	—
2220h	EER	Event Enable Register	—
2228h	EECR	Event Enable Clear Register	—
2230h	EESR	Event Enable Set Register	—
2238h	SER	Secondary Event Register	—
2240h	SECR	Secondary Event Clear Register	—
2250h	IER	Interrupt Enable Register	—
2258h	IECR	Interrupt Enable Clear Register	—
2260h	IESR	Interrupt Enable Set Register	—
2268h	IPR	Interrupt Pending Register	—
2270h	ICR	Interrupt Clear Register	—
2278h	IEVAL	Interrupt Evaluate Register	—
2280h	QER	QDMA Event Register	—
2284h	QEER	QDMA Event Enable Register	—
2288h	QEECR	QDMA Event Enable Clear Register	—
228Ch	QEESR	QDMA Event Enable Set Register	—
2290h	QSER	QDMA Secondary Event Register	—
2294h	QSECR	QDMA Secondary Event Clear Register	—
4000h-4FFFh	—	Parameter RAM (PaRAM)	—

18.4.2.1 Global Registers

18.4.2.1.1 Revision Identification Register (REVID)

The revision identification register (REVID) uniquely identifies the EDMA3CC and the specific revision of the EDMA3CC. The REVID is shown in Figure 18-43 and described in Table 18-21.

Figure 18-43. Revision ID Register (REVID)

31	0
REV	
R-4001 5300h	

LEGEND: R = Read only; -*n* = value after reset

Table 18-21. Revision ID Register (REVID) Field Descriptions

Bit	Field	Value	Description
31-0	REV	4001 5300h	Peripheral identifier. Uniquely identifies the EDMA3CC and the specific revision of the EDMA3CC.

18.4.2.1.2 EDMA3CC Configuration Register (CCCFG)

The EDMA3CC configuration register (CCCFG) provides the features/resources for the EDMA3CC in a particular device. The CCCFG is shown in Figure 18-44 and described in Table 18-22.

Figure 18-44. EDMA3CC Configuration Register (CCCFG)

31	26	25	24
Reserved		MP_EXIST	CHMAP_EXIST
R-x		R-0	R-0

23	22	21	20	19	18	16
Reserved		NUM_REGN		Reserved	NUM_EVQUE	
R-0		R-2h		R-x	R-1h	

15	14	12	11	10	8
Reserved	NUM_PAENTRY		Reserved	NUM_INTCH	
R-x	R-3h		R-x	R-3h	

7	6	4	3	2	0
Reserved	NUM_QDMACH		Reserved	NUM_DMACH	
R-x	R-4h		R-x	R-4h	

LEGEND: R = Read only; -*n* = value after reset; -x = value is indeterminate after reset

Table 18-22. EDMA3CC Configuration Register (CCCFG) Field Descriptions

Bit	Field	Value	Description
31-26	Reserved	0-3Fh	Reserved
25	MP_EXIST		Memory protection existence.
		0	No memory protection.
		1	Reserved
24	CHMAP_EXIST		Channel mapping existence.
		0	No channel mapping. This implies that there is fixed association for a channel number to a parameter entry number or, in other words, PaRAM entry *n* corresponds to channel *n*.
		1	Reserved
23-22	Reserved	0	Reserved
21-20	NUM_REGN	0-3h	Number of shadow regions.
		0-1h	Reserved
		2h	4 regions
		3h	Reserved
19	Reserved	0	Reserved
18-16	NUM_EVQUE	0-7h	Number of queues/number of transfer controllers.
		0	Reserved
		1h	2 event queues
		2h	2 transfer controllers
		3h-7h	Reserved
15	Reserved	0	Reserved
14-12	NUM_PAENTRY	0-7h	Number of PaRAM sets.
		0-2h	Reserved
		3h	128 PaRAM sets
		4h-7h	Reserved
11	Reserved	0	Reserved
10-8	NUM_INTCH	0-7h	Number of interrupt channels.
		0-2h	Reserved
		3h	32 interrupt channels
		4h-7h	Reserved
7	Reserved	0	Reserved
6-4	NUM_QDMACH	0-7h	Number of QDMA channels.
		0-3h	Reserved
		4h	8 QDMA channels
		5h-7h	Reserved
3	Reserved	0	Reserved
2-0	NUM_DMACH	0-7h	Number of DMA channels.
		0-3h	Reserved
		4h	32 DMA channels
		5h-7h	Reserved

18.4.2.1.3 QDMA Channel *n* Mapping Register (QCHMAP*n*)

Each QDMA channel in EDMA3CC can be associated with any PaRAM set available on the device. Furthermore, the specific trigger word (0-7) of the PaRAM set can be programmed. The PaRAM set association and trigger word for every QDMA channel register is configurable using the QDMA channel *n* mapping register (QCHMAP*n*). The QCHMAP*n* is shown in Figure 18-45 and described in Table 18-23.

NOTE: At reset the QDMA channel mapping registers for all QDMA channels point to the PaRAM set 0. Prior to using any QDMA channel, QCHMAP*n* should be programmed appropriately to point to a different PaRAM set.

Figure 18-45. QDMA Channel *n* Mapping Register (QCHMAP*n*)

31	16
Reserved	
R-0	

15	14	13	5	4	2	1	0
Reserved		PAENTRY		TRWORD		Reserved	
R-0		R/W-0		R/W-0		R-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 18-23. QDMA Channel *n* Mapping Register (QCHMAP*n*) Field Descriptions

Bit	Field	Value	Description
31-14	Reserved	0	Reserved
13-5	PAENTRY	0-1FFh	PAENTRY points to the PaRAM set number for QDMA channel *n*.
		0-7Fh	PaRAM set number 0 through 127
		80h-1FFh	Reserved
4-2	TRWORD	0-7h	Points to the specific PaRAM entry or the trigger word in the PaRAM set pointed to by PAENTRY. A write to the trigger word results in a QDMA event being recognized.
1-0	Reserved	0	Reserved

18.4.2.1.4 DMA Channel Queue Number Register *n* (DMAQNUM*n*)

The DMA channel queue number register *n* (DMAQNUM*n*) allows programmability of each of the 32 DMA channels in the EDMA3CC to submit its associated synchronization event to any event queue in the EDMA3CC. At reset, all channels point to event queue 0. The DMAQNUM*n* is shown in Figure 18-46 and described in Table 18-24. Table 18-25 shows the channels and their corresponding bits in DMAQNUM*n*.

NOTE: Since the event queues in EDMA3CC have a fixed association to the transfer controllers, that is, Q0 TRs are submitted to TC0 and Q1 TRs are submitted to TC1, by programming DMAQNUM*n* for a particular DMA channel also dictates which transfer controller is utilized for the data movement (or which EDMA3TC receives the TR request).

Figure 18-46. DMA Channel Queue Number Register *n* (DMAQNUM*n*)

31	30 28	27	26 24	23	22 20	19	18 16
Rsvd	E*n*	Rsvd	E*n*	Rsvd	E*n*	Rsvd	E*n*
R-0	R/W-0	R-0	R/W-0	R-0	R/W-0	R-0	R/W-0

15	14 12	11	10 8	7	6 4	3	2 0
Rsvd	E*n*	Rsvd	E*n*	Rsvd	E*n*	Rsvd	E*n*
R-0	R/W-0	R-0	R/W-0	R-0	R/W-0	R-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 18-24. DMA Channel Queue Number Register *n* (DMAQNUM*n*) Field Descriptions

Bit	Field	Value	Description
31-0	E*n*	0-7h	DMA queue number. Contains the event queue number to be used for the corresponding DMA channel. Programming DMAQNUM*n* for an event queue number to a value more then the number of queues available in the EDMA3CC results in undefined behavior.
		0	Event *n* is queued on Q0.
		1h	Event *n* is queued on Q1.
		2h-7h	Reserved

Table 18-25. Bits in DMAQNUM*n*

	DMAQNUM*n*			
E*n* bit	**0**	**1**	**2**	**3**
0-2	E0	E8	E16	E24
4-6	E1	E9	E17	E25
8-10	E2	E10	E18	E26
12-14	E3	E11	E19	E27
16-18	E4	E12	E20	E28
20-22	E5	E13	E21	E29
24-26	E6	E14	E22	E30
28-30	E7	E15	E23	E31

18.4.2.1.5 QDMA Channel Queue Number Register (QDMAQNUM)

The QDMA channel queue number register (QDMAQNUM) is used to program all the QDMA channels in the EDMA3CC to submit the associated QDMA event to any of the event queues in the EDMA3CC. The QDMAQNUM is shown in Figure 18-47 and described in Table 18-26.

Figure 18-47. QDMA Channel Queue Number Register (QDMAQNUM)

31	30 28	27	26 24	23	22 20	19	18 16
Rsvd	E7	Rsvd	E6	Rsvd	E5	Rsvd	E4
R-0	R/W-0	R-0	R/W-0	R-0	R/W-0	R-0	R/W-0

15	14 12	11	10 8	7	6 4	3	2 0
Rsvd	E3	Rsvd	E2	Rsvd	E1	Rsvd	E0
R-0	R/W-0	R-0	R/W-0	R-0	R/W-0	R-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 18-26. QDMA Channel Queue Number Register (QDMAQNUM) Field Descriptions

Bit	Field	Value	Description
31-0	E*n*	0-7h	QDMA queue number. Contains the event queue number to be used for the corresponding QDMA channel.
		0	Event *n* is queued on Q0.
		1h	Event *n* is queued on Q1.
		2h-7h	Reserved

18.4.2.1.6 Queue Priority Register (QUEPRI)

On previous architectures, the EDMA3TC priority was controlled by the queue priority register (QUEPRI) in the EDMA3CC memory-map. However for this device, the priority control for the transfer controllers is controlled by the chip-level registers in the System Configuration Module. You should use the chip-level registers and not QUEPRI to configure the TC priority.

18.4.2.2 Error Registers

The EDMA3CC contains a set of registers that provide information on missed DMA and/or QDMA events, and instances when event queue thresholds are exceeded. If any of the bits in these registers is set, it results in the EDMA3CC generating an error interrupt.

18.4.2.2.1 Event Missed Registers (EMR)

For a particular DMA channel, if a second event is received prior to the first event getting cleared/serviced, the bit corresponding to that channel is set/asserted in the event missed register (EMR). All trigger types are treated individually, that is, manual triggered (ESR), chain triggered (CER), and event triggered (ER) are all treated separately. The EMR bit for a channel is also set if an event on that channel encounters a NULL entry (or a NULL TR is serviced). If any EMR bit is set (and all errors, including bits in other error registers (QEMR, CCERR) were previously cleared), the EDMA3CC generates an error interrupt. See Section 18.2.9.4 for details on EDMA3CC error interrupt generation.

The EMR is shown in Figure 18-48 and described in Table 18-27.

Figure 18-48. Event Missed Register (EMR)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
E31	E30	E29	E28	E27	E26	E25	E24	E23	E22	E21	E20	E19	E18	E17	E16
R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
E15	E14	E13	E12	E11	E10	E9	E8	E7	E6	E5	E4	E3	E2	E1	E0
R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0

LEGEND: R = Read only; -*n* = value after reset

Table 18-27. Event Missed Register (EMR) Field Descriptions

Bit	Field	Value	Description
31-0	E*n*		Channel 0-31 event missed. E*n* is cleared by writing a 1 to the corresponding bit in the event missed clear register (EMCR).
		0	No missed event.
		1	Missed event occurred.

18.4.2.2.2 Event Missed Clear Registers (EMCR)

Once a missed event is posted in the event missed register (EMR), the bit remains set and you need to clear the set bit(s). This is done by way of CPU writes to the event missed clear register (EMCR). Writing a 1 to any of the bits clears the corresponding missed event (bit) in EMR; writing a 0 has no effect.

The EMCR is shown in Figure 18-49 and described in Table 18-28.

Figure 18-49. Event Missed Clear Register (EMCR)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
E31	E30	E29	E28	E27	E26	E25	E24	E23	E22	E21	E20	E19	E18	E17	E16
W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
E15	E14	E13	E12	E11	E10	E9	E8	E7	E6	E5	E4	E3	E2	E1	E0
W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0

LEGEND: W = Write only; -*n* = value after reset

Table 18-28. Event Missed Clear Register (EMCR) Field Descriptions

Bit	Field	Value	Description
31-0	E*n*		Event missed 0-31 clear. All error bits must be cleared before additional error interrupts will be asserted by the EDMA3CC.
		0	No effect.
		1	Corresponding missed event bit in the event missed register (EMR) is cleared (E*n* = 0).

18.4.2.2.3 QDMA Event Missed Register (QEMR)

For a particular QDMA channel, if two QDMA events are detected without the first event getting cleared/serviced, the bit corresponding to that channel is set/asserted in the QDMA event missed register (QEMR). The QEMR bits for a channel are also set if a QDMA event on the channel encounters a NULL entry (or a NULL TR is serviced). If any QEMR bit is set (and all errors, including bits in other error registers (EMR or CCERR) were previously cleared), the EDMA3CC generates an error interrupt. See Section 18.2.9.4 for details on EDMA3CC error interrupt generation.

The QEMR is shown in Figure 18-50 and described in Table 18-29.

Figure 18-50. QDMA Event Missed Register (QEMR)

31	16
Reserved	
R-0	

15	8	7	6	5	4	3	2	1	0
Reserved		E7	E6	E5	E4	E3	E2	E1	E0
R-0		R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0

LEGEND: R = Read only; -*n* = value after reset

Table 18-29. QDMA Event Missed Register (QEMR) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved
7-0	E*n*		Channel 0-7 QDMA event missed. E*n* is cleared by writing a 1 to the corresponding bit in the QDMA event missed clear register (QEMCR).
		0	No missed event.
		1	Missed event occurred.

18.4.2.2.4 QDMA Event Missed Clear Register (QEMCR)

Once a missed event is posted in the QDMA event missed registers (QEMR), the bit remains set and you need to clear the set bit(s). This is done by way of CPU writes to the QDMA event missed clear registers (QEMCR). Writing a 1 to any of the bits clears the corresponding missed event (bit) in QEMR; writing a 0 has no effect.

The QEMCR is shown in Figure 18-51 and described in Table 18-30.

Figure 18-51. QDMA Event Missed Clear Register (QEMCR)

31	16
Reserved	
R-0	

15	8	7	6	5	4	3	2	1	0
Reserved		E7	E6	E5	E4	E3	E2	E1	E0
R-0		W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0

LEGEND: W = Write only; -*n* = value after reset

Table 18-30. QDMA Event Missed Clear Register (QEMCR) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved
7-0	E*n*		QDMA event missed clear. All error bits must be cleared before additional error interrupts will be asserted by the EDMA3CC.
		0	No effect.
		1	Corresponding missed event bit in the QDMA event missed register (QEMR) is cleared (E*n* = 0).

18.4.2.2.5 EDMA3CC Error Register (CCERR)

The EDMA3CC error register (CCERR) indicates whether or not at any instant of time the number of events queued up in any of the event queues exceeds or equals the threshold/watermark value that is set in the queue watermark threshold register (QWMTHRA). Additionally, CCERR also indicates if when the number of outstanding TRs that have been programmed to return transfer completion code (TRs that have the TCINTEN or TCCHEN bit in OPT set to 1) to the EDMA3CC has exceeded the maximum allowed value of 31. If any bit in CCERR is set (and all errors, including bits in other error registers (EMR or QEMR) were previously cleared), the EDMA3CC generates an error interrupt. See Section 18.2.9.4 for details on EDMA3CC error interrupt generation. Once the error bits are set in CCERR, they can only be cleared by writing to the corresponding bits in the EDMA3CC error clear register (CCERRCLR).

The CCERR is shown in Figure 18-52 and described in Table 18-31.

Figure 18-52. EDMA3CC Error Register (CCERR)

31	17	16
Reserved		TCCERR
R-0		R-0

15	2	1	0
Reserved		QTHRXCD1	QTHRXCD0
R-0		R-0	R-0

LEGEND: R = Read only; -*n* = value after reset

Table 18-31. EDMA3CC Error Register (CCERR) Field Descriptions

Bit	Field	Value	Description
31-17	Reserved	0	Reserved
16	TCCERR		Transfer completion code error. TCCERR is cleared by writing a 1 to the corresponding bit in the EDMA3CC error clear register (CCERRCLR).
		0	Total number of allowed TCCs outstanding has not been reached.
		1	Total number of allowed TCCs has been reached.
15-2	Reserved	0	Reserved
1	QTHRXCD1		Queue threshold error for queue 1. QTHRXCD1 is cleared by writing a 1 to the corresponding bit in the EDMA3CC error clear register (CCERRCLR).
		0	Watermark/threshold has not been exceeded.
		1	Watermark/threshold has been exceeded.
0	QTHRXCD0		Queue threshold error for queue 0. QTHRXCD0 is cleared by writing a 1 to the corresponding bit in the EDMA3CC error clear register (CCERRCLR).
		0	Watermark/threshold has not been exceeded.
		1	Watermark/threshold has been exceeded.

18.4.2.2.6 EDMA3CC Error Clear Register (CCERRCLR)

The EDMA3CC error clear register (CCERRCLR) is used to clear any error bits that are set in the EDMA3CC error register (CCERR). In addition, CCERRCLR also clears the values of some bit fields in the queue status registers (QSTAT*n*) associated with a particular event queue. Writing a 1 to any of the bits clears the corresponding bit in CCERR; writing a 0 has no effect.

The CCERRCLR is shown in Figure 18-53 and described in Table 18-32.

Figure 18-53. EDMA3CC Error Clear Register (CCERRCLR)

31	17	16
Reserved		TCCERR
W-0		W-0

15	2	1	0
Reserved		QTHRXCD1	QTHRXCD0
W-0		W-0	W-0

LEGEND: W= Write only; -*n* = value after reset

Table 18-32. EDMA3CC Error Clear Register (CCERRCLR) Field Descriptions

Bit	Field	Value	Description
31-17	Reserved	0	Reserved
16	TCCERR		Transfer completion code error clear.
		0	No effect.
		1	Clears the TCCERR bit in the EDMA3CC error register (CCERR).
15-2	Reserved	0	Reserved
1	QTHRXCD1		Queue threshold error clear for queue 1.
		0	No effect.
		1	Clears the QTHRXCD1 bit in the EDMA3CC error register (CCERR) and the WM and THRXCD bits in the queue status register 1 (QSTAT1).
0	QTHRXCD0		Queue threshold error clear for queue 0.
		0	No effect.
		1	Clears the QTHRXCD0 bit in the EDMA3CC error register (CCERR) and the WM and THRXCD bits in the queue status register 0 (QSTAT0).

18.4.2.2.7 Error Evaluate Register (EEVAL)

The EDMA3CC error interrupt is asserted whenever an error bit is set in any of the error registers (EMR, QEMR, and CCERR). For subsequent error bits that get set, the EDMA3CC error interrupt is reasserted only when transitioning from an “all the error bits cleared” to “at least one error bit is set”. Alternatively, a CPU write of 1 to the EVAL bit in the error evaluate register (EEVAL) results in reasserting the EDMA3CC error interrupt, if there are any outstanding error bits set due to subsequent error conditions. Writes of 0 have no effect.

The EEVAL is shown in Figure 18-54 and described in Table 18-33.

Figure 18-54. Error Evaluate Register (EEVAL)

31	16
Reserved	
R-0	

15	2	1	0
Reserved		Rsvd	EVAL
R-0		R/W-0	W-0

LEGEND: R/W = Read/Write; R = Read only; W = Write only; -*n* = value after reset

Table 18-33. Error Evaluate Register (EEVAL) Field Descriptions

Bit	Field	Value	Description
31-2	Reserved	0	Reserved
1	Reserved	0	Reserved. Always write 0 to this bit; writes of 1 to this bit are not supported and attempts to do so may result in undefined behavior.
0	EVAL		Error interrupt evaluate.
		0	No effect.
		1	EDMA3CC error interrupt will be pulsed if any errors have not been cleared in any of the error registers (EMR, QEMR, or CCERR).

18.4.2.3 Region Access Enable Registers

The region access enable register group consists of the DMA access enable registers (DRAE*m*) and the QDMA access enable registers (QRAE*m*). Where *m* is the number of shadow regions in the EDMA3CC memory-map for a device. You can configure these registers to assign ownership of DMA/QDMA channels to a particular shadow region.

18.4.2.3.1 DMA Region Access Enable for Region m (DRAEm)

The DMA region access enable registers for shadow region *m* (DRAE*m*) is programmed to allow or disallow read/write accesses on a bit-by-bit bases for all DMA registers in the shadow region *m* view of the DMA channel registers. See the EDMA3CC register memory-map for a list of all the DMA channel and interrupt registers mapped in the shadow region view. Additionally, the DRAE*m* configuration determines completion of which DMA channels will result in assertion of the shadow region *m* DMA completion interrupt (see Section 18.2.9).

The DRAE*m* is shown in Figure 18-55 and described in Table 18-34.

Figure 18-55. DMA Region Access Enable Register for Region *m* (DRAE*m*)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
E31	E30	E29	E28	E27	E26	E25	E24	E23	E22	E21	E20	E19	E18	E17	E16
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
E15	E14	E13	E12	E11	E10	E9	E8	E7	E6	E5	E4	E3	E2	E1	E0
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; -*n* = value after reset

Table 18-34. DMA Region Access Enable Register for Region *m* (DRAE*m*) Field Descriptions

Bit	Field	Value	Description
31-0	E*n*		DMA region access enable for bit *n*/channel *n* in region *m*.
		0	Accesses via region *m* address space to bit *n* in any DMA channel register are not allowed. Reads return 0 on bit *n* and writes do not modify the state of bit *n*. Enabled interrupt bits for bit *n* do not contribute to the generation of a transfer completion interrupt for shadow region *m*.
		1	Accesses via region *m* address space to bit *n* in any DMA channel register are allowed. Reads return the value from bit *n* and writes modify the state of bit *n*. Enabled interrupt bits for bit *n* contribute to the generation of a transfer completion interrupt for shadow region *m*.

18.4.2.3.2 QDMA Region Access Enable Registers (QRAE*m*)

The QDMA region access enable registers for shadow region *m* (QRAE*m*) is programmed to allow or disallow read/write accesses on a bit-by-bit bases for all QDMA registers in the shadow region *m* view of the QDMA registers. This includes all 8-bit QDMA registers.

The QRAE*m* is shown in Figure 18-56 and described in Table 18-35.

Figure 18-56. QDMA Region Access Enable for Region *m* (QRAE*m*)

31								16
Reserved								
R-0								
15	8	7	6	5	4	3	2	1	0
Reserved		E7	E6	E5	E4	E3	E2	E1	E0
R-0		R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 18-35. QDMA Region Access Enable for Region *m* (QRAE*m*) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved
7-0	E*n*		QDMA region access enable for bit *n*/QDMA channel *n* in region *m*.
		0	Accesses via region *m* address space to bit *n* in any QDMA channel register are not allowed. Reads return 0 on bit *n* and writes do not modify the state of bit *n*.
		1	Accesses via region *m* address space to bit *n* in any QDMA channel register are allowed. Reads return the value from bit *n* and writes modify the state of bit *n*.

18.4.2.4 Status/Debug Visibility Registers

The following set of registers provide visibility into the event queues and a TR lifecycle. These are useful for system debug as they provide in-depth visibility for the events queued up in the event queue and also provide information on what parts of the EDMA3CC logic are active once the event has been received by the EDMA3CC.

18.4.2.4.1 Event Queue Entry Registers (QxEy)

The event queue entry registers (Q*x*E*y*) exist for all 16 queue entries (the maximum allowed queue entries) for all event queues (Q0 and Q1) in the EDMA3CC: Q0E0 to Q0E15 and Q1E0 to Q1E15. Each register details the event number (ENUM) and the event type (ETYPE). For example, if the value in Q1E4 is read as 0000 004Fh, this means the 4th entry in queue 1 is a manually-triggered event on DMA channel 15.

The Q*x*E*y* is shown in Figure 18-57 and described in Table 18-36.

Figure 18-57. Event Queue Entry Registers (Q*x*E*y*)

31	16
Reserved	
R-0	

15	8	7	6	5	4	0
Reserved		ETYPE		Rsvd	ENUM	
R-0		R-x		R-0	R-x	

LEGEND: R = Read only; -*n* = value after reset; -x = value is indeterminate after reset

Table 18-36. Event Queue Entry Registers (Q*x*E*y*) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved
7-6	ETYPE	0-3h	Event entry *y* in queue *x*. Specifies the specific event type for the given entry in the event queue.
		0	Event triggered via ER
		1h	Manual triggered via ESR
		2h	Chain triggered via CER
		3h	Autotriggered via QER
5	Reserved	0	Reserved
4-0	ENUM	0-1Fh	Event entry *y* in queue *x*. Event number:
		0-7h	QDMA channel number (0 to 7)
		0-1Fh	DMA channel/event number (0 to 31)

18.4.2.4.2 Queue *n* Status Registers (QSTAT*n*)

The queue *n* status register (QSTAT*n*) is shown in Figure 18-58 and described in Table 18-37.

Figure 18-58. Queue *n* Status Register (QSTAT*n*)

31	25	24	23	21	20	16
Reserved		THRXCD	Reserved		WM	
R-0		R-0	R-0		R-0	

15	13	12	8	7	4	3	0
Reserved		NUMVAL		Reserved		STRTPTR	
R-0		R-0		R-0		R-0	

LEGEND: R = Read only; -*n* = value after reset

Table 18-37. Queue *n* Status Register (QSTAT*n*) Field Descriptions

Bit	Field	Value	Description
31-25	Reserved	0	Reserved
24	THRXCD		Threshold exceeded. THRXCD is cleared by writing a 1 to the corresponding QTHRXCD*n* bit in the EDMA3CC error clear register (CCERRCLR).
		0	Threshold specified by the Q*n* bit in the queue watermark threshold A register (QWMTHRA) has not been exceeded.
		1	Threshold specified by the Q*n* bit in the queue watermark threshold A register (QWMTHRA) has been exceeded.
23-21	Reserved	0	Reserved
20-16	WM	0-1Fh	Watermark for maximum queue usage. Watermark tracks the most entries that have been in queue *n* since reset or since the last time that the watermark (WM) bit was cleared. WM is cleared by writing a 1 to the corresponding QTHRXCD*n* bit in the EDMA3CC error clear register (CCERRCLR).
		0-10h	Legal values are 0 (empty) to 10h (full).
		11h-1Fh	Reserved
15-13	Reserved	0	Reserved
12-8	NUMVAL	0-1Fh	Number of valid entries in queue *n*. The total number of entries residing in the queue manager FIFO at a given instant. Always enabled.
		0-10h	Legal values are 0 (empty) to 10h (full).
		11h-1Fh	Reserved
7-4	Reserved	0	Reserved
3-0	STRTPTR	0-Fh	Start pointer. The offset to the head entry of queue *n*, in units of entries. Always enabled. Legal values are 0 (0th entry) to Fh (15th entry).

18.4.2.4.3 Queue Watermark Threshold A Register (QWMTHRA)

The queue watermark threshold A register (QWMTHRA) is shown in Figure 18-59 and described in Table 18-38.

Figure 18-59. Queue Watermark Threshold A Register (QWMTHRA)

31	16
Reserved	
R-0	

15	13	12	8	7	5	4	0
Reserved		Q1		Reserved		Q0	
R-0		R/W-10h		R-0		R/W-10h	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 18-38. Queue Watermark Threshold A Register (QWMTHRA) Field Descriptions

Bit	Field	Value	Description
31-13	Reserved	0	Reserved
12-8	Q1	0-1Fh	Queue threshold for queue 1 value. The QTHRXCD1 bit in the EDMA3CC error register (CCERR) and the THRXCD bit in the queue status register 1 (QSTAT1) are set when the number of events in queue 1 at an instant in time (visible via the NUMVAL bit in QSTAT1) equals or exceeds the value specified by Q1.
		0-10h	The default is 16 (maximum allowed).
		11h	Disables the threshold errors.
		12h-1Fh	Reserved
7-5	Reserved	0	Reserved
4-0	Q0	0-1Fh	Queue threshold for queue 0 value. The QTHRXCD0 bit in the EDMA3CC error register (CCERR) and the THRXCD bit in the queue status register 0 (QSTAT0) are set when the number of events in queue 0 at an instant in time (visible via the NUMVAL bit in QSTAT0) equals or exceeds the value specified by Q0.
		0-10h	The default is 16 (maximum allowed).
		11h	Disables the threshold errors.
		12h-1Fh	Reserved

18.4.2.4.4 EDMA3CC Status Register (CCSTAT)

The EDMA3CC status register (CCSTAT) has a number of status bits that reflect which parts of the EDMA3CC logic is active at any given instant of time. The CCSTAT is shown in Figure 18-60 and described in Table 18-39.

Figure 18-60. EDMA3CC Status Register (CCSTAT)

31	24
Reserved	
R-0	

23	18	17	16
Reserved		QUEACTV1	QUEACTV0
R-0		R-0	R-0

15	14	13	8
Reserved		COMPACTV	
R-0		R-0	

7	5	4	3	2	1	0
Reserved		ACTV	WSTATACTV	TRACTV	QEVTACTV	EVTACTV
R-0		R-0	R-0	R-0	R-0	R-0

LEGEND: R = Read only; -*n* = value after reset

Table 18-39. EDMA3CC Status Register (CCSTAT) Field Descriptions

Bit	Field	Value	Description
31-18	Reserved	0	Reserved
17	QUEACTV1		Queue 1 active.
		0	No events are queued in queue 1.
		1	At least one TR is queued in queue 1.
16	QUEACTV0		Queue 0 active.
		0	No events are queued in queue 0.
		1	At least one TR is queued in queue 0.
15-14	Reserved	0	Reserved
13-8	COMPACTV	0-3Fh	Completion request active. The COMPACTV field reflects the count for the number of completion requests submitted to the transfer controllers. This count increments every time a TR is submitted and is programmed to report completion (the TCINTEN or TCCCHEN bits in OPT in the parameter entry associated with the TR are set to 1). The counter decrements for every valid TCC received back from the transfer controllers. If at any time the count reaches a value of 63, the EDMA3CC will not service any new TRs until the count is less then 63 (or return a transfer completion code from a transfer controller, which would decrement the count).
		0	No completion requests outstanding.
		1h-3Fh	Total of 1 completion request to 63 completion requests are outstanding.
7-5	Reserved	0	Reserved
4	ACTV		Channel controller active. Channel controller active is a logical-OR of each of the *ACTV bits. The ACTV bit remains high through the life of a TR.
		0	Channel is idle.
		1	Channel is busy.
3	WSTATACTV		Write status interface active.
		0	Write status req is idle and write status fifo is idle.
		1	Either the write status request is active or additional write status responses are pending in the write status fifo.
2	TRACTV		Transfer request active.
		0	Transfer request processing/submission logic is inactive.
		1	Transfer request processing/submission logic is active.

Table 18-39. EDMA3CC Status Register (CCSTAT) Field Descriptions (continued)

Bit	Field	Value	Description
1	QEVTACTV		QDMA event active.
		0	No enabled QDMA events are active within the EDMA3CC.
		1	At least one enabled QDMA event (QER) is active within the EDMA3CC.
0	EVTACTV		DMA event active.
		0	No enabled DMA events are active within the EDMA3CC.
		1	At least one enabled DMA event (ER and EER, ESR, CER) is active within the EDMA3CC.

18.4.2.5 DMA Channel Registers

The following registers pertain to the 32 DMA channels. The 32 DMA channels consist of registers (with the exception of DMAQNUM*n*) that each have 32 bits and the bit position of each register matches the DMA channel number.

The DMA channel registers are accessible via read/writes to the global address range. They are also accessible via read/writes to the shadow address range. The read/write ability to the registers in the shadow region is controlled by the DMA region access registers (DRAE*m*). These registers are described in Section 18.4.2.3.1 and the details for shadow region/global region usage is explained in Section 18.2.7.

18.4.2.5.1 Event Register (ER)

All external events are captured in the event register (ER). The events are latched even when the events are not enabled. If the event bit corresponding to the latched event is enabled (EER.E*n* = 1), then the event is evaluated by the EDMA3CC logic for an associated transfer request submission to the transfer controllers. The event register bits are automatically cleared (ER.E*n* = 0) once the corresponding events are prioritized and serviced. If ER.E*n* are already set and another event is received on the same channel/event, then the corresponding event is latched in the event miss register (EMR.E*n*), provided that the event was enabled (EER.E*n* = 1).

Event *n* can be cleared by the CPU writing a 1 to corresponding event bit in the event clear register (ECR). The setting of an event is a higher priority relative to clear operations (via hardware or software). If set and clear conditions occur concurrently, the set condition wins. If the event was previously set, then EMR would be set since an event is lost. If the event was previously clear, then the event remains set and is prioritized for submission to the event queues.

The ER is shown in Figure 18-61 and described in Table 18-40.

Figure 18-61. Event Register (ER)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
E31	E30	E29	E28	E27	E26	E25	E24	E23	E22	E21	E20	19	E18	E17	E16
R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
E15	E14	E13	E12	E11	E10	E9	E8	E7	E6	E5	E4	E3	E2	E1	E0
R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0

LEGEND: R = Read only; -*n* = value after reset

Table 18-40. Event Register (ER) Field Descriptions

Bit	Field	Value	Description
31-0	E*n*		Event 0-31. Events 0-31 are captured by the EDMA3CC and are latched into ER. The events are set (E*n* = 1) even when events are disabled (E*n* = 0 in the event enable register, EER).
		0	EDMA3CC event is not asserted.
		1	EDMA3CC event is asserted. Corresponding DMA event is prioritized versus other pending DMA/QDMA events for submission to the EDMA3TC.

18.4.2.5.2 Event Clear Register (ECR)

Once an event has been posted in the event register (ER), the event is cleared in two ways. If the event is enabled in the event enable register (EER) and the EDMA3CC submits a transfer request for the event to the EDMA3TC, it clears the corresponding event bit in the event register. If the event is disabled in the event enable register (EER), the CPU can clear the event by way of the event clear register (ECR).

Writing a 1 to any of the bits clears the corresponding event; writing a 0 has no effect. Once an event bit is set in the event register, it remains set until EDMA3CC submits a transfer request for that event or the CPU clears the event by setting the corresponding bit in ECR.

The ECR is shown in Figure 18-62 and described in Table 18-41.

Figure 18-62. Event Clear Register (ECR)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
E31	E30	E29	E28	E27	E26	E25	E24	E23	E22	E21	E20	E19	E18	E17	E16
W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
E15	E14	E13	E12	E11	E10	E9	E8	E7	E6	E5	E4	E3	E2	E1	E0
W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0

LEGEND: W = Write only; *-n* = value after reset

Table 18-41. Event Clear Register (ECR) Field Descriptions

Bit	Field	Value	Description
31-0	E*n*		Event clear for event 0-31. Any of the event bits in ECR is set to 1 to clear the event (E*n*) in the event register (ER). A write of 0 has no effect.
		0	No effect.
		1	EDMA3CC event is cleared in the event register (ER).

18.4.2.5.3 Event Set Register (ESR)

The event set register (ESR) allows the CPU (or EDMA programmers) to manually set events to initiate DMA transfer requests. CPU writes of 1 to any event set register (E*n*) bits set the corresponding bits in the registers. The set event is evaluated by the EDMA3CC logic for an associated transfer request submission to the transfer controllers. Writing a 0 has no effect.

The event set register operates independent of the event register (ER), and a write of 1 is always considered a valid event regardless of whether the event is enabled (the corresponding event bits are set or cleared in EER.E*n*).

Once the event is set in the event set register, it cannot be cleared by CPU writes, in other words, the event clear register (ECR) has no effect on the state of ESR. The bits will only be cleared once the transfer request corresponding to the event has been submitted to the transfer controller. The setting of an event is a higher priority relative to clear operations (via hardware). If set and clear conditions occur concurrently, the set condition wins. If the event was previously set, then EMR would be set since an event is lost. If the event was previously clear, then the event remains set and is prioritized for submission to the event queues.

Manually-triggered transfers via writes to ESR allow the CPU to submit DMA requests in the system, these are relevant for memory-to-memory transfer scenarios. If the ESR.E*n* bit is already set and another CPU write of 1 is attempted to the same bit, then the corresponding event is latched in the event missed registers (EMR.E*n* = 1).

The ESR is shown in Figure 18-63 and described in Table 18-42.

Figure 18-63. Event Set Register (ESR)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
E31	E30	E29	E28	E27	E26	E25	E24	E23	E22	E21	E20	E19	E18	E17	E16
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
E15	E14	E13	E12	E11	E10	E9	E8	E7	E6	E5	E4	E3	E2	E1	E0
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; -*n* = value after reset

Table 18-42. Event Set Register (ESR) Field Descriptions

Bit	Field	Value	Description
31-0	E*n*		Event set for event 0-31.
		0	No effect.
		1	Corresponding DMA event is prioritized versus other pending DMA/QDMA events for submission to the EDMA3TC.

18.4.2.5.4 Chained Event Register (CER)

When the OPTIONS parameter for a PaRAM entry is programmed to returned a chained completion code (ITCCHEN = 1 and/or TCCHEN = 1), then the value dictated by the TCC[5:0] (also programmed in OPT) forces the corresponding event bit to be set in the chained event register (CER). The set chained event is evaluated by the EDMA3CC logic for an associated transfer request submission to the transfer controllers. This results in a chained-triggered transfer.

The chained event registers do not have any enables. The generation of a chained event is essentially enabled by the PaRAM entry that has been configured for intermediate and/or final chaining on transfer completion. The E*n* bit is set (regardless of the state of EER.E*n*) when a chained completion code is returned from one of the transfer controllers or is generated by the EDMA3CC via the early completion path. The bits in the chained event register are cleared when the corresponding events are prioritized and serviced.

If the E*n* bit is already set and another chaining completion code is return for the same event, then the corresponding event is latched in the event missed register (EMR.E*n* = 1). The setting of an event is a higher priority relative to clear operations (via hardware). If set and clear conditions occur concurrently, the set condition wins. If the event was previously set, then EMR would be set since an event is lost. If the event was previously clear, then the event remains set and is prioritized for submission to the event queues.

The CER is shown in Figure 18-64 and described in Table 18-43.

Figure 18-64. Chained Event Register (CER)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
E31	E30	E29	E28	E27	E26	E25	E24	E23	E22	E21	E20	E19	E18	E17	E16
R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
E15	E14	E13	E12	E11	E10	E9	E8	E7	E6	E5	E4	E3	E2	E1	E0
R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0

LEGEND: R = Read only; -*n* = value after reset

Table 18-43. Chained Event Register (CER) Field Descriptions

Bit	Field	Value	Description
31-0	E*n*		Chained event for event 0-31.
		0	No effect.
		1	Corresponding DMA event is prioritized versus other pending DMA/QDMA events for submission to the EDMA3TC.

18.4.2.5.5 Event Enable Register (EER)

The EDMA3CC provides the option of selectively enabling/disabling each event in the event register (ER) by using the event enable register (EER). If an event bit in EER is set to 1 (using the event enable set register, EESR), it will enable that corresponding event. Alternatively, if an event bit in EER is cleared (using the event enable clear register, EECR), it will disable the corresponding event.

The event register latches all events that are captured by EDMA3CC, even if the events are disabled (although EDMA3CC does not process it). Enabling an event with a pending event already set in the event register enables the EDMA3CC to process the already set event like any other new event. The EER settings do not have any effect on chained events (CER.E*n* = 1) and manually set events (ESR.E*n* = 1).

The EER is shown in Figure 18-65 and described in Table 18-44.

Figure 18-65. Event Enable Register (EER)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
E31	E30	E29	E28	E27	E26	E25	E24	E23	E22	E21	E20	E19	E18	E17	E16
R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
E15	E14	E13	E12	E11	E10	E9	E8	E7	E6	E5	E4	E3	E2	E1	E0
R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0

LEGEND: R = Read only; -*n* = value after reset

Table 18-44. Event Enable Register (EER) Field Descriptions

Bit	Field	Value	Description
31-0	E*n*		Event enable for events 0-31.
		0	Event is not enabled. An external event latched in the event register (ER) is not evaluated by the EDMA3CC.
		1	Event is enabled. An external event latched in the event register (ER) is evaluated by the EDMA3CC.

18.4.2.5.6 Event Enable Clear Register (EECR)

The event enable register (EER) cannot be modified by directly writing to it. The intent is to ease the software burden for the case where multiple tasks are attempting to simultaneously modify these registers. The event enable clear register (EECR) is used to disable events. Writes of 1 to the bits in EECR clear the corresponding event bits in EER; writes of 0 have no effect.

The EECR is shown in Figure 18-66 and described in Table 18-45.

Figure 18-66. Event Enable Clear Register (EECR)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
E31	E30	E29	E28	E27	E26	E25	E24	E23	E22	E21	E20	E19	E18	E17	E16
W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
E15	E14	E13	E12	E11	E10	E9	E8	E7	E6	E5	E4	E3	E2	E1	E0
W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0

LEGEND: W = Write only; -*n* = value after reset

Table 18-45. Event Enable Clear Register (EECR) Field Descriptions

Bit	Field	Value	Description
31-0	E*n*		Event enable clear for events 0-31.
		0	No effect.
		1	Event is disabled. Corresponding bit in the event enable register (EER) is cleared (E*n* = 0).

18.4.2.5.7 Event Enable Set Register (EESR)

The event enable register (EER) cannot be modified by directly writing to it. The intent is to ease the software burden for the case where multiple tasks are attempting to simultaneously modify these registers. The event enable set register (EESR) is used to enable events. Writes of 1 to the bits in EESR set the corresponding event bits in EER; writes of 0 have no effect.

The EESR is shown in Figure 18-67 and described in Table 18-46.

Figure 18-67. Event Enable Set Register (EESR)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
E31	E30	E29	E28	E27	E26	E25	E24	E23	E22	E21	E20	E19	E18	E17	E16
W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
E15	E14	E13	E12	E11	E10	E9	E8	E7	E6	E5	E4	E3	E2	E1	E0
W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0

LEGEND: W = Write only; -*n* = value after reset

Table 18-46. Event Enable Set Register (EESR) Field Descriptions

Bit	Field	Value	Description
31-0	E*n*		Event enable set for events 0-31.
		0	No effect.
		1	Event is enabled. Corresponding bit in the event enable register (EER) is set (E*n* = 1).

18.4.2.5.8 Secondary Event Register (SER)

The secondary event register (SER) provides information on the state of a DMA channel or event (0 through 31). If the EDMA3CC receives a TR synchronization due to a manual-trigger, event-trigger, or chained-trigger source (ESR.E*n* = 1, ER.E*n* = 1, or CER.E*n* = 1), which results in the setting of a corresponding event bit in SER (SER.E*n* = 1), it implies that the corresponding DMA event is in the queue.

Once a bit corresponding to an event is set in SER, the EDMA3CC does not prioritize additional events on the same DMA channel. Depending on the condition that leads to the setting of the SER bits, either the EDMA3CC hardware or the software (using SECR) needs to clear the SER bits for the EDMA3CC to evaluate subsequent events and perform subsequent transfers on the same channel. Based on whether the associated TR is valid, or it is a null or dummy TR, the implications on the state of SER and the required user action in order to submit another DMA transfer might be different.

The SER is shown in Figure 18-68 and described in Table 18-47.

Figure 18-68. Secondary Event Register (SER)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
E31	E30	E29	E28	E27	E26	E25	E24	E23	E22	E21	E20	E19	E18	E17	E16
R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
E15	E14	E13	E12	E11	E10	E9	E8	E7	E6	E5	E4	E3	E2	E1	E0
R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0

LEGEND: R = Read only; -*n* = value after reset

Table 18-47. Secondary Event Register (SER) Field Descriptions

Bit	Field	Value	Description
31-0	E*n*		Secondary event register. The secondary event register is used to provide information on the state of an event.
		0	Event is not currently stored in the event queue.
		1	Event is currently stored in the event queue. Event arbiter will not prioritize additional events.

18.4.2.5.9 Secondary Event Clear Register (SECR)

The secondary event clear register (SECR) clears the status of the secondary event registers (SER). CPU writes of 1 clear the corresponding set bits in SER. Writes of 0 have no effect.

The SECR is shown in Figure 18-69 and described in Table 18-48.

Figure 18-69. Secondary Event Clear Register (SECR)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
E31	E30	E29	E28	E27	E26	E25	E24	E23	E22	E21	E20	E19	E18	E17	E16
W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
E15	E14	E13	E12	E11	E10	E9	E8	E7	E6	E5	E4	E3	E2	E1	E0
W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0

LEGEND: W = Write only; -*n* = value after reset

Table 18-48. Secondary Event Clear Register (SECR) Field Descriptions

Bit	Field	Value	Description
31-0	E*n*		Secondary event clear register
		0	No effect.
		1	Corresponding bit in the secondary event register (SER) is cleared (E*n* = 0).

18.4.2.6 Interrupt Registers

All DMA/QDMA channels can be set to assert an EDMA3CC completion interrupt to the CPU on transfer completion, by appropriately configuring the PaRAM entry associated with the channels. The following registers are used for the transfer completion interrupt reporting/generating by the EDMA3CC. See Section 18.2.9 for more details on EDMA3CC completion interrupt generation.

18.4.2.6.1 Interrupt Enable Registers (IER)

Interrupt enable register (IER) is used to enable/disable the transfer completion interrupt generation by the EDMA3CC for all DMA/QDMA channels. The IER cannot be written to directly. To set any interrupt bit in IER, a 1 must be written to the corresponding interrupt bit in the interrupt enable set registers (IESR). Similarly, to clear any interrupt bit in IER, a 1 must be written to the corresponding interrupt bit in the interrupt enable clear register (IECR).

The IER is shown in Figure 18-70 and described in Table 18-49.

Figure 18-70. Interrupt Enable Register (IER)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
I31	I30	I29	I28	I27I	I26	I25	I24	I23	I22	I21	I20	I19	I18	I17	I16
R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
I15	I14	I13	I12	I11	I10	I9	I8	I7	I6	I5	I4	I3	I2	I1	I0
R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0

LEGEND: R = Read only; -*n* = value after reset

Table 18-49. Interrupt Enable Register (IER) Field Descriptions

Bit	Field	Value	Description
31-0	E*n*		Interrupt enable for channels 0-31.
		0	Interrupt is not enabled.
		1	Interrupt is enabled.

18.4.2.6.2 Interrupt Enable Clear Register (IECR)

The interrupt enable clear register (IECR) is used to clear interrupts. Writes of 1 to the bits in IECR clear the corresponding interrupt bits in the interrupt enable registers (IER); writes of 0 have no effect.

The IECR is shown in Figure 18-71 and described in Table 18-50.

Figure 18-71. Interrupt Enable Clear Register (IECR)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
I31	I30	I29	I28	I27	I26	I25	I24	I23	I22	I21	I20	I19	I18	I17	16
W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
I15	I14	I13	I12	I11	I10	I9	I8	I7	I6	I5	I4	I3	I2	I1	I0
W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0

LEGEND: W = Write only; -*n* = value after reset

Table 18-50. Interrupt Enable Clear Register (IECR) Field Descriptions

Bit	Field	Value	Description
31-0	E*n*		Interrupt enable clear for channels 0-31.
		0	No effect
		1	Corresponding bit in the interrupt enable register (IER) is cleared (I*n* = 0).

18.4.2.6.3 Interrupt Enable Set Register (IESR)

The interrupt enable set register (IESR) is used to enable interrupts. Writes of 1 to the bits in IESR set the corresponding interrupt bits in the interrupt enable registers (IER); writes of 0 have no effect.

The IESR is shown in Figure 18-72 and described in Table 18-51.

Figure 18-72. Interrupt Enable Set Register (IESR)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
I31	I30	I29	I28	I27	I26	I25	I24	I23	I22	I21	I20	I19	II8	I17	I16
W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
I15	I14	I13	I12	I11	I10	I9	I8	I7	I6	I5	I4	I3	I2	I1	I0
W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0

LEGEND: W = Write only; -*n* = value after reset

Table 18-51. Interrupt Enable Set Register (IESR) Field Descriptions

Bit	Field	Value	Description
31-0	E*n*		Interrupt enable set for channels 0-31.
		0	No effect.
		1	Corresponding bit in the interrupt enable register (IER) is set (I*n* = 1).

18.4.2.6.4 Interrupt Pending Register (IPR)

If the TCINTEN and/or ITCINTEN bit in the channel option parameter (OPT) is set to 1 in the PaRAM entry associated with the channel (DMA or QDMA), then the EDMA3TC (for normal completion) or the EDMA3CC (for early completion) returns a completion code on transfer or intermediate transfer completion. The value of the returned completion code is equal to the TCC bit in OPT for the PaRAM entry associated with the channel.

When an interrupt transfer completion code with TCC = *n* is detected by the EDMA3CC, then the corresponding bit is set in the interrupt pending register (IPR.I*n*, if *n* = 0 to 31). Note that once a bit is set in the interrupt pending registers, it remains set; it is your responsibility to clear these bits. The bits set in IPR are cleared by writing a 1 to the corresponding bits in the interrupt clear registers (ICR).

The IPR is shown in Figure 18-73 and described in Table 18-52.

Figure 18-73. Interrupt Pending Register (IPR)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
I31	I30	I29	I28	I27	I26	I25	I24	I23	I22	I21	I20	I19	I18	I17	I16
R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
I15	I14	I13	I12	I11	I10	I9	I8	I7	I6	I5	I4	I3	I2	I1	I0
R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0

LEGEND: R = Read only; -*n* = value after reset

Table 18-52. Interrupt Pending Register (IPR) Field Descriptions

Bit	Field	Value	Description
31-0	I*n*		Interrupt pending for TCC = 0-31.
		0	Interrupt transfer completion code is not detected or was cleared.
		1	Interrupt transfer completion code is detected (I*n* = 1, *n* = EDMA3TC[5:0]).

18.4.2.6.5 Interrupt Clear Register (ICR)

The bits in the interrupt pending register (IPR) are cleared by writing a 1 to the corresponding bits in the interrupt clear register (ICR); writes of 0 have no effect. All set bits in IPR must be cleared to allow EDMA3CC to assert additional transfer completion interrupts.

The ICR is shown in Figure 18-74 and described in Table 18-53.

Figure 18-74. Interrupt Clear Register (ICR)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
I31	I30	I29	I28	I27	I26	I25	I24	I23	I22	I21	I20	I19	I18	I17	I16
W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
I15	I14	I13	I12	I11	I10	I9	I8	I7	I6	I5	I4	I3	I2	I1	I0
W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0

LEGEND: W = Write only; -*n* = value after reset

Table 18-53. Interrupt Clear Register (ICR) Field Descriptions

Bit	Field	Value	Description
31-0	I*n*		Interrupt clear register for TCC = 0-31.
		0	No effect.
		1	Corresponding bit in the interrupt pending register (IPR) is cleared (I*n* = 0).

18.4.2.6.6 Interrupt Evaluate Register (IEVAL)

The interrupt evaluate register (IEVAL) is the only register that physically exists in both the global region and the shadow regions. In other words, the read/write accessibility for the shadow region IEVAL is not affected by the DMA/QDMA region access registers (DRAE*m* and QRAE*m*). IEVAL is needed for robust ISR operations to ensure that interrupts are not missed by the CPU.

The IEVAL is shown in Figure 18-75 and described in Table 18-54.

Figure 18-75. Interrupt Evaluate Register (IEVAL)

31	16
Reserved	
R-0	

15	2	1	0
Reserved		Rsvd	EVAL
R-0		W-0	W-0

LEGEND: R = Read only; W = Write only; -*n* = value after reset

Table 18-54. Interrupt Evaluate Register (IEVAL) Field Descriptions

Bit	Field	Value	Description
31-2	Reserved	0	Reserved
1	Reserved	0	Reserved. Always write 0 to this bit; writes of 1 to this bit are not supported and attempts to do so may result in undefined behavior.
0	EVAL		Interrupt evaluate.
		0	No effect.
		1	Causes EDMA3CC completion interrupt to be pulsed, if any enabled (IER*n* = 1) interrupts are still pending (IPR*n* = 1). The EDMA3CC completion region interrupt that is pulsed depends on which IEVAL is being exercised. For example, writing to the EVAL bit in IEVAL0 pulses the region 0 completion interrupt, but writing to the EVAL bit in IEVAL1 pulses the region 1 completion interrupt.

18.4.2.7 QDMA Channel Registers

The following registers pertain to the 8 QDMA channels. The 8 QDMA channels consist of registers (with the exception of QDMAQNUM) that each have 8 bits and the bit position of each register matches the QDMA channel number.

The QDMA channel registers are accessible via read/writes to the global address range. They are also accessible via read/writes to the shadow address range. The read/write ability to the registers in the shadow region is controlled by the QDMA region access registers (QRAE*m*). These registers are described in Section 18.4.2.3.2 and the details for shadow region/global region usage is explained in Section 18.2.7.

18.4.2.7.1 QDMA Event Register (QER)

The QDMA event register (QER) channel *n* bit is set (E*n* = 1) when the CPU or any EDMA programmer (including EDMA3) performs a write to the trigger word (using the QDMA channel *n* mapping register (QCHMAP*n*)) in the PaRAM entry associated with QDMA channel *n* (which is also programmed using QCHMAP*n*). The E*n* bit is also set when the EDMA3CC performs a link update on a PaRAM address that matches the QCHMAP*n* settings. The QDMA event is latched only if the QDMA event enable register (QEER) channel *n* bit is also enabled (QEER.E*n* = 1). Once a bit is set in QER, then the corresponding QDMA event (auto-trigger) is evaluated by the EDMA3CC logic for an associated transfer request submission to the transfer controllers.

The setting of an event is a higher priority relative to clear operations (via hardware). If set and clear conditions occur concurrently, the set condition wins. If the event was previously set, then the QDMA event missed register (QEMR) would be set because an event is lost. If the event was previously clear, then the event remains set and is prioritized for submission to the event queues.

The set bits in QER are only cleared when the transfer request associated with the corresponding channels has been processed by the EDMA3CC and submitted to the transfer controller. If the E*n* bit is already set and a QDMA event for the same QDMA channel occurs prior to the original being cleared, then the second missed event is latched in QEMR (E*n* =1).

The QER is shown in Figure 18-76 and described in Table 18-55.

Figure 18-76. QDMA Event Register (QER)

31	16
Reserved	
R-0	

15	8	7	6	5	4	3	2	1	0
Reserved		E7	E6	E5	E4	E3	E2	E1	E0
R-0		R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0

LEGEND: R = Read only; -*n* = value after reset

Table 18-55. QDMA Event Register (QER) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved
7-0	E*n*		QDMA event for channels 0-7.
		0	No effect.
		1	Corresponding QDMA event is prioritized versus other pending DMA/QDMA events for submission to the EDMA3TC.

18.4.2.7.2 QDMA Event Enable Register (QEER)

The EDMA3CC provides the option of selectively enabling/disabling each channel in the QDMA event register (QER) by using the QDMA event enable register (QEER). If any of the event bits in QEER is set to 1 (using the QDMA event enable set register, QEESR), it will enable that corresponding event. Alternatively, if any event bit in QEER is cleared (using the QDMA event enable clear register, QEECR), it will disable the corresponding QDMA channel. The QDMA event register will not latch any event for a QDMA channel, if it is not enabled via QEER.

The QEER is shown in Figure 18-77 and described in Table 18-56.

Figure 18-77. QDMA Event Enable Register (QEER)

31	16
Reserved	
R-0	

15	8	7	6	5	4	3	2	1	0
Reserved		E7	E6	E5	E4	E3	E2	E1	E0
R-0		R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0

LEGEND: R = Read only; -*n* = value after reset

Table 18-56. QDMA Event Enable Register (QEER) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved
7-0	E*n*		QDMA event enable for channels 0-7.
		0	QDMA channel *n* is not enabled. QDMA event will not be recognized and will not latch in the QDMA event register (QER).
		1	QDMA channel *n* is enabled. QDMA events will be recognized and will get latched in the QDMA event register (QER).

18.4.2.7.3 QDMA Event Enable Clear Register (QEECR)

The QDMA event enable register (QEER) cannot be modified by directly writing to the register, in order to ease the software burden when multiple tasks are attempting to simultaneously modify these registers. The QDMA event enable clear register (QEECR) is used to disable events. Writes of 1 to the bits in QEECR clear the corresponding QDMA channel bits in QEER; writes of 0 have no effect.

The QEECR is shown in Figure 18-78 and described in Table 18-57.

Figure 18-78. QDMA Event Enable Clear Register (QEECR)

31	16
Reserved	
R-0	

15	8	7	6	5	4	3	2	1	0
Reserved		E7	E6	E5	E4	E3	E2	E1	E0
R-0		W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0

LEGEND: R = Read only; W = Write only; -*n* = value after reset

Table 18-57. QDMA Event Enable Clear Register (QEECR) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved
7-0	E*n*		QDMA event enable clear for channels 0-7.
		0	No effect.
		1	QDMA event is disabled. Corresponding bit in the QDMA event enable register (QEER) is cleared (E*n* = 0).

18.4.2.7.4 QDMA Event Enable Set Register (QEESR)

The QDMA event enable register (QEER) cannot be modified by directly writing to the register, in order to ease the software burden when multiple tasks are attempting to simultaneously modify these registers. The QDMA event enable set register (QEESR) is used to enable events. Writes of 1 to the bits in QEESR set the corresponding QDMA channel bits in QEER; writes of 0 have no effect.

The QEESR is shown in Figure 18-79 and described in Table 18-58.

Figure 18-79. QDMA Event Enable Set Register (QEESR)

31	16
Reserved	
R-0	

15	8	7	6	5	4	3	2	1	0
Reserved		E7	E6	E5	E4	E3	E2	E1	E0
R-0		W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0

LEGEND: R = Read only; W = Write only; -*n* = value after reset

Table 18-58. QDMA Event Enable Set Register (QEESR) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved
7-0	E*n*		QDMA event enable set for channels 0-7.
		0	No effect.
		1	QDMA event is enabled. Corresponding bit in the QDMA event enable register (QEER) is set (E*n* = 1).

18.4.2.7.5 QDMA Secondary Event Register (QSER)

The QDMA secondary event register (QSER) provides information on the state of a QDMA event. If at any time a bit corresponding to a QDMA channel is set in QSER, that implies that the corresponding QDMA event is in the queue. Once a bit corresponding to a QDMA channel is set in QSER, the EDMA3CC does not prioritize additional events on the same QDMA channel. Depending on the condition that lead to the setting of the QSER bits, either the EDMA3CC hardware or the software (using QSECR) needs to clear the QSER bits for the EDMA3CC to evaluate subsequent QDMA events on the channel. Based on whether the associated TR is valid, or it is a null or dummy TR, the implications on the state of QSER and the required user action in order to submit another QDMA transfer might be different.

The QSER is shown in Figure 18-80 and described in Table 18-59.

Figure 18-80. QDMA Secondary Event Register (QSER)

31	16
Reserved	
R-0	

15	8	7	6	5	4	3	2	1	0
Reserved		E7	E6	E5	E4	E3	E2	E1	E0
R-0		R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0

LEGEND: R = Read only; -*n* = value after reset

Table 18-59. QDMA Secondary Event Register (QSER) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved
7-0	E*n*		QDMA secondary event register for channels 0-7.
		0	QDMA event is not currently stored in the event queue.
		1	QDMA event is currently stored in event queue. EDMA3CC will not prioritize additional events.

18.4.2.7.6 QDMA Secondary Event Clear Register (QSECR)

The QDMA secondary event clear register (QSECR) clears the status of the QDMA secondary event register (QSER) and the QDMA event register (QER). CPU writes of 1 clear the corresponding set bits in QSER and QER. Writes of 0 have no effect. Note that this differs from the secondary event clear register (SECR) operation, which only clears the secondary event register (SER) bits and does not affect the event registers.

The QSECR is shown in Figure 18-81 and described in Table 18-60.

Figure 18-81. QDMA Secondary Event Clear Register (QSECR)

31	16
Reserved	
R-0	

15	8	7	6	5	4	3	2	1	0
Reserved		E7	E6	E5	E4	E3	E2	E1	E0
R-0		W-0	W-0	W-0	W-0	W-0	W-0	W-0	W-0

LEGEND: R = Read only; W = Write only; -*n* = value after reset

Table 18-60. QDMA Secondary Event Clear Register (QSECR) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved
7-0	E*n*		QDMA secondary event clear register for channels 0-7.
		0	No effect.
		1	Corresponding bit in the QDMA secondary event register (QSER) and the QDMA event register (QER) is cleared (E*n* = 0).

18.4.3 EDMA3 Transfer Controller (EDMA3TC) Registers

Table 18-61 lists the memory-mapped registers for the EDMA3 transfer controller (EDMA3TC). See your device-specific data manual for the memory address of these registers. All other register offset addresses not listed in Table 18-61 should be considered as reserved locations and the register contents should not be modified.

Table 18-61. EDMA3 Transfer Controller (EDMA3TC) Registers

Offset	Acronym	Register Description	Section
0h	REVID	Revision Identification Register	Section 18.4.3.1
4h	TCCFG	EDMA3TC Configuration Register	Section 18.4.3.2
100h	TCSTAT	EDMA3TC Channel Status Register	Section 18.4.3.3
120h	ERRSTAT	Error Status Register	Section 18.4.3.4.1
124h	ERREN	Error Enable Register	Section 18.4.3.4.2
128h	ERRCLR	Error Clear Register	Section 18.4.3.4.3
12Ch	ERRDET	Error Details Register	Section 18.4.3.4.4
130h	ERRCMD	Error Interrupt Command Register	Section 18.4.3.4.5
140h	RDRATE	Read Command Rate Register	Section 18.4.3.5
240h	SAOPT	Source Active Options Register	Section 18.4.3.6.1
244h	SASRC	Source Active Source Address Register	Section 18.4.3.6.2
248h	SACNT	Source Active Count Register	Section 18.4.3.6.3
24Ch	SADST	Source Active Destination Address Register	Section 18.4.3.6.4
250h	SABIDX	Source Active B-Index Register	Section 18.4.3.6.5
254h	SAMPPRXY	Source Active Memory Protection Proxy Register	Section 18.4.3.6.6
258h	SACNTRLD	Source Active Count Reload Register	Section 18.4.3.6.7
25Ch	SASRCBREF	Source Active Source Address B-Reference Register	Section 18.4.3.6.8
260h	SADSTBREF	Source Active Destination Address B-Reference Register	Section 18.4.3.6.9
280h	DFCNTRLD	Destination FIFO Set Count Reload Register	Section 18.4.3.6.10
284h	DFSRCBREF	Destination FIFO Set Source Address B-Reference Register	Section 18.4.3.6.11
288h	DFDSTBREF	Destination FIFO Set Destination Address B-Reference Register	Section 18.4.3.6.12
300h	DFOPT0	Destination FIFO Options Register 0	Section 18.4.3.6.13
304h	DFSRC0	Destination FIFO Source Address Register 0	Section 18.4.3.6.14
308h	DFCNT0	Destination FIFO Count Register 0	Section 18.4.3.6.15
30Ch	DFDST0	Destination FIFO Destination Address Register 0	Section 18.4.3.6.16
310h	DFBIDX0	Destination FIFO B-Index Register 0	Section 18.4.3.6.17
314h	DFMPPRXY0	Destination FIFO Memory Protection Proxy Register 0	Section 18.4.3.6.18
340h	DFOPT1	Destination FIFO Options Register 1	Section 18.4.3.6.13
344h	DFSRC1	Destination FIFO Source Address Register 1	Section 18.4.3.6.14
348h	DFCNT1	Destination FIFO Count Register 1	Section 18.4.3.6.15
34Ch	DFDST1	Destination FIFO Destination Address Register 1	Section 18.4.3.6.16
350h	DFBIDX1	Destination FIFO B-Index Register 1	Section 18.4.3.6.17
354h	DFMPPRXY1	Destination FIFO Memory Protection Proxy Register 1	Section 18.4.3.6.18
380h	DFOPT2	Destination FIFO Options Register 2	Section 18.4.3.6.13
384h	DFSRC2	Destination FIFO Source Address Register 2	Section 18.4.3.6.14
388h	DFCNT2	Destination FIFO Count Register 2	Section 18.4.3.6.15
38Ch	DFDST2	Destination FIFO Destination Address Register 2	Section 18.4.3.6.16
390h	DFBIDX2	Destination FIFO B-Index Register 2	Section 18.4.3.6.17
394h	DFMPPRXY2	Destination FIFO Memory Protection Proxy Register 2	Section 18.4.3.6.18
3C0h	DFOPT3	Destination FIFO Options Register 3	Section 18.4.3.6.13
3C4h	DFSRC3	Destination FIFO Source Address Register 3	Section 18.4.3.6.14
3C8h	DFCNT3	Destination FIFO Count Register 3	Section 18.4.3.6.15

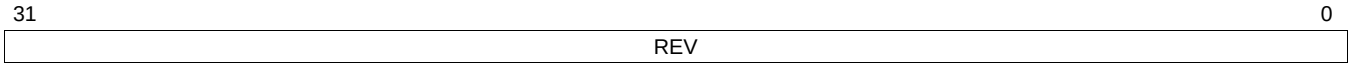
Table 18-61. EDMA3 Transfer Controller (EDMA3TC) Registers (continued)

Offset	Acronym	Register Description	Section
3CCh	DFDST3	Destination FIFO Destination Address Register 3	Section 18.4.3.6.16
3D0h	DFBIDX3	Destination FIFO B-Index Register 3	Section 18.4.3.6.17
3D4h	DFMPPRXY3	Destination FIFO Memory Protection Proxy Register 3	Section 18.4.3.6.18

18.4.3.1 Revision Identification Register (REVID)

The revision identification register (REVID) is a constant register that uniquely identifies the EDMA3TC and specific revision of the EDMA3TC. The REVID is shown in Figure 18-82 and described in Table 18-62.

Figure 18-82. Revision ID Register (REVID)



LEGEND: R = Read only; -*n* = value after reset

Table 18-62. Revision ID Register (REVID) Field Descriptions

Bit	Field	Value	Description
31-0	REV		Peripheral identifier.
		4000 3B00h	Uniquely identifies the EDMA3TC and the specific revision of the EDMA3TC.

18.4.3.2 EDMA3TC Configuration Register (TCCFG)

The EDMA3TC configuration register (TCCFG) is shown in Figure 18-83 and described in Table 18-63.

Figure 18-83. EDMA3TC Configuration Register (TCCFG)

31	16
Reserved	
R-0	

15	10	9	8	7	6	5	4	3	2	0
Reserved		DREGDEPTH		Reserved		BUSWIDTH		Rsvd	FIFOSIZE	
R-0		R-x		R-0		R-x		R-0	R-x	

LEGEND: R = Read only; -*n* = value after reset; -x = value is indeterminate after reset

Table 18-63. EDMA3TC Configuration Register (TCCFG) Field Descriptions

Bit	Field	Value	Description
31-10	Reserved	0	Reserved
9-8	DREGDEPTH	0-3h	Destination register FIFO depth parameterization.
		0	1 entry
		1h	2 entry
		2h	4 entry (for EDMA3TC0 and EDMA3TC1)
		3h	Reserved
7-6	Reserved	0	Reserved
5-4	BUSWIDTH	0-3h	Bus width parameterization.
		0	32-bit
		1h	64-bit (for EDMA3TC0 and EDMA3TC1)
		2h-3h	Reserved
3	Reserved	0	Reserved
2-0	FIFOSIZE	0-7h	FIFO size.
		0	32-byte FIFO
		1h	64-byte FIFO
		2h	128-byte FIFO (for EDMA3TC0 and EDMA3TC1)
		3h	256-byte FIFO
		4h-7h	Reserved

18.4.3.3 EDMA3TC Channel Status Register (TCSTAT)

The EDMA3TC channel status register (TCSTAT) is shown in Figure 18-84 and described in Table 18-64.

Figure 18-84. EDMA3TC Channel Status Register (TCSTAT)

31	16
Reserved	
R-0	

15	13	12	11	10	8
Reserved		DFSTRTPTR		Reserved	
R-0		R-0		R-0	

7	6	4	3	2	1	0
Reserved	DSTACTV		Reserved	WSACTV	SRCACTV	PROGBUSY
R-0	R-0		R-0	R-0	R-0	R-0

LEGEND: R = Read only; -*n* = value after reset

Table 18-64. EDMA3TC Channel Status Register (TCSTAT) Field Descriptions

Bit	Field	Value	Description
31-13	Reserved	0	Reserved
12-11	DFSTRTPTR	0-3h	Destination FIFO start pointer. The offset to the head entry of the destination register FIFO, in units of *entries*.
10-7	Reserved	0	Reserved
6-4	DSTACTV	0-7h	Destination active state. Specifies the number of transfer requests (TRs) that are resident in the destination register FIFO at a given instant. This bit field can be primarily used for advanced debugging.
		0	Destination FIFO is empty.
		1h	Destination FIFO contains 1 TR.
		2h	Destination FIFO contains 2 TR.
		3h	Destination FIFO contains 3 TR.
		4h	Destination FIFO contains 4 TR. (Full if DSTREGDEPTH == 4)
			If the destination register FIFO is empty, then any TR written to Prog Set immediately transitions to the destination register FIFO. If the destination register FIFO is not empty and not full, then any TR written to Prog Set immediately transitions to the destination register FIFO set if the source active state (SRCACTV) bit is set to idle.
			If the destination register FIFO is full, then TRs cannot transition to the destination register FIFO. The destination register FIFO becomes not full when the TR at the head of the destination register FIFO is completed.
		5h-7h	Reserved
3	Reserved	0	Reserved
2	WSACTV		Write status active.
		0	Write status is not pending. Write status has been received for all previously issued write commands.
		1	Write status is pending. Write status has not been received for all previously issued write commands.
1	SRCACTV		Source active state.
		0	Source active set is idle and is available for programming by the EDMA3CC. Source active register set contains a previously processed transfer request.
		1	Source active set is busy servicing a transfer request.
0	PROGBUSY		Program register set busy.
		0	Program set idle and is available for programming by the EDMA3CC.
		1	Program set busy.

18.4.3.4 Error Registers

18.4.3.4.1 Error Status Register (ERRSTAT)

The error status register (ERRSTAT) is shown in Figure 18-85 and described in Table 18-65.

Figure 18-85. Error Status Register (ERRSTAT)

31	16
Reserved	
R-0	

15	4	3	2	1	0
Reserved		MMRAERR	TRERR	Reserved	BUSERR
R-0		R-0	R-0	R-0	R-0

LEGEND: R = Read only; -*n* = value after reset

Table 18-65. Error Status Register (ERRSTAT) Field Descriptions

Bit	Field	Value	Description
31-4	Reserved	0	Reserved
3	MMRAERR		MMR address error.
		0	MMR address error is not detected.
		1	User attempted to read or write to an invalid address in configuration memory map.
2	TRERR		Transfer request (TR) error event.
		0	Transfer request (TR) error is not detected.
		1	Transfer request (TR) detected that violates constant addressing mode transfer (SAM or DAM is set to 1) alignment rules or has ACNT or BCNT == 0.
1	Reserved	0	Reserved
0	BUSERR		Bus error event.
		0	Bus error is not detected.
		1	EDMA3TC has detected an error at source or destination address. Error information can be read from the error details register (ERRDET).

18.4.3.4.2 Error Enable Register (ERREN)

The error enable register (ERREN) is shown in Figure 18-86 and described in Table 18-66. When any of the enable bits in ERREN is set, a bit set in the corresponding error status register (ERRSTAT) causes an assertion of the EDMA3TC interrupt.

Figure 18-86. Error Enable Register (ERREN)

31	16
Reserved	
R-0	

15	4	3	2	1	0
Reserved		MMRAERR	TRERR	Reserved	BUSERR
R-0		R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 18-66. Error Enable Register (ERREN) Field Descriptions

Bit	Field	Value	Description
31-4	Reserved	0	Reserved
3	MMRAERR		Interrupt enable for MMR address error (MMRAERR).
		0	MMRAERR is disabled.
		1	MMRAERR is enabled and contributes to the state of EDMA3TC error interrupt generation
2	TRERR		Interrupt enable for transfer request error (TRERR).
		0	TRERR is disabled.
		1	TRERR is enabled and contributes to the state of EDMA3TC error interrupt generation.
1	Reserved	0	Reserved. Always write 0 to this bit; writes of 1 to this bit are not supported and attempts to do so may result in undefined behavior.
0	BUSERR		Interrupt enable for bus error (BUSERR).
		0	BUSERR is disabled.
		1	BUSERR is enabled and contributes to the state of EDMA3TC error interrupt generation.

18.4.3.4.3 Error Clear Register (ERRCLR)

The error clear register (ERRCLR) is shown in Figure 18-87 and described in Table 18-67.

Figure 18-87. Error Clear Register (ERRCLR)

31	16
Reserved	
R-0	

15	4	3	2	1	0
Reserved		MMRAERR	TRERR	Reserved	BUSERR
R-0		W-0	W-0	R-0	W-0

LEGEND: R = Read only; W = Write only; -*n* = value after reset

Table 18-67. Error Clear Register (ERRCLR) Field Descriptions

Bit	Field	Value	Description
31-4	Reserved	0	Reserved
3	MMRAERR		Interrupt enable clear for the MMR address error (MMRAERR) bit in the error status register (ERRSTAT).
		0	No effect.
		1	Clears the MMRAERR bit in the error status register (ERRSTAT) but does not clear the error details register (ERRDET).
2	TRERR		Interrupt enable clear for the transfer request error (TRERR) bit in the error status register (ERRSTAT).
		0	No effect.
		1	Clears the TRERR bit in the error status register (ERRSTAT) but does not clear the error details register (ERRDET).
1	Reserved	0	Reserved
0	BUSERR		Interrupt clear for the bus error (BUSERR) bit in the error status register (ERRSTAT).
		0	No effect.
		1	Clears the BUSERR bit in the error status register (ERRSTAT) and clears the error details register (ERRDET).

18.4.3.4.4 Error Details Register (ERRDET)

The error details register (ERRDET) is shown in Figure 18-88 and described in Table 18-68.

Figure 18-88. Error Details Register (ERRDET)

31	18	17	16
Reserved		TCCHEN	TCINTEN
R-0		R-0	R-0

15	14	13	8	7	4	3	0
Reserved		TCC		Reserved		STAT	
R-0		R-0		R-0		R-0	

LEGEND: R = Read only; -*n* = value after reset

Table 18-68. Error Details Register (ERRDET) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved
17	TCCHEN	0-1	Transfer completion chaining enable. Contains the TCCHEN value in the channel options parameter (OPT) programmed by the channel controller for the read or write transaction that resulted in an error.
16	TCINTEN	0-1	Transfer completion interrupt enable. Contains the TCINTEN value in the channel options parameter (OPT) programmed by the channel controller for the read or write transaction that resulted in an error.
15-14	Reserved	0	Reserved
13 - 8	TCC	0-3Fh	Transfer complete code. Contains the TCC value in the channel options parameter (OPT) programmed by the channel controller for the read or write transaction that resulted in an error.
7-4	Reserved	0	Reserved
3-0	STAT	0-Fh	Transaction status. Stores the nonzero status/error code that was detected on the read status or write status bus. If read status and write status are returned on the same cycle, then the EDMA3TC chooses nonzero version. If both are nonzero, then the write status is treated as higher priority.
		0	No error
		1h	Read addressing error
		2h	Read privilege error
		3h	Read timeout error
		4h	Read data error
		5h-6h	Reserved
		7h	Read exclusive operation error
		8h	Reserved
		9h	Write addressing error
		Ah	Write privilege error
		Bh	Write timeout error
		Ch	Write data error
		Dh-Eh	Reserved
		Fh	Write exclusive operation error

18.4.3.4.5 Error Interrupt Command Register (ERRCMD)

The error interrupt command register (ERRCMD) is shown in Figure 18-89 and described in Table 18-69.

Figure 18-89. Error Interrupt Command Register (ERRCMD)

31	16
Reserved	
R-0	

15	1	0
Reserved		EVAL
R-0		W-0

LEGEND: R = Read only; W = Write only; -*n* = value after reset

Table 18-69. Error Interrupt Command Register (ERRCMD) Field Descriptions

Bit	Field	Value	Description
31-1	Reserved	0	Reserved
0	EVAL		Error evaluate.
		0	No effect.
		1	EDMA3TC error line is pulsed if any of the error status register (ERRSTAT) bits are set to 1.

18.4.3.5 Read Command Rate Register (RDRATE)

The EDMA3 transfer controller issues Read commands at a rate controlled by the Read command rate register (RDRATE). The RDRATE defines the number of idle cycles that the Read controller must wait before issuing subsequent commands. This applies both to commands within a transfer request packet (TRP) and for commands that are issued for different transfer requests (TRs). For instance, if RDRATE is set to 4 cycles between reads, there are 32 inactive cycles between reads.

RDRATE allows flexibility in transfer controller access requests to an endpoint. For an application, RDRATE can be manipulated to slow down the access rate, so that the endpoint may service requests from other masters during the inactive EDMA3TC cycles.

The RDRATE is shown in Figure 18-90 and described in Table 18-70.

NOTE: It is expected that the RDRATE value for a transfer controller is static, as it is decided based on the application requirement. It is not recommended to change this setting on the go.

Figure 18-90. Read Command Rate Register (RDRATE)

31	16
Reserved	
R-0	

15	3	2	0
Reserved		RDRATE	
R-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 18-70. Read Command Rate Register (RDRATE) Field Descriptions

Bit	Field	Value	Description
31-3	Reserved	0	Reserved
2-0	RDRATE	0-7h	Read rate. Controls the number of cycles between Read commands. This is a global setting that applies to all TRs for this EDMA3TC.
		0	Reads issued as fast as possible.
		1h	4 EDMA3TC cycles between reads.
		2h	8 EDMA3TC cycles between reads.
		3h	16 EDMA3TC cycles between reads.
		4h	32 EDMA3TC cycles between reads.
		5h-7h	Reserved

18.4.3.6 EDMA3TC Channel Registers

The EDMA3TC channel registers are split into three parts: the programming registers, the source active registers, and the destination FIFO registers. This section describes the registers and their functions. The program register set is programmed by the channel controller and is for internal use. The source active registers and the destination FIFO registers are read-only and are provided to facilitate advanced debug capabilities. The number of destination FIFO register sets depends on the destination FIFO depth. Both TC0 and TC1 have a destination FIFO depth of 4, and there are four sets of destination FIFO registers.

18.4.3.6.1 Source Active Options Register (SAOPT)

The source active options register (SAOPT) is shown in Figure 18-91 and described in Table 18-71.

Figure 18-91. Source Active Options Register (SAOPT)

31	23	22	21	20	19	18	17	16
Reserved		TCCHEN	Rsvd	TCINTEN	Reserved		TCC	
R-0		R/W-0	R-0	R/W-0	R-0		R/W-0	

15	12	11	10	8	7	6	4	3	2	1	0
TCC		Rsvd	FWID		Rsvd	PRI[1]		Reserved		DAM	SAM
R/W-0		R-0	R/W-0		R-0	R/W-0		R-0		R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

(1) On previous architectures, the EDMA3TC priority was controlled by the queue priority register (QUEPRI) in the EDMA3CC memory-map. However for this device, the priority control for the transfer controllers is controlled by the chip-level registers in the System Configuration Module. You should use the chip-level registers and not QUEPRI to configure the TC priority.

Table 18-71. Source Active Options Register (SAOPT) Field Descriptions

Bit	Field	Value	Description
31-23	Reserved	0	Reserved
22	TCCHEN		Transfer complete chaining enable.
		0	Transfer complete chaining is disabled.
		1	Transfer complete chaining is enabled.
21	Reserved	0	Reserved
20	TCINTEN		Transfer complete interrupt enable.
		0	Transfer complete interrupt is disabled.
		1	Transfer complete interrupt is enabled.
19-18	Reserved	0	Reserved
17-12	TCC	0-3Fh	Transfer complete code. This 6-bit code is used to set the relevant bit in CER or IPR of the EDMA3CC.
11	Reserved	0	Reserved
10-8	FWID	0-7h	FIFO width. Applies if either SAM or DAM is set to constant addressing mode.
		0	FIFO width is 8 bits.
		1h	FIFO width is 16 bits.
		2h	FIFO width is 32 bits.
		3h	FIFO width is 64 bits.
		4h	FIFO width is 128 bits.
		5h-7h	Reserved
7	Reserved	0	Reserved
6-4	PRI	0-7h	Transfer priority. Reflects the values programmed in the queue priority register (QUEPRI) in the EDMA3CC.
		0	Priority 0 - Highest priority
		1h-6h	Priority 1 to priority 6
		7h	Priority 7 - Lowest priority
3-2	Reserved	0	Reserved

Table 18-71. Source Active Options Register (SAOPT) Field Descriptions (continued)

Bit	Field	Value	Description
1	DAM		Destination address mode within an array.
		0	Increment (INCR) mode. Destination addressing within an array increments.
		1	Constant addressing (CONST) mode. Destination addressing within an array wraps around upon reaching FIFO width.
0	SAM		Source address mode within an array.
		0	Increment (INCR) mode. Source addressing within an array increments.
		1	Constant addressing (CONST) mode. Source addressing within an array wraps around upon reaching FIFO width.

18.4.3.6.2 Source Active Source Address Register (SASRC)

The source active source address register (SASRC) is shown in Figure 18-92 and described in Table 18-72.

Figure 18-92. Source Active Source Address Register (SASRC)

31	0
SADDR	
R-0	

LEGEND: R = Read only; -*n* = value after reset

Table 18-72. Source Active Source Address Register (SASRC) Field Descriptions

Bit	Field	Value	Description
31-0	SADDR	0-FFFF FFFFh	Source address for program register set. EDMA3TC updates value according to source addressing mode (SAM bit in the source active options register, SAOPT) .

18.4.3.6.3 Source Active Count Register (SACNT)

The source active count register (SACNT) is shown in Figure 18-93 and described in Table 18-73.

Figure 18-93. Source Active Count Register (SACNT)

31	16
BCNT	
R-0	
15	0
ACNT	
R-0	

LEGEND: R = Read only; -*n* = value after reset

Table 18-73. Source Active Count Register (SACNT) Field Descriptions

Bit	Field	Value	Description
31-16	BCNT	0-FFFFh	B dimension count. Number of arrays to be transferred, where each array is ACNT in length. It is decremented after each Read command appropriately. Represents the amount of data remaining to be Read. It should be 0 when transfer request (TR) is complete.
15-0	ACNT	0-FFFFh	A dimension count. Number of bytes to be transferred in first dimension. It is decremented after each Read command appropriately. Represents the amount of data remaining to be Read. It should be 0 when transfer request (TR) is complete.

18.4.3.6.4 Source Active Destination Address Register (SADST)

The source active destination address register (SADST) is shown in Figure 18-94 and described in Table 18-74.

Figure 18-94. Source Active Destination Address Register (SADST)

31	0
DADDR	
R-0	

LEGEND: R = Read only; -*n* = value after reset

Table 18-74. Source Active Destination Address Register (SADST) Field Descriptions

Bit	Field	Value	Description
31-0	DADDR	0	Always reads as 0

18.4.3.6.5 Source Active B-Index Register (SABIDX)

The source active B-index register (SABIDX) is shown in Figure 18-95 and described in Table 18-75.

Figure 18-95. Source Active B-Index Register (SABIDX)

31	16
DSTBIDX	
R-0	
15	0
SRCBIDX	
R-0	

LEGEND: R = Read only; -*n* = value after reset

Table 18-75. Source Active B-Index Register (SABIDX) Field Descriptions

Bit	Field	Value	Description
31-16	DSTBIDX	0	B-Index offset between destination arrays. Represents the offset in bytes between the starting address of each destination. Always reads as 0.
15-0	SRCBIDX	0-FFFFh	B-Index offset between source arrays. Represents the offset in bytes between the starting address of each source array.

18.4.3.6.6 Source Active Memory Protection Proxy Register (SAMPPRXY)

The source active memory protection proxy register (SAMPPRXY) is shown in Figure 18-96 and described in Table 18-76.

Figure 18-96. Source Active Memory Protection Proxy Register (SAMPPRXY)

31	16
Reserved	
R-0	

15	9	8	7	4	3	0
Reserved		PRIV	Reserved		PRIVID	
R-0		R-0	R-0		R-0	

LEGEND: R = Read only; -*n* = value after reset

Table 18-76. Source Active Memory Protection Proxy Register (SAMPPRXY) Field Descriptions

Bit	Field	Value	Description
31-9	Reserved	0	Reserved
8	PRIV		Privilege level. The privilege level used by the host to set up the parameter entry in the channel controller. This field is set up when the associated TR is submitted to the EDMA3TC. The privilege ID is used while issuing Read and write command to the target endpoints so that the target endpoints can perform memory protection checks based on the PRIV of the host that set up the DMA transaction.
		0	User-level privilege
		1	Supervisor-level privilege
7-4	Reserved	0	Reserved
3-0	PRIVID	0-Fh	Privilege ID. This contains the privilege ID of the host that set up the parameter entry in the channel controller. This field is set up when the associated TR is submitted to the EDMA3TC. This PRIVID value is used while issuing Read and write commands to the target endpoints so that the target endpoints can perform memory protection checks based on the PRIVID of the host that set up the DMA transaction.
		0	For any other master that sets up the PaRAM entry.
		1	If DSP sets up the PaRAM entry.

18.4.3.6.7 Source Active Count Reload Register (SACNTRLD)

The source active count reload register (SACNTRLD) is shown in Figure 18-97 and described in Table 18-77.

Figure 18-97. Source Active Count Reload Register (SACNTRLD)

31	16
Reserved	
R-0	

15	0
ACNTRLD	
R-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 18-77. Source Active Count Reload Register (SACNTRLD) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	Reserved
15-0	ACNTRLD	0-FFFFh	A-count reload value. Represents the originally programmed value of ACNT. The reload value is used to reinitialize ACNT after each array is serviced.

18.4.3.6.8 Source Active Source Address B-Reference Register (SASRCBREF)

The source active source address B-reference register (SASRCBREF) is shown in Figure 18-98 and described in Table 18-78.

Figure 18-98. Source Active Source Address B-Reference Register (SASRCBREF)

31	0
SADDRBREF	
R-0	

LEGEND: R = Read only; -*n* = value after reset

Table 18-78. Source Active Source Address B-Reference Register (SASRCBREF) Field Descriptions

Bit	Field	Value	Description
31-0	SADDRBREF	0-FFFF FFFFh	Source address B-reference. Represents the starting address for the array currently being Read.

18.4.3.6.9 Source Active Destination Address B-Reference Register (SADSTBREF)

The source active destination address B-reference register (SADSTBREF) is shown in Figure 18-99 and described in Table 18-79.

Figure 18-99. Source Active Destination Address B-Reference Register (SADSTBREF)

31	0
DADDRBREF	
R-0	

LEGEND: R = Read only; -*n* = value after reset

Table 18-79. Source Active Destination Address B-Reference Register (SADSTBREF) Field Descriptions

Bit	Field	Value	Description
31-0	DADDRBREF	0	Always reads as 0

18.4.3.6.10 Destination FIFO Set Count Reload Register (DFCNTRLD)

The destination FIFO set count reload register (DFCNTRLD) is shown in Figure 18-100 and described in Table 18-80.

Figure 18-100. Destination FIFO Set Count Reload Register (DFCNTRLD)

31	16
Reserved	
R-0	

15	0
ACNTRLD	
R-0	

LEGEND: R = Read only; -*n* = value after reset

Table 18-80. Destination FIFO Set Count Reload Register (DFCNTRLD) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	Reserved
15-0	ACNTRLD	0-FFFFh	A-count reload value. Represents the originally programmed value of ACNT. The reload value is used to reinitialize ACNT after each array is serviced.

18.4.3.6.11 Destination FIFO Set Source Address B-Reference Register (DFSRCBREF)

The destination FIFO set source address B-reference register (DFSRCBREF) is shown in Figure 18-101 and described in Table 18-81.

Figure 18-101. Destination FIFO Set Source Address B-Reference Register (DFSRCBREF)

31	0
SADDRBREF	
R-0	

LEGEND: R = Read only; -*n* = value after reset

Table 18-81. Destination FIFO Set Source Address B-Reference Register (DFSRCBREF) Field Descriptions

Bit	Field	Value	Description
31-0	SADDRBREF	0	Not applicable. Always Read as 0.

18.4.3.6.12 Destination FIFO Set Destination Address B-Reference (DFDSTBREF)

The destination FIFO set destination address B-reference register (DFDSTBREF) is shown in Figure 18-102 and described in Table 18-82.

Figure 18-102. Destination FIFO Set Destination Address B-Reference Register (DFDSTBREF)

31	0
DADDRBREF	
R-0	

LEGEND: R = Read only; -*n* = value after reset

Table 18-82. Destination FIFO Set Destination Address B-Reference Register (DFDSTBREF) Field Descriptions

Bit	Field	Value	Description
31-0	DADDRBREF	0-FFFF FFFFh	Destination address reference for the destination FIFO register set. Represents the starting address for the array currently being written.

18.4.3.6.13 Destination FIFO Options Register *n* (DFOPT*n*)

The destination FIFO options register *n* (DFOPT*n*) is shown in Figure 18-103 and described in Table 18-83.

Figure 18-103. Destination FIFO Options Register *n* (DFOPT*n*)

31	23	22	21	20	19	18	17	16
Reserved		TCCHEN	Rsvd	TCINTEN	Reserved		TCC	
R-0		R/W-0	R-0	R/W-0	R-0		R/W-0	

15	12	11	10	8	7	6	4	3	2	1	0
TCC		Rsvd	FWID		Rsvd	PRI		Reserved		DAM	SAM
R/W-0		R-0	R/W-0		R-0	R/W-0		R-0		R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 18-83. Destination FIFO Options Register *n* (DFOPT*n*) Field Descriptions

Bit	Field	Value	Description
31-23	Reserved	0	Reserved
22	TCCHEN		Transfer complete chaining enable.
		0	Transfer complete chaining is disabled.
		1	Transfer complete chaining is enabled.
21	Reserved	0	Reserved
20	TCINTEN		Transfer complete interrupt enable.
		0	Transfer complete interrupt is disabled.
		1	Transfer complete interrupt is enabled.
19-18	Reserved	0	Reserved
17-12	TCC	0-3Fh	Transfer complete code. This 6-bit code is used to set the relevant bit in CER or IPR of the EDMA3CC.
11	Reserved	0	Reserved
10-8	FWID	0-7h	FIFO width. Applies if either SAM or DAM is set to constant addressing mode.
		0	FIFO width is 8 bits.
		1h	FIFO width is 16 bits.
		2h	FIFO width is 32 bits.
		3h	FIFO width is 64 bits.
		4h	FIFO width is 128 bits.
		5h-7h	Reserved
7	Reserved	0	Reserved
6-4	PRI	0-7h	Transfer priority.
		0	Priority 0 - Highest priority
		1h-6h	Priority 1 to priority 6
		7h	Priority 7 - Lowest priority
3-2	Reserved	0	Reserved
1	DAM		Destination address mode within an array.
		0	Increment (INCR) mode. Destination addressing within an array increments.
		1	Constant addressing (CONST) mode. Destination addressing within an array wraps around upon reaching FIFO width.
0	SAM		Source address mode within an array.
		0	Increment (INCR) mode. Source addressing within an array increments.
		1	Constant addressing (CONST) mode. Source addressing within an array wraps around upon reaching FIFO width.

18.4.3.6.14 Destination FIFO Source Address Register *n* (DFSRC*n*)

The destination FIFO source address register *n* (DFSRC*n*) is shown in Figure 18-104 and described in Table 18-84.

Figure 18-104. Destination FIFO Source Address Register *n* (DFSRC*n*)

31	0
SADDR	
R-0	

LEGEND: R = Read only; -*n* = value after reset

Table 18-84. Destination FIFO Source Address Register *n* (DFSRC*n*) Field Descriptions

Bit	Field	Value	Description
31-0	SADDR	0	Always Read as 0.

18.4.3.6.15 Destination FIFO Count Register *n* (DFCNT*n*)

The destination FIFO count register *n* (DFCNT*n*) is shown in Figure 18-105 and described in Table 18-85.

Figure 18-105. Destination FIFO Count Register *n* (DFCNT*n*)

31	16
BCNT	
R-0	
15	0
ACNT	
R-0	

LEGEND: R = Read only; -*n* = value after reset

Table 18-85. Destination FIFO Count Register *n* (DFCNT*n*) Field Descriptions

Bit	Field	Value	Description
31-16	BCNT	0-FFFFh	B-dimension count. Number of arrays to be transferred, where each array is ACNT in length. Count/count remaining for destination register set. Represents the amount of data remaining to be written.
15-0	ACNT	0-FFFFh	A-dimension count. Number of bytes to be transferred in first dimension count/count remaining for destination register set. Represents the amount of data remaining to be written.

18.4.3.6.16 Destination FIFO Destination Address Register *n* (DFDST*n*)

The destination FIFO destination address register *n* (DFDST*n*) is shown in Figure 18-106 and described in Table 18-86.

Figure 18-106. Destination FIFO Destination Address Register *n* (DFDST*n*)

31	0
DADDR	
R-0	

LEGEND: R = Read only; -*n* = value after reset

Table 18-86. Destination FIFO Destination Address Register *n* (DFDST*n*) Field Descriptions

Bit	Field	Value	Description
31-0	DADDR	0	Destination address for the destination FIFO register set. When a transfer request (TR) is complete, the final value should be the address of the last write command issued.

18.4.3.6.17 Destination FIFO B-Index Register *n* (DFBIDX*n*)

The destination FIFO B-index register *n* (DFBIDX*n*) is shown in Figure 18-107 and described in Table 18-87.

Figure 18-107. Destination FIFO B-Index Register *n* (DFBIDX*n*)

31	16
DSTBIDX	
R-0	
15	0
SRCBIDX	
R-0	

LEGEND: R = Read only; -*n* = value after reset

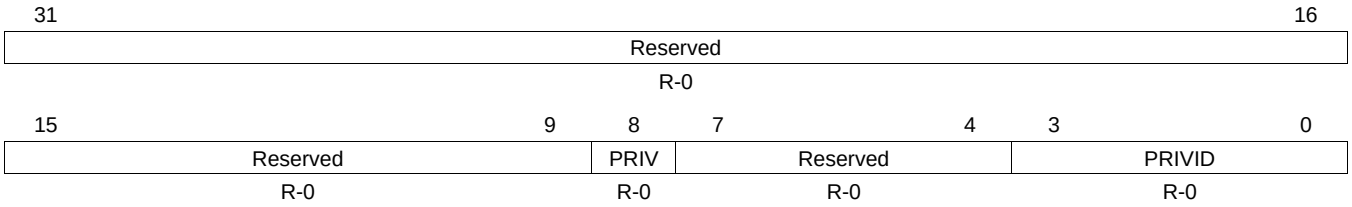
Table 18-87. Destination FIFO B-Index Register *n* (DFBIDX*n*) Field Descriptions

Bit	Field	Value	Description
31-16	DSTBIDX	0-FFFFh	B-Index offset between destination arrays. Represents the offset in bytes between the starting address of each destination.
15-0	SRCBIDX	0	B-Index offset between source arrays. Represents the offset in bytes between the starting address of each source array. Always Read as 0.

18.4.3.6.18 Destination FIFO Memory Protection Proxy Register *n* (DFMPPRXY*n*)

The destination FIFO memory protection proxy register *n* (DFMPPRXY*n*) is shown in Figure 18-108 and described in Table 18-88.

Figure 18-108. Destination FIFO Memory Protection Proxy Register *n* (DFMPPRXY*n*)



LEGEND: R = Read only; -*n* = value after reset

Table 18-88. Destination FIFO Memory Protection Proxy Register *n* (DFMPPRXY*n*) Field Descriptions

Bit	Field	Value	Description
31-9	Reserved	0	Reserved
8	PRIV		Privilege level. This contains the privilege level used by the EDMA programmer to set up the parameter entry in the channel controller. This field is set up when the associated TR is submitted to the EDMA3TC. The privilege ID is used while issuing Read and write command to the target endpoints so that the target endpoints can perform memory protection checks based on the PRIV of the host that set up the DMA transaction.
		0	User-level privilege
		1	Supervisor-level privilege
7-4	Reserved	0	Reserved
3-0	PRIVID	0-Fh	Privilege ID. This contains the Privilege ID of the EDMA programmer that set up the parameter entry in the channel controller. This field is set up when the associated TR is submitted to the EDMA3TC. This PRIVID value is used while issuing Read and write commands to the target endpoints so that the target endpoints can perform memory protection checks based on the PRIVID of the host that set up the DMA transaction.
		0	For any other master that sets up the PaRAM entry
		1	If DSP sets up the PaRAM entry

18.5 Tips

18.5.1 Debug Checklist

This section lists some tips to keep in mind while debugging applications using the EDMA3. Table 18-89 provides some common issues and their probable causes and resolutions.

Table 18-89. Debug List

Issue	Description/Solution
The transfer associated with the channel does not happen. The channel does not get serviced.	The EDMA3 channel controller (EDMA3CC) may not service a transfer request, even though the associated PaRAM set is programmed appropriately. Check for the following: 1) Verify that events are enabled, that is, if an external/peripheral event is latched in the event register (ER), make sure that the event is enabled in the event enable register (EER). Similarly for QDMA channels, make sure that QDMA events are appropriately enabled in the QDMA event enable register (QEER). 2) Verify that the DMA or QDMA secondary event register (SER) bits corresponding to the particular event or channel are not set.
The secondary event register bits are set, not allowing additional transfers to occur on a channel.	It is possible that a trigger event was received when the parameter set associated with the channel/event was a NULL set for a previous transfer on the channel. This is typical in two cases: 1) QDMA channels: Typically if the parameter set is nonstatic and expected to be terminated by a NULL set (OPT.STATIC = 0, LINK = FFFFh), the parameter set is updated with a NULL set after submission of the last TR. Because QDMA channels are autotriggered, this update caused the generation of an event. An event generated for a NULL set causes an error condition and results in setting the bits corresponding to the QDMA channel in QEMR and QSER. This will disable further prioritization of the channel. 2) DMA channels used in a continuous mode: The peripheral may be set up to continuously generate infinite events (for instance, in case of the McBSP, every time the data shifts out from DXR, it generates an XEVT). The parameter set may be programmed to expect only a finite number of events and to be terminated by a NULL link. After the expected number of events, the parameter set is reloaded with a NULL parameter set. Because the peripheral will generate additional events, an error condition is set in SER.E*n* and EMR.E*n*, preventing further event prioritization. You must ensure that the number of events received is limited to the expected number of events for which the parameter set is programmed, or you must ensure that bits corresponding to a particular channel or event are not set in the secondary event registers (SER/QSER) and the event missed registers (EMR/QEMR) before trying to perform subsequent transfers for the event/channel.
Completion interrupts are not asserted, or no further interrupts are received after the first completion interrupt.	You must ensure the following: 1) The interrupt generation is enabled in the OPT of the associated PaRAM set (TCINTEN = 1 and/or ITCINTEN = 1). 2) The interrupts are enabled in the EDMA3 channel controller (EDMA3CC), via the interrupt enable register (IER). 3) The corresponding interrupts are enabled in the device interrupt controller. 4) The set interrupts are cleared in the interrupt pending register (IPR) before exiting the transfer completion interrupt service routine (ISR). See Section 18.2.9.1.2 for details on writing EDMA3 ISRs. 5) If working with shadow region interrupts, make sure that the DMA region access enable registers (DRAE) are set up properly, because DRAE act as secondary enables for shadow region completion interrupts, along with IER. If working with shadow region interrupts, make sure that the bits corresponding to the transfer completion code (TCC) value are also enabled in DRAE. For instance, if the PaRAM set associated with channel 0 returns a completion code of 31 (OPT.TCC = 31), make sure that DRAE.E31 is also set for a shadow region completion interrupt because the interrupt pending register bit set will be IPR.I31.

18.5.2 Miscellaneous Programming/Debug Tips

1. For several registers, the setting and clearing of bits needs to be done via separate dedicated registers. For example, the event register (ER) bits can only be cleared by writing a 1 to the corresponding bits in the event clear register (ECR). Similarly, the event enable register (EER) bits can only be set with writes of 1 to the corresponding bits in the event enable set registers (EESR) and can only be cleared with writes of 1 to the corresponding bits in the event enable clear register (EECR).
2. Writes to the shadow region memory maps are governed by region access enable registers (DRAE/QRAE). If the appropriate channels are not enabled in these registers, read/write access to the shadow region memory map is not enabled.
3. When working with shadow region completion interrupts, ensure that the DMA region access enable registers (DRAE) for every region are set in a mutually exclusive way (unless it is a requirement for an application). If there is an overlap in the allocated channels and transfer completion codes (setting of interrupt pending register bits) in the region resource allocation, it results in multiple shadow region completion interrupts. For example, if DRAE0.E0 and DRAE1.E0 are both set, then on completion of a transfer that returns a TCC = 0, they will generate both shadow region 0 and 1 completion interrupts.
4. While programming a non-dummy parameter set, ensure the CCNT is not left to zero.
5. Enable the EDMA3CC error interrupt in the device controller and attach an interrupt service routine (ISR) to ensure that error conditions are not missed in an application and are appropriately addressed with the ISR.
6. Depending on the application, you may want to break large transfers into smaller transfers and use self-chaining to prevent starvation of other events in an event queue.
7. In applications where a large transfer is broken into sets of small transfers using chaining or other methods, you might choose to use the early chaining option to reduce the time between the sets of transfers and increase the throughput. However, keep in mind that with early completion, all data might have not been received at the end point when completion is reported because the EDMA3CC internally signals completion when the TR is submitted to the EDMA3TC, potentially before any data has been transferred.
8. The event queue entries can be observed to determine the last few events if there is a system failure (provided the entries were not bypassed).
9. In order to put the EDMA3CC and EDMA3TC in power-down modes, you should ensure that there is no activity with the EDMA3CC and EDMA3TC. The EDMA3CC status register (CCSTAT) and the EDMA3TC channel status register (TCSTAT) should be used.

18.6 Setting Up a Transfer

The following list provides a quick guide for the typical steps involved in setting up a transfer.

1. Initiating a DMA/QDMA channel:
   (a) Determine the type of channel (QDMA or DMA) to be used.
   (b) If using a QDMA channel, program the QDMA channel *n* mapping register (QCHMAP*n*) with the parameter set number to which the channel maps and the trigger word.
   (c) If the channel is being used in the context of a shadow region, ensure the DMA region access enable register (DRAE) for the region is properly set up to allow read/write accesses to bits in the event register and interrupt register in the shadow region memory-map. The subsequent steps in this process should be done using the respective shadow region registers. (Shadow region descriptions and usage are provided in Section 18.2.7.1.)
   (d) Determine the type of triggering used.
      (i) If external events are used for triggering (DMA channels), enable the respective event in EER by writing into EESR.
      (ii) If a QDMA channel is used, enable the channel in QEER by writing into QEESR.
   (e) Queue setup.
      (i) If a QDMA channel is used, set up QDMAQNUM to map the channel to the respective event queue.
      (ii) If a DMA channel is used, set up DMAQNUM to map the event to the respective event queue.
2. Parameter set setup: Program the PaRAM set number associated with the channel. Note that if it is a QDMA channel, the PaRAM entry that is configured as trigger word is written last. Alternatively, enable the QDMA channel just before the write to the trigger word.
   See Section 18.3 for parameter set field setups for different types of transfers. See the sections on chaining (Section 18.2.8) and interrupt completion (Section 18.2.9) on how to set up final/intermediate completion chaining and/or interrupts.
3. Interrupt setup:
   (a) If working in the context of a shadow region, ensure the relevant bits in DRAE are set.
   (b) Enable the interrupt in IER by writing into IESR.
   (c) Ensure that the EDMA3CC completion interrupt is enabled properly in the device interrupt controller.
   (d) Set up the interrupt controller properly to receive the expected EDMA3 interrupt.
4. Initiate transfer (this step is highly dependent on the event trigger source):
   (a) If the source is an external event coming from a peripheral, the peripheral will be enabled to start generating relevant EDMA3 events that can be latched to the ER transfer.
   (b) For QDMA events, writes to the trigger word will initiate the transfer.
   (c) Manually-triggered transfers will be initiated by writes to the event set register (ESR).
   (d) Chained-trigger events initiate when a previous transfer returns a transfer completion code equal to the chained channel number.
5. Wait for completion:
   (a) If the interrupts are enabled as mentioned in step 3, then the EDMA3CC generates a completion interrupt to the CPU whenever transfer completion results in setting the corresponding bits in the interrupt pending register (IPR). The set bits must be cleared in IPR by writing to the corresponding bit in ICR.
   (b) If polling for completion (interrupts not enabled in the device controller), then the application code can wait on the expected bits to be set in IPR. Again, the set bits in IPR must be manually cleared by writing to ICR before the next set of transfers is performed for the same transfer completion code values.

EMAC/MDIO Module

This chapter provides a functional description of the Ethernet Media Access Controller (EMAC) and physical layer (PHY) device Management Data Input/Output (MDIO) module integrated in the device.

Topic **Page**

19.1 Introduction

19.1.1 Purpose of the Peripheral

The EMAC module is used to move data between the device and another host connected to the same network, in compliance with the Ethernet protocol.

The EMAC controls the flow of packet data from the system to the PHY. The MDIO module controls PHY configuration and status monitoring.

Both the EMAC and the MDIO modules interface to the system core through a custom interface that allows efficient data transmission and reception. This custom interface is referred to as the EMAC control module and is considered integral to the EMAC/MDIO peripheral.

19.1.2 Features

The EMAC/MDIO has the following features:

- Synchronous 10/100 Mbps operation.
- Standard Media Independent Interface (MII) and/or Reduced Media Independent Interface (RMII) to physical layer device (PHY).
- EMAC acts as DMA master to either internal or external device memory space.
- Eight receive channels with VLAN tag discrimination for receive quality-of-service (QOS) support.
- Eight transmit channels with round-robin or fixed priority for transmit quality-of-service (QOS) support.
- Ether-Stats and 802.3-Stats statistics gathering.
- Transmit CRC generation selectable on a per channel basis.
- Broadcast frames selection for reception on a single channel.
- Multicast frames selection for reception on a single channel.
- Promiscuous receive mode frames selection for reception on a single channel (all frames, all good frames, short frames, error frames).
- Hardware flow control.
- 8k-byte local EMAC descriptor memory that allows the peripheral to operate on descriptors without affecting the CPU. The descriptor memory holds enough information to transfer up to 512 Ethernet packets without CPU intervention. (This memory is also known as CPPI RAM.)
- Programmable interrupt logic permits the software driver to restrict the generation of back-to-back interrupts, which allows more work to be performed in a single call to the interrupt service routine.

19.1.3 Functional Block Diagram

Figure 19-1 shows the three main functional modules of the EMAC/MDIO peripheral:

- EMAC control module
- EMAC module
- MDIO module

The EMAC control module is the main interface between the device core processor to the EMAC and MDIO modules. The EMAC control module controls device interrupts and incorporates an 8k-byte internal RAM to hold EMAC buffer descriptors (also known as CPPI RAM).

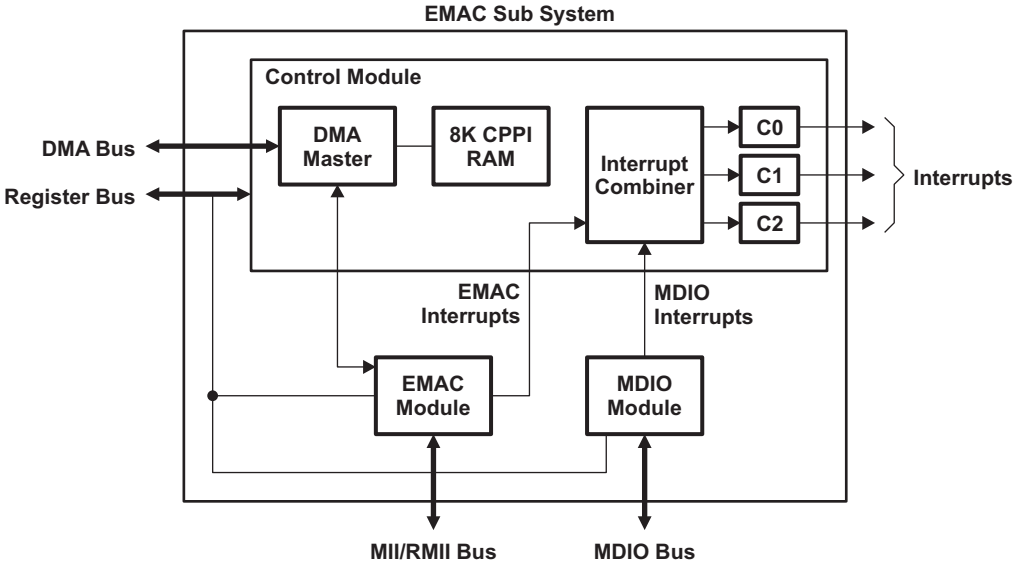
The MDIO module implements the 802.3 serial management interface to interrogate and control up to 32 Ethernet PHYs connected to the device by using a shared two-wire bus. Host software uses the MDIO module to configure the autonegotiation parameters of each PHY attached to the EMAC, retrieve the negotiation results, and configure required parameters in the EMAC module for correct operation. The module is designed to allow almost transparent operation of the MDIO interface, with very little maintenance from the core processor.

The EMAC module provides an efficient interface between the processor and the network. The EMAC on this device supports 10Base-T (10 Mbits/sec) and 100BaseTX (100 Mbits/sec), half-duplex and full-duplex mode, and hardware flow control and quality-of-service (QOS) support.

Figure 19-1 shows the main interface between the EMAC control module and the CPU. The following connections are made to the device core:

- The DMA bus connection from the EMAC control module allows the EMAC module to read and write both internal and external memory through the DMA memory transfer controller.
- The EMAC control, EMAC, and MDIO modules all have control registers. These registers are memory-mapped into device memory space via the device configuration bus. Along with these registers, the control module's internal CPPI RAM is mapped into this same range.
- The EMAC and MDIO interrupts are combined into four interrupt signals within the control module. Three configurable interrupt cores within the control module receive all four interrupt signals from the combiner and submit interrupt requests to the CPU.

Figure 19-1. EMAC and MDIO Block Diagram



19.1.4 Industry Standard(s) Compliance Statement

The EMAC peripheral conforms to the IEEE 802.3 standard, describing the Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer specifications. The IEEE 802.3 standard has also been adopted by ISO/IEC and re-designated as ISO/IEC 8802-3:2000(E).

However, the EMAC deviates from the standard in the way it handles transmit underflow errors. The EMAC MII interface does not use the Transmit Coding Error signal MTXER. Instead of driving the error pin when an underflow condition occurs on a transmitted frame, the EMAC intentionally generates an incorrect checksum by inverting the frame CRC, so that the transmitted frame is detected as an error by the network.

19.1.5 Terminology

The following is a brief explanation of some terms used in this chapter.

Term	Meaning
Broadcast MAC Address	A special Ethernet MAC address used to send data to all Ethernet devices on the local network. The broadcast address is FFh-FFh-FFh-FFh-FFh-FFh. The LSB of the first byte is odd, qualifying it as a group address; however, its value is reserved for broadcast. It is classified separately by the EMAC.
Descriptor (Packet Buffer Descriptor)	A small memory structure that describes a larger block of memory in terms of size, location, and state. Descriptors are used by the EMAC and application to describe the memory buffers that hold Ethernet data.
Device	In this chapter, device refers to the processor.
Ethernet MAC Address (MAC Address)	A unique 6-byte address that identifies an Ethernet device on the network. In an Ethernet packet, a MAC address is used twice, first to identify the packet's destination, and second to identify the packet's sender or source. An Ethernet MAC address is normally specified in hexadecimal, using dashes to separate bytes. For example, 08h-00h-28h-32h-17h-42h. The first three bytes normally designate the manufacturer of the device. However, when the first byte of the address is odd (LSB is 1), the address is a group address (broadcast or multicast). The second bit specifies whether the address is globally or locally administrated (not considered in this chapter).
Ethernet Packet (Packet)	An Ethernet packet is the collection of bytes that represents the data portion of a single Ethernet frame on the wire.
Full Duplex	Full-duplex operation allows simultaneous communication between a pair of stations using point-to-point media (dedicated channel). Full-duplex operation does not require that transmitters defer, nor do they monitor or react to receive activity, as there is no contention for a shared medium in this mode. Full-duplex mode can only be used when all of the following are true: • The physical medium is capable of supporting simultaneous transmission and reception without interference. • There are exactly two stations connected with a full duplex point-to-point link. As there is no contention for use of a shared medium, the multiple access (that is, CSMA/CD) algorithms are unnecessary. • Both stations on the LAN are capable of, and have been configured to use, full-duplex operation. The most common configuration envisioned for full-duplex operation consists of a central bridge (also known as a switch) with a dedicated LAN connecting each bridge port to a single device. Full-duplex operation constitutes a proper subset of the MAC functionality required for half-duplex operation.

Term	Meaning
Half Duplex	In half-duplex mode, the CSMA/CD media access method is the means by which two or more stations share a common transmission medium. To transmit, a station waits (defers) for a quiet period on the medium, that is, no other station is transmitting. It then sends the intended message in bit-serial form. If, after initiating a transmission, the message collides with that of another station, then each transmitting station intentionally transmits for an additional predefined period to ensure propagation of the collision throughout the system. The station remains silent for a random amount of time (backoff) before attempting to transmit again.
Host	The host is an intelligent system resource that configures and manages each communications control module. The host is responsible for allocating memory, initializing all data structures, and responding to port (EMAC) interrupts. In this chapter, host refers to the device.
Jabber	A condition wherein a station transmits for a period of time longer than the maximum permissible packet length, usually due to a fault condition.
Link	The transmission path between any two instances of generic cabling.
Multicast MAC Address	A class of MAC address that sends a packet to potentially more than one recipient. A group address is specified by setting the LSB of the first MAC address byte to 1. Thus, 01h-02h-03h-04h-05h-06h is a valid multicast address. Typically, an Ethernet MAC looks for only certain multicast addresses on a network to reduce traffic load. The multicast address list of acceptable packets is specified by the application.
Physical Layer and Media Notation	To identify different Ethernet technologies, a simple, three-field, type notation is used. The Physical Layer type used by the Ethernet is specified by these fields: <data rate in Mb/s><medium type><maximum segment length (×100m)> The definitions for the technologies mentioned in this chapter are: • 10Base-T: IEEE 802.3 Physical Layer specification for a 10 Mb/s CSMA/CD local area network over two pairs of twisted-pair telephone wire. • 100Base-T: IEEE 802.3 Physical Layer specification for a 100 Mb/s CSMA/CD local area network over two pairs of Category 5 unshielded twisted-pair (UTP) or shielded twisted-pair (STP) wire. • Twisted pair: A cable element that consists of two insulated conductors twisted together in a regular fashion to form a balanced transmission line.
Port	Ethernet device.
Promiscuous Mode	EMAC receives frames that do not match its address.

19.2 Architecture

This section discusses the architecture and basic function of the EMAC/MDIO module.

19.2.1 Clock Control

All internal EMAC logic is clocked synchronously on one clock domain. See your device-specific data manual for information.

The MDIO clock is based on a divide-down of the peripheral clock and is specified to run up to 2.5 MHz (although typical operation would be 1.0 MHz). Because the peripheral clock frequency is variable, the application software or driver must control the divide-down value.

The transmit and receive clock sources are provided by the external PHY to the MII_TXCLK and MII_RXCLK pins or to the RMII reference clock pin. Data is transmitted and received with respect to the reference clocks of the interface pins.

The MII interface frequencies for the transmit and receive clocks are fixed by the IEEE 802.3 specification as:

- 2.5 MHz at 10 Mbps
- 25 MHz at 100 Mbps

The RMII interface frequency for the transmit and receive clocks are fixed at 50 MHz for both 10 Mbps and 100 Mbps.

19.2.2 Memory Map

The EMAC peripheral includes internal memory that is used to hold buffer descriptions of the Ethernet packets to be received and transmitted. This internal RAM is 2K × 32 bits in size. Data can be written to and read from the EMAC internal memory by either the EMAC or the CPU. It is used to store buffer descriptors that are 4-words (16-bytes) deep. This 8K local memory holds enough information to transfer up to 512 Ethernet packets without CPU intervention. This EMAC RAM is also referred to as the CPPI buffer descriptor memory because it complies with the Communications Port Programming Interface (CPPI) v3.0 standard.

The packet buffer descriptors can also be placed in other on- and off-chip memories such as L2 and EMIF. There are some tradeoffs in terms of cache performance and throughput when descriptors are placed in the system memory, versus when they are placed in the EMAC's internal memory. In general, the EMAC throughput is better when the descriptors are placed in the local EMAC CPPI RAM.

19.2.3 Signal Descriptions

Support of interfaces (MII and/or RMII) varies between devices. See your device-specific data manual for information.

19.2.3.1 Media Independent Interface (MII) Connections

Figure 19-2 shows a device with integrated EMAC and MDIO interfaced via a MII connection in a typical system. The EMAC module does not include a transmit error (MTXER) pin. In the case of transmit error, CRC inversion is used to negate the validity of the transmitted frame.

The individual EMAC and MDIO signals for the MII interface are summarized in Table 19-1. For more information, refer to either the IEEE 802.3 standard or ISO/IEC 8802-3:2000(E).

Figure 19-2. Ethernet Configuration—MII Connections

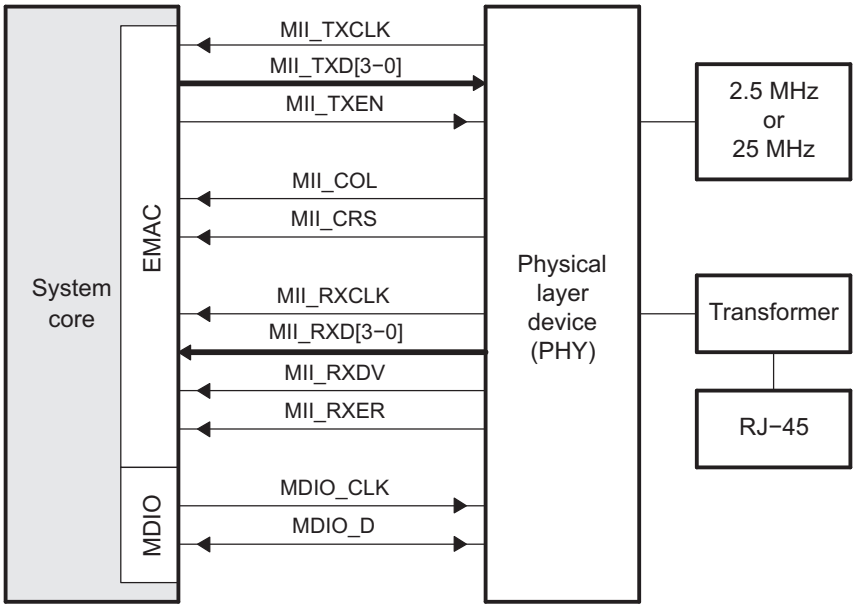


Table 19-1. EMAC and MDIO Signals for MII Interface

Signal	Type	Description
MII_TXCLK	I	Transmit clock (MII_TXCLK). The transmit clock is a continuous clock that provides the timing reference for transmit operations. The MII_TXD and MII_TXEN signals are tied to this clock. The clock is generated by the PHY and is 2.5 MHz at 10 Mbps operation and 25 MHz at 100 Mbps operation.
MII_TXD[3-0]	O	Transmit data (MII_TXD). The transmit data pins are a collection of 4 data signals comprising 4 bits of data. MTDX0 is the least-significant bit (LSB). The signals are synchronized by MII_TXCLK and valid only when MII_TXEN is asserted.
MII_TXEN	O	Transmit enable (MII_TXEN). The transmit enable signal indicates that the MII_TXD pins are generating nibble data for use by the PHY. It is driven synchronously to MII_TXCLK.
MII_COL	I	Collision detected (MII_COL). In half-duplex operation, the MII_COL pin is asserted by the PHY when it detects a collision on the network. It remains asserted while the collision condition persists. This signal is not necessarily synchronous to MII_TXCLK nor MII_RXCLK. In full-duplex operation, the MII_COL pin is used for hardware transmit flow control. Asserting the MII_COL pin will stop packet transmissions; packets in the process of being transmitted when MII_COL is asserted will complete transmission. The MII_COL pin should be held low if hardware transmit flow control is not used.
MII_CRS	I	Carrier sense (MII_CRS). In half-duplex operation, the MII_CRS pin is asserted by the PHY when the network is not idle in either transmit or receive. The pin is deasserted when both transmit and receive are idle. This signal is not necessarily synchronous to MII_TXCLK nor MII_RXCLK. In full-duplex operation, the MII_CRS pin should be held low.
MII_RXCLK	I	Receive clock (MII_RXCLK). The receive clock is a continuous clock that provides the timing reference for receive operations. The MII_RXD, MII_RXDV, and MII_RXER signals are tied to this clock. The clock is generated by the PHY and is 2.5 MHz at 10 Mbps operation and 25 MHz at 100 Mbps operation.
MII_RXD[3-0]	I	Receive data (MII_RXD). The receive data pins are a collection of 4 data signals comprising 4 bits of data. MRDX0 is the least-significant bit (LSB). The signals are synchronized by MII_RXCLK and valid only when MII_RXDV is asserted.
MII_RXDV	I	Receive data valid (MII_RXDV). The receive data valid signal indicates that the MII_RXD pins are generating nibble data for use by the EMAC. It is driven synchronously to MII_RXCLK.
MII_RXER	I	Receive error (MII_RXER). The receive error signal is asserted for one or more MII_RXCLK periods to indicate that an error was detected in the received frame. This is meaningful only during data reception when MII_RXDV is active.
MDIO_CLK	O	Management data clock (MDIO_CLK). The MDIO data clock is sourced by the MDIO module on the system. It is used to synchronize MDIO data access operations done on the MDIO pin. The frequency of this clock is controlled by the CLKDIV bits in the MDIO control register (CONTROL).
MDIO_D	I/O	Management data input output (MDIO_D). The MDIO data pin drives PHY management data into and out of the PHY by way of an access frame consisting of start of frame, read/write indication, PHY address, register address, and data bit cycles. The MDIO_D pin acts as an output for all but the data bit cycles at which time it is an input for read operations.

19.2.3.2 Reduced Media Independent Interface (RMII) Connections

Figure 19-3 shows a device with integrated EMAC and MDIO interfaced via a RMII connection in a typical system.

The individual EMAC and MDIO signals for the RMII interface are summarized in Table 19-2. For more information, refer to either the IEEE 802.3 standard or ISO/IEC 8802-3:2000(E).

Figure 19-3. Ethernet Configuration—RMII Connections

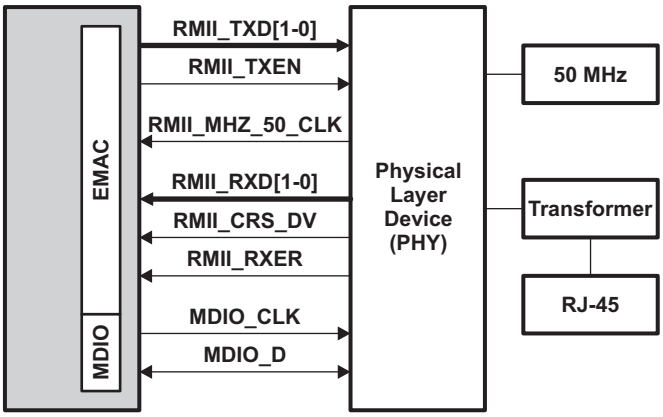


Table 19-2. EMAC and MDIO Signals for RMII Interface

Signal	Type	Description
RMII_TXD[1-0]	O	Transmit data (RMII_TXD). The transmit data pins are a collection of 2 bits of data. RMTDX0 is the least-significant bit (LSB). The signals are synchronized by RMII_MHZ_50_CLK and valid only when RMII_TXEN is asserted.
RMII_TXEN	O	Transmit enable (RMII_TXEN). The transmit enable signal indicates that the RMII_TXD pins are generating data for use by the PHY. RMII_TXEN is synchronous to RMII_MHZ_50_CLK.
RMII_MHZ_50_CLK	I	RMII reference clock (RMII_MHZ_50_CLK). The reference clock is used to synchronize all RMII signals. RMII_MHZ_50_CLK must be continuous and fixed at 50 MHz.
RMII_RXD[1-0]	I	Receive data (RMII_RXD). The receive data pins are a collection of 2 bits of data. RMRDX0 is the least-significant bit (LSB). The signals are synchronized by RMII_MHZ_50_CLK and valid only when RMII_CRS_DV is asserted and RMII_RXER is deasserted.
RMII_CRS_DV	I	Carrier sense/receive data valid (RMII_CRS_DV). Multiplexed signal between carrier sense and receive data valid.
RMII_RXER	I	Receive error (RMII_RXER). The receive error signal is asserted to indicate that an error was detected in the received frame.
MDIO_CLK	O	Management data clock (MDIO_CLK). The MDIO data clock is sourced by the MDIO module on the system. It is used to synchronize MDIO data access operations done on the MDIO pin. The frequency of this clock is controlled by the CLKDIV bits in the MDIO control register (CONTROL).
MDIO_D	I/O	Management data input output (MDIO_D). The MDIO data pin drives PHY management data into and out of the PHY by way of an access frame consisting of start of frame, read/write indication, PHY address, register address, and data bit cycles. The MDIO_D pin acts as an output for all but the data bit cycles at which time it is an input for read operations.

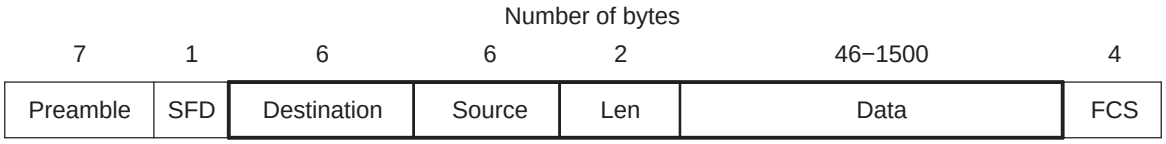
19.2.4 Ethernet Protocol Overview

A brief overview of the Ethernet protocol is given in the following subsections. See the IEEE 802.3 standard document for in-depth information on the Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method.

19.2.4.1 Ethernet Frame Format

All the Ethernet technologies use the same frame structure. The format of an Ethernet frame is shown in Figure 19-4 and described in Table 19-3. The Ethernet packet, which is the collection of bytes representing the data portion of a single Ethernet frame on the wire, is shown outlined in bold. The Ethernet frames are of variable lengths, with no frame smaller than 64 bytes or larger than RXMAXLEN bytes (header, data, and CRC).

Figure 19-4. Ethernet Frame Format



Legend: SFD=Start Frame Delimeter; FCS=Frame Check Sequence (CRC)

Table 19-3. Ethernet Frame Description

Field	Bytes	Description
Preamble	7	Preamble. These 7 bytes have a fixed value of 55h and serve to wake up the receiving EMAC ports and to synchronize their clocks to that of the sender's clock.
SFD	1	Start of Frame Delimiter. This field with a value of 5Dh immediately follows the preamble pattern and indicates the start of important data.
Destination	6	Destination address. This field contains the Ethernet MAC address of the EMAC port for which the frame is intended. It may be an individual or multicast (including broadcast) address. When the destination EMAC port receives an Ethernet frame with a destination address that does not match any of its MAC physical addresses, and no promiscuous, multicast or broadcast channel is enabled, it discards the frame.
Source	6	Source address. This field contains the MAC address of the Ethernet port that transmits the frame to the Local Area Network.
Len	2	Length/Type field. The length field indicates the number of EMAC client data bytes contained in the subsequent data field of the frame. This field can also be used to identify the type of data the frame is carrying.
Data	46 to (RXMAXLEN - 18)	Data field. This field carries the datagram containing the upper layer protocol frame, that is, IP layer datagram. The maximum transfer unit (MTU) of Ethernet is (RXMAXLEN - 18) bytes. This means that if the upper layer protocol datagram exceeds (RXMAXLEN - 18) bytes, then the host has to fragment the datagram and send it in multiple Ethernet packets. The minimum size of the data field is 46 bytes. This means that if the upper layer datagram is less then 46 bytes, the data field has to be extended to 46 bytes by appending extra bits after the data field, but prior to calculating and appending the FCS.
FCS	4	Frame Check Sequence. A cyclic redundancy check (CRC) is used by the transmit and receive algorithms to generate a CRC value for the FCS field. The frame check sequence covers the 60 to 1514 bytes of the packet data. Note that this 4-byte field may or may not be included as part of the packet data, depending on how the EMAC is configured.

19.2.4.2 Ethernet's Multiple Access Protocol

Nodes in an Ethernet Local Area Network are interconnected by a broadcast channel -- when an EMAC port transmits a frame, all the adapters on the local network receive the frame. Carrier Sense Multiple Access with Collision Detection (CSMA/CD) algorithms are used when the EMAC operates in half-duplex mode. When operating in full-duplex mode, there is no contention for use of a shared medium because there are exactly two ports on the local network.

Each port runs the CSMA/CD protocol without explicit coordination with the other ports on the Ethernet network. Within a specific port, the CSMA/CD protocol works as follows:

1. The port obtains data from upper layer protocols at its node, prepares an Ethernet frame, and puts the frame in a buffer.
2. If the port senses that the medium is idle, it starts to transmit the frame. If the port senses that the transmission medium is busy, it waits until it no longer senses energy (plus an Inter-Packet Gap time) and then starts to transmit the frame.
3. While transmitting, the port monitors for the presence of signal energy coming from other ports. If the port transmits the entire frame without detecting signal energy from other Ethernet devices, the port is done with the frame.
4. If the port detects signal energy from other ports while transmitting, it stops transmitting its frame and instead transmits a 48-bit jam signal.
5. After transmitting the jam signal, the port enters an exponential backoff phase. If a data frame encounters back-to-back collisions, the port chooses a random value that is dependent on the number of collisions. The port then waits an amount of time that is a multiple of this random value and returns to step 2.

19.2.5 Programming Interface

19.2.5.1 Packet Buffer Descriptors

The buffer descriptor is a central part of the EMAC module and is how the application software describes Ethernet packets to be sent and empty buffers to be filled with incoming packet data. The basic descriptor format is shown in Figure 19-5 and described in Table 19-4.

For example, consider three packets to be transmitted: Packet A is a single fragment (60 bytes), Packet B is fragmented over three buffers (1514 bytes total), and Packet C is a single fragment (1514 bytes). The linked list of descriptors to describe these three packets is shown in Figure 19-6.

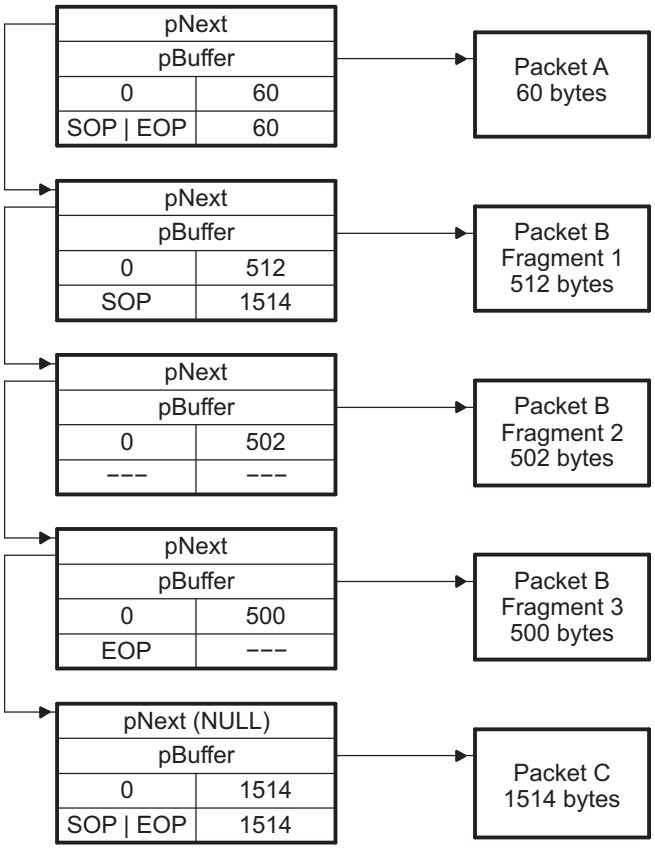
Figure 19-5. Basic Descriptor Format

	Bit Fields	
Word Offset	31 16	15 0
0	Next Descriptor Pointer	
1	Buffer Pointer	
2	Buffer Offset	Buffer Length
3	Flags	Packet Length

Table 19-4. Basic Descriptor Description

Word Offset	Field	Field Description
0	Next Descriptor Pointer	The next descriptor pointer is used to create a single linked list of descriptors. Each descriptor describes a packet or a packet fragment. When a descriptor points to a single buffer packet or the first fragment of a packet, the start of packet (SOP) flag is set in the flags field. When a descriptor points to a single buffer packet or the last fragment of a packet, the end of packet (EOP) flag is set. When a packet is fragmented, each fragment must have its own descriptor and appear sequentially in the descriptor linked list.
1	Buffer Pointer	The buffer pointer refers to the actual memory buffer that contains packet data during transmit operations, or is an empty buffer ready to receive packet data during receive operations.
2	Buffer Offset	The buffer offset is the offset from the start of the packet buffer to the first byte of valid data. This field only has meaning when the buffer descriptor points to a buffer that actually contains data.
	Buffer Length	The buffer length is the actual number of valid packet data bytes stored in the buffer. If the buffer is empty and waiting to receive data, this field represents the size of the empty buffer.
3	Flags	The flags field contains more information about the buffer, such as, is it the first fragment in a packet (SOP), the last fragment in a packet (EOP), or contains an entire contiguous Ethernet packet (both SOP and EOP). The flags are described in Section 19.2.5.4 and Section 19.2.5.5.
	Packet Length	The packet length only has meaning for buffers that both contain data and are the start of a new packet (SOP). In the case of SOP descriptors, the packet length field contains the length of the entire Ethernet packet, regardless if it is contained in a single buffer or fragmented over several buffers.

Figure 19-6. Typical Descriptor Linked List



19.2.5.2 Transmit and Receive Descriptor Queues

The EMAC module processes descriptors in linked lists as discussed in Section 19.2.5.1. The lists used by the EMAC are maintained by the application software through the use of the head descriptor pointer registers (HDP). The EMAC supports eight channels for transmit and eight channels for receive. The corresponding head descriptor pointers are:

- TX*n*HDP - Transmit Channel *n* DMA Head Descriptor Pointer Register
- RX*n*HDP - Receive Channel *n* DMA Head Descriptor Pointer Register

After an EMAC reset and before enabling the EMAC for send and receive, all 16 head descriptor pointer registers must be initialized to 0.

The EMAC uses a simple system to determine if a descriptor is currently owned by the EMAC or by the application software. There is a flag in the buffer descriptor flags called OWNER. When this flag is set, the packet that is referenced by the descriptor is considered to be owned by the EMAC. Note that ownership is done on a packet based granularity, not on descriptor granularity, so only SOP descriptors make use of the OWNER flag. As packets are processed, the EMAC patches the SOP descriptor of the corresponding packet and clears the OWNER flag. This is an indication that the EMAC has finished processing all descriptors up to and including the first with the EOP flag set, indicating the end of the packet (note this may only be one descriptor with both the SOP and EOP flags set).

To add a descriptor or a linked list of descriptors to an EMAC descriptor queue for the first time, the software application simply writes the pointer to the descriptor or first descriptor of a list to the corresponding HDP register. Note that the last descriptor in the list must have its “next” pointer cleared to 0. This is the only way the EMAC has of detecting the end of the list. Therefore, in the case where only a single descriptor is added, its “next descriptor” pointer must be initialized to 0.

The HDP must never be written to while a list is active. To add additional descriptors to a descriptor list already owned by the EMAC, the NULL “next” pointer of the last descriptor of the previous list is patched with a pointer to the first descriptor of the new list. The list of new descriptors to be appended to the existing list must itself be NULL terminated before the pointer patch is performed.

There is a potential race condition where the EMAC may read the “next” pointer of a descriptor as NULL in the instant before an application appends additional descriptors to the list by patching the pointer. This case is handled by the software application always examining the buffer descriptor flags of all EOP packets, looking for a special flag called end of queue (EOQ). The EOQ flag is set by the EMAC on the last descriptor of a packet when the descriptor’s “next” pointer is NULL. This is the way the EMAC indicates to the software application that it believes it has reached the end of the list. When the software application sees the EOQ flag set, the application may at that time submit the new list, or the portion of the appended list that was missed by writing the new list pointer to the same HDP that started the process.

This process applies when adding packets to a transmit list, and empty buffers to a receive list.

19.2.5.3 Transmit and Receive EMAC Interrupts

The EMAC processes descriptors in linked list chains as discussed in Section 19.2.5.1, using the linked list queue mechanism discussed in Section 19.2.5.2.

The EMAC synchronizes descriptor list processing through the use of interrupts to the software application. The interrupts are controlled by the application using the interrupt masks, global interrupt enable, and the completion pointer register (CP). The CP is also called the interrupt acknowledge register.

The EMAC supports eight channels for transmit and eight channels for receive. The corresponding completion pointer registers are:

- TX*n*CP - Transmit Channel *n* Completion Pointer (Interrupt Acknowledge) Register
- RX*n*CP - Receive Channel *n* Completion Pointer (Interrupt Acknowledge) Register

These registers serve two purposes. When read, they return the pointer to the last descriptor that the EMAC has processed. When written by the software application, the value represents the last descriptor processed by the software application. When these two values do not match, the interrupt is active.

Interrupts in the EMAC control module are routed to three independent interrupt cores which are then mapped to CPU interrupt controllers. The system configuration determines whether or not an active interrupt actually interrupts the CPU. In general the following settings are required for basic EMAC transmit and receive interrupts:

1. EMAC transmit and receive interrupts are enabled by setting the mask registers RXINTMASKSET and TXINTMASKSET
2. Global interrupts for the appropriate interrupt core registers are set in the EMAC control module: C*n*RXEN and C*n*TXEN on core *n*
3. The CPU interrupt controller is configured to accept C*n*_RX_PULSE and C*n*_TX_PULSE interrupts from the EMAC control module

Whether or not the interrupt is enabled, the current state of the receive or transmit channel interrupt can be examined directly by the software application reading the EMAC receive interrupt status (unmasked) register (RXINTSTATRAW) and transmit interrupt status (unmasked) register (TXINTSTATRAW).

After servicing transmit or receive interrupts, the application software must acknowledge both the EMAC and EMAC control module interrupts.

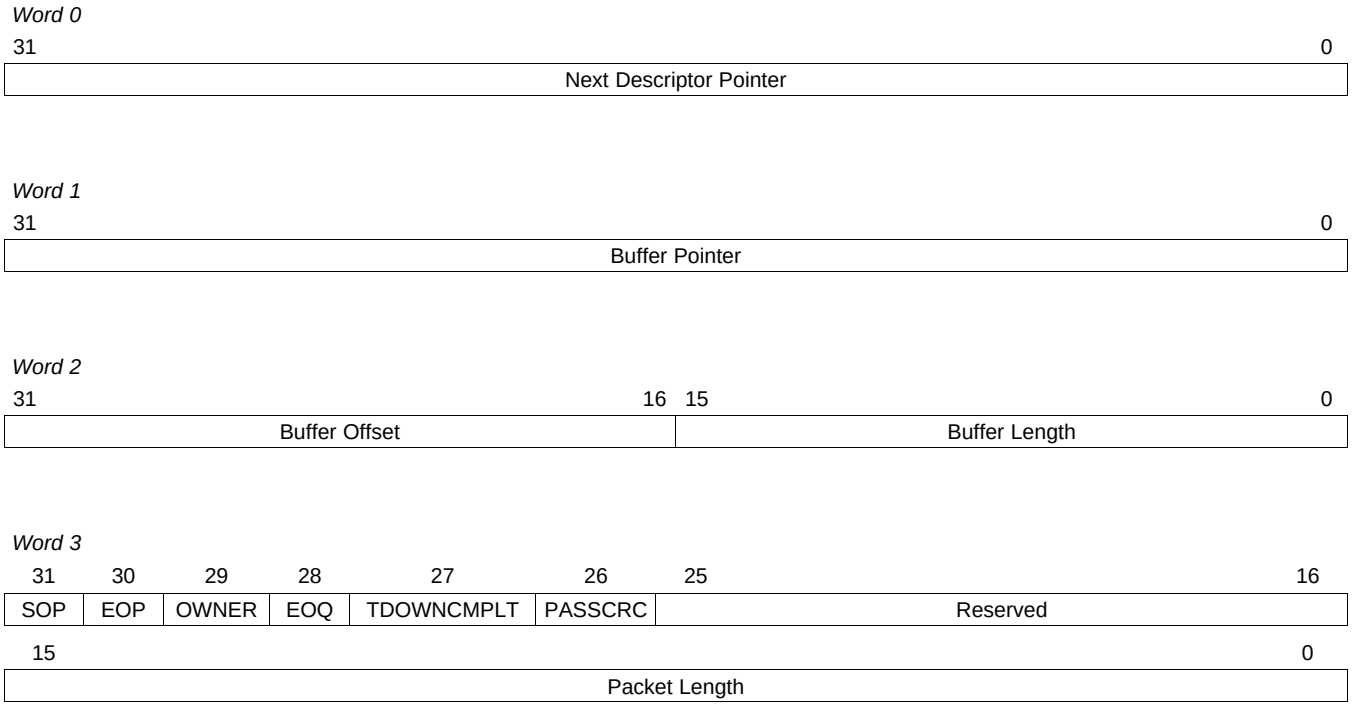
EMAC interrupts are acknowledged when the application software updates the value of TX*n*CP or RX*n*CP with a value that matches the internal value kept by the EMAC. This mechanism ensures that the application software never misses an EMAC interrupt because the interrupt acknowledgment is tied directly to the buffer descriptor processing.

EMAC control module interrupts are acknowledged when the application software writes the appropriate C*n*TX or C*n*RX key to the EMAC End-Of-Interrupt Vector register (MACEOIVECTOR). The MACEOIVECTOR behaves as an interrupt pulse interlock -- once the EMAC control module has issued an interrupt pulse to the CPU, it will not generate further pulses of the same type until the original pulse has been acknowledged.

19.2.5.4 Transmit Buffer Descriptor Format

A transmit (TX) buffer descriptor (Figure 19-7) is a contiguous block of four 32-bit data words aligned on a 32-bit boundary that describes a packet or a packet fragment. Example 19-1 shows the transmit buffer descriptor described by a C structure.

Figure 19-7. Transmit Buffer Descriptor Format



Example 19-1. Transmit Buffer Descriptor in C Structure Format

```
/*
// EMAC Descriptor
//
// The following is the format of a single buffer descriptor
// on the EMAC.
*/
typedef struct _EMAC_Desc {
 struct _EMAC_Desc *pNext; /* Pointer to next descriptor in chain */
 Uint8 *pBuffer; /* Pointer to data buffer */
 Uint32 BufOffLen; /* Buffer Offset(MSW) and Length(LSW) */
 Uint32 PktFlgLen; /* Packet Flags(MSW) and Length(LSW) */
} EMAC_Desc;

/* Packet Flags */
#define EMAC_DSC_FLAG_SOP 0x80000000u
#define EMAC_DSC_FLAG_EOP 0x40000000u
#define EMAC_DSC_FLAG_OWNER 0x20000000u
#define EMAC_DSC_FLAG_EOQ 0x10000000u
#define EMAC_DSC_FLAG_TDOWNCMPLT 0x08000000u
#define EMAC_DSC_FLAG_PASSCRC 0x04000000u
```

19.2.5.4.1 Next Descriptor Pointer

The next descriptor pointer points to the 32-bit word aligned memory address of the next buffer descriptor in the transmit queue. This pointer is used to create a linked list of buffer descriptors. If the value of this pointer is zero, then the current buffer is the last buffer in the queue. The software application must set this value prior to adding the descriptor to the active transmit list. This pointer is not altered by the EMAC.

The value of pNext should never be altered once the descriptor is in an active transmit queue, unless its current value is NULL. If the pNext pointer is initially NULL, and more packets need to be queued for transmit, the software application may alter this pointer to point to a newly appended descriptor. The EMAC will use the new pointer value and proceed to the next descriptor unless the pNext value has already been read. In this latter case, the transmitter will halt on the transmit channel in question, and the software application may restart it at that time. The software can detect this case by checking for an end of queue (EOQ) condition flag on the updated packet descriptor when it is returned by the EMAC.

19.2.5.4.2 Buffer Pointer

The buffer pointer is the byte-aligned memory address of the memory buffer associated with the buffer descriptor. The software application must set this value prior to adding the descriptor to the active transmit list. This pointer is not altered by the EMAC.

19.2.5.4.3 Buffer Offset

This 16-bit field indicates how many unused bytes are at the start of the buffer. For example, a value of 0000h indicates that no unused bytes are at the start of the buffer and that valid data begins on the first byte of the buffer, while a value of 000Fh indicates that the first 15 bytes of the buffer are to be ignored by the EMAC and that valid buffer data starts on byte 16 of the buffer. The software application must set this value prior to adding the descriptor to the active transmit list. This field is not altered by the EMAC.

Note that this value is only checked on the first descriptor of a given packet (where the start of packet (SOP) flag is set). It can not be used to specify the offset of subsequent packet fragments. Also, since the buffer pointer may point to any byte–aligned address, this field may be entirely superfluous, depending on the device driver architecture.

The range of legal values for this field is 0 to (Buffer Length – 1).

19.2.5.4.4 Buffer Length

This 16-bit field indicates how many valid data bytes are in the buffer. On single fragment packets, this value is also the total length of the packet data to be transmitted. If the buffer offset field is used, the offset bytes are not counted as part of this length. This length counts only valid data bytes. The software application must set this value prior to adding the descriptor to the active transmit list. This field is not altered by the EMAC.

19.2.5.4.5 Packet Length

This 16-bit field specifies the number of data bytes in the entire packet. Any leading buffer offset bytes are not included. The sum of the buffer length fields of each of the packet's fragments (if more than one) must be equal to the packet length. The software application must set this value prior to adding the descriptor to the active transmit list. This field is not altered by the EMAC. This value is only checked on the first descriptor of a given packet (where the start of packet (SOP) flag is set).

19.2.5.4.6 Start of Packet (SOP) Flag

When set, this flag indicates that the descriptor points to a packet buffer that is the start of a new packet. In the case of a single fragment packet, both the SOP and end of packet (EOP) flags are set. Otherwise, the descriptor pointing to the last packet buffer for the packet sets the EOP flag. This bit is set by the software application and is not altered by the EMAC.

19.2.5.4.7 End of Packet (EOP) Flag

When set, this flag indicates that the descriptor points to a packet buffer that is last for a given packet. In the case of a single fragment packet, both the start of packet (SOP) and EOP flags are set. Otherwise, the descriptor pointing to the last packet buffer for the packet sets the EOP flag. This bit is set by the software application and is not altered by the EMAC.

19.2.5.4.8 Ownership (OWNER) Flag

When set, this flag indicates that all the descriptors for the given packet (from SOP to EOP) are currently owned by the EMAC. This flag is set by the software application on the SOP packet descriptor before adding the descriptor to the transmit descriptor queue. For a single fragment packet, the SOP, EOP, and OWNER flags are all set. The OWNER flag is cleared by the EMAC once it is finished with all the descriptors for the given packet. Note that this flag is valid on SOP descriptors only.

19.2.5.4.9 End of Queue (EOQ) Flag

When set, this flag indicates that the descriptor in question was the last descriptor in the transmit queue for a given transmit channel, and that the transmitter has halted. This flag is initially cleared by the software application prior to adding the descriptor to the transmit queue. This bit is set by the EMAC when the EMAC identifies that a descriptor is the last for a given packet (the EOP flag is set), and there are no more descriptors in the transmit list (next descriptor pointer is NULL).

The software application can use this bit to detect when the EMAC transmitter for the corresponding channel has halted. This is useful when the application appends additional packet descriptors to a transmit queue list that is already owned by the EMAC. Note that this flag is valid on EOP descriptors only.

19.2.5.4.10 Teardown Complete (TDOWNCMPLT) Flag

This flag is used when a transmit queue is being torn down, or aborted, instead of allowing it to be transmitted. This would happen under device driver reset or shutdown conditions. The EMAC sets this bit in the SOP descriptor of each packet as it is aborted from transmission.

Note that this flag is valid on SOP descriptors only. Also note that only the first packet in an unsent list has the TDOWNCMPLT flag set. Subsequent descriptors are not processed by the EMAC.

19.2.5.4.11 Pass CRC (PASSCRC) Flag

This flag is set by the software application in the SOP packet descriptor before it adds the descriptor to the transmit queue. Setting this bit indicates to the EMAC that the 4 byte Ethernet CRC is already present in the packet data, and that the EMAC should not generate its own version of the CRC.

When the CRC flag is cleared, the EMAC generates and appends the 4-byte CRC. The buffer length and packet length fields do not include the CRC bytes. When the CRC flag is set, the 4-byte CRC is supplied by the software application and is already appended to the end of the packet data. The buffer length and packet length fields include the CRC bytes, as they are part of the valid packet data. Note that this flag is valid on SOP descriptors only.

19.2.5.5 Receive Buffer Descriptor Format

A receive (RX) buffer descriptor (Figure 19-8) is a contiguous block of four 32-bit data words aligned on a 32-bit boundary that describes a packet or a packet fragment. Example 19-2 shows the receive buffer descriptor described by a C structure.

19.2.5.5.1 Next Descriptor Pointer

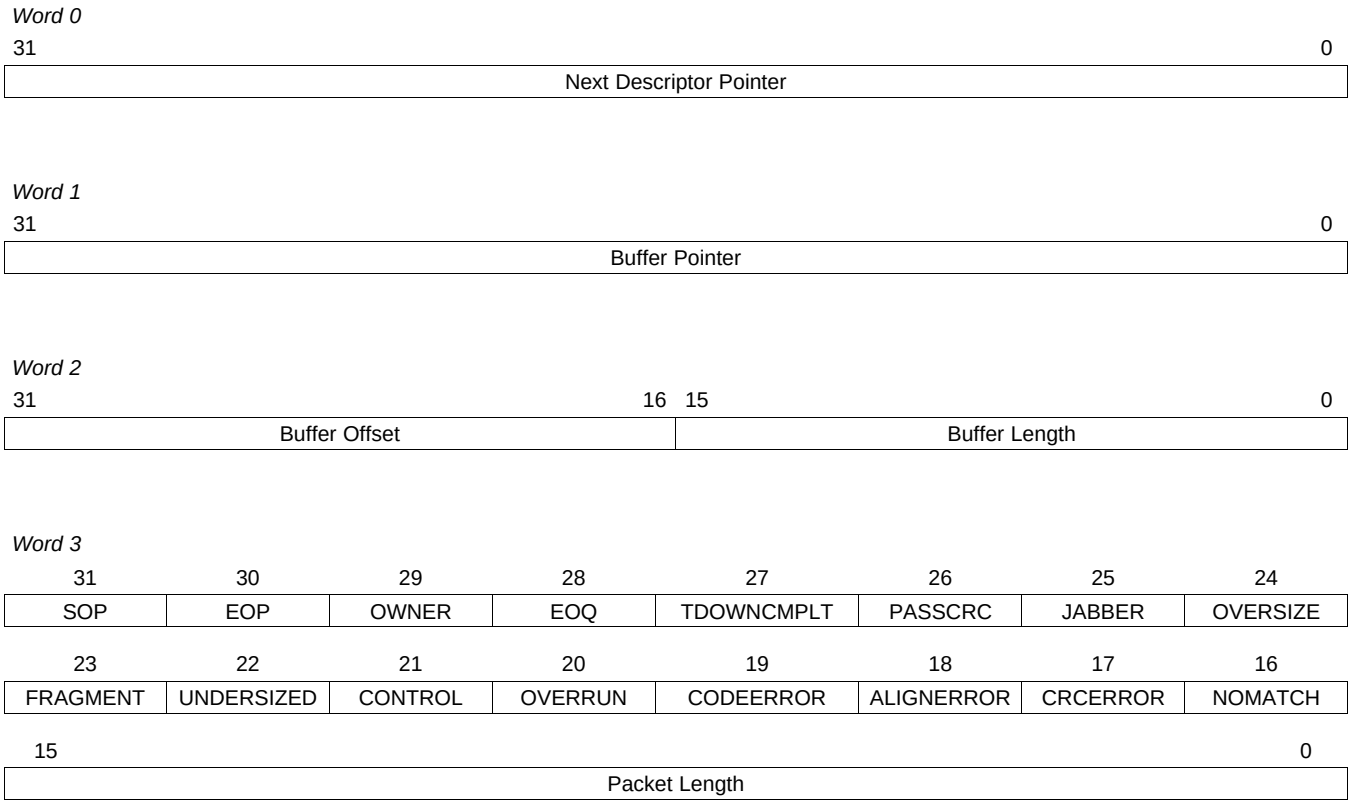
This pointer points to the 32–bit word aligned memory address of the next buffer descriptor in the receive queue. This pointer is used to create a linked list of buffer descriptors. If the value of this pointer is zero, then the current buffer is the last buffer in the queue. The software application must set this value prior to adding the descriptor to the active receive list. This pointer is not altered by the EMAC.

The value of pNext should never be altered once the descriptor is in an active receive queue, unless its current value is NULL. If the pNext pointer is initially NULL, and more empty buffers can be added to the pool, the software application may alter this pointer to point to a newly appended descriptor. The EMAC will use the new pointer value and proceed to the next descriptor unless the pNext value has already been read. In this latter case, the receiver will halt the receive channel in question, and the software application may restart it at that time. The software can detect this case by checking for an end of queue (EOQ) condition flag on the updated packet descriptor when it is returned by the EMAC.

19.2.5.5.2 Buffer Pointer

The buffer pointer is the byte-aligned memory address of the memory buffer associated with the buffer descriptor. The software application must set this value prior to adding the descriptor to the active receive list. This pointer is not altered by the EMAC.

Figure 19-8. Receive Buffer Descriptor Format



Example 19-2. Receive Buffer Descriptor in C Structure Format

```
/*
// EMAC Descriptor
//
// The following is the format of a single buffer descriptor
// on the EMAC.
*/
typedef struct _EMAC_Desc {
 struct _EMAC_Desc *pNext; /* Pointer to next descriptor in chain */
 Uint8 *pBuffer; /* Pointer to data buffer */
 Uint32 BufOffLen; /* Buffer Offset(MSW) and Length(LSW) */
 Uint32 PktFlgLen; /* Packet Flags(MSW) and Length(LSW) */
} EMAC_Desc;

/* Packet Flags */
#define EMAC_DSC_FLAG_SOP 0x80000000u
#define EMAC_DSC_FLAG_EOP 0x40000000u
#define EMAC_DSC_FLAG_OWNER 0x20000000u
#define EMAC_DSC_FLAG_EOQ 0x10000000u
#define EMAC_DSC_FLAG_TDOWNCMPLT 0x08000000u
#define EMAC_DSC_FLAG_PASSCRC 0x04000000u
#define EMAC_DSC_FLAG_JABBER 0x02000000u
#define EMAC_DSC_FLAG_OVERSIZE 0x01000000u
#define EMAC_DSC_FLAG_FRAGMENT 0x00800000u
#define EMAC_DSC_FLAG_UNDERSIZED 0x00400000u
#define EMAC_DSC_FLAG_CONTROL 0x00200000u
#define EMAC_DSC_FLAG_OVERRUN 0x00100000u
#define EMAC_DSC_FLAG_CODEERROR 0x00080000u
#define EMAC_DSC_FLAG_ALIGNERROR 0x00040000u
#define EMAC_DSC_FLAG_CRCERROR 0x00020000u
#define EMAC_DSC_FLAG_NOMATCH 0x00010000u
```

19.2.5.5.3 Buffer Offset

This 16-bit field must be initialized to zero by the software application before adding the descriptor to a receive queue.

Whether or not this field is updated depends on the setting of the RXBUFFEROFFSET register. When the offset register is set to a non-zero value, the received packet is written to the packet buffer at an offset given by the value of the register, and this value is also written to the buffer offset field of the descriptor.

When a packet is fragmented over multiple buffers because it does not fit in the first buffer supplied, the buffer offset only applies to the first buffer in the list, which is where the start of packet (SOP) flag is set in the corresponding buffer descriptor. In other words, the buffer offset field is only updated by the EMAC on SOP descriptors.

The range of legal values for the BUFFEROFFSET register is 0 to (Buffer Length – 1) for the smallest value of buffer length for all descriptors in the list.

19.2.5.5.4 Buffer Length

This 16-bit field is used for two purposes:

- Before the descriptor is first placed on the receive queue by the application software, the buffer length field is first initialized by the software to have the physical size of the empty data buffer pointed to by the buffer pointer field.
- After the empty buffer has been processed by the EMAC and filled with received data bytes, the buffer length field is updated by the EMAC to reflect the actual number of valid data bytes written to the buffer.

19.2.5.5.5 Packet Length

This 16-bit field specifies the number of data bytes in the entire packet. This value is initialized to zero by the software application for empty packet buffers. The value is filled in by the EMAC on the first buffer used for a given packet. This is signified by the EMAC setting a start of packet (SOP) flag. The packet length is set by the EMAC on all SOP buffer descriptors.

19.2.5.5.6 Start of Packet (SOP) Flag

When set, this flag indicates that the descriptor points to a packet buffer that is the start of a new packet. In the case of a single fragment packet, both the SOP and end of packet (EOP) flags are set. Otherwise, the descriptor pointing to the last packet buffer for the packet has the EOP flag set. This flag is initially cleared by the software application before adding the descriptor to the receive queue. This bit is set by the EMAC on SOP descriptors.

19.2.5.5.7 End of Packet (EOP) Flag

When set, this flag indicates that the descriptor points to a packet buffer that is last for a given packet. In the case of a single fragment packet, both the start of packet (SOP) and EOP flags are set. Otherwise, the descriptor pointing to the last packet buffer for the packet has the EOP flag set. This flag is initially cleared by the software application before adding the descriptor to the receive queue. This bit is set by the EMAC on EOP descriptors.

19.2.5.5.8 Ownership (OWNER) Flag

When set, this flag indicates that the descriptor is currently owned by the EMAC. This flag is set by the software application before adding the descriptor to the receive descriptor queue. This flag is cleared by the EMAC once it is finished with a given set of descriptors, associated with a received packet. The flag is updated by the EMAC on SOP descriptor only. So when the application identifies that the OWNER flag is cleared on an SOP descriptor, it may assume that all descriptors up to and including the first with the EOP flag set have been released by the EMAC. (Note that in the case of single buffer packets, the same descriptor will have both the SOP and EOP flags set.)

19.2.5.5.9 End of Queue (EOQ) Flag

When set, this flag indicates that the descriptor in question was the last descriptor in the receive queue for a given receive channel, and that the corresponding receiver channel has halted. This flag is initially cleared by the software application prior to adding the descriptor to the receive queue. This bit is set by the EMAC when the EMAC identifies that a descriptor is the last for a given packet received (also sets the EOP flag), and there are no more descriptors in the receive list (next descriptor pointer is NULL).

The software application can use this bit to detect when the EMAC receiver for the corresponding channel has halted. This is useful when the application appends additional free buffer descriptors to an active receive queue. Note that this flag is valid on EOP descriptors only.

19.2.5.5.10 Teardown Complete (TDOWNCMPLT) Flag

This flag is used when a receive queue is being torn down, or aborted, instead of being filled with received data. This would happen under device driver reset or shutdown conditions. The EMAC sets this bit in the descriptor of the first free buffer when the tear down occurs. No additional queue processing is performed.

19.2.5.5.11 Pass CRC (PASSCRC) Flag

This flag is set by the EMAC in the SOP buffer descriptor if the received packet includes the 4-byte CRC. This flag should be cleared by the software application before submitting the descriptor to the receive queue.

19.2.5.5.12 Jabber Flag

This flag is set by the EMAC in the SOP buffer descriptor, if the received packet is a jabber frame and was not discarded because the RXCEFEN bit was set in the RXMBPENABLE. Jabber frames are frames that exceed the RXMAXLEN in length, and have CRC, code, or alignment errors.

19.2.5.5.13 Oversize Flag

This flag is set by the EMAC in the SOP buffer descriptor, if the received packet is an oversized frame and was not discarded because the RXCEFEN bit was set in the RXMBPENABLE.

19.2.5.5.14 Fragment Flag

This flag is set by the EMAC in the SOP buffer descriptor, if the received packet is only a packet fragment and was not discarded because the RXCEFEN bit was set in the RXMBPENABLE.

19.2.5.5.15 Undersized Flag

This flag is set by the EMAC in the SOP buffer descriptor, if the received packet is undersized and was not discarded because the RXCSFEN bit was set in the RXMBPENABLE.

19.2.5.5.16 Control Flag

This flag is set by the EMAC in the SOP buffer descriptor, if the received packet is an EMAC control frame and was not discarded because the RXCMFEN bit was set in the RXMBPENABLE.

19.2.5.5.17 Overrun Flag

This flag is set by the EMAC in the SOP buffer descriptor, if the received packet was aborted due to a receive overrun.

19.2.5.5.18 Code Error (CODEERROR) Flag

This flag is set by the EMAC in the SOP buffer descriptor, if the received packet contained a code error and was not discarded because the RXCEFEN bit was set in the RXMBPENABLE.

19.2.5.5.19 Alignment Error (ALIGNERROR) Flag

This flag is set by the EMAC in the SOP buffer descriptor, if the received packet contained an alignment error and was not discarded because the RXCEFEN bit was set in the RXMBPENABLE.

19.2.5.5.20 CRC Error (CRCERROR) Flag

This flag is set by the EMAC in the SOP buffer descriptor, if the received packet contained a CRC error and was not discarded because the RXCEFEN bit was set in the RXMBPENABLE.

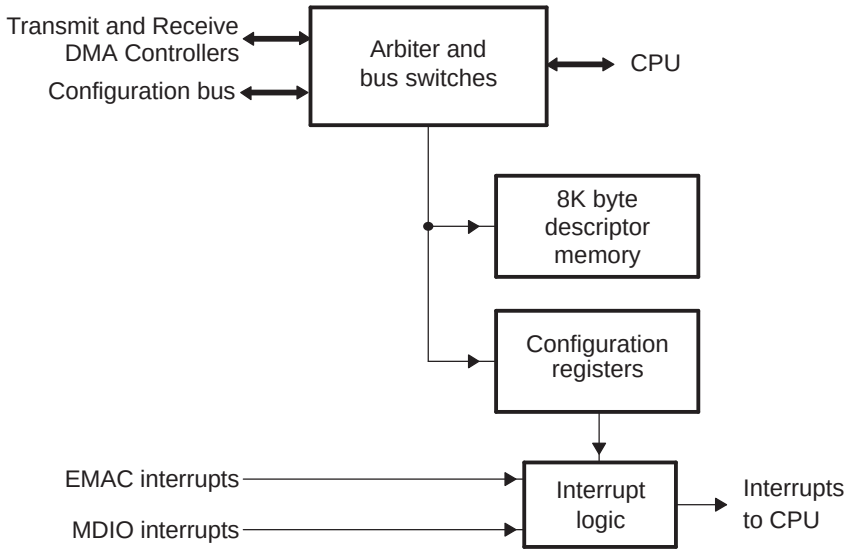
19.2.5.5.21 No Match (NOMATCH) Flag

This flag is set by the EMAC in the SOP buffer descriptor, if the received packet did not pass any of the EMAC's address match criteria and was not discarded because the RXCAFEN bit was set in the RXMBPENABLE. Although the packet is a valid Ethernet data packet, it was only received because the EMAC is in promiscuous mode.

19.2.6 EMAC Control Module

The EMAC control module (Figure 19-9) interfaces the EMAC and MDIO modules to the rest of the system, and also provides a local memory space to hold EMAC packet buffer descriptors. Local memory is used to help avoid contention with device memory spaces. Other functions include the bus arbiter, and interrupt logic control.

Figure 19-9. EMAC Control Module Block Diagram



19.2.6.1 Internal Memory

The EMAC control module includes 8K bytes of internal memory (CPPI buffer descriptor memory). The internal memory block is essential for allowing the EMAC to operate more independently of the CPU. It also prevents memory underflow conditions when the EMAC issues read or write requests to descriptor memory. (Memory accesses to read or write the actual Ethernet packet data are protected by the EMAC's internal FIFOs).

A descriptor is a 16-byte memory structure that holds information about a single Ethernet packet buffer, which may contain a full or partial Ethernet packet. Thus with the 8K memory block provided for descriptor storage, the EMAC module can send and received up to a combined 512 packets before it needs to be serviced by application or driver software.

19.2.6.2 Bus Arbiter

The EMAC control module bus arbiter operates transparently to the rest of the system. It is used:

- To arbitrate between the CPU and EMAC buses for access to internal descriptor memory.
- To arbitrate between internal EMAC buses for access to system memory.

19.2.6.3 Interrupt Control

Interrupt conditions generated by the EMAC and MDIO modules are combined into four interrupt signals that are routed to three independent interrupt cores in the EMAC control module; the interrupt cores then relay the interrupt signals to the CPU interrupt controller. The EMAC control module uses two sets of registers to control the interrupt signals to the CPU:

- C*n*RXTHRESHEN, C*n*RXEN, C*n*TXEN, and C*n*MISCEN registers enable the interrupt core pulse signals that are mapped to the CPU interrupt controller
- INTCONTROL, C*n*RXIMAX, and C*n*TXIMAX registers enable interrupt pacing to limit the number of interrupt pulses generated per millisecond

Interrupts must be acknowledged by writing the appropriate value to the EMAC End-Of-Interrupt Vector (MACEOIVECTOR). The MACEOIVECTOR behaves as an interrupt pulse interlock -- once the EMAC control module has issued an interrupt pulse to the CPU, it will not generate further pulses of the same type until the original pulse has been acknowledged.

19.2.7 MDIO Module

The MDIO module is used to manage up to 32 physical layer (PHY) devices connected to the Ethernet Media Access Controller (EMAC). The device supports a single PHY being connected to the EMAC at any given time. The MDIO module is designed to allow almost transparent operation of the MDIO interface with little maintenance from the CPU.

The MDIO module continuously polls 32 MDIO addresses in order to enumerate all PHY devices in the system. Once a PHY device has been detected, the MDIO module reads the MDIO PHY link status register (LINK) to monitor the PHY link state. Link change events are stored in the MDIO module, which can interrupt the CPU. This storing of the events allows the CPU to poll the link status of the PHY device without continuously performing MDIO module accesses. However, when the CPU must access the MDIO module for configuration and negotiation, the MDIO module performs the MDIO read or write operation independent of the CPU. This independent operation allows the processor to poll for completion or interrupt the CPU once the operation has completed.

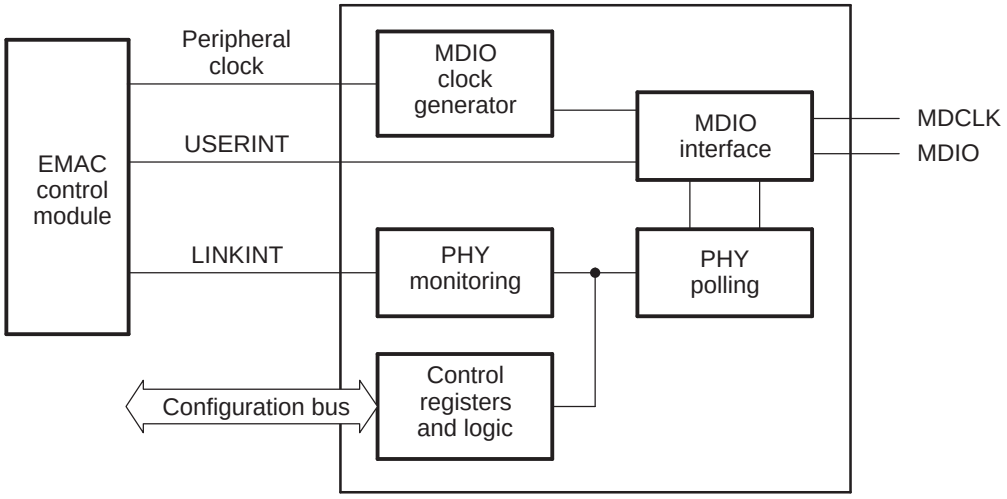
The MDIO module does not support the "Clause 45" interface.

19.2.7.1 MDIO Module Components

The MDIO module (Figure 19-10) interfaces to the PHY components through two MDIO pins (MDIO_CLK and MDIO), and to the CPU through the EMAC control module and the configuration bus. The MDIO module consists of the following logical components:

- MDIO clock generator
- Global PHY detection and link state monitoring
- Active PHY monitoring
- PHY register user access

Figure 19-10. MDIO Module Block Diagram



19.2.7.1.1 MDIO Clock Generator

The MDIO clock generator controls the MDIO clock based on a divide-down of the peripheral clock in the EMAC control module. The MDIO clock is specified to run up to 2.5 MHz, although typical operation would be 1.0 MHz. Since the peripheral clock frequency is variable, the application software or driver controls the divide-down amount. See your device-specific data manual for peripheral clock speeds.

19.2.7.1.2 Global PHY Detection and Link State Monitoring

The MDIO module continuously polls all 32 MDIO addresses in order to enumerate the PHY devices in the system. The module tracks whether or not a PHY on a particular address has responded, and whether or not the PHY currently has a link. Using this information allows the software application to quickly determine which MDIO address the PHY is using.

19.2.7.1.3 Active PHY Monitoring

Once a PHY candidate has been selected for use, the MDIO module transparently monitors its link state by reading the MDIO PHY link status register (LINK). Link change events are stored on the MDIO device and can optionally interrupt the CPU. This allows the system to poll the link status of the PHY device without continuously performing costly MDIO accesses.

19.2.7.1.4 PHY Register User Access

When the CPU must access MDIO for configuration and negotiation, the PHY access module performs the actual MDIO read or write operation independent of the CPU. This allows the CPU to poll for completion or receive an interrupt when the read or write operation has been performed. The user access registers USERACCESS*n* allows the software to submit the access requests for the PHY connected to the device.

19.2.7.2 MDIO Module Operational Overview

The MDIO module implements the 802.3 serial management interface to interrogate and control an Ethernet PHY, using a shared two-wired bus. It separately performs autodetection and records the current link status of up to 32 PHYs, polling all 32 MDIO addresses.

Application software uses the MDIO module to configure the autonegotiation parameters of the PHY attached to the EMAC, retrieve the negotiation results, and configure required parameters in the EMAC.

In this device, the Ethernet PHY attached to the system can be directly controlled and queried. The Media Independent Interface (MII) address of this PHY device is specified in one of the PHYADRMON bits in the MDIO user PHY select register (USERPHYSEL*n*). The MDIO module can be programmed to trigger a CPU interrupt on a PHY link change event, by setting the LINKINTENB bit in USERPHYSEL*n*. Reads and writes to registers in this PHY device are performed using the MDIO user access register (USERACCESS*n*).

The MDIO module powers-up in an idle state until specifically enabled by setting the ENABLE bit in the MDIO control register (CONTROL). At this time, the MDIO clock divider and preamble mode selection are also configured. The MDIO preamble is enabled by default, but can be disabled when the connected PHY does not require it. Once the MDIO module is enabled, the MDIO interface state machine continuously polls the PHY link status (by reading the generic status register) of all possible 32 PHY addresses and records the results in the MDIO PHY alive status register (ALIVE) and MDIO PHY link status register (LINK). The corresponding bit for the connected PHY (0-31) is set in ALIVE, if the PHY responded to the read request. The corresponding bit is set in LINK, if the PHY responded and also is currently linked. In addition, any PHY register read transactions initiated by the application software using USERACCESS*n* causes ALIVE to be updated.

The USERPHYSEL*n* is used to track the link status of the connected PHY address. A change in the link status of the PHY being monitored sets the appropriate bit in the MDIO link status change interrupt registers (LINKINTRAW and LINKINTMASKED), if enabled by the LINKINTENB bit in USERPHYSEL*n*.

While the MDIO module is enabled, the host issues a read or write transaction over the MII management interface using the DATA, PHYADR, REGADR, and WRITE bits in USERACCESS*n*. When the application sets the GO bit in USERACCESS*n*, the MDIO module begins the transaction without any further intervention from the CPU. Upon completion, the MDIO module clears the GO bit and sets the corresponding USERINTRAW bit (0 or 1) in the MDIO user command complete interrupt register (USERINTRAW) corresponding to USERACCESS*n* used. The corresponding USERINTMASKED bit (0 or 1) in the MDIO user command complete interrupt register (USERINTMASKED) may also be set, depending on the mask setting configured in the MDIO user command complete interrupt mask set register (USERINTMASKSET) and the MDIO user interrupt mask clear register (USERINTMASKCLEAR).

A round-robin arbitration scheme is used to schedule transactions that may be queued using both USERACCESS0 and USERACCESS1. The application software must check the status of the GO bit in USERACCESS*n* before initiating a new transaction, to ensure that the previous transaction has completed. The application software can use the ACK bit in USERACCESS*n* to determine the status of a read transaction.

19.2.7.2.1 Initializing the MDIO Module

The following steps are performed by the application software or device driver to initialize the MDIO device:

1. Configure the PREAMBLE and CLKDIV bits in the MDIO control register (CONTROL).
2. Enable the MDIO module by setting the ENABLE bit in CONTROL.
3. The MDIO PHY alive status register (ALIVE) can be read in polling fashion until a PHY connected to the system responded, and the MDIO PHY link status register (LINK) can determine whether this PHY already has a link.
4. Setup the appropriate PHY addresses in the MDIO user PHY select register (USERPHYSEL*n*), and set the LINKINTENB bit to enable a link change event interrupt if desirable.
5. If an interrupt on general MDIO register access is desired, set the corresponding bit in the MDIO user command complete interrupt mask set register (USERINTMASKSET) to use the MDIO user access register (USERACCESS*n*). Since only one PHY is used in this device, the application software can use one USERACCESS*n* to trigger a completion interrupt; the other USERACCESS*n* is not setup.

19.2.7.2.2 Writing Data To a PHY Register

The MDIO module includes a user access register (USERACCESS*n*) to directly access a specified PHY device. To write a PHY register, perform the following:

1. Check to ensure that the GO bit in the MDIO user access register (USERACCESS*n*) is cleared.
2. Write to the GO, WRITE, REGADR, PHYADR, and DATA bits in USERACCESS*n* corresponding to the PHY and PHY register you want to write.
3. The write operation to the PHY is scheduled and completed by the MDIO module. Completion of the write operation can be determined by polling the GO bit in USERACCESS*n* for a 0.
4. Completion of the operation sets the corresponding USERINTRAW bit (0 or 1) in the MDIO user command complete interrupt register (USERINTRAW) corresponding to USERACCESS*n* used. If interrupts have been enabled on this bit using the MDIO user command complete interrupt mask set register (USERINTMASKSET), then the bit is also set in the MDIO user command complete interrupt register (USERINTMASKED) and an interrupt is triggered on the CPU.

19.2.7.2.3 Reading Data From a PHY Register

The MDIO module includes a user access register (USERACCESS*n*) to directly access a specified PHY device. To read a PHY register, perform the following:

1. Check to ensure that the GO bit in the MDIO user access register (USERACCESS*n*) is cleared.
2. Write to the GO, REGADR, and PHYADR bits in USERACCESS*n* corresponding to the PHY and PHY register you want to read.
3. The read data value is available in the DATA bits in USERACCESS*n* after the module completes the read operation on the serial bus. Completion of the read operation can be determined by polling the GO and ACK bits in USERACCESS*n*. Once the GO bit has cleared, the ACK bit is set on a successful read.
4. Completion of the operation sets the corresponding USERINTRAW bit (0 or 1) in the MDIO user command complete interrupt register (USERINTRAW) corresponding to USERACCESS*n* used. If interrupts have been enabled on this bit using the MDIO user command complete interrupt mask set register (USERINTMASKSET), then the bit is also set in the MDIO user command complete interrupt register (USERINTMASKED) and an interrupt is triggered on the CPU.

19.2.7.2.4 Example of MDIO Register Access Code

The MDIO module uses the MDIO user access register (USERACCESS*n*) to access the PHY control registers. Software functions that implement the access process may simply be the following four macros:

- PHYREG_read(regadr, phyadr) — Start the process of reading a PHY register
- PHYREG_write(regadr, phyadr, data) — Start the process of writing a PHY register
- PHYREG_wait( ) — Synchronize operation (make sure read/write is idle)
- PHYREG_waitResults(results) — Wait for read to complete and return data read

Note that it is not necessary to wait after a write operation, as long as the status is checked before every operation to make sure the MDIO hardware is idle. An alternative approach is to call PHYREG_wait() after every write, and PHYREG_waitResults( ) after every read, then the hardware can be assumed to be idle when starting a new operation.

The implementation of these macros using the chip support library (CSL) is shown in Example 19-3 (USERACCESS0 is assumed).

Note that this implementation does not check the ACK bit in USERACCESS*n* on PHY register reads (does not follow the procedure outlined in Section 19.2.7.2.3). Since the MDIO PHY alive status register (ALIVE) is used to initially select a PHY, it is assumed that the PHY is acknowledging read operations. It is possible that a PHY could become inactive at a future point in time. An example of this would be a PHY that can have its MDIO addresses changed while the system is running. It is not very likely, but this condition can be tested by periodically checking the PHY state in ALIVE.

Example 19-3. MDIO Register Access Macros

```
#define PHYREG_read(regadr, phyadr)
    MDIO_REGS->USERACCESS0 =
        CSL_FMK(MDIO_USERACCESS0_GO,1u)                         | /
        CSL_FMK(MDIO_USERACCESS0_REGADR,regadr)                 | /
        CSL_FMK(MDIO_USERACCESS0_PHYADR,phyadr)
#define PHYREG_write(regadr, phyadr, data)
    MDIO_REGS->USERACCESS0 =
        CSL_FMK(MDIO_USERACCESS0_GO,1u)                         | /
        CSL_FMK(MDIO_USERACCESS0_WRITE,1)                       | /
        CSL_FMK(MDIO_USERACCESS0_REGADR,regadr)                 | /
        CSL_FMK(MDIO_USERACCESS0_PHYADR,phyadr)                 | /
        CSL_FMK(MDIO_USERACCESS0_DATA, data)
#define PHYREG_wait()
    while( CSL_FEXT(MDIO_REGS->USERACCESS0,MDIO_USERACCESS0_GO) )
#define PHYREG_waitResults( results ) {
    while( CSL_FEXT(MDIO_REGS->USERACCESS0,MDIO_USERACCESS0_GO) );
results = CSL_FEXT(MDIO_REGS->USERACCESS0, MDIO_USERACCESS0_DATA); }
```

19.2.8 EMAC Module

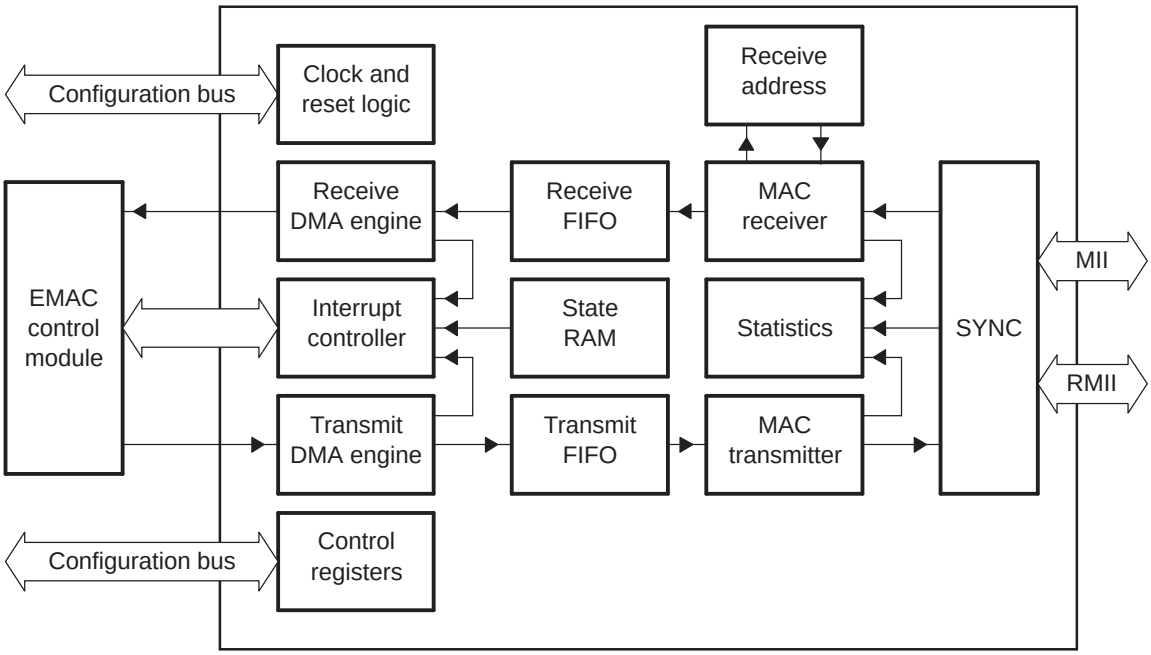
This section discusses the architecture and basic function of the EMAC module.

19.2.8.1 EMAC Module Components

The EMAC module (Figure 19-11) interfaces to the outside world through the Media Independent Interface (MII) and/or Reduced Media Independent Interface (RMII). The interface between the EMAC module and the system core is provided through the EMAC control module. The EMAC consists of the following logical components:

- The receive path includes: receive DMA engine, receive FIFO, and MAC receiver
- The transmit path includes: transmit DMA engine, transmit FIFO, and MAC transmitter
- Statistics logic
- State RAM
- Interrupt controller
- Control registers and logic
- Clock and reset logic

Figure 19-11. EMAC Module Block Diagram



19.2.8.1.1 Receive DMA Engine

The receive DMA engine is the interface between the receive FIFO and the system core. It interfaces to the CPU through the bus arbiter in the EMAC control module. This DMA engine is totally independent of the device DMA.

19.2.8.1.2 Receive FIFO

The receive FIFO consists of three cells of 64-bytes each and associated control logic. The FIFO buffers receive data in preparation for writing into packet buffers in device memory.

19.2.8.1.3 MAC Receiver

The MAC receiver detects and processes incoming network frames, de-frames them, and puts them into the receive FIFO. The MAC receiver also detects errors and passes statistics to the statistics RAM.

19.2.8.1.4 Transmit DMA Engine

The transmit DMA engine is the interface between the transmit FIFO and the CPU. It interfaces to the CPU through the bus arbiter in the EMAC control module.

19.2.8.1.5 Transmit FIFO

The transmit FIFO consists of three cells of 64-bytes each and associated control logic. The FIFO buffers data in preparation for transmission.

19.2.8.1.6 MAC Transmitter

The MAC transmitter formats frame data from the transmit FIFO and transmits the data using the CSMA/CD access protocol. The frame CRC can be automatically appended, if required. The MAC transmitter also detects transmission errors and passes statistics to the statistics registers.

19.2.8.1.7 Statistics Logic

The Ethernet statistics are counted and stored in the statistics logic RAM. This statistics RAM keeps track of 36 different Ethernet packet statistics.

19.2.8.1.8 State RAM

State RAM contains the head descriptor pointers and completion pointers registers for both transmit and receive channels.

19.2.8.1.9 EMAC Interrupt Controller

The interrupt controller contains the interrupt related registers and logic. The 26 raw EMAC interrupts are input to this submodule and masked module interrupts are output.

19.2.8.1.10 Control Registers and Logic

The EMAC is controlled by a set of memory-mapped registers. The control logic also signals transmit, receive, and status related interrupts to the CPU through the EMAC control module.

19.2.8.1.11 Clock and Reset Logic

The clock and reset submodule generates all the EMAC clocks and resets. For more details on reset capabilities, see Section 29.2.15.1.

19.2.8.2 EMAC Module Operational Overview

After reset, initialization, and configuration, the host may initiate transmit operations. Transmit operations are initiated by host writes to the appropriate transmit channel head descriptor pointer contained in the state RAM block. The transmit DMA controller then fetches the first packet in the packet chain from memory. The DMA controller writes the packet into the transmit FIFO in bursts of 64-byte cells. When the threshold number of cells, configurable using the TXCELLTHRESH bit in the FIFO control register (FIFOCONTROL), have been written to the transmit FIFO, or a complete packet, whichever is smaller, the MAC transmitter then initiates the packet transmission. The SYNC block transmits the packet over the MII or RMII interfaces in accordance with the 802.3 protocol. Transmit statistics are counted by the statistics block.

Receive operations are initiated by host writes to the appropriate receive channel head descriptor pointer after host initialization and configuration. The SYNC submodule receives packets and strips off the Ethernet related protocol. The packet data is input to the MAC receiver, which checks for address match and processes errors. Accepted packets are then written to the receive FIFO in bursts of 64-byte cells. The receive DMA controller then writes the packet data to memory. Receive statistics are counted by the statistics block.

The EMAC module operates independently of the CPU. It is configured and controlled by its register set mapped into device memory. Information about data packets is communicated by use of 16-byte descriptors that are placed in an 8K-byte block of RAM in the EMAC control module (CPPI buffer descriptor memory).

For transmit operations, each 16-byte descriptor describes a packet or packet fragment in the system's internal or external memory. For receive operations, each 16-byte descriptor represents a free packet buffer or buffer fragment. On both transmit and receive, an Ethernet packet is allowed to span one or more memory fragments, represented by one 16-byte descriptor per fragment. In typical operation, there is only one descriptor per receive buffer, but transmit packets may be fragmented, depending on the software architecture.

An interrupt is issued to the CPU whenever a transmit or receive operation has completed. However, it is not necessary for the CPU to service the interrupt while there are additional resources available. In other words, the EMAC continues to receive Ethernet packets until its receive descriptor list has been exhausted. On transmit operations, the transmit descriptors need only be serviced to recover their associated memory buffer. Thus, it is possible to delay servicing of the EMAC interrupt if there are real-time tasks to perform.

Eight channels are supplied for both transmit and receive operations. On transmit, the eight channels represent eight independent transmit queues. The EMAC can be configured to treat these channels as an equal priority "round-robin" queue or as a set of eight fixed-priority queues. On receive, the eight channels represent eight independent receive queues with packet classification. Packets are classified based on the destination MAC address. Each of the eight channels is assigned its own MAC address, enabling the EMAC module to act like eight virtual MAC adapters. Also, specific types of frames can be sent to specific channels. For example, multicast, broadcast, or other (promiscuous, error, etc.), can each be received on a specific receive channel queue.

The EMAC keeps track of 36 different statistics, plus keeps the status of each individual packet in its corresponding packet descriptor.

19.2.9 MAC Interface

The following sections discuss the operation of the Media Independent Interface (MII) and Reduced Media Independent Interface (RMII) in 10 Mbps and 100 Mbps mode. An IEEE 802.3 compliant Ethernet MAC controls the interface.

19.2.9.1 Data Reception

19.2.9.1.1 Receive Control

Data received from the PHY is interpreted and output to the EMAC receive FIFO. Interpretation involves detection and removal of the preamble and start-of-frame delimiter, extraction of the address and frame length, data handling, error checking and reporting, cyclic redundancy checking (CRC), and statistics control signal generation. Address detection and frame filtering is performed outside the MAC interface.

19.2.9.1.2 Receive Inter-Frame Interval

The 802.3 standard requires an interpacket gap (IPG), which is 96 bit times. However, the EMAC can tolerate a reduced IPG of 8 bit times with a correct preamble and start frame delimiter. This interval between frames must comprise (in the following order):

1. An Interpacket Gap (IPG).
2. A 7-byte preamble (all bytes 55h).
3. A 1-byte start of frame delimiter (5Dh).

19.2.9.1.3 Receive Flow Control

When enabled and triggered, receive flow control is initiated to limit the EMAC from further frame reception. Two forms of receive buffer flow control are available:

- Collision-based flow control for half-duplex mode
- IEEE 802.3x pause frames flow control for full-duplex mode

In either case, receive flow control prevents frame reception by issuing the flow control appropriate for the current mode of operation. Receive flow control prevents reception of frames on the EMAC until all of the triggering conditions clear, at which time frames may again be received by the EMAC.

Receive flow control is enabled by the RXBUFFERFLOWEN bit in the MAC control register (MACCONTROL). The EMAC is configured for collision or IEEE 802.3X flow control using the FULLDUPLEX bit in MACCONTROL. Receive flow control is triggered when the number of free buffers in any enabled receive channel free buffer count register (RX*n*FREEBUFFER) is less than or equal to the receive channel flow control threshold register (RX*n*FLOWTHRESH) value. Receive flow control is independent of receive QOS, except that both use the free buffer values.

19.2.9.1.3.1 Collision-Based Receive Buffer Flow Control

Collision-based receive buffer flow control provides a means of preventing frame reception when the EMAC is operating in half-duplex mode (the FULLDUPLEX bit is cleared in MACCONTROL). When receive flow control is enabled and triggered, the EMAC generates collisions for received frames. The jam sequence transmitted is the 12-byte sequence C3.C3.C3.C3.C3.C3.C3.C3.C3.C3.C3.C3h. The jam sequence begins no later than approximately as the source address starts to be received. Note that these forced collisions are not limited to a maximum of 16 consecutive collisions, and are independent of the normal back-off algorithm.

Receive flow control does not depend on the value of the incoming frame destination address. A collision is generated for any incoming packet, regardless of the destination address, if any EMAC enabled channel's free buffer register value is less than or equal to the channel's flow threshold value.

19.2.9.1.3.2 IEEE 802.3x-Based Receive Buffer Flow Control

IEEE 802.3x-based receive buffer flow control provides a means of preventing frame reception when the EMAC is operating in full-duplex mode (the FULLDUPLEX bit is set in MACCONTROL). When receive flow control is enabled and triggered, the EMAC transmits a pause frame to request that the sending station stop transmitting for the period indicated within the transmitted pause frame.

The EMAC transmits a pause frame to the reserved multicast address at the first available opportunity (immediately if currently idle or following the completion of the frame currently being transmitted). The pause frame contains the maximum possible value for the pause time (FFFFh). The EMAC counts the receive pause frame time (decrements FF00h to 0) and retransmits an outgoing pause frame, if the count reaches 0. When the flow control request is removed, the EMAC transmits a pause frame with a zero pause time to cancel the pause request.

Note that transmitted pause frames are only a request to the other end station to stop transmitting. Frames that are received during the pause interval are received normally (provided the receive FIFO is not full).

Pause frames are transmitted if enabled and triggered, regardless of whether or not the EMAC is observing the pause time period from an incoming pause frame.

The EMAC transmits pause frames as described below:

- The 48-bit reserved multicast destination address 01.80.C2.00.00.01h.
- The 48-bit source address (set using the MACSRCADDRLO and MACSRCADDRHI registers).
- The 16-bit length/type field containing the value 88.08h.
- The 16-bit pause opcode equal to 00.01h.
- The 16-bit pause time value of FF.FFh. A pause-quantum is 512 bit-times. Pause frames sent to cancel a pause request have a pause time value of 00.00h.
- Zero padding to 64-byte data length (EMAC transmits only 64-byte pause frames).

- The 32-bit frame-check sequence (CRC word).

All quantities are hexadecimal and are transmitted most-significant byte first. The least-significant bit (LSB) is transferred first in each byte.

If the RXBUFFERFLOWEN bit in MACCONTROL is cleared to 0 while the pause time is nonzero, then the pause time is cleared to 0 and a zero count pause frame is sent.

19.2.9.2 Data Transmission

The EMAC passes data to the PHY from the transmit FIFO (when enabled). Data is synchronized to the transmit clock rate. Transmission begins when there are TXCELLTHRESH cells of 64 bytes each, or a complete packet, in the FIFO.

19.2.9.2.1 Transmit Control

A jam sequence is output if a collision is detected on a transmit packet. If the collision was late (after the first 64 bytes have been transmitted), the collision is ignored. If the collision is not late, the controller will back off before retrying the frame transmission. When operating in full-duplex mode, the carrier sense (MII_CRS) and collision-sensing (MII_COL) modes are disabled.

19.2.9.2.2 CRC Insertion

If the SOP buffer descriptor PASSCRC flag is cleared, the EMAC generates and appends a 32-bit Ethernet CRC onto the transmitted data. For the EMAC-generated CRC case, a CRC (or placeholder) at the end of the data is allowed but not required. The buffer byte count value should not include the CRC bytes, if they are present.

If the SOP buffer descriptor PASSCRC flag is set, then the last four bytes of the transmit data are transmitted as the frame CRC. The four CRC data bytes should be the last four bytes of the frame and should be included in the buffer byte count value. The MAC performs no error checking on the outgoing CRC.

19.2.9.2.3 Adaptive Performance Optimization (APO)

The EMAC incorporates adaptive performance optimization (APO) logic that may be enabled by setting the TXPACE bit in the MAC control register (MACCONTROL). Transmission pacing to enhance performance is enabled when the TXPACE bit is set. Adaptive performance pacing introduces delays into the normal transmission of frames, delaying transmission attempts between stations, reducing the probability of collisions occurring during heavy traffic (as indicated by frame deferrals and collisions), thereby, increasing the chance of successful transmission.

When a frame is deferred, suffers a single collision, multiple collisions, or excessive collisions, the pacing counter is loaded with an initial value of 31. When a frame is transmitted successfully (without experiencing a deferral, single collision, multiple collision, or excessive collision), the pacing counter is decremented by 1, down to 0.

With pacing enabled, a new frame is permitted to immediately (after one interpacket gap) attempt transmission only if the pacing counter is 0. If the pacing counter is nonzero, the frame is delayed by the pacing delay of approximately four interpacket gap (IPG)delays. APO only affects the IPG preceding the first attempt at transmitting a frame; APO does not affect the back-off algorithm for retransmitted frames.

19.2.9.2.4 Interpacket-Gap (IPG) Enforcement

The measurement reference for the IPG of 96 bit times is changed depending on frame traffic conditions. If a frame is successfully transmitted without collision and MII_CRS is deasserted within approximately 48 bit times of MII_TXEN being deasserted, then 96 bit times is measured from MII_TXEN. If the frame suffered a collision or MII_CRS is not deasserted until more than approximately 48 bit times after MII_TXEN is deasserted, then 96 bit times (approximately, but not less) is measured from MII_CRS.

19.2.9.2.5 Back Off

The EMAC implements the 802.3 binary exponential back-off algorithm.

19.2.9.2.6 Transmit Flow Control

Incoming pause frames are acted upon, when enabled, to prevent the EMAC from transmitting any further frames. Incoming pause frames are only acted upon when the FULLDUPLEX and TXFLOWEN bits in the MAC control register (MACCONTROL) are set. Pause frames are not acted upon in half-duplex mode. Pause frame action is taken if enabled, but normally the frame is filtered and not transferred to memory. MAC control frames are transferred to memory, if the RXCMFEN bit in the receive multicast/broadcast/promiscuous channel enable register (RXMBPENABLE) is set. The TXFLOWEN and FULLDUPLEX bits affect whether or not MAC control frames are acted upon, but they have no affect upon whether or not MAC control frames are transferred to memory or filtered.

Pause frames are a subset of MAC control frames with an opcode field of 0001h. Incoming pause frames are only acted upon by the EMAC if:

- TXFLOWEN bit is set in MACCONTROL
- The frame's length is 64 to RXMAXLEN bytes inclusive
- The frame contains no CRC error or align/code errors

The pause time value from valid frames is extracted from the two bytes following the opcode. The pause time is loaded into the EMAC transmit pause timer and the transmit pause time period begins. If a valid pause frame is received during the transmit pause time period of a previous transmit pause frame then:

- If the destination address is not equal to the reserved multicast address or any enabled or disabled unicast address, then the transmit pause timer immediately expires, or
- If the new pause time value is 0, then the transmit pause timer immediately expires, else
- The EMAC transmit pause timer immediately is set to the new pause frame pause time value. (Any remaining pause time from the previous pause frame is discarded).

If the TXFLOWEN bit in MACCONTROL is cleared, then the pause timer immediately expires.

The EMAC does not start the transmission of a new data frame any sooner than 512 bit-times after a pause frame with a nonzero pause time has finished being received (MII_RXDV going inactive). No transmission begins until the pause timer has expired (the EMAC may transmit pause frames in order to initiate outgoing flow control). Any frame already in transmission when a pause frame is received is completed and unaffected.

Incoming pause frames consist of:

- A 48-bit destination address equal to one of the following:
  - The reserved multicast destination address 01.80.C2.00.00.01h
  - Any EMAC 48-bit unicast address. Pause frames are accepted, regardless of whether the channel is enabled or not.
- The 16-bit length/type field containing the value 88.08h.
- The 48-bit source address of the transmitting device.
- The 16-bit pause opcode equal to 00.01h.
- The 16-bit pause time. A pause-quantum is 512 bit-times.
- Padding to 64-byte data length.
- The 32-bit frame-check sequence (CRC word).

All quantities are hexadecimal and are transmitted most-significant byte first. The least-significant bit (LSB) is transferred first in each byte.

The padding is required to make up the frame to a minimum of 64 bytes. The standard allows pause frames longer than 64 bytes to be discarded or interpreted as valid pause frames. The EMAC recognizes any pause frame between 64 bytes and RXMAXLEN bytes in length.

19.2.9.2.7 Speed, Duplex, and Pause Frame Support

The MAC operates at 10 Mbps or 100 Mbps, in half-duplex or full-duplex mode, and with or without pause frame support as configured by the host.

19.2.10 Packet Receive Operation

19.2.10.1 Receive DMA Host Configuration

To configure the receive DMA for operation the host must:

- Initialize the receive addresses.
- Initialize the receive channel *n* DMA head descriptor pointer registers (RX*n*HDP) to 0.
- Write the MAC address hash *n* registers (MACHASH1 and MACHASH2), if multicast addressing is desired.
- If flow control is to be enabled, initialize:
  - the receive channel *n* free buffer count registers (RX*n*FREEBUFFER)
  - the receive channel *n* flow control threshold register (RX*n*FLOWTHRESH)
  - the receive filter low priority frame threshold register (RXFILTERLOWTHRESH)
- Enable the desired receive interrupts using the receive interrupt mask set register (RXINTMASKSET) and the receive interrupt mask clear register (RXINTMASKCLEAR).
- Set the appropriate configuration bits in the MAC control register (MACCONTROL).
- Write the receive buffer offset register (RXBUFFEROFFSET) value (typically zero).
- Setup the receive channel(s) buffer descriptors and initialize RX*n*HDP.
- Enable the receive DMA controller by setting the RXEN bit in the receive control register (RXCONTROL).
- Configure and enable the receive operation, as desired, in the receive multicast/broadcast/promiscuous channel enable register (RXMBPENABLE) and by using the receive unicast set register (RXUNICASTSET) and the receive unicast clear register (RXUNICASTCLEAR).

19.2.10.2 Receive Channel Enabling

Each of the eight receive channels has an enable bit (RXCH*n*EN) in the receive unicast set register (RXUNICASTSET) that is controlled using RXUNICASTSET and the receive unicast clear register (RXUNICASTCLEAR). The RXCH*n*EN bits determine whether the given channel is enabled (when set to 1) to receive frames with a matching unicast or multicast destination address.

The RXBROADEN bit in the receive multicast/broadcast/promiscuous channel enable register (RXMBPENABLE) determines if broadcast frames are enabled or filtered. If broadcast frames are enabled (when set to 1), then they are copied to only a single channel selected by the RXBROADCH bit in RXMBPENABLE.

The RXMULTEN bit in RXMBPENABLE determines if hash matching multicast frames are enabled or filtered. Incoming multicast addresses (group addresses) are hashed into an index in the hash table. If the indexed bit is set then the frame hash matches and will be transferred to the channel selected by the RXMULTCH bit in RXMBPENABLE when multicast frames are enabled. The multicast hash bits are set in the MAC address hash *n* registers (MACHASH1 and MACHASH2).

The RXPROMCH bit in RXMBPENABLE selects the promiscuous channel to receive frames selected by the RXCMFEN, RXCSFEN, RXCEFEN, and RXCAFEN bits. These four bits allow reception of MAC control frames, short frames, error frames, and all frames (promiscuous), respectively.

19.2.10.3 Receive Address Matching

All eight MAC addresses corresponding to the eight receive channels share the upper 40 bits. Only the lower byte is unique for each address. All eight receive addresses should be initialized, because pause frames are acted upon regardless of whether a channel is enabled or not.

A MAC address is written by first writing the address number (channel) to be written into the MAC index register (MACINDEX). The upper 32 bits of address are then written to the MAC address high bytes register (MACADDRHI), which is followed by writing the lower 16 bits of address to the MAC address low bytes register (MACADDRLO). Since all eight MAC addresses share the upper 40 bits of address, MACADDRHI needs to be written only the first time (for the first channel configured).

19.2.10.4 Hardware Receive QOS Support

Hardware receive quality of service (QOS) is supported, when enabled, by the Tag Protocol Identifier format and the associated Tag Control Information (TCI) format priority field. When the incoming frame length/type value is equal to 81.00h, the EMAC recognizes the frame as an Ethernet Encoded Tag Protocol Type. The two octets immediately following the protocol type contain the 16-bit TCI field. Bits 15-13 of the TCI field contain the received frames priority (0 to 7). The received frame is a low-priority frame, if the priority value is 0 to 3; the received frame is a high-priority frame, if the priority value is 4 to 7. All frames that have a length/type field value not equal to 81.00h are low-priority frames. Received frames that contain priority information are determined by the EMAC as:

- A 48-bit (6 bytes) destination address equal to:
  - The destination station's individual unicast address.
  - The destination station's multicast address (MACHASH1 and MACHASH2).
  - The broadcast address of all ones.
- A 48-byte (6 bytes) source address.
- The 16-bit (2 bytes) length/type field containing the value 81.00h.
- The 16-bit (2 bytes) TCI field with the priority field in the upper 3 bits.
- Data bytes
- The 4 bytes CRC.

The receive filter low priority frame threshold register (RXFILTERLOWTHRESH) and the receive channel *n* free buffer count registers (RX*n*FREEBUFFER) are used in conjunction with the priority information to implement receive hardware QOS. Low-priority frames are filtered if the number of free buffers (RX*n*FREEBUFFER) for the frame channel is less than or equal to the filter low threshold (RXFILTERLOWTHRESH) value. Hardware QOS is enabled by the RXQOSEN bit in the receive multicast/broadcast/promiscuous channel enable register (RXMBPENABLE).

19.2.10.5 Host Free Buffer Tracking

The host must track free buffers for each enabled channel (including unicast, multicast, broadcast, and promiscuous), if receive QOS or receive flow control is used. Disabled channel free buffer values are do not cares. During initialization, the host should write the number of free buffers for each enabled channel to the appropriate receive channel *n* free buffer count registers (RX*n*FREEBUFFER). The EMAC decrements the appropriate channel's free buffer value for each buffer used. When the host reclaims the frame buffers, the host should write the channel free buffer register with the number of reclaimed buffers (write to increment). There are a maximum of 65,535 free buffers available. RX*n*FREEBUFFER only needs to be updated by the host if receive QOS or flow control is used.

19.2.10.6 Receive Channel Teardown

The host commands a receive channel teardown by writing the channel number to the receive teardown register (RXTEARDOWN). When a teardown command is issued to an enabled receive channel, the following occurs:

- Any current frame in reception completes normally.
- The TDOWNCMPLT flag is set in the next buffer descriptor in the chain, if there is one.
- The channel head descriptor pointer is cleared to 0.
- A receive interrupt for the channel is issued to the host.
- The corresponding receive channel *n* completion pointer register (RX*n*CP) contains the value FFFF FFCh.

Channel teardown may be commanded on any channel at any time. The host is informed of the teardown completion by the set teardown complete (TDOWNCMPLT) buffer descriptor bit. The EMAC does not clear any channel enables due to a teardown command. A teardown command to an inactive channel issues an interrupt that software should acknowledge with an FFFF FFFCh acknowledge value to RX*n*CP (note that there is no buffer descriptor in this case). Software may read RX*n*CP to determine if the interrupt was due to a commanded teardown. The read value is FFFF FFFCh, if the interrupt was due to a teardown command.

19.2.10.7 Receive Frame Classification

Received frames are proper (good) frames, if they are between 64 bytes and the value in the receive maximum length register (RXMAXLEN) bytes in length (inclusive) and contain no code, align, or CRC errors.

Received frames are long frames, if their frame count exceeds the value in RXMAXLEN. The RXMAXLEN reset (default) value is 5EEh (1518 in decimal). Long received frames are either oversized or jabber frames. Long frames with no errors are oversized frames; long frames with CRC, code, or alignment errors are jabber frames.

Received frames are short frames, if their frame count is less than 64 bytes. Short frames that address match and contain no errors are undersized frames; short frames with CRC, code, or alignment errors are fragment frames. If the frame length is less than or equal to 20, then the frame CRC is passed, regardless of whether the RXPASSCRC bit is set or cleared in the receive multicast/broadcast/promiscuous channel enable register (RXMBPENABLE).

A received long packet always contains RXMAXLEN number of bytes transferred to memory (if the RXCEFEN bit is set in RXMBPENABLE), regardless of the value of the RXPASSCRC bit. Following is an example with RXMAXLEN set to 1518:

- If the frame length is 1518, then the packet is not a long packet and there are 1514 or 1518 bytes transferred to memory depending on the value of the RXPASSCRC bit.
- If the frame length is 1519, there are 1518 bytes transferred to memory regardless of the RXPASSCRC bit value. The last three bytes are the first three CRC bytes.
- If the frame length is 1520, there are 1518 bytes transferred to memory regardless of the RXPASSCRC bit value. The last two bytes are the first two CRC bytes.
- If the frame length is 1521, there are 1518 bytes transferred to memory regardless of the RXPASSCRC bit value. The last byte is the first CRC byte.
- If the frame length is 1522, there are 1518 bytes transferred to memory. The last byte is the last data byte.

19.2.10.8 Promiscuous Receive Mode

When the promiscuous receive mode is enabled by setting the RXCAFEN bit in the receive multicast/broadcast/promiscuous channel enable register (RXMBPENABLE), nonaddress matching frames that would normally be filtered are transferred to the promiscuous channel. Address matching frames that would normally be filtered due to errors are transferred to the address match channel when the RXCAFEN and RXCEFEN bits in RXMBPENABLE are set. A frame is considered to be an address matching frame only if it is enabled to be received on a unicast, multicast, or broadcast channel. Frames received to disabled unicast, multicast, or broadcast channels are considered nonaddress matching.

MAC control frames address match only if the RXCMFEN bit in RXMBPENABLE is set. The RXCEFEN and RXCSFEN bits in RXMBPENABLE determine whether error frames are transferred to memory or not, but they do not determine whether error frames are address matching or not. Short frames are a special type of error frames.

A single channel is selected as the promiscuous channel by the RXPROMCH bit in RXMBPENABLE. The promiscuous receive mode is enabled by the RXCMFEN, RXCEFEN, RXCSFEN, and RXCAFEN bits in RXMBPENABLE. Table 19-5 shows the effects of the promiscuous enable bits. Proper frames are frames that are between 64 bytes and the value in the receive maximum length register (RXMAXLEN) bytes in length inclusive and contain no code, align, or CRC errors.

Table 19-5. Receive Frame Treatment Summary

Address Match	RXCAFEN	RXCEFEN	RXCMFEN	RXCSFEN	Receive Frame Treatment
0	0	X	X	X	No frames transferred.
0	1	0	0	0	Proper frames transferred to promiscuous channel.
0	1	0	0	1	Proper/undersized data frames transferred to promiscuous channel.
0	1	0	1	0	Proper data and control frames transferred to promiscuous channel.
0	1	0	1	1	Proper/undersized data and control frames transferred to promiscuous channel.
0	1	1	0	0	Proper/oversize/jabber/code/align/CRC data frames transferred to promiscuous channel. No control or undersized/fragment frames are transferred.
0	1	1	0	1	Proper/undersized/fragment/oversize/jabber/code/ align/CRC data frames transferred to promiscuous channel. No control frames are transferred.
0	1	1	1	0	Proper/oversize/jabber/code/align/CRC data and control frames transferred to promiscuous channel. No undersized frames are transferred.
0	1	1	1	1	All nonaddress matching frames with and without errors transferred to promiscuous channel.
1	X	0	0	0	Proper data frames transferred to address match channel.
1	X	0	0	1	Proper/undersized data frames transferred to address match channel.
1	X	0	1	0	Proper data and control frames transferred to address match channel.
1	X	0	1	1	Proper/undersized data and control frames transferred to address match channel.
1	X	1	0	0	Proper/oversize/jabber/code/align/CRC data frames transferred to address match channel. No control or undersized frames are transferred.
1	X	1	0	1	Proper/oversize/jabber/fragment/undersized/code/ align/CRC data frames transferred to address match channel. No control frames are transferred.
1	X	1	1	0	Proper/oversize/jabber/code/align/CRC data and control frames transferred to address match channel. No undersized/fragment frames are transferred.
1	X	1	1	1	All address matching frames with and without errors transferred to the address match channel

19.2.10.9 Receive Overrun

The types of receive overrun are:

- FIFO start of frame overrun (FIFO_SOF)
- FIFO middle of frame overrun (FIFO_MOF)
- DMA start of frame overrun (DMA_SOF)
- DMA middle of frame overrun (DMA_MOF)

The statistics counters used to track these types of receive overrun are:

- Receive start of frame overruns register (RXSOFOVERRUNS)
- Receive middle of frame overruns register (RXMOFOVERRUNS)
- Receive DMA overruns register (RXDMAOVERRUNS)

Start of frame overruns happen when there are no resources available when frame reception begins. Start of frame overruns increment the appropriate overrun statistic(s) and the frame is filtered.

Middle of frame overruns happen when there are some resources to start the frame reception, but the resources run out during frame reception. In normal operation, a frame that overruns after starting the frame reception is filtered and the appropriate statistic(s) are incremented; however, the RXCEFEN bit in the receive multicast/broadcast/promiscuous channel enable register (RXMBPENABLE) affects overrun frame treatment. Table 19-6 shows how the overrun condition is handled for the middle of frame overrun.

Table 19-6. Middle of Frame Overrun Treatment

Address Match	RXCAFEN	RXCEFEN	Middle of Frame Overrun Treatment
0	0	X	Overrun frame filtered.
0	1	0	Overrun frame filtered.
0	1	1	As much frame data as possible is transferred to the promiscuous channel until overrun. The appropriate overrun statistic(s) is incremented and the OVERRUN and NOMATCH flags are set in the SOP buffer descriptor. Note that the RXMAXLEN number of bytes cannot be reached for an overrun to occur (it would be truncated and be a jabber or oversize).
1	X	0	Overrun frame filtered with the appropriate overrun statistic(s) incremented.
1	X	1	As much frame data as possible is transferred to the address match channel until overrun. The appropriate overrun statistic(s) is incremented and the OVERRUN flag is set in the SOP buffer descriptor. Note that the RXMAXLEN number of bytes cannot be reached for an overrun to occur (it would be truncated).

19.2.11 Packet Transmit Operation

The transmit DMA is an eight channel interface. Priority between the eight queues may be either fixed or round-robin as selected by the TXPTYPE bit in the MAC control register (MACCONTROL). If the priority type is fixed, then channel 7 has the highest priority and channel 0 has the lowest priority. Round-robin priority proceeds from channel 0 to channel 7.

19.2.11.1 Transmit DMA Host Configuration

To configure the transmit DMA for operation the host must perform:

- Write the MAC source address low bytes register (MACSRCADDRLO) and the MAC source address high bytes register (MACSRCADDRHI) (used for pause frames on transmit).
- Initialize the transmit channel *n* DMA head descriptor pointer registers (TX*n*HDP) to 0.
- Enable the desired transmit interrupts using the transmit interrupt mask set register (TXINTMASKSET) and the transmit interrupt mask clear register (TXINTMASKCLEAR).
- Set the appropriate configuration bits in the MAC control register (MACCONTROL).
- Setup the transmit channel(s) buffer descriptors in host memory.
- Enable the transmit DMA controller by setting the TXEN bit in the transmit control register (TXCONTROL).
- Write the appropriate TX*n*HDP with the pointer to the first descriptor to start transmit operations.

19.2.11.2 Transmit Channel Teardown

The host commands a transmit channel teardown by writing the channel number to the transmit teardown register (TXTEARDOWN). When a teardown command is issued to an enabled transmit channel, the following occurs:

- Any frame currently in transmission completes normally.
- The TDOWNCMPLT flag is set in the next SOP buffer descriptor in the chain, if there is one.
- The channel head descriptor pointer is cleared to 0.
- A transmit interrupt is issued to inform the host of the channel teardown.
- The corresponding transmit channel *n* completion pointer register (TX*n*CP) contains the value FFFF FFFCh.
- The host should acknowledge a teardown interrupt with an FFFF FFFCh acknowledge value.

Channel teardown may be commanded on any channel at any time. The host is informed of the teardown completion by the set teardown complete (TDOWNCMPLT) buffer descriptor bit. The EMAC does not clear any channel enables due to a teardown command. A teardown command to an inactive channel issues an interrupt that software should acknowledge with an FFFF FFFCh acknowledge value to TX*n*CP (note that there is no buffer descriptor in this case). Software may read the interrupt acknowledge location (TX*n*CP) to determine if the interrupt was due to a commanded teardown. The read value is FFFF FFFCh, if the interrupt was due to a teardown command.

19.2.12 Receive and Transmit Latency

The transmit and receive FIFOs each contain three 64-byte cells. The EMAC begins transmission of a packet on the wire after TXCELLTHRESH (configurable through the FIFO control register) cells, or a complete packet, are available in the FIFO.

Transmit underrun cannot occur for packet sizes of TXCELLTHRESH times 64 bytes (or less). For larger packet sizes, transmit underrun occurs if the memory latency is greater than the time required to transmit a 64-byte cell on the wire; this is 5.12 µs in 100 Mbps mode and 51.2 µs in 10 Mbps mode. The memory latency time includes all buffer descriptor reads for the entire cell data.

Receive overrun is prevented if the receive memory cell latency is less than the time required to transmit a 64-byte cell on the wire: 5.12 µs in 100 Mbps mode, or 51.2 µs in 10 Mbps mode. The latency time includes any required buffer descriptor reads for the cell data.

Latency to system's internal and external RAM can be controlled through the use of the transfer node priority allocation register available at the device level. Latency to descriptor RAM is low because RAM is local to the EMAC, as it is part of the EMAC control module.

19.2.13 Transfer Node Priority

The device contains a chip-level master priority register that is used to set the priority of the transfer node used in issuing memory transfer requests to system memory.

Although the EMAC has internal FIFOs to help alleviate memory transfer arbitration problems, the average transfer rate of data read and written by the EMAC to internal or external processor memory must be at least that of the Ethernet wire rate. In addition, the internal FIFO system can not withstand a single memory latency event greater than the time it takes to fill or empty a TXCELLTHRESH number of internal 64 byte FIFO cells.

For 100 Mbps operation, these restrictions translate into the following rules:

- The short-term average, each 64-byte memory read/write request from the EMAC must be serviced in no more than 5.12 µs.
- Any single latency event in request servicing can be no longer than (5.12 × TXCELLTHRESH) µs.

19.2.14 Reset Considerations

19.2.14.1 Software Reset Considerations

Peripheral clock and reset control is done through the Power and Sleep Controller (PSC) module included with the device. For more on how the EMAC, MDIO, and EMAC control module are disabled or placed in reset at runtime from the registers located in the PSC module, see Section 29.2.16.

With the EMAC still in reset (PSC in the default state):

1. Program the PINMUX register(s) as required for the desired interface (MII or RMII), see the Pin Multiplexing Control Registers (PINMUX0-PINMUX19) in the *System Configuration (SYSCFG) Module* chapter and your device-specific data manual for details.
2. Program the PSC to enable the EMAC. For information on how to enable the EMAC peripheral from the PSC, see the *Power and Sleep Controller (PSC)* chapter.

Within the peripheral itself, the EMAC component of the Ethernet MAC peripheral can be placed in a reset state by writing to the soft reset register (SOFTRESET). Writing a 1 to the SOFTRESET bit, causes the EMAC logic to be reset and the register values to be set to their default values. Software reset occurs when the receive and transmit DMA controllers are in an idle state to avoid locking up the configuration bus; it is the responsibility of the software to verify that there are no pending frames to be transferred. After writing a 1 to the SOFTRESET bit, it may be polled to determine if the reset has occurred. If a 1 is read, the reset has not yet occurred; if a 0 is read, then a reset has occurred.

After a software reset operation, all the EMAC registers need to be reinitialized for proper data transmission, including the FULLDUPLEX bit setting in the MAC control register (MACCONTROL).

Unlike the EMAC module, the MDIO and EMAC control modules cannot be placed in reset from a register inside their memory map.

19.2.14.2 Hardware Reset Considerations

When a hardware reset occurs, the EMAC peripheral has its register values reset and all the components return to their default state. After the hardware reset, the EMAC needs to be initialized before being able to resume its data transmission, as described in Section 29.2.19.

A hardware reset is the only means of recovering from the error interrupts (HOSTPEND), which are triggered by errors in packet buffer descriptors. Before doing a hardware reset, you should inspect the error codes in the MAC status register (MACSTATUS) that gives information about the type of software error that needs to be corrected. For detailed information on error interrupts, see Section 19.2.16.1.4.

19.2.15 Initialization

19.2.15.1 Enabling the EMAC/MDIO Peripheral

When the device is powered on, the EMAC peripheral may be in a disabled state. Before any EMAC specific initialization can take place, the EMAC needs to be enabled; otherwise, its registers cannot be written and the reads will all return a value of zero.

The EMAC/MDIO is enabled through the Power and Sleep Controller (PSC) registers. For information on how to enable the EMAC peripheral from the PSC, see the *Power and Sleep Controller (PSC)* chapter.

When first enabled, the EMAC peripheral registers are set to their default values. After enabling the peripheral, you may proceed with the module specific initialization.

19.2.15.2 EMAC Control Module Initialization

The EMAC control module is used for global interrupt enables and to pace interrupts using 1ms time windows. There is also an 8K block of CPPI RAM local to the EMAC that is used to hold packet buffer descriptors.

Note that although the EMAC control module and the EMAC module have slightly different functions, in practice, the type of maintenance performed on the EMAC control module is more commonly conducted from the EMAC module software (as opposed to the MDIO module).

The initialization of the EMAC control module consists of two parts:

1. Configuration of the interrupt to the CPU.
2. Initialization of the EMAC control module:
   - Setting the interrupt pace counts using the EMAC control module registers INTCONTROL, C*n*RXIMAX, and C*n*TXIMAX
   - Initializing the EMAC and MDIO modules
   - Enabling interrupts in the EMAC control module using the EMAC control module interrupt control registers C*n*RXTHRESHEN, C*n*RXEN, C*n*TXEN, and CnMISCEN.

The process of mapping the EMAC interrupts to the CPU is done through the CPU interrupt controller. Once the interrupt is mapped to a CPU interrupt, general masking and unmasking of interrupts (to control reentrancy) should be done at the chip level by manipulating the interrupt core enable mask registers.

19.2.15.3 MDIO Module Initialization

The MDIO module is used to initially configure and monitor one or more external PHY devices. Other than initializing the software state machine (details on this state machine can be found in the IEEE 802.3 standard), all that needs to be done for the MDIO module is to enable the MDIO engine and to configure the clock divider. To set the clock divider, supply an MDIO clock of 1 MHz. For example, if the peripheral clock is 50 MHz, the divider can be set to 50.

Both the state machine enable and the MDIO clock divider are controlled through the MDIO control register (CONTROL). If none of the potentially connected PHYs require the access preamble, the PREAMBLE bit in CONTROL can also be set to speed up PHY register access.

If the MDIO module is to operate on an interrupt basis, the interrupts can be enabled at this time using the MDIO user command complete interrupt mask set register (USERINTMASKSET) for register access and the MDIO user PHY select register (USERPHYSEL*n*) if a target PHY is already known.

Once the MDIO state machine has been initialized and enabled, it starts polling all 32 PHY addresses on the MDIO bus, looking for an active PHY. Since it can take up to 50 µs to read one register, it can be some time before the MDIO module provides an accurate representation of whether a PHY is available. Also, a PHY can take up to 3 seconds to negotiate a link. Thus, it is advisable to run the MDIO software off a time-based event rather than polling.

For more information on PHY control registers, see your PHY device documentation.

19.2.15.4 EMAC Module Initialization

The EMAC module is used to send and receive data packets over the network. This is done by maintaining up to eight transmit and receive descriptor queues. The EMAC module configuration must also be kept up-to-date based on PHY negotiation results returned from the MDIO module. Most of the work in developing an application or device driver for Ethernet is programming this module.

The following is the initialization procedure a device driver would follow to get the EMAC to the state where it is ready to receive and send Ethernet packets. Some of these steps are not necessary when performed immediately after device reset.

1. If enabled, clear the device interrupt enable bits in the EMAC control module interrupt control registers C*n*RXTHRESHEN, C*n*RXEN, C*n*TXEN, and C*n*MISCEN.
2. Clear the MAC control register (MACCONTROL), receive control register (RXCONTROL), and transmit control register (TXCONTROL) (not necessary immediately after reset).
3. Initialize all 16 header descriptor pointer registers (RX*n*HDP and TX*n*HDP) to 0.
4. Clear all 36 statistics registers by writing 0 (not necessary immediately after reset).
5. Setup the local Ethernet MAC address by programming the MAC index register (MACINDEX), MAC address high bytes register (MACADDRHI), and MAC address low bytes register (MACADDRLO). Be sure to program all eight MAC address registers - whether the receive channel is to be enabled or not. Duplicate the same MAC address across all unused channels. When using more than one receive channel, start with channel 0 and progress upwards.
6. If buffer flow control is to be enabled, initialize the receive channel *n* free buffer count registers (RX*n*FREEBUFFER), receive channel *n* flow control threshold register (RX*n*FLOWTHRESH), and receive filter low priority frame threshold register (RXFILTERLOWTHRESH).
7. Most device drivers open with no multicast addresses, so clear the MAC address hash registers (MACHASH1 and MACHASH2) to 0.
8. Write the receive buffer offset register (RXBUFFEROFFSET) value (typically zero).
9. Initially clear all unicast channels by writing FFh to the receive unicast clear register (RXUNICASTCLEAR). If unicast is desired, it can be enabled now by writing the receive unicast set register (RXUNICASTSET). Some drivers will default to unicast on device open while others will not.
10. Setup the receive multicast/broadcast/promiscuous channel enable register (RXMBPENABLE) with an initial configuration. The configuration is based on the current receive filter settings of the device driver. Some drivers may enable things like broadcast and multicast packets immediately, while others may not.
11. Set the appropriate configuration bits in MACCONTROL (do not set the GMIIEN bit yet).
12. Clear all unused channel interrupt bits by writing the receive interrupt mask clear register (RXINTMASKCLEAR) and the transmit interrupt mask clear register (TXINTMASKCLEAR).
13. Enable the receive and transmit channel interrupt bits in the receive interrupt mask set register (RXINTMASKSET) and the transmit interrupt mask set register (TXINTMASKSET) for the channels to be used, and enable the HOSTMASK and STATMASK bits using the MAC interrupt mask set register (MACINTMASKSET).
14. Initialize the receive and transmit descriptor list queues.
15. Prepare receive by writing a pointer to the head of the receive buffer descriptor list to RX*n*HDP.
16. Enable the receive and transmit DMA controllers by setting the RXEN bit in RXCONTROL and the TXEN bit in TXCONTROL. Then set the GMIIEN bit in MACCONTROL.
17. Enable the device interrupt in EMAC control module registers C*n*RXTHRESHEN, C*n*RXEN, C*n*TXEN, and C*n*MISCEN.

19.2.16 Interrupt Support

19.2.16.1 EMAC Module Interrupt Events and Requests

The EMAC module generates 26 interrupt events:

- TXPEND*n*: Transmit packet completion interrupt for transmit channels 0 through 7
- RXPEND*n*: Receive packet completion interrupt for receive channels 0 through 7
- RXTHRESHPEND*n*: Receive packet completion interrupt for receive channels 0 through 7 when flow control is enabled and the number of free buffers is below the threshold
- STATPEND: Statistics interrupt
- HOSTPEND: Host error interrupt

19.2.16.1.1 Transmit Packet Completion Interrupts

The transmit DMA engine has eight channels, with each channel having a corresponding interrupt (TXPEND*n*). The transmit interrupts are level interrupts that remain asserted until cleared by the CPU.

Each of the eight transmit channel interrupts may be individually enabled by setting the appropriate bit in the transmit interrupt mask set register (TXINTMASKSET) to 1. Each of the eight transmit channel interrupts may be individually disabled by clearing the appropriate bit by writing a 1 to the transmit interrupt mask clear register (TXINTMASKCLEAR). The raw and masked transmit interrupt status may be read by reading the transmit interrupt status (unmasked) register (TXINTSTATRAW) and the transmit interrupt status (masked) register (TXINTSTATMASKED), respectively.

When the EMAC completes the transmission of a packet, the EMAC issues an interrupt to the CPU (via the EMAC control module) when it writes the packet's last buffer descriptor address to the appropriate channel queue's transmit completion pointer located in the state RAM block. The interrupt is generated by the write when enabled by the interrupt mask, regardless of the value written.

Upon interrupt reception, the CPU processes one or more packets from the buffer chain and then acknowledges an interrupt by writing the address of the last buffer descriptor processed to the queue's associated transmit completion pointer in the transmit DMA state RAM.

The data written by the host (buffer descriptor address of the last processed buffer) is compared to the data in the register written by the EMAC port (address of last buffer descriptor used by the EMAC). If the two values are not equal (which means that the EMAC has transmitted more packets than the CPU has processed interrupts for), the transmit packet completion interrupt signal remains asserted. If the two values are equal (which means that the host has processed all packets that the EMAC has transferred), the pending interrupt is cleared. The value that the EMAC is expecting is found by reading the transmit channel *n* completion pointer register (TX*n*CP).

The EMAC write to the completion pointer actually stores the value in the state RAM. The CPU written value does not actually change the register value. The host written value is compared to the register content (which was written by the EMAC) and if the two values are equal then the interrupt is removed; otherwise, the interrupt remains asserted. The host may process multiple packets prior to acknowledging an interrupt, or the host may acknowledge interrupts for every packet.

The application software must acknowledge the EMAC control module after processing packets by writing the appropriate C*n*RX key to the EMAC End-Of-Interrupt Vector register (MACEOIVECTOR). See Section 19.3.3.12 for the acknowledge key values.

19.2.16.1.2 Receive Packet Completion Interrupts

The receive DMA engine has eight channels, which each channel having a corresponding interrupt (RXPEND*n*). The receive interrupts are level interrupts that remain asserted until cleared by the CPU.

Each of the eight receive channel interrupts may be individually enabled by setting the appropriate bit in the receive interrupt mask set register (RXINTMASKSET) to 1. Each of the eight receive channel interrupts may be individually disabled by clearing the appropriate bit by writing a 1 in the receive interrupt mask clear register (RXINTMASKCLEAR). The raw and masked receive interrupt status may be read by reading the receive interrupt status (unmasked) register (RXINTSTATRAW) and the receive interrupt status (masked) register (RXINTSTATMASKED), respectively.

When the EMAC completes a packet reception, the EMAC issues an interrupt to the CPU by writing the packet's last buffer descriptor address to the appropriate channel queue's receive completion pointer located in the state RAM block. The interrupt is generated by the write when enabled by the interrupt mask, regardless of the value written.

Upon interrupt reception, the CPU processes one or more packets from the buffer chain and then acknowledges one or more interrupt(s) by writing the address of the last buffer descriptor processed to the queue's associated receive completion pointer in the receive DMA state RAM.

The data written by the host (buffer descriptor address of the last processed buffer) is compared to the data in the register written by the EMAC (address of last buffer descriptor used by the EMAC). If the two values are not equal (which means that the EMAC has received more packets than the CPU has processed interrupts for), the receive packet completion interrupt signal remains asserted. If the two values are equal (which means that the host has processed all packets that the EMAC has received), the pending interrupt is de-asserted. The value that the EMAC is expecting is found by reading the receive channel *n* completion pointer register (RX*n*CP).

The EMAC write to the completion pointer actually stores the value in the state RAM. The CPU written value does not actually change the register value. The host written value is compared to the register content (which was written by the EMAC) and if the two values are equal then the interrupt is removed; otherwise, the interrupt remains asserted. The host may process multiple packets prior to acknowledging an interrupt, or the host may acknowledge interrupts for every packet.

The application software must acknowledge the EMAC control module after processing packets by writing the appropriate C*n*TX key to the EMAC End-Of-Interrupt Vector register (MACEOIVECTOR). See Section 19.3.3.12 for the acknowledge key values.

19.2.16.1.3 Statistics Interrupt

The statistics level interrupt (STATPEND) is issued when any statistics value is greater than or equal to 8000 0000h, if enabled by setting the STATMASK bit in the MAC interrupt mask set register (MACINTMASKSET) to 1. The statistics interrupt is removed by writing to decrement any statistics value greater than 8000 0000h. As long as the most-significant bit of any statistics value is set, the interrupt remains asserted.

The application software must akcnowledge the EMAC control module after receiving statistics interrupts by writing the appropriate C*n*MISC key to the EMAC End-Of-Interrupt Vector register (MACEOIVECTOR). See Section 19.3.3.12 for the acknowledge key values.

19.2.16.1.4 Host Error Interrupt

The host error interrupt (HOSTPEND) is issued, if enabled, under error conditions dealing with the handling of buffer descriptors, detected during transmit or receive DMA transactions. The failure of the software application to supply properly formatted buffer descriptors results in this error. The error bit can only be cleared by resetting the EMAC module in hardware.

The host error interrupt is enabled by setting the HOSTMASK bit in the MAC interrupt mask set register (MACINTMASKSET) to 1. The host error interrupt is disabled by clearing the appropriate bit by writing a 1 in the MAC interrupt mask clear register (MACINTMASKCLEAR). The raw and masked host error interrupt status may be read by reading the MAC interrupt status (unmasked) register (MACINTSTATRAW) and the MAC interrupt status (masked) register (MACINTSTATMASKED), respectively.

The transmit host error conditions are:

- SOP error
- Ownership bit not set in SOP buffer
- Zero next buffer descriptor pointer with EOP
- Zero buffer pointer
- Zero buffer length
- Packet length error

The receive host error conditions are:

- Ownership bit not set in input buffer
- Zero buffer pointer

The application software must acknowledge the EMAC control module after receiving host error interrupts by writing the appropriate C*n*MISC key to the EMAC End-Of-Interrupt Vector (MACEOIVECTOR). See Section 19.3.3.12 for the acknowledge key values.

19.2.16.1.5 Receive Threshold Interrupts

Each of the eight receive channels have a corresponding receive threshold interrupt (RX*n*THRESHPEND). The receive threshold interrupts are level interrupts that remain asserted until the triggering condition is cleared by the host. Each of the eight threshold interrupts may be individually enabled by setting to 1 the appropriate bit in the RXINTMASKSET register. Each of the eight channel interrupts may be individually disabled by clearing to zero the appropriate bit by writing a 1 in the receive interrupt mask clear register (RXINTMASKCLEAR). The raw and masked interrupt receive interrupt status may be read by reading the receive interrupt status (unmasked) register (RXINTSTATRAW) and the receive interrupt status (masked) register (RXINTSTATMASKED),respectively.

An RX*n*THRESHPEND interrupt bit is asserted when enabled and when the channel's associated free buffer count (RX*n*FREEBUFFER) is less than or equal to the channel's associated flow control threshold register (RX*n*FLOWTHRESH). The receive threshold interrupts use the same free buffer count and threshold logic as does flow control, but the interrupts are independently enabled from flow control. The threshold interrupts are intended to give the host an indication that resources are running low for a particular channel(s).

The applications software must acknowledge the EMAC control module after receiving threshold interrupts by writing the appropriate C*n*RXTHRESH key to the EMAC End-Of-Interrupt Vector (MACEOIVECTOR). See Section 19.3.3.12 for the acknowledge key values.

19.2.16.2 MDIO Module Interrupt Events and Requests

The MDIO module generates two interrupt events:

- LINKINT0: Serial interface link change interrupt. Indicates a change in the state of the PHY link selected by the USERPHYSEL0 register
- USERINT0: Serial interface user command event complete interrupt selected by the USERACCESS0 register

19.2.16.2.1 Link Change Interrupt

The MDIO module asserts a link change interrupt (LINKINT0) if there is a change in the link state of the PHY corresponding to the address in the PHYADRMON bit in the MDIO register USERPHYSEL0, and if the LINKINTENB bit is also set in USERPHYSEL0. This interrupt event is also captured in the LINKINTRAW bit in the MDIO link status change interrupt register (LINKINTRAW). LINKINTRAW bits 0 and 1 correspond to USERPHYSEL0 and USERPHYSEL1, respectively.

When the interrupt is enabled and generated, the corresponding LINKINTMASKED bit is also set in the MDIO link status change interrupt register (LINKINTMASKED). The interrupt is cleared by writing back the same bit to LINKINTMASKED (write to clear).

The application software must acknowledge the EMAC control module after receiving MDIO interrupts by writing the appropriate C*n*MISC key to the EMAC End-Of-Interrupt Vector (MACEOIVECTOR). See Section 19.3.3.12 for the acknowledge key values.

19.2.16.2.2 User Access Completion Interrupt

When the GO bit in one of the MDIO register USERACCESS0 transitions from 1 to 0 (indicating completion of a user access) and the corresponding USERINTMASKSET bit in the MDIO user command complete interrupt mask set register (USERINTMASKSET) corresponding to USERACCESS0 is set, a user access completion interrupt (USERINT) is asserted. This interrupt event is also captured in the USERINTRAW bit in the MDIO user command complete interrupt register (USERINTRAW). USERINTRAW bits 0 and bit 1 correspond to USERACCESS0 and USERACCESS1, respectively.

When the interrupt is enabled and generated, the corresponding USERINTMASKED bit is also set in the MDIO user command complete interrupt register (USERINTMASKED). The interrupt is cleared by writing back the same bit to USERINTMASKED (write to clear).

The application software must acknowledge the EMAC control module after receiving MDIO interrupts by writing the appropriate C*n*MISC key to the EMAC End-Of-Interrupt Vector (MACEOIVECTOR). See Section 19.3.3.12 for the acknowledge key values.

19.2.16.3 Proper Interrupt Processing

All the interrupts signaled from the EMAC and MDIO modules are level driven, so if they remain active, their level remains constant; the CPU core may require edge- or pulse-triggered interrupts. In order to properly convert the level-driven interrupt signal to an edge- or pulse-triggered signal, the application software must make use of the interrupt control logic contained in the EMAC control module.

Section 19.2.6.3 discusses the interrupt control contained in the EMAC control module. For safe interrupt processing, upon entry to the ISR, the software application should disable interrupts using the EMAC control module registers C*n*RXTHRESHEN, C*n*RXEN, CnTXEN, CnMISCEN, and then reenable them upon leaving the ISR. If any interrupt signals are active at that time, this creates another rising edge on the interrupt signal going to the CPU interrupt controller, thus triggering another interrupt. The EMAC control module also uses the EMAC control module registers INTCONTROL, C*n*TXIMAX, and C*n*RXIMAX to implement interrupt pacing. The application software must acknowledge the EMAC control module by writing the appropriate key to the EMAC End-Of-Interrupt Vector (MACEOIVECTOR). See Section 19.3.3.12 for the acknowledge key values.

19.2.16.4 Interrupt Multiplexing

The EMAC control module combines different interrupt signals from both the EMAC and MDIO modules into four interrupt signals (C*n*RXTHRESHPULSE, C*n*RXPULSE, C*n*TXPULSE, C*n*MISCPULSE) that are routed to three independent interrupt cores in the control module. Each interrupt core is capable of relaying all four interrupt signals out of the control module. Some devices may have an individual interrupt core dedicated to a specific CPU or interrupt controller. This configuration gives users of devices greater flexibility when allocating system resources for EMAC management.

When an interrupt is generated, the reason for the interrupt can be read from the MAC input vector register (MACINVECTOR) located in the EMAC memory map. MACINVECTOR combines the status of the following 28 interrupt signals: TXPEND*n*, RXPEND*n*, RXTHRESHPEND*n*, STATPEND, HOSTPEND, LINKINT0, and USERINT0.

For more details on the interrupt mapping, see the *DSP Subsystem* chapter and the *ARM Interrupt Controller (AINTC)* chapter.

19.2.17 Power Management

Each of the three main components of the EMAC peripheral can independently be placed in reduced-power modes to conserve power during periods of low activity. The power management of the EMAC peripheral is controlled by the processor Power and Sleep Controller (PSC). The PSC acts as a master controller for power management on behalf of all of the peripherals on the device.

The power conservation modes available for each of the three components of the EMAC/MDIO peripheral are:

- *Idle/Disabled state*. This mode stops the clocks going to the peripheral, and prevents all the register accesses. After reenabling the peripheral from this idle state, all the registers values prior to setting into the disabled state are restored, and data transmission can proceed. No reinitialization is required.
- *Synchronized reset.* This state is similar to the Power-on Reset (POR) state, when the processor is turned-on; reset to the peripheral is asserted, and clocks to the peripheral are gated after that. The registers are reset to their default value. When powering-up after a synchronized reset, all the EMAC submodules need to be reinitialized before any data transmission can happen.

For more information on the use of the PSC, see the *Power and Sleep Controller (PSC)* chapter.

19.2.18 Emulation Considerations

EMAC emulation control is implemented for compatibility with other peripherals. The SOFT and FREE bits in the emulation control register (EMCONTROL) allow EMAC operation to be suspended.

When the emulation suspend state is entered, the EMAC stops processing receive and transmit frames at the next frame boundary. Any frame currently in reception or transmission is completed normally without suspension. For transmission, any complete or partial frame in the transmit cell FIFO is transmitted. For receive, frames that are detected by the EMAC after the suspend state is entered are ignored. No statistics are kept for ignored frames.

Table 19-7 shows how the SOFT and FREE bits affect the operation of the emulation suspend.

NOTE: Emulation suspend has not been tested.

Table 19-7. Emulation Control

SOFT	FREE	Description
0	0	Normal operation
1	0	Emulation suspend
X	1	Normal operation

19.3 Registers

This section discusses the registers of the EMAC/MDIO module.

19.3.1 EMAC Control Module Registers

Table 19-8 lists the memory-mapped registers for the EMAC control module. See your device-specific data manual for the memory address of these registers.

Table 19-8. EMAC Control Module Registers

Offset	Acronym	Register Description	Section
0h	REVID	EMAC Control Module Revision ID Register	Section 19.3.1.1
4h	SOFTRESET	EMAC Control Module Software Reset Register	Section 19.3.1.2
Ch	INTCONTROL	EMAC Control Module Interrupt Control Register	Section 19.3.1.3
10h	C0RXTHRESHEN	EMAC Control Module Interrupt Core 0 Receive Threshold Interrupt Enable Register	Section 19.3.1.4
14h	C0RXEN	EMAC Control Module Interrupt Core 0 Receive Interrupt Enable Register	Section 19.3.1.5
18h	C0TXEN	EMAC Control Module Interrupt Core 0 Transmit Interrupt Enable Register	Section 19.3.1.6
1Ch	C0MISCEN	EMAC Control Module Interrupt Core 0 Miscellaneous Interrupt Enable Register	Section 19.3.1.7
20h	C1RXTHRESHEN	EMAC Control Module Interrupt Core 1 Receive Threshold Interrupt Enable Register	Section 19.3.1.4
24h	C1RXEN	EMAC Control Module Interrupt Core 1 Receive Interrupt Enable Register	Section 19.3.1.5
28h	C1TXEN	EMAC Control Module Interrupt Core 1 Transmit Interrupt Enable Register	Section 19.3.1.6
2Ch	C1MISCEN	EMAC Control Module Interrupt Core 1 Miscellaneous Interrupt Enable Register	Section 19.3.1.7
30h	C2RXTHRESHEN	EMAC Control Module Interrupt Core 2 Receive Threshold Interrupt Enable Register	Section 19.3.1.4
34h	C2RXEN	EMAC Control Module Interrupt Core 2 Receive Interrupt Enable Register	Section 19.3.1.5
38h	C2TXEN	EMAC Control Module Interrupt Core 2 Transmit Interrupt Enable Register	Section 19.3.1.6
3Ch	C2MISCEN	EMAC Control Module Interrupt Core 2 Miscellaneous Interrupt Enable Register	Section 19.3.1.7
40h	C0RXTHRESHSTAT	EMAC Control Module Interrupt Core 0 Receive Threshold Interrupt Status Register	Section 19.3.1.8
44h	C0RXSTAT	EMAC Control Module Interrupt Core 0 Receive Interrupt Status Register	Section 19.3.1.9
48h	C0TXSTAT	EMAC Control Module Interrupt Core 0 Transmit Interrupt Status Register	Section 19.3.1.10
4Ch	C0MISCSTAT	EMAC Control Module Interrupt Core 0 Miscellaneous Interrupt Status Register	Section 19.3.1.11
50h	C1RXTHRESHSTAT	EMAC Control Module Interrupt Core 1 Receive Threshold Interrupt Status Register	Section 19.3.1.8
54h	C1RXSTAT	EMAC Control Module Interrupt Core 1 Receive Interrupt Status Register	Section 19.3.1.9
58h	C1TXSTAT	EMAC Control Module Interrupt Core 1 Transmit Interrupt Status Register	Section 19.3.1.10
5Ch	C1MISCSTAT	EMAC Control Module Interrupt Core 1 Miscellaneous Interrupt Status Register	Section 19.3.1.11
60h	C2RXTHRESHSTAT	EMAC Control Module Interrupt Core 2 Receive Threshold Interrupt Status Register	Section 19.3.1.8
64h	C2RXSTAT	EMAC Control Module Interrupt Core 2 Receive Interrupt Status Register	Section 19.3.1.9

Table 19-8. EMAC Control Module Registers (continued)

Offset	Acronym	Register Description	Section
68h	C2TXSTAT	EMAC Control Module Interrupt Core 2 Transmit Interrupt Status Register	Section 19.3.1.10
6Ch	C2MISCSTAT	EMAC Control Module Interrupt Core 2 Miscellaneous Interrupt Status Register	Section 19.3.1.11
70h	C0RXIMAX	EMAC Control Module Interrupt Core 0 Receive Interrupts Per Millisecond Register	Section 19.3.1.12
74h	C0TXIMAX	EMAC Control Module Interrupt Core 0 Transmit Interrupts Per Millisecond Register	Section 19.3.1.13
78h	C1RXIMAX	EMAC Control Module Interrupt Core 1 Receive Interrupts Per Millisecond Register	Section 19.3.1.12
7Ch	C1TXIMAX	EMAC Control Module Interrupt Core 1 Transmit Interrupts Per Millisecond Register	Section 19.3.1.13
80h	C2RXIMAX	EMAC Control Module Interrupt Core 2 Receive Interrupts Per Millisecond Register	Section 19.3.1.12
84h	C2TXIMAX	EMAC Control Module Interrupt Core 2 Transmit Interrupts Per Millisecond Register	Section 19.3.1.13

19.3.1.1 EMAC Control Module Revision ID Register (REVID)

The EMAC control module revision ID register (REVID) is shown in Figure 19-12 and described in Table 19-9.

Figure 19-12. EMAC Control Module Revision ID Register (REVID)

31	0
REV	
R-4EC8 0100h	

LEGEND: R = Read only; -*n* = value after reset

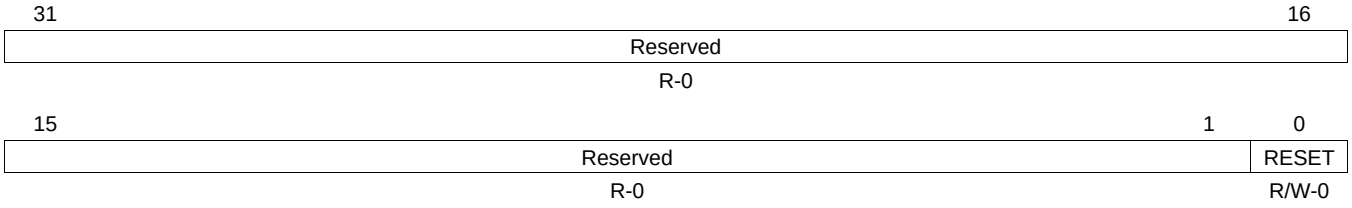
Table 19-9. EMAC Control Module Revision ID Register (REVID) Field Descriptions

Bit	Field	Value	Description
31-0	REV		Identifies the EMAC Control Module revision.
		4EC8 0100h	Current revision of the EMAC Control Module.

19.3.1.2 EMAC Control Module Software Reset Register (SOFTRESET)

The EMAC Control Module Software Reset Register (SOFTRESET) is shown in Figure 19-13 and described in Table 19-10.

Figure 19-13. EMAC Control Module Software Reset Register (SOFTRESET)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 19-10. EMAC Control Module Software Reset Register (SOFTRESET)

Bit	Field	Value	Description
31-1	Reserved	0	Reserved
0	RESET		Software reset bit for the EMAC Control Module. Clears the interrupt status, control registers, and CPPI Ram on the clock cycle following a write of 1.
		0	No software reset.
		1	Perform a software reset.

19.3.1.3 EMAC Control Module Interrupt Control Register (INTCONTROL)

The EMAC control module interrupt control register (INTCONTROL) is shown in Figure 19-14 and described in Table 19-11 . The settings in the INTCONTROL register are used in conjunction with the CnRXIMAX and CnTXIMAX registers.

Figure 19-14. EMAC Control Module Interrupt Control Register (INTCONTROL)

31	24
Reserved	
R-0	

23	22	21	20	19	18	17	16
Reserved		C2TXPACEEN	C2RXPACEEN	C1TXPACEEN	C1RXPACEEN	C0TXPACEEN	C0RXPACEEN
R-0		R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

15	12	11	0
Reserved		INTPRESCALE	
R-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 19-11. EMAC Control Module Interrupt Control Register (INTCONTROL)

Bit	Field	Value	Description
31-22	Reserved	0	Reserved
21	C2TXPACEEN		Enable pacing for TX interrupt pulse generation on Interrupt Core 2
		0	Pacing for TX interrupts on Core 2 disabled.
		1	Pacing for TX interrupts on Core 2 enabled.
20	C2RXPACEEN		Enable pacing for RX interrupt pulse generation on Interrupt Core 2
		0	Pacing for RX interrupts on Core 2 disabled.
		1	Pacing for RX interrupts on Core 2 enabled.
19	C1TXPACEEN		Enable pacing for TX interrupt pulse generation on Interrupt Core 1
		0	Pacing for TX interrupts on Core 1 disabled.
		1	Pacing for TX interrupts on Core 1 enabled.
18	C1RXPACEEN		Enable pacing for RX interrupt pulse generation on Interrupt Core 1
		0	Pacing for RX interrupts on Core 1 disabled.
		1	Pacing for RX interrupts on Core 1 enabled.
17	C0TXPACEEN		Enable pacing for TX interrupt pulse generation on Interrupt Core 0
		0	Pacing for TX interrupts on Core 0 disabled.
		1	Pacing for TX interrupts on Core 0 enabled.
16	C0RXPACEEN		Enable pacing for RX interrupt pulse generation on Interrupt Core 0
		0	Pacing for RX interrupts on Core 0 disabled.
		1	Pacing for RX interrupts on Core 0 enabled.
15-12	Reserved	0	Reserved
11-0	INTPRESCALE	0-7FFh	Number of internal EMAC module reference clock periods within a 4 µs time window (see your device-specific data manual for information).

19.3.1.4 EMAC Control Module Interrupt Core Receive Threshold Interrupt Enable Registers (C0RXTHRESHEN-C2RXTHRESHEN)

The EMAC control module interrupt core 0-2 receive threshold interrupt enable register (C*n*RXTHRESHEN) is shown in Figure 19-15 and described in Table 19-12.

Figure 19-15. EMAC Control Module Interrupt Core 0-2 Receive Threshold Interrupt Enable Register (C*n*RXTHRESHEN)

31							16
Reserved							
R-0							
15							8
Reserved							
R-0							
7	6	5	4	3	2	1	0
RXCH7 THRESHEN	RXCH6 THRESHEN	RXCH5 THRESHEN	RXCH4 THRESHEN	RXCH3 THRESHEN	RXCH2 THRESHEN	RXCH1 THRESHEN	RXCH0 THRESHEN
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 19-12. EMAC Control Module Interrupt Core 0-2 Receive Threshold Interrupt Enable Register (C*n*RXTHRESHEN)

Bit	Field	Value	Description
31-8	Reserved	0	Reserved
7	RXCH7THRESHEN		Enable CnRXTHRESHPULSE interrupt generation for RX Channel 7
		0	CnRXTHRESHPULSE generation is disabled for RX Channel 7.
		1	CnRXTHRESHPULSE generation is enabled for RX Channel 7.
6	RXCH6THRESHEN		Enable CnRXTHRESHPULSE interrupt generation for RX Channel 6
		0	CnRXTHRESHPULSE generation is disabled for RX Channel 6.
		1	CnRXTHRESHPULSE generation is enabled for RX Channel 6.
5	RXCH5THRESHEN		Enable CnRXTHRESHPULSE interrupt generation for RX Channel 5
		0	CnRXTHRESHPULSE generation is disabled for RX Channel 5.
		1	CnRXTHRESHPULSE generation is enabled for RX Channel 5.
4	RXCH4THRESHEN		Enable CnRXTHRESHPULSE interrupt generation for RX Channel 4
		0	CnRXTHRESHPULSE generation is disabled for RX Channel 4.
		1	CnRXTHRESHPULSE generation is enabled for RX Channel 4.
3	RXCH3THRESHEN		Enable CnRXTHRESHPULSE interrupt generation for RX Channel 3
		0	CnRXTHRESHPULSE generation is disabled for RX Channel 3.
		1	CnRXTHRESHPULSE generation is enabled for RX Channel 3.
2	RXCH2THRESHEN		Enable CnRXTHRESHPULSE interrupt generation for RX Channel 2
		0	CnRXTHRESHPULSE generation is disabled for RX Channel 2.
		1	CnRXTHRESHPULSE generation is enabled for RX Channel 2.
1	RXCH1THRESHEN		Enable CnRXTHRESHPULSE interrupt generation for RX Channel 1
		0	CnRXTHRESHPULSE generation is disabled for RX Channel 1.
		1	CnRXTHRESHPULSE generation is enabled for RX Channel 1.
0	RXCH0THRESHEN		Enable CnRXTHRESHPULSE interrupt generation for RX Channel 0
		0	CnRXTHRESHPULSE generation is disabled for RX Channel 0.
		1	CnRXTHRESHPULSE generation is enabled for RX Channel 0.

19.3.1.5 EMAC Control Module Interrupt Core Receive Interrupt Enable Registers (C0RXEN-C2RXEN)

The EMAC control module interrupt core 0-2 receive interrupt enable register (C*n*RXEN) is shown in Figure 19-16 and described in Table 19-13

Figure 19-16. EMAC Control Module Interrupt Core 0-2 Receive Interrupt Enable Register (C*n*RXEN)

31							16
Reserved							
R-0							
15							8
Reserved							
R-0							
7	6	5	4	3	2	1	0
RXCH7EN	RXCH6EN	RXCH5EN	RXCH4EN	RXCH3EN	RXCH2EN	RXCH1EN	RXCH0EN
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 19-13. EMAC Control Module Interrupt Core 0-2 Receive Interrupt Enable Register (C*n*RXEN)

Bit	Field	Value	Description
31-8	Reserved	0	Reserved
7	RXCH7EN		Enable CnRXPULSE interrupt generation for RX Channel 7
		0	CnRXPULSE generation is disabled for RX Channel 7.
		1	CnRXPULSE generation is enabled for RX Channel 7.
6	RXCH6EN		Enable CnRXPULSE interrupt generation for RX Channel 6
		0	CnRXPULSE generation is disabled for RX Channel 6.
		1	CnRXPULSE generation is enabled for RX Channel 6.
5	RXCH5EN		Enable CnRXPULSE interrupt generation for RX Channel 5
		0	CnRXPULSE generation is disabled for RX Channel 5.
		1	CnRXPULSE generation is enabled for RX Channel 5.
4	RXCH4EN		Enable CnRXPULSE interrupt generation for RX Channel 4
		0	CnRXPULSE generation is disabled for RX Channel 4.
		1	CnRXPULSE generation is enabled for RX Channel 4.
3	RXCH3EN		Enable CnRXPULSE interrupt generation for RX Channel 3
		0	CnRXPULSE generation is disabled for RX Channel 3.
		1	CnRXPULSE generation is enabled for RX Channel 3.
2	RXCH2EN		Enable CnRXPULSE interrupt generation for RX Channel 2
		0	CnRXPULSE generation is disabled for RX Channel 2.
		1	CnRXPULSE generation is enabled for RX Channel 2.
1	RXCH1EN		Enable CnRXPULSE interrupt generation for RX Channel 1
		0	CnRXPULSE generation is disabled for RX Channel 1.
		1	CnRXPULSE generation is enabled for RX Channel 1.
0	RXCH0EN		Enable CnRXPULSE interrupt generation for RX Channel 0
		0	CnRXPULSE generation is disabled for RX Channel 0.
		1	CnRXPULSE generation is enabled for RX Channel 0.

19.3.1.6 EMAC Control Module Interrupt Core Transmit Interrupt Enable Registers (C0TXEN-C2TXEN)

The EMAC control module interrupt core 0-2 transmit interrupt enable register (C*n*TXEN) is shown in Figure 19-17 and described in Table 19-14

Figure 19-17. EMAC Control Module Interrupt Core 0-2 Transmit Interrupt Enable Register (C*n*TXEN)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
R-0															

15	14	13	12	11	10	9	8
Reserved							
R-0							

7	6	5	4	3	2	1	0
TXCH7EN	TXCH6EN	TXCH5EN	TXCH4EN	TXCH3EN	TXCH2EN	TXCH1EN	TXCH0EN
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 19-14. EMAC Control Module Interrupt Core 0-2 Transmit Interrupt Enable Register (C*n*TXEN)

Bit	Field	Value	Description
31-8	Reserved	0	Reserved
7	TXCH7EN		Enable CnTXPULSE interrupt generation for TX Channel 7
		0	CnTXPULSE generation is disabled for TX Channel 7.
		1	CnTXPULSE generation is enabled for TX Channel 7.
6	TXCH6EN		Enable CnTXPULSE interrupt generation for TX Channel 6
		0	CnTXPULSE generation is disabled for TX Channel 6.
		1	CnTXPULSE generation is enabled for TX Channel 6.
5	TXCH5EN		Enable CnTXPULSE interrupt generation for TX Channel 5
		0	CnTXPULSE generation is disabled for TX Channel 5.
		1	CnTXPULSE generation is enabled for TX Channel 5.
4	TXCH4EN		Enable CnTXPULSE interrupt generation for TX Channel 4
		0	CnTXPULSE generation is disabled for TX Channel 4.
		1	CnTXPULSE generation is enabled for TX Channel 4.
3	TXCH3EN		Enable CnTXPULSE interrupt generation for TX Channel 3
		0	CnTXPULSE generation is disabled for TX Channel 3.
		1	CnTXPULSE generation is enabled for TX Channel 3.
2	TXCH2EN		Enable CnTXPULSE interrupt generation for TX Channel 2
		0	CnTXPULSE generation is disabled for TX Channel 2.
		1	CnTXPULSE generation is enabled for TX Channel 2.
1	TXCH1EN		Enable CnTXPULSE interrupt generation for TX Channel 1
		0	CnTXPULSE generation is disabled for TX Channel 1.
		1	CnTXPULSE generation is enabled for TX Channel 1.
0	TXCH0EN		Enable CnTXPULSE interrupt generation for TX Channel 0
		0	CnTXPULSE generation is disabled for TX Channel 0.
		1	CnTXPULSE generation is enabled for TX Channel 0.

19.3.1.7 EMAC Control Module Interrupt Core Miscellaneous Interrupt Enable Registers (C0MISCEN-C2MISCEN)

The EMAC control module interrupt core 0-2 miscellaneous interrupt enable register (C*n*MISCEN) is shown in Figure 19-18 and described in Table 19-15

Figure 19-18. EMAC Control Module Interrupt Core 0-2 Miscellaneous Interrupt Enable Register (C*n*MISCEN)

31	16
Reserved	
R-0	

15	4	3	2	1	0
Reserved		STATPENDEN	HOSTPENDEN	LINKINT0EN	USERINT0EN
R-0		R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 19-15. EMAC Control Module Interrupt Core 0-2 Miscellaneous Interrupt Enable Register (C*n*MISCEN)

Bit	Field	Value	Description
31-4	Reserved	0	Reserved
3	STATPENDEN		Enable CnMISCPULSE interrupt generation when EMAC statistics interrupts are generated
		0	CnMISCPULSE generation is disabled for EMAC STATPEND interrupts.
		1	CnMISCPULSE generation is enabled for EMAC STATPEND interrupts.
2	HOSTPENDEN		Enable CnMISCPULSE interrupt generation when EMAC host interrupts are generated
		0	CnMISCPULSE generation is disabled for EMAC HOSTPEND interrupts.
		1	CnMISCPULSE generation is enabled for EMAC HOSTPEND interrupts.
1	LINKINT0EN		Enable CnMISCPULSE interrupt generation when MDIO LINKINT0 interrupts (corresponding to USERPHYSEL0) are generated
		0	CnMISCPULSE generation is disabled for MDIO LINKINT0 interrupts.
		1	CnMISCPULSE generation is enabled for MDIO LINKINT0 interrupts.
0	USERINT0EN		Enable CnMISCPULSE interrupt generation when MDIO USERINT0 interrupts (corresponding to USERACCESS0) are generated
		0	CnMISCPULSE generation is disabled for MDIO USERINT0.
		1	CnMISCPULSE generation is enabled for MDIO USERINT0.

19.3.1.8 EMAC Control Module Interrupt Core Receive Threshold Interrupt Status Registers (C0RXTHRESHSTAT-C2RXTHRESHSTAT)

The EMAC control module interrupt core 0-2 receive threshold interrupt status register (C*n*RXTHRESHSTAT) is shown in Figure 19-19 and described in Table 19-16

Figure 19-19. EMAC Control Module Interrupt Core 0-2 Receive Threshold Interrupt Status Register (C*n*RXTHRESHSTAT)

31							16
Reserved							
R-0							

15							8
Reserved							
R-0							

7	6	5	4	3	2	1	0
RXCH7THRESHSTAT	RXCH6THRESHSTAT	RXCH5THRESHSTAT	RXCH4THRESHSTAT	RXCH3THRESHSTAT	RXCH2THRESHSTAT	RXCH1THRESHSTAT	RXCH0THRESHSTAT
R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0

LEGEND: R = Read only; -*n* = value after reset

Table 19-16. EMAC Control Module Interrupt Core 0-2 Receive Threshold Interrupt Status Register (C*n*RXTHRESHSTAT)

Bit	Field	Value	Description
31-8	Reserved	0	Reserved
7	RXCH7THRESHSTAT		Interrupt status for RX Channel 7 masked by the CnRXTHRESHEN register
		0	RX Channel 7 does not satisfy conditions to generate a CnRXTHRESHPULSE interrupt.
		1	RX Channel 7 satisfies conditions to generate a CnRXTHRESHPULSE interrupt.
6	RXCH6THRESHSTAT		Interrupt status for RX Channel 6 masked by the CnRXTHRESHEN register
		0	RX Channel 6 does not satisfy conditions to generate a CnRXTHRESHPULSE interrupt.
		1	RX Channel 6 satisfies conditions to generate a CnRXTHRESHPULSE interrupt.
5	RXCH5THRESHSTAT		Interrupt status for RX Channel 5 masked by the CnRXTHRESHEN register
		0	RX Channel 5 does not satisfy conditions to generate a CnRXTHRESHPULSE interrupt.
		1	RX Channel 5 satisfies conditions to generate a CnRXTHRESHPULSE interrupt.
4	RXCH4THRESHSTAT		Interrupt status for RX Channel 4 masked by the CnRXTHRESHEN register
		0	RX Channel 4 does not satisfy conditions to generate a CnRXTHRESHPULSE interrupt.
		1	RX Channel 4 satisfies conditions to generate a CnRXTHRESHPULSE interrupt.
3	RXCH3THRESHSTAT		Interrupt status for RX Channel 3 masked by the CnRXTHRESHEN register
		0	RX Channel 3 does not satisfy conditions to generate a CnRXTHRESHPULSE interrupt.
		1	RX Channel 3 satisfies conditions to generate a CnRXTHRESHPULSE interrupt.
2	RXCH2THRESHSTAT		Interrupt status for RX Channel 2 masked by the CnRXTHRESHEN register
		0	RX Channel 2 does not satisfy conditions to generate a CnRXTHRESHPULSE interrupt.
		1	RX Channel 2 satisfies conditions to generate a CnRXTHRESHPULSE interrupt.
1	RXCH1THRESHSTAT		Interrupt status for RX Channel 1 masked by the CnRXTHRESHEN register
		0	RX Channel 1 does not satisfy conditions to generate a CnRXTHRESHPULSE interrupt.
		1	RX Channel 1 satisfies conditions to generate a CnRXTHRESHPULSE interrupt.
0	RXCH0THRESHSTAT		Interrupt status for RX Channel 0 masked by the CnRXTHRESHEN register
		0	RX Channel 0 does not satisfy conditions to generate a CnRXTHRESHPULSE interrupt.
		1	RX Channel 0 satisfies conditions to generate a CnRXTHRESHPULSE interrupt.

19.3.1.9 EMAC Control Module Interrupt Core Receive Interrupt Status Registers (C0RXSTAT-C2RXSTAT)

The EMAC control module interrupt core 0-2 receive interrupt status register (C*n*RXSTAT) is shown in Figure 19-20 and described in Table 19-17

Figure 19-20. EMAC Control Module Interrupt Core 0-2 Receive Interrupt Status Register (C*n*RXSTAT)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
R-0															

15	14	13	12	11	10	9	8
Reserved							
R-0							

7	6	5	4	3	2	1	0
RXCH7STAT	RXCH6STAT	RXCH5STAT	RXCH4STAT	RXCH3STAT	RXCH2STAT	RXCH1STAT	RXCH0STAT
R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0

LEGEND: R = Read only; -*n* = value after reset

Table 19-17. EMAC Control Module Interrupt Core 0-2 Receive Interrupt Status Register (C*n*RXSTAT)

Bit	Field	Value	Description
31-8	Reserved	0	Reserved
7	RXCH7STAT		Interrupt status for RX Channel 7 masked by the CnRXEN register
		0	RX Channel 7 does not satisfy conditions to generate a CnRXPULSE interrupt.
		1	RX Channel 7 satisfies conditions to generate a CnRXPULSE interrupt.
6	RXCH6STAT		Interrupt status for RX Channel 6 masked by the CnRXEN register
		0	RX Channel 6 does not satisfy conditions to generate a CnRXPULSE interrupt.
		1	RX Channel 6 satisfies conditions to generate a CnRXPULSE interrupt.
5	RXCH5STAT		Interrupt status for RX Channel 5 masked by the CnRXEN register
		0	RX Channel 5 does not satisfy conditions to generate a CnRXPULSE interrupt.
		1	RX Channel 5 satisfies conditions to generate a CnRXPULSE interrupt.
4	RXCH4STAT		Interrupt status for RX Channel 4 masked by the CnRXEN register
		0	RX Channel 4 does not satisfy conditions to generate a CnRXPULSE interrupt.
		1	RX Channel 4 satisfies conditions to generate a CnRXPULSE interrupt.
3	RXCH3STAT		Interrupt status for RX Channel 3 masked by the CnRXEN register
		0	RX Channel 3 does not satisfy conditions to generate a CnRXPULSE interrupt.
		1	RX Channel 3 satisfies conditions to generate a CnRXPULSE interrupt.
2	RXCH2STAT		Interrupt status for RX Channel 2 masked by the CnRXEN register
		0	RX Channel 2 does not satisfy conditions to generate a CnRXPULSE interrupt.
		1	RX Channel 2 satisfies conditions to generate a CnRXPULSE interrupt.
1	RXCH1STAT		Interrupt status for RX Channel 1 masked by the CnRXEN register
		0	RX Channel 1 does not satisfy conditions to generate a CnRXPULSE interrupt.
		1	RX Channel 1 satisfies conditions to generate a CnRXPULSE interrupt.
0	RXCH0STAT		Interrupt status for RX Channel 0 masked by the CnRXEN register
		0	RX Channel 0 does not satisfy conditions to generate a CnRXPULSE interrupt.
		1	RX Channel 0 satisfies conditions to generate a CnRXPULSE interrupt.

19.3.1.10 EMAC Control Module Interrupt Core Transmit Interrupt Status Registers (C0TXSTAT-C2TXSTAT)

The EMAC control module interrupt core 0-2 transmit interrupt status register (C*n*TXSTAT) is shown in Figure 19-21 and described in Table 19-18

Figure 19-21. EMAC Control Module Interrupt Core 0-2 Transmit Interrupt Status Register (C*n*TXSTAT)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
R-0															

15	14	13	12	11	10	9	8
Reserved							
R-0							

7	6	5	4	3	2	1	0
TXCH7STAT	TXCH6STAT	TXCH5STAT	TXCH4STAT	TXCH3STAT	TXCH2STAT	TXCH1STAT	TXCH0STAT
R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0

LEGEND: R = Read only; -*n* = value after reset

Table 19-18. EMAC Control Module Interrupt Core 0-2 Transmit Interrupt Status Register (C*n*TXSTAT)

Bit	Field	Value	Description
31-8	Reserved	0	Reserved
7	TXCH7STAT		Interrupt status for TX Channel 7 masked by the CnTXEN register
		0	TX Channel 7 does not satisfy conditions to generate a CnTXPULSE interrupt.
		1	TX Channel 7 satisfies conditions to generate a CnTXPULSE interrupt.
6	TXCH6STAT		Interrupt status for TX Channel 6 masked by the CnTXEN register
		0	TX Channel 6 does not satisfy conditions to generate a CnTXPULSE interrupt.
		1	TX Channel 6 satisfies conditions to generate a CnTXPULSE interrupt.
5	TXCH5STAT		Interrupt status for TX Channel 5 masked by the CnTXEN register
		0	TX Channel 5 does not satisfy conditions to generate a CnTXPULSE interrupt.
		1	TX Channel 5 satisfies conditions to generate a CnTXPULSE interrupt.
4	TXCH4STAT		Interrupt status for TX Channel 4 masked by the CnTXEN register
		0	TX Channel 4 does not satisfy conditions to generate a CnTXPULSE interrupt.
		1	TX Channel 4 satisfies conditions to generate a CnTXPULSE interrupt.
3	TXCH3STAT		Interrupt status for TX Channel 3 masked by the CnTXEN register
		0	TX Channel 3 does not satisfy conditions to generate a CnTXPULSE interrupt.
		1	TX Channel 3 satisfies conditions to generate a CnTXPULSE interrupt.
2	TXCH2STAT		Interrupt status for TX Channel 2 masked by the CnTXEN register
		0	TX Channel 2 does not satisfy conditions to generate a CnTXPULSE interrupt.
		1	TX Channel 2 satisfies conditions to generate a CnTXPULSE interrupt.
1	TXCH1STAT		Interrupt status for TX Channel 1 masked by the CnTXEN register
		0	TX Channel 1 does not satisfy conditions to generate a CnTXPULSE interrupt.
		1	TX Channel 1 satisfies conditions to generate a CnTXPULSE interrupt.
0	TXCH0STAT		Interrupt status for TX Channel 0 masked by the CnTXEN register
		0	TX Channel 0 does not satisfy conditions to generate a CnTXPULSE interrupt.
		1	TX Channel 0 satisfies conditions to generate a CnTXPULSE interrupt.

19.3.1.11 EMAC Control Module Interrupt Core Miscellaneous Interrupt Status Registers (C0MISCSTAT-C2MISCSTAT)

The EMAC control module interrupt core 0-2 miscellaneous interrupt status register (C*n*MISCSTAT) is shown in Figure 19-22 and described in Table 19-19

Figure 19-22. EMAC Control Module Interrupt Core 0-2 Miscellaneous Interrupt Status Register (C*n*MISCSTAT)

31	16
Reserved	
R-0	

15	4	3	2	1	0
Reserved		STATPENDSTAT	HOSTPENDSTAT	LINKINT0STAT	USERINT0STAT
R-0		R-0	R-0	R-0	R-0

LEGEND: R = Read only; -*n* = value after reset

Table 19-19. EMAC Control Module Interrupt Core 0-2 Miscellaneous Interrupt Status Register (C*n*MISCSTAT)

Bit	Field	Value	Description
31-4	Reserved	0	Reserved
3	STATPENDSTAT		Interrupt status for EMAC STATPEND masked by the CnMISCEN register
		0	EMAC STATPEND does not satisfy conditions to generate a CnMISCPULSE interrupt.
		1	EMAC STATPEND satisfies conditions to generate a CnMISCPULSE interrupt.
2	HOSTPENDSTAT		Interrupt status for EMAC HOSTPEND masked by the CnMISCEN register
		0	EMAC HOSTPEND does not satisfy conditions to generate a CnMISCPULSE interrupt.
		1	EMAC HOSTPEND satisfies conditions to generate a CnMISCPULSE interrupt.
1	LINKINT0STAT		Interrupt status for MDIO LINKINT0 masked by the CnMISCEN register
		0	MDIO LINKINT0 does not satisfy conditions to generate a CnMISCPULSE interrupt.
		1	MDIO LINKINT0 satisfies conditions to generate a CnMISCPULSE interrupt.
0	USERINT0STAT		Interrupt status for MDIO USERINT0 masked by the CnMISCEN register
		0	MDIO USERINT0 does not satisfy conditions to generate a CnMISCPULSE interrupt.
		1	MDIO USERINT0 satisfies conditions to generate a CnMISCPULSE interrupt.

19.3.1.12 EMAC Control Module Interrupt Core Receive Interrupts Per Millisecond Registers (C0RXIMAX-C2RXIMAX)

The EMAC control module interrupt core 0-2 receive interrupts per millisecond register (C*n*RXIMAX) is shown in Figure 19-23 and described in Table 19-20

Figure 19-23. EMAC Control Module Interrupt Core 0-2 Receive Interrupts Per Millisecond Register (C*n*RXIMAX)

31	16
Reserved	
R-0	

15	6	5	0
Reserved		RXIMAX	
R-0		R/W-0	

LEGEND: R = Read only; R/W = Read/Write; -*n* = value after reset

Table 19-20. EMAC Control Module Interrupt Core 0-2 Receive Interrupts Per Millisecond Register (C*n*RXIMAX)

Bit	Field	Value	Description
31-6	Reserved	0	Reserved
5-0	RXIMAX	2-3Fh	RXIMAX is the desired number of CnRXPULSE interrupts generated per millisecond when CnRXPACEEN is enabled in INTCONTROL.

The pacing mechanism can be described by the following pseudo-code:

```
while(1) {
    interrupt_count = 0;

    /* Count interrupts over a 1ms window */
    for(i = 0; i < INTCONTROL[INTPRESCALE]*250; i++) {
        interrupt_count += NEW_INTERRUPT_EVENTS();

        if(i < INTCONTROL[INTPRESCALE]*pace_counter)
            BLOCK_EMAC_INTERRUPTS();
        else
            ALLOW_EMAC_INTERRUPTS();
    }

    ALLOW_EMAC_INTERRUPTS();

    if(interrupt_count > 2*RXIMAX)
        pace_counter = 255;
    else if(interrupt_count > 1.5*RXIMAX)
        pace_counter = previous_pace_counter*2 + 1;
    else if(interrupt_count > 1.0*RXIMAX)
        pace_counter = previous_pace_counter + 1;
    else if(interrupt_count > 0.5*RXIMAX)
        pace_counter = previous_pace_counter - 1;
    else if(interrupt_count != 0)
        pace_counter = previous_pace_counter/2;
    else
        pace_counter = 0;

    previous_pace_counter = pace_counter;
}
```

19.3.1.13 EMAC Control Module Interrupt Core Transmit Interrupts Per Millisecond Registers (C0TXIMAX-C2TXIMAX)

The EMAC control module interrupt core 0-2 transmit interrupts per millisecond register (C*n*TXIMAX) is shown in Figure 19-24 and described in Table 19-21

Figure 19-24. EMAC Control Module Interrupt Core 0-2 Transmit Interrupts Per Millisecond Register (C*n*TXIMAX)

31	16
Reserved	
R-0	

15	6	5	0
Reserved		TXIMAX	
R-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 19-21. EMAC Control Module Interrupt Core 0-2 Transmit Interrupts Per Millisecond Register (C*n*TXIMAX)

Bit	Field	Value	Description
31-6	Reserved	0	Reserved
5-0	TXIMAX	2-3Fh	TXIMAX is the desired number of CnTXPULSE interrupts generated per millisecond when CnTXPACEEN is enabled in INTCONTROL.

The pacing mechanism can be described by the following pseudo-code:

```
while(1) {
    interrupt_count = 0;

    /* Count interrupts over a 1ms window */
    for(i = 0; i < INTCONTROL[INTPRESCALE]*250; i++) {
        interrupt_count += NEW_INTERRUPT_EVENTS();

        if(i < INTCONTROL[INTPRESCALE]*pace_counter)
            BLOCK_EMAC_INTERRUPTS();
        else
            ALLOW_EMAC_INTERRUPTS();
    }

    ALLOW_EMAC_INTERRUPTS();

    if(interrupt_count > 2*TXIMAX)
        pace_counter = 255;
    else if(interrupt_count > 1.5*TXIMAX)
        pace_counter = previous_pace_counter*2 + 1;
    else if(interrupt_count > 1.0*TXIMAX)
        pace_counter = previous_pace_counter + 1;
    else if(interrupt_count > 0.5*TXIMAX)
        pace_counter = previous_pace_counter - 1;
    else if(interrupt_count != 0)
        pace_counter = previous_pace_counter/2;
    else
        pace_counter = 0;

    previous_pace_counter = pace_counter;
}
```

19.3.2 MDIO Registers

Table 19-22 lists the memory-mapped registers for the MDIO module. See your device-specific data manual for the memory address of these registers.

Table 19-22. Management Data Input/Output (MDIO) Registers

Offset	Acronym	Register Description	Section
0h	REVID	MDIO Revision ID Register	Section 19.3.2.1
4h	CONTROL	MDIO Control Register	Section 19.3.2.2
8h	ALIVE	PHY Alive Status register	Section 19.3.2.3
Ch	LINK	PHY Link Status Register	Section 19.3.2.4
10h	LINKINTRAW	MDIO Link Status Change Interrupt (Unmasked) Register	Section 19.3.2.5
14h	LINKINTMASKED	MDIO Link Status Change Interrupt (Masked) Register	Section 19.3.2.6
20h	USERINTRAW	MDIO User Command Complete Interrupt (Unmasked) Register	Section 19.3.2.7
24h	USERINTMASKED	MDIO User Command Complete Interrupt (Masked) Register	Section 19.3.2.8
28h	USERINTMASKSET	MDIO User Command Complete Interrupt Mask Set Register	Section 19.3.2.9
2Ch	USERINTMASKCLEAR	MDIO User Command Complete Interrupt Mask Clear Register	Section 19.3.2.10
80h	USERACCESS0	MDIO User Access Register 0	Section 19.3.2.11
84h	USERPHYSEL0	MDIO User PHY Select Register 0	Section 19.3.2.12
88h	USERACCESS1	MDIO User Access Register 1	Section 19.3.2.13
8Ch	USERPHYSEL1	MDIO User PHY Select Register 1	Section 19.3.2.14

19.3.2.1 MDIO Revision ID Register (REVID)

The MDIO revision ID register (REVID) is shown in Figure 19-25 and described in Table 19-23.

Figure 19-25. MDIO Revision ID Register (REVID)

31	0
REV	
R-0007 0104h	

LEGEND: R = Read only; -*n* = value after reset

Table 19-23. MDIO Revision ID Register (REVID) Field Descriptions

Bit	Field	Value	Description
31-0	REV		Identifies the MDIO Module revision.
		0007 0104h	Current revision of the MDIO Module.

19.3.2.2 MDIO Control Register (CONTROL)

The MDIO control register (CONTROL) is shown in Figure 19-26 and described in Table 19-24.

Figure 19-26. MDIO Control Register (CONTROL)

31	30	29	28 24	23 21	20	19	18	17 16
IDLE	ENABLE	Rsvd	HIGHEST_USER_CHANNEL	Reserved	PREAMBLE	FAULT	FAULTENB	Reserved
R-1	R/W-0	R-0	R-1	R-0	R/W-0	R/W1C-0	R/W-0	R-0

15 0
CLKDIV
R/W-FFh

LEGEND: R/W = Read/Write; R = Read only; W1C = Write 1 to clear (writing a 0 has no effect); -*n* = value after reset

Table 19-24. MDIO Control Register (CONTROL) Field Descriptions

Bit	Field	Value	Description
31	IDLE		State machine IDLE status bit.
		0	State machine is not in idle state.
		1	State machine is in idle state.
30	ENABLE		State machine enable control bit. If the MDIO state machine is active at the time it is disabled, it will complete the current operation before halting and setting the idle bit.
		0	Disables the MDIO state machine.
		1	Enable the MDIO state machine.
29	Reserved	0	Reserved
28-24	HIGHEST_USER_CHANNEL	0-1Fh	Highest user channel that is available in the module. It is currently set to 1. This implies that MDIOUserAccess1 is the highest available user access channel.
23-21	Reserved	0	Reserved
20	PREAMBLE		Preamble disable
		0	Standard MDIO preamble is used.
		1	Disables this device from sending MDIO frame preambles.
19	FAULT		Fault indicator. This bit is set to 1 if the MDIO pins fail to read back what the device is driving onto them. This indicates a physical layer fault and the module state machine is reset. Writing a 1 to this bit clears this bit, writing a 0 has no effect.
		0	No failure
		1	Physical layer fault; the MDIO state machine is reset.
18	FAULTENB		Fault detect enable. This bit has to be set to 1 to enable the physical layer fault detection.
		0	Disables the physical layer fault detection.
		1	Enables the physical layer fault detection.
17-16	Reserved	0	Reserved
15-0	CLKDIV	0-FFFFh	Clock Divider bits. This field specifies the division ratio between the peripheral clock and the frequency of MDIO_CLK. MDIO_CLK is disabled when CLKDIV is cleared to 0. MDIO_CLK frequency = peripheral clock frequency/(CLKDIV + 1).

19.3.2.3 PHY Acknowledge Status Register (ALIVE)

The PHY acknowledge status register (ALIVE) is shown in Figure 19-27 and described in Table 19-25.

Figure 19-27. PHY Acknowledge Status Register (ALIVE)

31	0
ALIVE	
R/W1C-0	

LEGEND: R/W = Read/Write; W1C = Write 1 to clear (writing a 0 has no effect); -*n* = value after reset

Table 19-25. PHY Acknowledge Status Register (ALIVE) Field Descriptions

Bit	Field	Value	Description
31-0	ALIVE		MDIO Alive bits. Each of the 32 bits of this register is set if the most recent access to the PHY with address corresponding to the register bit number was acknowledged by the PHY; the bit is reset if the PHY fails to acknowledge the access. Both the user and polling accesses to a PHY will cause the corresponding alive bit to be updated. The alive bits are only meant to be used to give an indication of the presence or not of a PHY with the corresponding address. Writing a 1 to any bit will clear it, writing a 0 has no effect.
		0	The PHY fails to acknowledge the access.
		1	The most recent access to the PHY with an address corresponding to the register bit number was acknowledged by the PHY.

19.3.2.4 PHY Link Status Register (LINK)

The PHY link status register (LINK) is shown in Figure 19-28 and described in Table 19-26.

Figure 19-28. PHY Link Status Register (LINK)

31	0
LINK	
R-0	

LEGEND: R = Read only; -*n* = value after reset

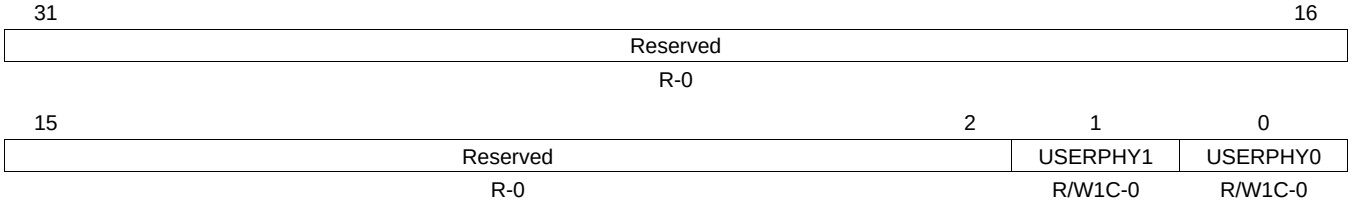
Table 19-26. PHY Link Status Register (LINK) Field Descriptions

Bit	Field	Value	Description
31-0	LINK		MDIO Link state bits. This register is updated after a read of the generic status register of a PHY. The bit is set if the PHY with the corresponding address has link and the PHY acknowledges the read transaction. The bit is reset if the PHY indicates it does not have link or fails to acknowledge the read transaction. Writes to the register have no effect.
		0	The PHY indicates it does not have a link or fails to acknowledge the read transaction
		1	The PHY with the corresponding address has a link and the PHY acknowledges the read transaction.

19.3.2.5 MDIO Link Status Change Interrupt (Unmasked) Register (LINKINTRAW)

The MDIO link status change interrupt (unmasked) register (LINKINTRAW) is shown in Figure 19-29 and described in Table 19-27.

Figure 19-29. MDIO Link Status Change Interrupt (Unmasked) Register (LINKINTRAW)



LEGEND: R/W = Read/Write; R = Read only; W1C = Write 1 to clear (writing a 0 has no effect); -*n* = value after reset

Table 19-27. MDIO Link Status Change Interrupt (Unmasked) Register (LINKINTRAW) Field Descriptions

Bit	Field	Value	Description
31-2	Reserved	0	Reserved
1	USERPHY1		MDIO Link change event, raw value. When asserted, the bit indicates that there was an MDIO link change event (that is, change in the LINK register) corresponding to the PHY address in USERPHYSEL1. Writing a 1 will clear the event, writing a 0 has no effect.
		0	No MDIO link change event.
		1	An MDIO link change event (change in the LINK register) corresponding to the PHY address in MDIO user PHY select register USERPHYSEL1
0	USERPHY0		MDIO Link change event, raw value. When asserted, the bit indicates that there was an MDIO link change event (that is, change in the LINK register) corresponding to the PHY address in USERPHYSEL0. Writing a 1 will clear the event, writing a 0 has no effect.
		0	No MDIO link change event.
		1	An MDIO link change event (change in the LINK register) corresponding to the PHY address in MDIO user PHY select register USERPHYSEL0

19.3.2.6 MDIO Link Status Change Interrupt (Masked) Register (LINKINTMASKED)

The MDIO link status change interrupt (masked) register (LINKINTMASKED) is shown in Figure 19-30 and described in Table 19-28.

Figure 19-30. MDIO Link Status Change Interrupt (Masked) Register (LINKINTMASKED)

31	16
Reserved	
R-0	

15	2	1	0
Reserved		USERPHY1	USERPHY0
R-0		R/W1C-0	R/W1C-0

LEGEND: R/W = Read/Write; R = Read only; W1C = Write 1 to clear (writing a 0 has no effect); -*n* = value after reset

Table 19-28. MDIO Link Status Change Interrupt (Masked) Register (LINKINTMASKED) Field Descriptions

Bit	Field	Value	Description
31-2	Reserved	0	Reserved
1	USERPHY1		MDIO Link change interrupt, masked value. When asserted, the bit indicates that there was an MDIO link change event (that is, change in the LINK register) corresponding to the PHY address in USERPHYSEL1 and the corresponding LINKINTENB bit was set. Writing a 1 will clear the event, writing a 0 has no effect.
		0	No MDIO link change event.
		1	An MDIO link change event (change in the LINK register) corresponding to the PHY address in MDIO user PHY select register USERPHYSEL1 and the LINKINTENB bit in USERPHYSEL1 is set to 1.
0	USERPHY0		MDIO Link change interrupt, masked value. When asserted, the bit indicates that there was an MDIO link change event (that is, change in the LINK register) corresponding to the PHY address in USERPHYSEL0 and the corresponding LINKINTENB bit was set. Writing a 1 will clear the event, writing a 0 has no effect.
		0	No MDIO link change event.
		1	An MDIO link change event (change in the LINK register) corresponding to the PHY address in MDIO user PHY select register USERPHYSEL0 and the LINKINTENB bit in USERPHYSEL0 is set to 1.

19.3.2.7 MDIO User Command Complete Interrupt (Unmasked) Register (USERINTRAW)

The MDIO user command complete interrupt (unmasked) register (USERINTRAW) is shown in Figure 19-31 and described in Table 19-29.

Figure 19-31. MDIO User Command Complete Interrupt (Unmasked) Register (USERINTRAW)

31	16
Reserved	
R-0	

15	2	1	0
Reserved		USERACCESS1	USERACCESS0
R-0		R/W1C-0	R/W1C-0

LEGEND: R/W = Read/Write; R = Read only; W1C = Write 1 to clear (writing a 0 has no effect); -*n* = value after reset

Table 19-29. MDIO User Command Complete Interrupt (Unmasked) Register (USERINTRAW) Field Descriptions

Bit	Field	Value	Description
31-2	Reserved	0	Reserved
1	USERACCESS1		MDIO User command complete event bit. When asserted, the bit indicates that the previously scheduled PHY read or write command using the USERACCESS1 register has completed. Writing a 1 will clear the event, writing a 0 has no effect.
		0	No MDIO user command complete event.
		1	The previously scheduled PHY read or write command using MDIO user access register USERACCESS1 has completed.
0	USERACCESS0		MDIO User command complete event bit. When asserted, the bit indicates that the previously scheduled PHY read or write command using the USERACCESS0 register has completed. Writing a 1 will clear the event, writing a 0 has no effect.
		0	No MDIO user command complete event.
		1	The previously scheduled PHY read or write command using MDIO user access register USERACCESS0 has completed.

19.3.2.8 MDIO User Command Complete Interrupt (Masked) Register (USERINTMASKED)

The MDIO user command complete interrupt (masked) register (USERINTMASKED) is shown in Figure 19-32 and described in Table 19-30.

Figure 19-32. MDIO User Command Complete Interrupt (Masked) Register (USERINTMASKED)

31	16
Reserved	
R-0	

15	2	1	0
Reserved		USERACCESS1	USERACCESS0
R-0		R/W1C-0	R/W1C-0

LEGEND: R/W = Read/Write; R = Read only; W1C = Write 1 to clear (writing a 0 has no effect); *-n* = value after reset

Table 19-30. MDIO User Command Complete Interrupt (Masked) Register (USERINTMASKED) Field Descriptions

Bit	Field	Value	Description
31-2	Reserved	0	Reserved
1	USERACCESS1		Masked value of MDIO User command complete interrupt. When asserted, The bit indicates that the previously scheduled PHY read or write command using that particular USERACCESS1 register has completed. Writing a 1 will clear the interrupt, writing a 0 has no effect.
		0	No MDIO user command complete event.
		1	The previously scheduled PHY read or write command using MDIO user access register USERACCESS1 has completed and the corresponding bit in USERINTMASKSET is set to 1.
0	USERACCESS0		Masked value of MDIO User command complete interrupt. When asserted, The bit indicates that the previously scheduled PHY read or write command using that particular USERACCESS0 register has completed. Writing a 1 will clear the interrupt, writing a 0 has no effect.
		0	No MDIO user command complete event.
		1	The previously scheduled PHY read or write command using MDIO user access register USERACCESS0 has completed and the corresponding bit in USERINTMASKSET is set to 1.

19.3.2.9 MDIO User Command Complete Interrupt Mask Set Register (USERINTMASKSET)

The MDIO user command complete interrupt mask set register (USERINTMASKSET) is shown in Figure 19-33 and described in Table 19-31.

Figure 19-33. MDIO User Command Complete Interrupt Mask Set Register (USERINTMASKSET)

31	16
Reserved	
R-0	

15	2	1	0
Reserved		USERACCESS1	USERACCESS0
R-0		R/W1S-0	R/W1S-0

LEGEND: R/W = Read/Write; R = Read only; W1S = Write 1 to set (writing a 0 has no effect); -*n* = value after reset

Table 19-31. MDIO User Command Complete Interrupt Mask Set Register (USERINTMASKSET) Field Descriptions

Bit	Field	Value	Description
31-2	Reserved	0	Reserved
1	USERACCESS1		MDIO user interrupt mask set for USERINTMASKED[1]. Setting a bit to 1 will enable MDIO user command complete interrupts for the USERACCESS1 register. MDIO user interrupt for USERACCESS1 is disabled if the corresponding bit is 0. Writing a 0 to this bit has no effect.
		0	MDIO user command complete interrupts for the MDIO user access register USERACCESS0 is disabled.
		1	MDIO user command complete interrupts for the MDIO user access register USERACCESS0 is enabled.
0	USERACCESS0		MDIO user interrupt mask set for USERINTMASKED[0]. Setting a bit to 1 will enable MDIO user command complete interrupts for the USERACCESS0 register. MDIO user interrupt for USERACCESS0 is disabled if the corresponding bit is 0. Writing a 0 to this bit has no effect.
		0	MDIO user command complete interrupts for the MDIO user access register USERACCESS0 is disabled.
		1	MDIO user command complete interrupts for the MDIO user access register USERACCESS0 is enabled.

19.3.2.10 MDIO User Command Complete Interrupt Mask Clear Register (USERINTMASKCLEAR)

The MDIO user command complete interrupt mask clear register (USERINTMASKCLEAR) is shown in Figure 19-34 and described in Table 19-32.

Figure 19-34. MDIO User Command Complete Interrupt Mask Clear Register (USERINTMASKCLEAR)

31	16
Reserved	
R-0	

15	2	1	0
Reserved		USERACCESS1	USERACCESS0
R-0		R/W1C-0	R/W1C-0

LEGEND: R/W = Read/Write; R = Read only; W1C = Write 1 to clear (writing a 0 has no effect); *-n* = value after reset

Table 19-32. MDIO User Command Complete Interrupt Mask Clear Register (USERINTMASKCLEAR) Field Descriptions

Bit	Field	Value	Description
31-2	Reserved	0	Reserved
1	USERACCESS1		MDIO user command complete interrupt mask clear for USERINTMASKED[1]. Setting the bit to 1 will disable further user command complete interrupts for USERACCESS1. Writing a 0 to this bit has no effect.
		0	MDIO user command complete interrupts for the MDIO user access register USERACCESS1 is enabled.
		1	MDIO user command complete interrupts for the MDIO user access register USERACCESS1 is disabled.
0	USERACCESS0		MDIO user command complete interrupt mask clear for USERINTMASKED[0]. Setting the bit to 1 will disable further user command complete interrupts for USERACCESS0. Writing a 0 to this bit has no effect.
		0	MDIO user command complete interrupts for the MDIO user access register USERACCESS0 is enabled.
		1	MDIO user command complete interrupts for the MDIO user access register USERACCESS0 is disabled.

19.3.2.11 MDIO User Access Register 0 (USERACCESS0)

The MDIO user access register 0 (USERACCESS0) is shown in Figure 19-35 and described in Table 19-33.

Figure 19-35. MDIO User Access Register 0 (USERACCESS0)

31	30	29	28 26	25 21	20 16
GO	WRITE	ACK	Reserved	REGADR	PHYADR
R/W1S-0	R/W-0	R/W-0	R-0	R/W-0	R/W-0

15 0
DATA
R/W-0

LEGEND: R/W = Read/Write; R = Read only; W1S = Write 1 to set (writing a 0 has no effect); -*n* = value after reset

Table 19-33. MDIO User Access Register 0 (USERACCESS0) Field Descriptions

Bit	Field	Value	Description
31	GO	0-1	Go bit. Writing a 1 to this bit causes the MDIO state machine to perform an MDIO access when it is convenient for it to do so; this is not an instantaneous process. Writing a 0 to this bit has no effect. This bit is writeable only if the MDIO state machine is enabled. This bit will self clear when the requested access has been completed. Any writes to USERACCESS0 are blocked when the GO bit is 1.
30	WRITE		Write enable bit. Setting this bit to 1 causes the MDIO transaction to be a register write; otherwise, it is a register read.
		0	The user command is a read operation.
		1	The user command is a write operation.
29	ACK	0-1	Acknowledge bit. This bit is set if the PHY acknowledged the read transaction.
28-26	Reserved	0	Reserved
25-21	REGADR	0-1Fh	Register address bits. This field specifies the PHY register to be accessed for this transaction
20-16	PHYADR	0-1Fh	PHY address bits. This field specifies the PHY to be accessed for this transaction.
15-0	DATA	0-FFFFh	User data bits. These bits specify the data value read from or to be written to the specified PHY register.

19.3.2.12 MDIO User PHY Select Register 0 (USERPHYSEL0)

The MDIO user PHY select register 0 (USERPHYSEL0) is shown in Figure 19-36 and described in Table 19-34.

Figure 19-36. MDIO User PHY Select Register 0 (USERPHYSEL0)

31	16
Reserved	
R-0	

15	8	7	6	5	4	0
Reserved		LINKSEL	LINKINTENB	Rsvd	PHYADRMON	
R-0		R/W-0	R/W-0	R-0	R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 19-34. MDIO User PHY Select Register 0 (USERPHYSEL0) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved
7	LINKSEL		Link status determination select bit. Default value is 0, which implies that the link status is determined by the MDIO state machine. This is the only option supported on this device.
		0	The link status is determined by the MDIO state machine.
		1	Not supported.
6	LINKINTENB		Link change interrupt enable. Set to 1 to enable link change status interrupts for PHY address specified in PHYADRMON. Link change interrupts are disabled if this bit is cleared to 0.
		0	Link change interrupts are disabled.
		1	Link change status interrupts for PHY address specified in PHYADDRMON bits are enabled.
5	Reserved	0	Reserved
4-0	PHYADRMON	0-1Fh	PHY address whose link status is to be monitored.

19.3.2.13 MDIO User Access Register 1 (USERACCESS1)

The MDIO user access register 1 (USERACCESS1) is shown in Figure 19-37 and described in Table 19-35.

Figure 19-37. MDIO User Access Register 1 (USERACCESS1)

31	30	29	28 26	25 21	20 16
GO	WRITE	ACK	Reserved	REGADR	PHYADR
R/W1S-0	R/W-0	R/W-0	R-0	R/W-0	R/W-0

15 0
DATA
R/W-0

LEGEND: R/W = Read/Write; R = Read only; W1S = Write 1 to set (writing a 0 has no effect); -*n* = value after reset

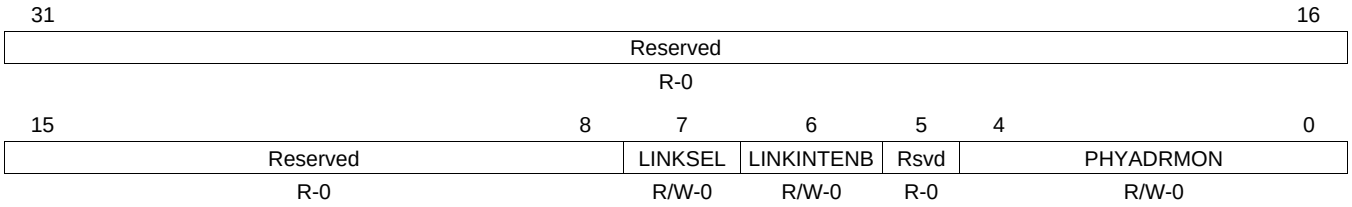
Table 19-35. MDIO User Access Register 1 (USERACCESS1) Field Descriptions

Bit	Field	Value	Description
31	GO	0-1	Go bit. Writing 1 to this bit causes the MDIO state machine to perform an MDIO access when it is convenient for it to do so; this is not an instantaneous process. Writing 0 to this bit has no effect. This bit is writeable only if the MDIO state machine is enabled. This bit will self clear when the requested access has been completed. Any writes to USERACCESS0 are blocked when the GO bit is 1.
30	WRITE		Write enable bit. Setting this bit to 1 causes the MDIO transaction to be a register write; otherwise, it is a register read.
		0	The user command is a read operation.
		1	The user command is a write operation.
29	ACK	0-1	Acknowledge bit. This bit is set if the PHY acknowledged the read transaction.
28-26	Reserved	0	Reserved
25-21	REGADR	0-1Fh	Register address bits. This field specifies the PHY register to be accessed for this transaction
20-16	PHYADR	0-1Fh	PHY address bits. This field specifies the PHY to be accessed for this transaction.
15-0	DATA	0-FFFFh	User data bits. These bits specify the data value read from or to be written to the specified PHY register.

19.3.2.14 MDIO User PHY Select Register 1 (USERPHYSEL1)

The MDIO user PHY select register 1 (USERPHYSEL1) is shown in Figure 19-38 and described in Table 19-36.

Figure 19-38. MDIO User PHY Select Register 1 (USERPHYSEL1)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 19-36. MDIO User PHY Select Register 1 (USERPHYSEL1) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved
7	LINKSEL		Link status determination select bit. Default value is 0, which implies that the link status is determined by the MDIO state machine. This is the only option supported on this device.
		0	The link status is determined by the MDIO state machine.
		1	Not supported.
6	LINKINTENB		Link change interrupt enable. Set to 1 to enable link change status interrupts for the PHY address specified in PHYADRMON. Link change interrupts are disabled if this bit is cleared to 0.
		0	Link change interrupts are disabled.
		1	Link change status interrupts for PHY address specified in PHYADDRMON bits are enabled.
5	Reserved	0	PHY address whose link status is to be monitored.
4-0	PHYADRMON	0-1Fh	PHY address whose link status is to be monitored.

19.3.3 EMAC Module Registers

Table 19-37 lists the memory-mapped registers for the EMAC. See your device-specific data manual for the memory address of these registers.

Table 19-37. Ethernet Media Access Controller (EMAC) Registers

Offset	Acronym	Register Description	Section
0h	TXREVID	Transmit Revision ID Register	Section 19.3.3.1
4h	TXCONTROL	Transmit Control Register	Section 19.3.3.2
8h	TXTEARDOWN	Transmit Teardown Register	Section 19.3.3.3
10h	RXREVID	Receive Revision ID Register	Section 19.3.3.4
14h	RXCONTROL	Receive Control Register	Section 19.3.3.5
18h	RXTEARDOWN	Receive Teardown Register	Section 19.3.3.6
80h	TXINTSTATRAW	Transmit Interrupt Status (Unmasked) Register	Section 19.3.3.7
84h	TXINTSTATMASKED	Transmit Interrupt Status (Masked) Register	Section 19.3.3.8
88h	TXINTMASKSET	Transmit Interrupt Mask Set Register	Section 19.3.3.9
8Ch	TXINTMASKCLEAR	Transmit Interrupt Clear Register	Section 19.3.3.10
90h	MACINVECTOR	MAC Input Vector Register	Section 19.3.3.11
94h	MACEOIVECTOR	MAC End Of Interrupt Vector Register	Section 19.3.3.12
A0h	RXINTSTATRAW	Receive Interrupt Status (Unmasked) Register	Section 19.3.3.13
A4h	RXINTSTATMASKED	Receive Interrupt Status (Masked) Register	Section 19.3.3.14
A8h	RXINTMASKSET	Receive Interrupt Mask Set Register	Section 19.3.3.15
ACh	RXINTMASKCLEAR	Receive Interrupt Mask Clear Register	Section 19.3.3.16
B0h	MACINTSTATRAW	MAC Interrupt Status (Unmasked) Register	Section 19.3.3.17
B4h	MACINTSTATMASKED	MAC Interrupt Status (Masked) Register	Section 19.3.3.18
B8h	MACINTMASKSET	MAC Interrupt Mask Set Register	Section 19.3.3.19
BCh	MACINTMASKCLEAR	MAC Interrupt Mask Clear Register	Section 19.3.3.20
100h	RXMBPENABLE	Receive Multicast/Broadcast/Promiscuous Channel Enable Register	Section 19.3.3.21
104h	RXUNICASTSET	Receive Unicast Enable Set Register	Section 19.3.3.22
108h	RXUNICASTCLEAR	Receive Unicast Clear Register	Section 19.3.3.23
10Ch	RXMAXLEN	Receive Maximum Length Register	Section 19.3.3.24
110h	RXBUFFEROFFSET	Receive Buffer Offset Register	Section 19.3.3.25
114h	RXFILTERLOWTHRESH	Receive Filter Low Priority Frame Threshold Register	Section 19.3.3.26
120h	RX0FLOWTHRESH	Receive Channel 0 Flow Control Threshold Register	Section 19.3.3.27
124h	RX1FLOWTHRESH	Receive Channel 1 Flow Control Threshold Register	Section 19.3.3.27
128h	RX2FLOWTHRESH	Receive Channel 2 Flow Control Threshold Register	Section 19.3.3.27
12Ch	RX3FLOWTHRESH	Receive Channel 3 Flow Control Threshold Register	Section 19.3.3.27
130h	RX4FLOWTHRESH	Receive Channel 4 Flow Control Threshold Register	Section 19.3.3.27
134h	RX5FLOWTHRESH	Receive Channel 5 Flow Control Threshold Register	Section 19.3.3.27
138h	RX6FLOWTHRESH	Receive Channel 6 Flow Control Threshold Register	Section 19.3.3.27
13Ch	RX7FLOWTHRESH	Receive Channel 7 Flow Control Threshold Register	Section 19.3.3.27
140h	RX0FREEBUFFER	Receive Channel 0 Free Buffer Count Register	Section 19.3.3.28
144h	RX1FREEBUFFER	Receive Channel 1 Free Buffer Count Register	Section 19.3.3.28
148h	RX2FREEBUFFER	Receive Channel 2 Free Buffer Count Register	Section 19.3.3.28
14Ch	RX3FREEBUFFER	Receive Channel 3 Free Buffer Count Register	Section 19.3.3.28
150h	RX4FREEBUFFER	Receive Channel 4 Free Buffer Count Register	Section 19.3.3.28
154h	RX5FREEBUFFER	Receive Channel 5 Free Buffer Count Register	Section 19.3.3.28
158h	RX6FREEBUFFER	Receive Channel 6 Free Buffer Count Register	Section 19.3.3.28
15Ch	RX7FREEBUFFER	Receive Channel 7 Free Buffer Count Register	Section 19.3.3.28
160h	MACCONTROL	MAC Control Register	Section 19.3.3.29

Table 19-37. Ethernet Media Access Controller (EMAC) Registers (continued)

Offset	Acronym	Register Description	Section
164h	MACSTATUS	MAC Status Register	Section 19.3.3.30
168h	EMCONTROL	Emulation Control Register	Section 19.3.3.31
16Ch	FIFOCONTROL	FIFO Control Register	Section 19.3.3.32
170h	MACCONFIG	MAC Configuration Register	Section 19.3.3.33
174h	SOFTRESET	Soft Reset Register	Section 19.3.3.34
1D0h	MACSRCADDRLO	MAC Source Address Low Bytes Register	Section 19.3.3.35
1D4h	MACSRCADDRHI	MAC Source Address High Bytes Register	Section 19.3.3.36
1D8h	MACHASH1	MAC Hash Address Register 1	Section 19.3.3.37
1DCh	MACHASH2	MAC Hash Address Register 2	Section 19.3.3.38
1E0h	BOFFTEST	Back Off Test Register	Section 19.3.3.39
1E4h	TPACETEST	Transmit Pacing Algorithm Test Register	Section 19.3.3.40
1E8h	RXPAUSE	Receive Pause Timer Register	Section 19.3.3.41
1ECh	TXPAUSE	Transmit Pause Timer Register	Section 19.3.3.42
500h	MACADDRLO	MAC Address Low Bytes Register, Used in Receive Address Matching	Section 19.3.3.43
504h	MACADDRHI	MAC Address High Bytes Register, Used in Receive Address Matching	Section 19.3.3.44
508h	MACINDEX	MAC Index Register	Section 19.3.3.45
600h	TX0HDP	Transmit Channel 0 DMA Head Descriptor Pointer Register	Section 19.3.3.46
604h	TX1HDP	Transmit Channel 1 DMA Head Descriptor Pointer Register	Section 19.3.3.46
608h	TX2HDP	Transmit Channel 2 DMA Head Descriptor Pointer Register	Section 19.3.3.46
60Ch	TX3HDP	Transmit Channel 3 DMA Head Descriptor Pointer Register	Section 19.3.3.46
610h	TX4HDP	Transmit Channel 4 DMA Head Descriptor Pointer Register	Section 19.3.3.46
614h	TX5HDP	Transmit Channel 5 DMA Head Descriptor Pointer Register	Section 19.3.3.46
618h	TX6HDP	Transmit Channel 6 DMA Head Descriptor Pointer Register	Section 19.3.3.46
61Ch	TX7HDP	Transmit Channel 7 DMA Head Descriptor Pointer Register	Section 19.3.3.46
620h	RX0HDP	Receive Channel 0 DMA Head Descriptor Pointer Register	Section 19.3.3.47
624h	RX1HDP	Receive Channel 1 DMA Head Descriptor Pointer Register	Section 19.3.3.47
628h	RX2HDP	Receive Channel 2 DMA Head Descriptor Pointer Register	Section 19.3.3.47
62Ch	RX3HDP	Receive Channel 3 DMA Head Descriptor Pointer Register	Section 19.3.3.47
630h	RX4HDP	Receive Channel 4 DMA Head Descriptor Pointer Register	Section 19.3.3.47
634h	RX5HDP	Receive Channel 5 DMA Head Descriptor Pointer Register	Section 19.3.3.47
638h	RX6HDP	Receive Channel 6 DMA Head Descriptor Pointer Register	Section 19.3.3.47
63Ch	RX7HDP	Receive Channel 7 DMA Head Descriptor Pointer Register	Section 19.3.3.47
640h	TX0CP	Transmit Channel 0 Completion Pointer Register	Section 19.3.3.48
644h	TX1CP	Transmit Channel 1 Completion Pointer Register	Section 19.3.3.48
648h	TX2CP	Transmit Channel 2 Completion Pointer Register	Section 19.3.3.48
64Ch	TX3CP	Transmit Channel 3 Completion Pointer Register	Section 19.3.3.48
650h	TX4CP	Transmit Channel 4 Completion Pointer Register	Section 19.3.3.48
654h	TX5CP	Transmit Channel 5 Completion Pointer Register	Section 19.3.3.48
658h	TX6CP	Transmit Channel 6 Completion Pointer Register	Section 19.3.3.48
65Ch	TX7CP	Transmit Channel 7 Completion Pointer Register	Section 19.3.3.48
660h	RX0CP	Receive Channel 0 Completion Pointer Register	Section 19.3.3.49
664h	RX1CP	Receive Channel 1 Completion Pointer Register	Section 19.3.3.49
668h	RX2CP	Receive Channel 2 Completion Pointer Register	Section 19.3.3.49
66Ch	RX3CP	Receive Channel 3 Completion Pointer Register	Section 19.3.3.49
670h	RX4CP	Receive Channel 4 Completion Pointer Register	Section 19.3.3.49
674h	RX5CP	Receive Channel 5 Completion Pointer Register	Section 19.3.3.49

Table 19-37. Ethernet Media Access Controller (EMAC) Registers (continued)

Offset	Acronym	Register Description	Section
678h	RX6CP	Receive Channel 6 Completion Pointer Register	Section 19.3.3.49
67Ch	RX7CP	Receive Channel 7 Completion Pointer Register	Section 19.3.3.49
		Network Statistics Registers	
200h	RXGOODFRAMES	Good Receive Frames Register	Section 19.3.3.50.1
204h	RXBCASTFRAMES	Broadcast Receive Frames Register	Section 19.3.3.50.2
208h	RXMCASTFRAMES	Multicast Receive Frames Register	Section 19.3.3.50.3
20Ch	RXPAUSEFRAMES	Pause Receive Frames Register	Section 19.3.3.50.4
210h	RXCRCERRORS	Receive CRC Errors Register	Section 19.3.3.50.5
214h	RXALIGNCODEERRORS	Receive Alignment/Code Errors Register	Section 19.3.3.50.6
218h	RXOVERSIZED	Receive Oversized Frames Register	Section 19.3.3.50.7
21Ch	RXJABBER	Receive Jabber Frames Register	Section 19.3.3.50.8
220h	RXUNDERSIZED	Receive Undersized Frames Register	Section 19.3.3.50.9
224h	RXFRAGMENTS	Receive Frame Fragments Register	Section 19.3.3.50.10
228h	RXFILTERED	Filtered Receive Frames Register	Section 19.3.3.50.11
22Ch	RXQOSFILTERED	Receive QOS Filtered Frames Register	Section 19.3.3.50.12
230h	RXOCTETS	Receive Octet Frames Register	Section 19.3.3.50.13
234h	TXGOODFRAMES	Good Transmit Frames Register	Section 19.3.3.50.14
238h	TXBCASTFRAMES	Broadcast Transmit Frames Register	Section 19.3.3.50.15
23Ch	TXMCASTFRAMES	Multicast Transmit Frames Register	Section 19.3.3.50.16
240h	TXPAUSEFRAMES	Pause Transmit Frames Register	Section 19.3.3.50.17
244h	TXDEFERRED	Deferred Transmit Frames Register	Section 19.3.3.50.18
248h	TXCOLLISION	Transmit Collision Frames Register	Section 19.3.3.50.19
24Ch	TXSINGLECOLL	Transmit Single Collision Frames Register	Section 19.3.3.50.20
250h	TXMULTICOLL	Transmit Multiple Collision Frames Register	Section 19.3.3.50.21
254h	TXEXCESSIVECOLL	Transmit Excessive Collision Frames Register	Section 19.3.3.50.22
258h	TXLATECOLL	Transmit Late Collision Frames Register	Section 19.3.3.50.23
25Ch	TXUNDERRUN	Transmit Underrun Error Register	Section 19.3.3.50.24
260h	TXCARRIERSENSE	Transmit Carrier Sense Errors Register	Section 19.3.3.50.25
264h	TXOCTETS	Transmit Octet Frames Register	Section 19.3.3.50.26
268h	FRAME64	Transmit and Receive 64 Octet Frames Register	Section 19.3.3.50.27
26Ch	FRAME65T127	Transmit and Receive 65 to 127 Octet Frames Register	Section 19.3.3.50.28
270h	FRAME128T255	Transmit and Receive 128 to 255 Octet Frames Register	Section 19.3.3.50.29
274h	FRAME256T511	Transmit and Receive 256 to 511 Octet Frames Register	Section 19.3.3.50.30
278h	FRAME512T1023	Transmit and Receive 512 to 1023 Octet Frames Register	Section 19.3.3.50.31
27Ch	FRAME1024TUP	Transmit and Receive 1024 to RXMAXLEN Octet Frames Register	Section 19.3.3.50.32
280h	NETOCTETS	Network Octet Frames Register	Section 19.3.3.50.33
284h	RXSOFOVERRUNS	Receive FIFO or DMA Start of Frame Overruns Register	Section 19.3.3.50.34
288h	RXMOFOVERRUNS	Receive FIFO or DMA Middle of Frame Overruns Register	Section 19.3.3.50.35
28Ch	RXDMAOVERRUNS	Receive DMA Overruns Register	Section 19.3.3.50.36

19.3.3.1 Transmit Revision ID Register (TXREVID)

The transmit revision ID register (TXREVID) is shown in Figure 19-39 and described in Table 19-38.

Figure 19-39. Transmit Revision ID Register (TXREVID)

31	0
TXREV	
R-4EC0 020Dh	

LEGEND: R = Read only; -*n* = value after reset

Table 19-38. Transmit Revision ID Register (TXREVID) Field Descriptions

Bit	Field	Value	Description
31-0	TXREV		Transmit module revision
		4EC0 020Dh	Current transmit revision value

19.3.3.2 Transmit Control Register (TXCONTROL)

The transmit control register (TXCONTROL) is shown in Figure 19-40 and described in Table 19-39.

Figure 19-40. Transmit Control Register (TXCONTROL)

31	16
Reserved	
R-0	

15	1	0
Reserved		TXEN
R-0		R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 19-39. Transmit Control Register (TXCONTROL) Field Descriptions

Bit	Field	Value	Description
31-1	Reserved	0	Reserved
0	TXEN		Transmit enable
		0	Transmit is disabled.
		1	Transmit is enabled.

19.3.3.3 Transmit Teardown Register (TXTEARDOWN)

The transmit teardown register (TXTEARDOWN) is shown in Figure 19-41 and described in Table 19-40.

Figure 19-41. Transmit Teardown Register (TXTEARDOWN)

31	16
Reserved	
R-0	

15	3	2	0
Reserved		TXTDNCH	
R-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 19-40. Transmit Teardown Register (TXTEARDOWN) Field Descriptions

Bit	Field	Value	Description
31-3	Reserved	0	Reserved
2-0	TXTDNCH	0-7h	Transmit teardown channel. The transmit channel teardown is commanded by writing the encoded value of the transmit channel to be torn down. The teardown register is read as 0.
		0	Teardown transmit channel 0
		1h	Teardown transmit channel 1
		2h	Teardown transmit channel 2
		3h	Teardown transmit channel 3
		4h	Teardown transmit channel 4
		5h	Teardown transmit channel 5
		6h	Teardown transmit channel 6
		7h	Teardown transmit channel 7

19.3.3.4 Receive Revision ID Register (RXREVID)

The receive revision ID register (RXREVID) is shown in Figure 19-42 and described in Table 19-41.

Figure 19-42. Receive Revision ID Register (RXREVID)

31	0
RXREV	
R-4EC0 020Dh	

LEGEND: R = Read only; -*n* = value after reset

Table 19-41. Receive Revision ID Register (RXREVID) Field Descriptions

Bit	Field	Value	Description
31-0	RXREV		Receive module revision
		4EC0 020Dh	Current receive revision value

19.3.3.5 Receive Control Register (RXCONTROL)

The receive control register (RXCONTROL) is shown in Figure 19-43 and described in Table 19-42.

Figure 19-43. Receive Control Register (RXCONTROL)

31	16
Reserved	
R-0	

15	1	0
Reserved		RXEN
R-0		R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 19-42. Receive Control Register (RXCONTROL) Field Descriptions

Bit	Field	Value	Description
31-1	Reserved	0	Reserved
0	RXEN		Receive enable
		0	Receive is disabled.
		1	Receive is enabled.

19.3.3.6 Receive Teardown Register (RXTEARDOWN)

The receive teardown register (RXTEARDOWN) is shown in Figure 19-44 and described in Table 19-43.

Figure 19-44. Receive Teardown Register (RXTEARDOWN)

31	16
Reserved	
R-0	

15	3	2	0
Reserved		RXTDNCH	
R-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 19-43. Receive Teardown Register (RXTEARDOWN) Field Descriptions

Bit	Field	Value	Description
31-3	Reserved	0	Reserved
2-0	RXTDNCH	0-7h	Receive teardown channel. The receive channel teardown is commanded by writing the encoded value of the receive channel to be torn down. The teardown register is read as 0.
		0	Teardown receive channel 0
		1h	Teardown receive channel 1
		2h	Teardown receive channel 2
		3h	Teardown receive channel 3
		4h	Teardown receive channel 4
		5h	Teardown receive channel 5
		6h	Teardown receive channel 6
		7h	Teardown receive channel 7

19.3.3.7 Transmit Interrupt Status (Unmasked) Register (TXINTSTATRAW)

The transmit interrupt status (unmasked) register (TXINTSTATRAW) is shown in Figure 19-45 and described in Table 19-44.

Figure 19-45. Transmit Interrupt Status (Unmasked) Register (TXINTSTATRAW)

31	30	29	28	27	26	25	24
Reserved							
R-0							

23	22	21	20	19	18	17	16
Reserved							
R-0							

15	14	13	12	11	10	9	8
Reserved							
R-0							

7	6	5	4	3	2	1	0
TX7PEND	TX6PEND	TX5PEND	TX4PEND	TX3PEND	TX2PEND	TX1PEND	TX0PEND
R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0

LEGEND: R = Read only; -*n* = value after reset

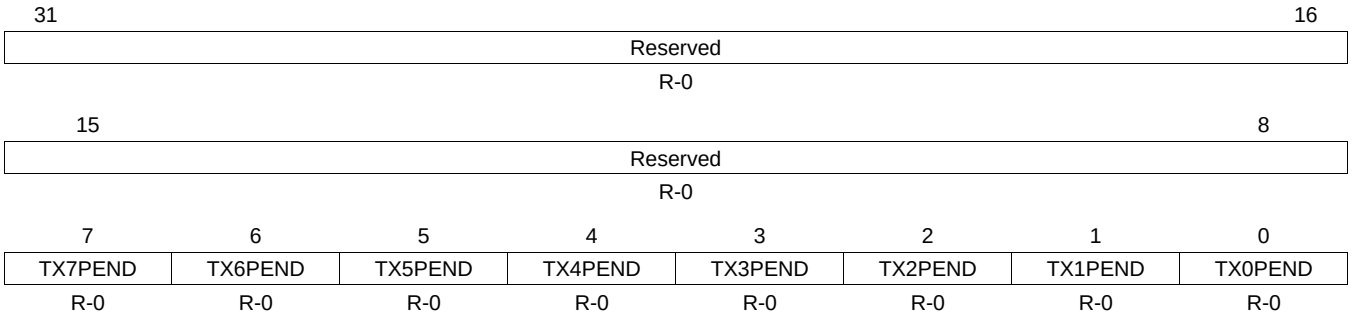
Table 19-44. Transmit Interrupt Status (Unmasked) Register (TXINTSTATRAW) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved
7	TX7PEND	0-1	TX7PEND raw interrupt read (before mask)
6	TX6PEND	0-1	TX6PEND raw interrupt read (before mask)
5	TX5PEND	0-1	TX5PEND raw interrupt read (before mask)
4	TX4PEND	0-1	TX4PEND raw interrupt read (before mask)
3	TX3PEND	0-1	TX3PEND raw interrupt read (before mask)
2	TX2PEND	0-1	TX2PEND raw interrupt read (before mask)
1	TX1PEND	0-1	TX1PEND raw interrupt read (before mask)
0	TX0PEND	0-1	TX0PEND raw interrupt read (before mask)

19.3.3.8 Transmit Interrupt Status (Masked) Register (TXINTSTATMASKED)

The transmit interrupt status (masked) register (TXINTSTATMASKED) is shown in Figure 19-46 and described in Table 19-45.

Figure 19-46. Transmit Interrupt Status (Masked) Register (TXINTSTATMASKED)



LEGEND: R = Read only; -*n* = value after reset

Table 19-45. Transmit Interrupt Status (Masked) Register (TXINTSTATMASKED) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved
7	TX7PEND	0-1	TX7PEND masked interrupt read
6	TX6PEND	0-1	TX6PEND masked interrupt read
5	TX5PEND	0-1	TX5PEND masked interrupt read
4	TX4PEND	0-1	TX4PEND masked interrupt read
3	TX3PEND	0-1	TX3PEND masked interrupt read
2	TX2PEND	0-1	TX2PEND masked interrupt read
1	TX1PEND	0-1	TX1PEND masked interrupt read
0	TX0PEND	0-1	TX0PEND masked interrupt read

19.3.3.9 Transmit Interrupt Mask Set Register (TXINTMASKSET)

The transmit interrupt mask set register (TXINTMASKSET) is shown in Figure 19-47 and described in Table 19-46.

Figure 19-47. Transmit Interrupt Mask Set Register (TXINTMASKSET)

31	30	29	28	27	26	25	16
Reserved							
R-0							

15	14	13	12	11	10	9	8
Reserved							
R-0							

7	6	5	4	3	2	1	0
TX7MASK	TX6MASK	TX5MASK	TX4MASK	TX3MASK	TX2MASK	TX1MASK	TX0MASK
R/W1S-0	R/W1S-0	R/W1S-0	R/W1S-0	R/W1S-0	R/W1S-0	R/W1S-0	R/W1S-0

LEGEND: R/W = Read/Write; R = Read only; W1S = Write 1 to set (writing a 0 has no effect); -*n* = value after reset

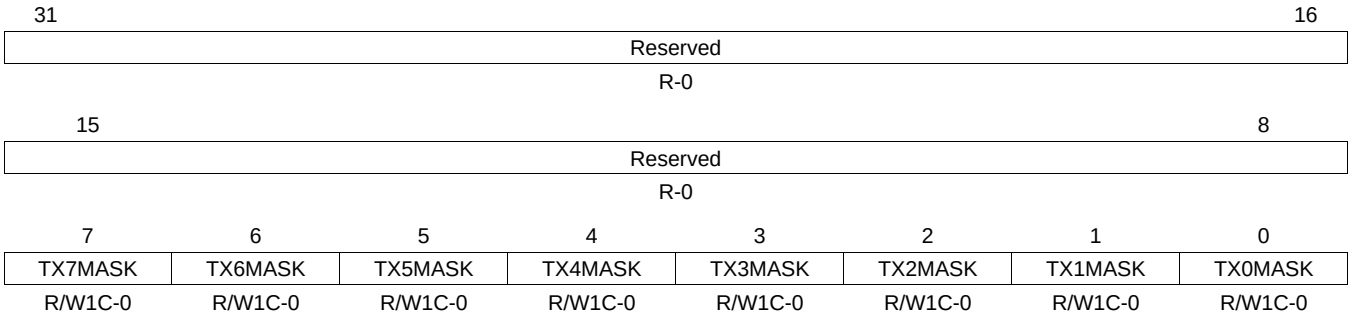
Table 19-46. Transmit Interrupt Mask Set Register (TXINTMASKSET) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved
7	TX7MASK	0-1	Transmit channel 7 interrupt mask set bit. Write 1 to enable interrupt, a write of 0 has no effect.
6	TX6MASK	0-1	Transmit channel 6 interrupt mask set bit. Write 1 to enable interrupt, a write of 0 has no effect.
5	TX5MASK	0-1	Transmit channel 5 interrupt mask set bit. Write 1 to enable interrupt, a write of 0 has no effect.
4	TX4MASK	0-1	Transmit channel 4 interrupt mask set bit. Write 1 to enable interrupt, a write of 0 has no effect.
3	TX3MASK	0-1	Transmit channel 3 interrupt mask set bit. Write 1 to enable interrupt, a write of 0 has no effect.
2	TX2MASK	0-1	Transmit channel 2 interrupt mask set bit. Write 1 to enable interrupt, a write of 0 has no effect.
1	TX1MASK	0-1	Transmit channel 1 interrupt mask set bit. Write 1 to enable interrupt, a write of 0 has no effect.
0	TX0MASK	0-1	Transmit channel 0 interrupt mask set bit. Write 1 to enable interrupt, a write of 0 has no effect.

19.3.3.10 Transmit Interrupt Mask Clear Register (TXINTMASKCLEAR)

The transmit interrupt mask clear register (TXINTMASKCLEAR) is shown in Figure 19-48 and described in Table 19-47.

Figure 19-48. Transmit Interrupt Mask Clear Register (TXINTMASKCLEAR)



LEGEND: R/W = Read/Write; R = Read only; W1C = Write 1 to clear (writing a 0 has no effect); *-n* = value after reset

Table 19-47. Transmit Interrupt Mask Clear Register (TXINTMASKCLEAR) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved
7	TX7MASK	0-1	Transmit channel 7 interrupt mask clear bit. Write 1 to disable interrupt, a write of 0 has no effect.
6	TX6MASK	0-1	Transmit channel 6 interrupt mask clear bit. Write 1 to disable interrupt, a write of 0 has no effect.
5	TX5MASK	0-1	Transmit channel 5 interrupt mask clear bit. Write 1 to disable interrupt, a write of 0 has no effect.
4	TX4MASK	0-1	Transmit channel 4 interrupt mask clear bit. Write 1 to disable interrupt, a write of 0 has no effect.
3	TX3MASK	0-1	Transmit channel 3 interrupt mask clear bit. Write 1 to disable interrupt, a write of 0 has no effect.
2	TX2MASK	0-1	Transmit channel 2 interrupt mask clear bit. Write 1 to disable interrupt, a write of 0 has no effect.
1	TX1MASK	0-1	Transmit channel 1 interrupt mask clear bit. Write 1 to disable interrupt, a write of 0 has no effect.
0	TX0MASK	0-1	Transmit channel 0 interrupt mask clear bit. Write 1 to disable interrupt, a write of 0 has no effect.

19.3.3.11 MAC Input Vector Register (MACINVECTOR)

The MAC input vector register (MACINVECTOR) is shown in Figure 19-49 and described in Table 19-48.

Figure 19-49. MAC Input Vector Register (MACINVECTOR)

31 28	27	26	25	24	23 16
Reserved	STATPEND	HOSTPEND	LINKINT0	USERINT0	TXPEND
R-0	R-0	R-0	R-0	R-0	R-0

15 8	7 0
RXTHRESHPEND	RXPEND
R-0	R-0

LEGEND: R = Read only; -*n* = value after reset

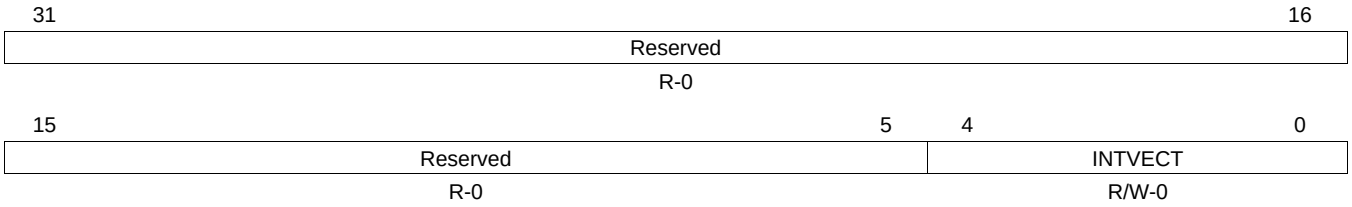
Table 19-48. MAC Input Vector Register (MACINVECTOR) Field Descriptions

Bit	Field	Value	Description
31-28	Reserved	0	Reserved
27	STATPEND	0-1	EMAC module statistics interrupt (STATPEND) pending status bit
26	HOSTPEND	0-1	EMAC module host error interrupt (HOSTPEND) pending status bit
25	LINKINT0	0-1	MDIO module USERPHYSEL0 (LINKINT0) status bit
24	USERINT0	0-1	MDIO module USERACCESS0 (USERINT0) status bit
23-16	TXPEND	0-FFh	Transmit channels 0-7 interrupt (TX*n*PEND) pending status. Bit 16 is TX0PEND.
15-8	RXTHRESHPEND	0-FFh	Receive channels 0-7 interrupt (RX*n*THRESHPEND) pending status. Bit 8 is RX0THRESHPEND.
7-0	RXPEND	0-FFh	Receive channels 0-7 interrupt (RX*n*PEND) pending status bit. Bit 0 is RX0PEND.

19.3.3.12 MAC End Of Interrupt Vector Register (MACEOIVECTOR)

The MAC end of interrupt vector register (MACEOIVECTOR) is shown in Figure 19-50 and described in Table 19-49.

Figure 19-50. MAC End Of Interrupt Vector Register (MACEOIVECTOR)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 19-49. MAC End Of Interrupt Vector Register (MACEOIVECTOR) Field Descriptions

Bit	Field	Value	Description
31-5	Reserved	0	Reserved
4-0	INTVECT	0-1Fh	Acknowledge EMAC Control Module Interrupts
		0h	Acknowledge C0RXTHRESH Interrupt
		1h	Acknowledge C0RX Interrupt
		2h	Acknowledge C0TX Interrupt
		3h	Acknowledge C0MISC Interrupt (STATPEND, HOSTPEND, MDIO LINKINT0, MDIO USERINT0)
		4h	Acknowledge C1RXTHRESH Interrupt
		5h	Acknowledge C1RX Interrupt
		6h	Acknowledge C1TX Interrupt
		7h	Acknowledge C1MISC Interrupt (STATPEND, HOSTPEND, MDIO LINKINT0, MDIO USERINT0)
		8h	Acknowledge C2RXTHRESH Interrupt
		9h	Acknowledge C2RX Interrupt
		Ah	Acknowledge C2TX Interrupt
		Bh	Acknowledge C2MISC Interrupt (STATPEND, HOSTPEND, MDIO LINKINT0, MDIO USERINT0)
		Ch-1Fh	Reserved

19.3.3.13 Receive Interrupt Status (Unmasked) Register (RXINTSTATRAW)

The receive interrupt status (unmasked) register (RXINTSTATRAW) is shown in Figure 19-51 and described in Table 19-50.

Figure 19-51. Receive Interrupt Status (Unmasked) Register (RXINTSTATRAW)

31							16
Reserved							
R-0							
15	14	13	12	11	10	9	8
RX7THRESHPEND	RX6THRESHPEND	RX5THRESHPEND	RX4THRESHPEND	RX3THRESHPEND	RX2THRESHPEND	RX1THRESHPEND	RX0THRESHPEND
R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0
7	6	5	4	3	2	1	0
RX7PEND	RX6PEND	RX5PEND	RX4PEND	RX3PEND	RX2PEND	RX1PEND	RX0PEND
R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0

LEGEND: R = Read only; -*n* = value after reset

Table 19-50. Receive Interrupt Status (Unmasked) Register (RXINTSTATRAW) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	Reserved
15	RX7THRESHPEND	0-1	RX7THRESHPEND raw interrupt read (before mask)
14	RX6THRESHPEND	0-1	RX6THRESHPEND raw interrupt read (before mask)
13	RX5THRESHPEND	0-1	RX5THRESHPEND raw interrupt read (before mask)
12	RX4THRESHPEND	0-1	RX4THRESHPEND raw interrupt read (before mask)
11	RX3THRESHPEND	0-1	RX3THRESHPEND raw interrupt read (before mask)
10	RX2THRESHPEND	0-1	RX2THRESHPEND raw interrupt read (before mask)
9	RX1THRESHPEND	0-1	RX1THRESHPEND raw interrupt read (before mask)
8	RX0THRESHPEND	0-1	RX0THRESHPEND raw interrupt read (before mask)
7	RX7PEND	0-1	RX7PEND raw interrupt read (before mask)
6	RX6PEND	0-1	RX6PEND raw interrupt read (before mask)
5	RX5PEND	0-1	RX5PEND raw interrupt read (before mask)
4	RX4PEND	0-1	RX4PEND raw interrupt read (before mask)
3	RX3PEND	0-1	RX3PEND raw interrupt read (before mask)
2	RX2PEND	0-1	RX2PEND raw interrupt read (before mask)
1	RX1PEND	0-1	RX1PEND raw interrupt read (before mask)
0	RX0PEND	0-1	RX0PEND raw interrupt read (before mask)

19.3.3.14 Receive Interrupt Status (Masked) Register (RXINTSTATMASKED)

The receive interrupt status (masked) register (RXINTSTATMASKED) is shown in Figure 19-52 and described in Table 19-51.

Figure 19-52. Receive Interrupt Status (Masked) Register (RXINTSTATMASKED)

31							16
Reserved							
R-0							
15	14	13	12	11	10	9	8
RX7THRESHPEND	RX6THRESHPEND	RX5THRESHPEND	RX4THRESHPEND	RX3THRESHPEND	RX2THRESHPEND	RX1THRESHPEND	RX0THRESHPEND
R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0
7	6	5	4	3	2	1	0
RX7PEND	RX6PEND	RX5PEND	RX4PEND	RX3PEND	RX2PEND	RX1PEND	RX0PEND
R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0

LEGEND: R = Read only; -*n* = value after reset

Table 19-51. Receive Interrupt Status (Masked) Register (RXINTSTATMASKED) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	Reserved
15	RX7THRESHPEND	0-1	RX7THRESHPEND masked interrupt read
14	RX6THRESHPEND	0-1	RX6THRESHPEND masked interrupt read
13	RX5THRESHPEND	0-1	RX5THRESHPEND masked interrupt read
12	RX4THRESHPEND	0-1	RX4THRESHPEND masked interrupt read
11	RX3THRESHPEND	0-1	RX3THRESHPEND masked interrupt read
10	RX2THRESHPEND	0-1	RX2THRESHPEND masked interrupt read
9	RX1THRESHPEND	0-1	RX1THRESHPEND masked interrupt read
8	RX0THRESHPEND	0-1	RX0THRESHPEND masked interrupt read
7	RX7PEND	0-1	RX7PEND masked interrupt read
6	RX6PEND	0-1	RX6PEND masked interrupt read
5	RX5PEND	0-1	RX5PEND masked interrupt read
4	RX4PEND	0-1	RX4PEND masked interrupt read
3	RX3PEND	0-1	RX3PEND masked interrupt read
2	RX2PEND	0-1	RX2PEND masked interrupt read
1	RX1PEND	0-1	RX1PEND masked interrupt read
0	RX0PEND	0-1	RX0PEND masked interrupt read

19.3.3.15 Receive Interrupt Mask Set Register (RXINTMASKSET)

The receive interrupt mask set register (RXINTMASKSET) is shown in Figure 19-53 and described in Table 19-52.

Figure 19-53. Receive Interrupt Mask Set Register (RXINTMASKSET)

31							16
Reserved							
R-0							
15	14	13	12	11	10	9	8
RX7THRESHMASK	RX6THRESHMASK	RX5THRESHMASK	RX4THRESHMASK	RX3THRESHMASK	RX2THRESHMASK	RX1THRESHMASK	RX0THRESHMASK
R/W1S-0	R/W1S-0	R/W1S-0	R/W1S-0	R/W1S-0	R/W1S-0	R/W1S-0	R/W1S-0
7	6	5	4	3	2	1	0
RX7MASK	RX6MASK	RX5MASK	RX4MASK	RX3MASK	RX2MASK	RX1MASK	RX0MASK
R/W1S-0	R/W1S-0	R/W1S-0	R/W1S-0	R/W1S-0	R/W1S-0	R/W1S-0	R/W1S-0

LEGEND: R/W = Read/Write; R = Read only; W1S = Write 1 to set (writing a 0 has no effect); -*n* = value after reset

Table 19-52. Receive Interrupt Mask Set Register (RXINTMASKSET) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	Reserved
15	RX7THRESHMASK	0-1	Receive channel 7 threshold mask set bit. Write 1 to enable interrupt; a write of 0 has no effect.
14	RX6THRESHMASK	0-1	Receive channel 6 threshold mask set bit. Write 1 to enable interrupt; a write of 0 has no effect.
13	RX5THRESHMASK	0-1	Receive channel 5 threshold mask set bit. Write 1 to enable interrupt; a write of 0 has no effect.
12	RX4THRESHMASK	0-1	Receive channel 4 threshold mask set bit. Write 1 to enable interrupt; a write of 0 has no effect.
11	RX3THRESHMASK	0-1	Receive channel 3 threshold mask set bit. Write 1 to enable interrupt; a write of 0 has no effect.
10	RX2THRESHMASK	0-1	Receive channel 2 threshold mask set bit. Write 1 to enable interrupt; a write of 0 has no effect.
9	RX1THRESHMASK	0-1	Receive channel 1 threshold mask set bit. Write 1 to enable interrupt; a write of 0 has no effect.
8	RX0THRESHMASK	0-1	Receive channel 0 threshold mask set bit. Write 1 to enable interrupt; a write of 0 has no effect.
7	RX7MASK	0-1	Receive channel 7 mask set bit. Write 1 to enable interrupt; a write of 0 has no effect.
6	RX6MASK	0-1	Receive channel 6 mask set bit. Write 1 to enable interrupt; a write of 0 has no effect.
5	RX5MASK	0-1	Receive channel 5 mask set bit. Write 1 to enable interrupt; a write of 0 has no effect.
4	RX4MASK	0-1	Receive channel 4 mask set bit. Write 1 to enable interrupt; a write of 0 has no effect.
3	RX3MASK	0-1	Receive channel 3 mask set bit. Write 1 to enable interrupt; a write of 0 has no effect.
2	RX2MASK	0-1	Receive channel 2 mask set bit. Write 1 to enable interrupt; a write of 0 has no effect.
1	RX1MASK	0-1	Receive channel 1 mask set bit. Write 1 to enable interrupt; a write of 0 has no effect.
0	RX0MASK	0-1	Receive channel 0 mask set bit. Write 1 to enable interrupt; a write of 0 has no effect.

19.3.3.16 Receive Interrupt Mask Clear Register (RXINTMASKCLEAR)

The receive interrupt mask clear register (RXINTMASKCLEAR) is shown in Figure 19-54 and described in Table 19-53.

Figure 19-54. Receive Interrupt Mask Clear Register (RXINTMASKCLEAR)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
R-0															

15	14	13	12	11	10	9	8
RX7THRESHMASK	RX6THRESHMASK	RX5THRESHMASK	RX4THRESHMASK	RX3THRESHMASK	RX2THRESHMASK	RX1THRESHMASK	RX0THRESHMASK
R/W1C-0	R/W1C-0	R/W1C-0	R/W1C-0	R/W1C-0	R/W1C-0	R/W1C-0	R/W1C-0

7	6	5	4	3	2	1	0
RX7MASK	RX6MASK	RX5MASK	RX4MASK	RX3MASK	RX2MASK	RX1MASK	RX0MASK
R/W1C-0	R/W1C-0	R/W1C-0	R/W1C-0	R/W1C-0	R/W1C-0	R/W1C-0	R/W1C-0

LEGEND: R/W = Read/Write; R = Read only; W1C = Write 1 to clear (writing a 0 has no effect); -*n* = value after reset

Table 19-53. Receive Interrupt Mask Clear Register (RXINTMASKCLEAR) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	Reserved
15	RX7THRESHMASK	0-1	Receive channel 7 threshold mask clear bit. Write 1 to disable interrupt; a write of 0 has no effect.
14	RX6THRESHMASK	0-1	Receive channel 6 threshold mask clear bit. Write 1 to disable interrupt; a write of 0 has no effect.
13	RX5THRESHMASK	0-1	Receive channel 5 threshold mask clear bit. Write 1 to disable interrupt; a write of 0 has no effect.
12	RX4THRESHMASK	0-1	Receive channel 4 threshold mask clear bit. Write 1 to disable interrupt; a write of 0 has no effect.
11	RX3THRESHMASK	0-1	Receive channel 3 threshold mask clear bit. Write 1 to disable interrupt; a write of 0 has no effect.
10	RX2THRESHMASK	0-1	Receive channel 2 threshold mask clear bit. Write 1 to disable interrupt; a write of 0 has no effect.
9	RX1THRESHMASK	0-1	Receive channel 1 threshold mask clear bit. Write 1 to disable interrupt; a write of 0 has no effect.
8	RX0THRESHMASK	0-1	Receive channel 0 threshold mask clear bit. Write 1 to disable interrupt; a write of 0 has no effect.
7	RX7MASK	0-1	Receive channel 7 mask clear bit. Write 1 to disable interrupt; a write of 0 has no effect.
6	RX6MASK	0-1	Receive channel 6 mask clear bit. Write 1 to disable interrupt; a write of 0 has no effect.
5	RX5MASK	0-1	Receive channel 5 mask clear bit. Write 1 to disable interrupt; a write of 0 has no effect.
4	RX4MASK	0-1	Receive channel 4 mask clear bit. Write 1 to disable interrupt; a write of 0 has no effect.
3	RX3MASK	0-1	Receive channel 3 mask clear bit. Write 1 to disable interrupt; a write of 0 has no effect.
2	RX2MASK	0-1	Receive channel 2 mask clear bit. Write 1 to disable interrupt; a write of 0 has no effect.
1	RX1MASK	0-1	Receive channel 1 mask clear bit. Write 1 to disable interrupt; a write of 0 has no effect.
0	RX0MASK	0-1	Receive channel 0 mask clear bit. Write 1 to disable interrupt; a write of 0 has no effect.

19.3.3.17 MAC Interrupt Status (Unmasked) Register (MACINTSTATRAW)

The MAC interrupt status (unmasked) register (MACINTSTATRAW) is shown in Figure 19-55 and described in Table 19-54.

Figure 19-55. MAC Interrupt Status (Unmasked) Register (MACINTSTATRAW)

31	16
Reserved	
R-0	

15	2	1	0
Reserved		HOSTPEND	STATPEND
R-0		R-0	R-0

LEGEND: R = Read only; -*n* = value after reset

Table 19-54. MAC Interrupt Status (Unmasked) Register (MACINTSTATRAW) Field Descriptions

Bit	Field	Value	Description
31-2	Reserved	0	Reserved
1	HOSTPEND	0-1	Host pending interrupt (HOSTPEND); raw interrupt read (before mask).
0	STATPEND	0-1	Statistics pending interrupt (STATPEND); raw interrupt read (before mask).

19.3.3.18 MAC Interrupt Status (Masked) Register (MACINTSTATMASKED)

The MAC interrupt status (masked) register (MACINTSTATMASKED) is shown in Figure 19-56 and described in Table 19-55.

Figure 19-56. MAC Interrupt Status (Masked) Register (MACINTSTATMASKED)

31	16
Reserved	
R-0	

15	2	1	0
Reserved		HOSTPEND	STATPEND
R-0		R-0	R-0

LEGEND: R = Read only; -*n* = value after reset

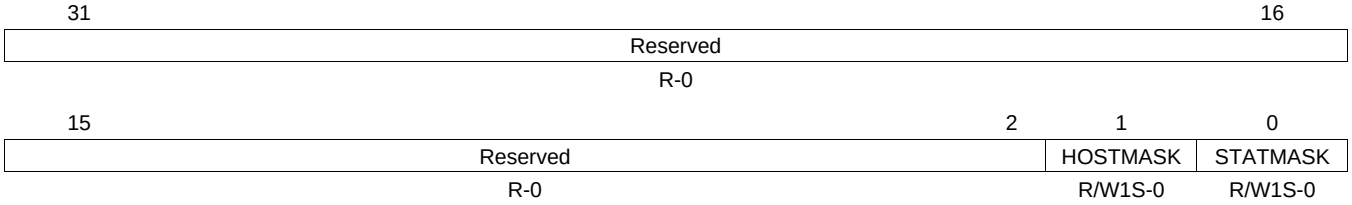
Table 19-55. MAC Interrupt Status (Masked) Register (MACINTSTATMASKED) Field Descriptions

Bit	Field	Value	Description
31-2	Reserved	0	Reserved
1	HOSTPEND	0-1	Host pending interrupt (HOSTPEND); masked interrupt read.
0	STATPEND	0-1	Statistics pending interrupt (STATPEND); masked interrupt read.

19.3.3.19 MAC Interrupt Mask Set Register (MACINTMASKSET)

The MAC interrupt mask set register (MACINTMASKSET) is shown in Figure 19-57 and described in Table 19-56.

Figure 19-57. MAC Interrupt Mask Set Register (MACINTMASKSET)



LEGEND: R/W = Read/Write; R = Read only; W1S = Write 1 to set (writing a 0 has no effect); -*n* = value after reset

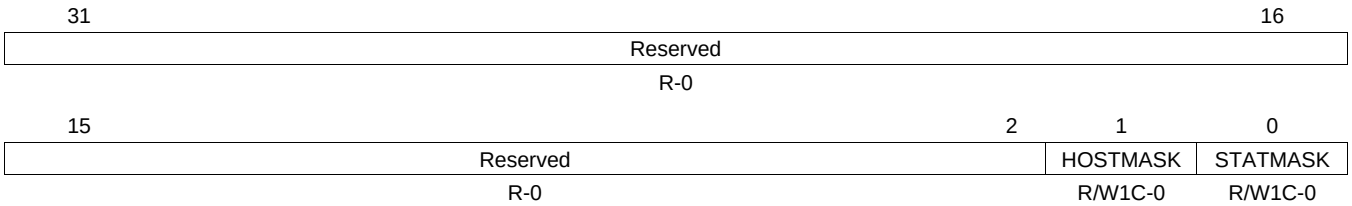
Table 19-56. MAC Interrupt Mask Set Register (MACINTMASKSET) Field Descriptions

Bit	Field	Value	Description
31-2	Reserved	0	Reserved
1	HOSTMASK	0-1	Host error interrupt mask set bit. Write 1 to enable interrupt, a write of 0 has no effect.
0	STATMASK	0-1	Statistics interrupt mask set bit. Write 1 to enable interrupt, a write of 0 has no effect.

19.3.3.20 MAC Interrupt Mask Clear Register (MACINTMASKCLEAR)

The MAC interrupt mask clear register (MACINTMASKCLEAR) is shown in Figure 19-58 and described in Table 19-57.

Figure 19-58. MAC Interrupt Mask Clear Register (MACINTMASKCLEAR)



LEGEND: R/W = Read/Write; R = Read only; W1C = Write 1 to clear (writing a 0 has no effect); -*n* = value after reset

Table 19-57. MAC Interrupt Mask Clear Register (MACINTMASKCLEAR) Field Descriptions

Bit	Field	Value	Description
31-2	Reserved	0	Reserved
1	HOSTMASK	0-1	Host error interrupt mask clear bit. Write 1 to disable interrupt, a write of 0 has no effect.
0	STATMASK	0-1	Statistics interrupt mask clear bit. Write 1 to disable interrupt, a write of 0 has no effect.

19.3.3.21 Receive Multicast/Broadcast/Promiscuous Channel Enable Register (RXMBPENABLE)

The receive multicast/broadcast/promiscuous channel enable register (RXMBPENABLE) is shown in Figure 19-59 and described in Table 19-58.

Figure 19-59. Receive Multicast/Broadcast/Promiscuous Channel Enable Register (RXMBPENABLE)

31	30	29	28	27	25	24
Reserved	RXPASSCRC	RXQOSEN	RXNOCHAIN	Reserved		RXCMFEN
R-0	R/W-0	R/W-0	R/W-0	R-0		R/W-0

23	22	21	20	19	18	16
RXCSFEN	RXCEFEN	RXCAFEN	Reserved		RXPROMCH	
R/W-0	R/W-0	R/W-0	R-0		R/W-0	

15	14	13	12	11	10	8
Reserved		RXBROADEN	Reserved		RXBROADCH	
R-0		R/W-0	R-0		R/W-0	

7	6	5	4	3	2	0
Reserved		RXMULTEN	Reserved		RXMULTCH	
R-0		R/W-0	R-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 19-58. Receive Multicast/Broadcast/Promiscuous Channel Enable Register (RXMBPENABLE) Field Descriptions

Bit	Field	Value	Description
31	Reserved	0	Reserved
30	RXPASSCRC		Pass receive CRC enable bit
		0	Received CRC is discarded for all channels and is not included in the buffer descriptor packet length field.
		1	Received CRC is transferred to memory for all channels and is included in the buffer descriptor packet length.
29	RXQOSEN		Receive quality of service enable bit
		0	Receive QOS is disabled.
		1	Receive QOS is enabled.
28	RXNOCHAIN		Receive no buffer chaining bit
		0	Received frames can span multiple buffers.
		1	The Receive DMA controller transfers each frame into a single buffer, regardless of the frame or buffer size. All remaining frame data after the first buffer is discarded. The buffer descriptor buffer length field will contain the entire frame byte count (up to 65535 bytes).
27-25	Reserved	0	Reserved
24	RXCMFEN		Receive copy MAC control frames enable bit. Enables MAC control frames to be transferred to memory. MAC control frames are normally acted upon (if enabled), but not copied to memory. MAC control frames that are pause frames will be acted upon if enabled in MACCONTROL, regardless of the value of RXCMFEN. Frames transferred to memory due to RXCMFEN will have the CONTROL bit set in their EOP buffer descriptor.
		0	MAC control frames are filtered (but acted upon if enabled).
		1	MAC control frames are transferred to memory.
23	RXCSFEN		Receive copy short frames enable bit. Enables frames or fragments shorter than 64 bytes to be copied to memory. Frames transferred to memory due to RXCSFEN will have the FRAGMENT or UNDERSIZE bit set in their EOP buffer descriptor. Fragments are short frames that contain CRC / align / code errors and undersized are short frames without errors.
		0	Short frames are filtered.
		1	Short frames are transferred to memory.

Table 19-58. Receive Multicast/Broadcast/Promiscuous Channel Enable Register (RXMBPENABLE) Field Descriptions (continued)

Bit	Field	Value	Description
22	RXCEFEN		Receive copy error frames enable bit. Enables frames containing errors to be transferred to memory. The appropriate error bit will be set in the frame EOP buffer descriptor.
		0	Frames containing errors are filtered.
		1	Frames containing errors are transferred to memory.
21	RXCAFEN		Receive copy all frames enable bit. Enables frames that do not address match (includes multicast frames that do not hash match) to be transferred to the promiscuous channel selected by RXPROMCH bits. Such frames will be marked with the NOMATCH bit in their EOP buffer descriptor.
		0	Frames that do not address match are filtered.
		1	Frames that do not address match are transferred to the promiscuous channel selected by RXPROMCH bits.
20-19	Reserved	0	Reserved
18-16	RXPROMCH	0-7h	Receive promiscuous channel select
		0	Select channel 0 to receive promiscuous frames
		1h	Select channel 1 to receive promiscuous frames
		2h	Select channel 2 to receive promiscuous frames
		3h	Select channel 3 to receive promiscuous frames
		4h	Select channel 4 to receive promiscuous frames
		5h	Select channel 5 to receive promiscuous frames
		6h	Select channel 6 to receive promiscuous frames
		7h	Select channel 7 to receive promiscuous frames
15-14	Reserved	0	Reserved
13	RXBROADEN		Receive broadcast enable. Enable received broadcast frames to be copied to the channel selected by RXBROADCH bits.
		0	Broadcast frames are filtered.
		1	Broadcast frames are copied to the channel selected by RXBROADCH bits.
12-11	Reserved	0	Reserved
10-8	RXBROADCH	0-7h	Receive broadcast channel select
		0	Select channel 0 to receive broadcast frames
		1h	Select channel 1 to receive broadcast frames
		2h	Select channel 2 to receive broadcast frames
		3h	Select channel 3 to receive broadcast frames
		4h	Select channel 4 to receive broadcast frames
		5h	Select channel 5 to receive broadcast frames
		6h	Select channel 6 to receive broadcast frames
		7h	Select channel 7 to receive broadcast frames
7-6	Reserved	0	Reserved
5	RXMULTEN		RX multicast enable. Enable received hash matching multicast frames to be copied to the channel selected by RXMULTCH bits.
		0	Multicast frames are filtered.
		1	Multicast frames are copied to the channel selected by RXMULTCH bits.
4-3	Reserved	0	Reserved

Table 19-58. Receive Multicast/Broadcast/Promiscuous Channel Enable Register (RXMBPENABLE) Field Descriptions (continued)

Bit	Field	Value	Description
2-0	RXMULTCH	0-7h	Receive multicast channel select
		0	Select channel 0 to receive multicast frames
		1h	Select channel 1 to receive multicast frames
		2h	Select channel 2 to receive multicast frames
		3h	Select channel 3 to receive multicast frames
		4h	Select channel 4 to receive multicast frames
		5h	Select channel 5 to receive multicast frames
		6h	Select channel 6 to receive multicast frames
		7h	Select channel 7 to receive multicast frames

19.3.3.22 Receive Unicast Enable Set Register (RXUNICASTSET)

The receive unicast enable set register (RXUNICASTSET) is shown in Figure 19-60 and described in Table 19-59.

Figure 19-60. Receive Unicast Enable Set Register (RXUNICASTSET)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
R-0															

15	14	13	12	11	10	9	8
Reserved							
R-0							

7	6	5	4	3	2	1	0
RXCH7EN	RXCH6EN	RXCH5EN	RXCH4EN	RXCH3EN	RXCH2EN	RXCH1EN	RXCH0EN
R/W1S-0	R/W1S-0	R/W1S-0	R/W1S-0	R/W1S-0	R/W1S-0	R/W1S-0	R/W1S-0

LEGEND: R/W = Read/Write; R = Read only; W1S = Write 1 to set (writing a 0 has no effect); -*n* = value after reset

Table 19-59. Receive Unicast Enable Set Register (RXUNICASTSET) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved
7	RXCH7EN	0-1	Receive channel 7 unicast enable set bit. Write 1 to set the enable, a write of 0 has no effect. May be read.
6	RXCH6EN	0-1	Receive channel 6 unicast enable set bit. Write 1 to set the enable, a write of 0 has no effect. May be read.
5	RXCH5EN	0-1	Receive channel 5 unicast enable set bit. Write 1 to set the enable, a write of 0 has no effect. May be read.
4	RXCH4EN	0-1	Receive channel 4 unicast enable set bit. Write 1 to set the enable, a write of 0 has no effect. May be read.
3	RXCH3EN	0-1	Receive channel 3 unicast enable set bit. Write 1 to set the enable, a write of 0 has no effect. May be read.
2	RXCH2EN	0-1	Receive channel 2 unicast enable set bit. Write 1 to set the enable, a write of 0 has no effect. May be read.
1	RXCH1EN	0-1	Receive channel 1 unicast enable set bit. Write 1 to set the enable, a write of 0 has no effect. May be read.
0	RXCH0EN	0-1	Receive channel 0 unicast enable set bit. Write 1 to set the enable, a write of 0 has no effect. May be read.

19.3.3.23 Receive Unicast Clear Register (RXUNICASTCLEAR)

The receive unicast clear register (RXUNICASTCLEAR) is shown in Figure 19-61 and described in Table 19-60.

Figure 19-61. Receive Unicast Clear Register (RXUNICASTCLEAR)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
R-0															

15	14	13	12	11	10	9	8
Reserved							
R-0							

7	6	5	4	3	2	1	0
RXCH7EN	RXCH6EN	RXCH5EN	RXCH4EN	RXCH3EN	RXCH2EN	RXCH1EN	RXCH0EN
R/W1C-0	R/W1C-0	R/W1C-0	R/W1C-0	R/W1C-0	R/W1C-0	R/W1C-0	R/W1C-0

LEGEND: R/W = Read/Write; R = Read only; W1C = Write 1 to clear (writing a 0 has no effect); *-n* = value after reset

Table 19-60. Receive Unicast Clear Register (RXUNICASTCLEAR) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved
7	RXCH7EN	0-1	Receive channel 7 unicast enable clear bit. Write 1 to clear the enable, a write of 0 has no effect.
6	RXCH6EN	0-1	Receive channel 6 unicast enable clear bit. Write 1 to clear the enable, a write of 0 has no effect.
5	RXCH5EN	0-1	Receive channel 5 unicast enable clear bit. Write 1 to clear the enable, a write of 0 has no effect.
4	RXCH4EN	0-1	Receive channel 4 unicast enable clear bit. Write 1 to clear the enable, a write of 0 has no effect.
3	RXCH3EN	0-1	Receive channel 3 unicast enable clear bit. Write 1 to clear the enable, a write of 0 has no effect.
2	RXCH2EN	0-1	Receive channel 2 unicast enable clear bit. Write 1 to clear the enable, a write of 0 has no effect.
1	RXCH1EN	0-1	Receive channel 1 unicast enable clear bit. Write 1 to clear the enable, a write of 0 has no effect.
0	RXCH0EN	0-1	Receive channel 0 unicast enable clear bit. Write 1 to clear the enable, a write of 0 has no effect.

19.3.3.24 Receive Maximum Length Register (RXMAXLEN)

The receive maximum length register (RXMAXLEN) is shown in Figure 19-62 and described in Table 19-61.

Figure 19-62. Receive Maximum Length Register (RXMAXLEN)

31	16
Reserved	
R-0	
15	**0**
RXMAXLEN	
R/W-5EEh	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 19-61. Receive Maximum Length Register (RXMAXLEN) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	Reserved
15-0	RXMAXLEN	0-FFFFh	Receive maximum frame length. These bits determine the maximum length of a received frame. The reset value is 5EEh (1518). Frames with byte counts greater than RXMAXLEN are long frames. Long frames with no errors are oversized frames. Long frames with CRC, code, or alignment error are jabber frames.

19.3.3.25 Receive Buffer Offset Register (RXBUFFEROFFSET)

The receive buffer offset register (RXBUFFEROFFSET) is shown in Figure 19-63 and described in Table 19-62.

Figure 19-63. Receive Buffer Offset Register (RXBUFFEROFFSET)

31	16
Reserved	
R-0	
15	**0**
RXBUFFEROFFSET	
R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 19-62. Receive Buffer Offset Register (RXBUFFEROFFSET) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	Reserved
15-0	RXBUFFEROFFSET	0-FFFFh	Receive buffer offset value. These bits are written by the EMAC into each frame SOP buffer descriptor Buffer Offset field. The frame data begins after the RXBUFFEROFFSET value of bytes. A value of 0 indicates that there are no unused bytes at the beginning of the data, and that valid data begins on the first byte of the buffer. A value of Fh (15) indicates that the first 15 bytes of the buffer are to be ignored by the EMAC and that valid buffer data starts on byte 16 of the buffer. This value is used for all channels.

19.3.3.26 Receive Filter Low Priority Frame Threshold Register (RXFILTERLOWTHRESH)

The receive filter low priority frame threshold register (RXFILTERLOWTHRESH) is shown in Figure 19-64 and described in Table 19-63.

Figure 19-64. Receive Filter Low Priority Frame Threshold Register (RXFILTERLOWTHRESH)

31	16
Reserved	
R-0	

15	8	7	0
Reserved		RXFILTERTHRESH	
R-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 19-63. Receive Filter Low Priority Frame Threshold Register (RXFILTERLOWTHRESH) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved
7-0	RXFILTERTHRESH	0-FFh	Receive filter low threshold. These bits contain the free buffer count threshold value for filtering low priority incoming frames. This field should remain 0, if no filtering is desired.

19.3.3.27 Receive Channel Flow Control Threshold Registers (RX0FLOWTHRESH-RX7FLOWTHRESH)

The receive channel 0-7 flow control threshold register (RX*n*FLOWTHRESH) is shown in Figure 19-65 and described in Table 19-64.

Figure 19-65. Receive Channel *n* Flow Control Threshold Register (RX*n*FLOWTHRESH)

31	16
Reserved	
R-0	

15	8	7	0
Reserved		RX*n*FLOWTHRESH	
R-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 19-64. Receive Channel *n* Flow Control Threshold Register (RX*n*FLOWTHRESH) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved
7-0	RX*n*FLOWTHRESH	0-FFh	Receive flow threshold. These bits contain the threshold value for issuing flow control on incoming frames for channel *n* (when enabled).

19.3.3.28 Receive Channel Free Buffer Count Registers (RX0FREEBUFFER-RX7FREEBUFFER)

The receive channel 0-7 free buffer count register (RX*n*FREEBUFFER) is shown in Figure 19-66 and described in Table 19-65.

Figure 19-66. Receive Channel *n* Free Buffer Count Register (RX*n*FREEBUFFER)

31	16
Reserved	
R-0	

15	0
RX*n*FREEBUF	
WI-0	

LEGEND: R = Read only; WI = Write to increment; -*n* = value after reset

Table 19-65. Receive Channel *n* Free Buffer Count Register (RX*n*FREEBUFFER) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	Reserved
15-0	RX*n*FREEBUF	0-FFh	Receive free buffer count. These bits contain the count of free buffers available. The RXFILTERTHRESH value is compared with this field to determine if low priority frames should be filtered. The RX*n*FLOWTHRESH value is compared with this field to determine if receive flow control should be issued against incoming packets (if enabled). This is a write-to-increment field. This field rolls over to 0 on overflow. If hardware flow control or QOS is used, the host must initialize this field to the number of available buffers (one register per channel). The EMAC decrements the associated channel register for each received frame by the number of buffers in the received frame. The host must write this field with the number of buffers that have been freed due to host processing.

19.3.3.29 MAC Control Register (MACCONTROL)

The MAC control register (MACCONTROL) is shown in Figure 19-67 and described in Table 19-66.

Figure 19-67. MAC Control Register (MACCONTROL)

31	16
Reserved	
R-0	

15	14	13	12	11	10	9	8
RMIISPEED	RXOFFLENBLOCK	RXOWNERSHIP	Rsvd	CMDIDLE	TXSHORTGAPEN	TXPTYPE	Reserved
R/W-0	R/W-0	R/W-0	R-0	R/W-0	R/W-0	R/W-0	R-0

7	6	5	4	3	2	1	0
Reserved	TXPACE	GMIIEN	TXFLOWEN	RXBUFFERFLOWEN	Reserved	LOOPBACK	FULLDUPLEX
R-0	R/W-0	R/W-0	R/W-0	R/W-0	R-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 19-66. MAC Control Register (MACCONTROL) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	Reserved
15	RMIISPEED		RMII interface transmit and receive speed select.
		0	Operate RMII interface in 10 Mbps speed mode.
		1	Operate RMII interface in 100 Mbps speed mode.
14	RXOFFLENBLOCK		Receive offset / length word write block.
		0	Do not block the DMA writes to the receive buffer descriptor offset / buffer length word.
		1	Block all EMAC DMA controller writes to the receive buffer descriptor offset / buffer length words during packet processing. When this bit is set, the EMAC will never write the third word to any receive buffer descriptor.
13	RXOWNERSHIP		Receive ownership write bit value.
		0	The EMAC writes the Receive ownership bit to 0 at the end of packet processing.
		1	The EMAC writes the Receive ownership bit to 1 at the end of packet processing. If you do not use the ownership mechanism, you can set this mode to preclude the necessity of software having to set this bit each time the buffer descriptor is used.
12	Reserved	0	Reserved
11	CMDIDLE		Command Idle bit
		0	Idle is not commanded.
		1	Idle is commanded (read IDLE in the MACSTATUS register).
10	TXSHORTGAPEN		Transmit Short Gap Enable
		0	Transmit with a short IPG is disabled. Normal 96-bit time IPG is inserted between packets.
		1	Transmit with a short IPG is enabled. Shorter 88-bit time IPG is inserted between packets.
9	TXPTYPE		Transmit queue priority type
		0	The queue uses a round-robin scheme to select the next channel for transmission.
		1	The queue uses a fixed-priority (channel 7 highest priority) scheme to select the next channel for transmission.
8-7	Reserved	0	Reserved
6	TXPACE		Transmit pacing enable bit
		0	Transmit pacing is disabled.
		1	Transmit pacing is enabled.
5	GMIIEN		GMII enable bit
		0	GMII RX and TX are held in reset.
		1	GMII RX and TX are enabled for receive and transmit.

Table 19-66. MAC Control Register (MACCONTROL) Field Descriptions (continued)

Bit	Field	Value	Description
4	TXFLOWEN		Transmit flow control enable bit. This bit determines if incoming pause frames are acted upon in full-duplex mode. Incoming pause frames are not acted upon in half-duplex mode, regardless of this bit setting. The RXMBPENABLE bits determine whether or not received pause frames are transferred to memory.
		0	Transmit flow control is disabled. Full-duplex mode: incoming pause frames are not acted upon.
		1	Transmit flow control is enabled. Full-duplex mode: incoming pause frames are acted upon.
3	RXBUFFERFLOWEN		Receive buffer flow control enable bit
		0	Receive flow control is disabled. Half-duplex mode: no flow control generated collisions are sent. Full-duplex mode: no outgoing pause frames are sent.
		1	Receive flow control is enabled. Half-duplex mode: collisions are initiated when receive buffer flow control is triggered. Full-duplex mode: outgoing pause frames are sent when receive flow control is triggered.
2	Reserved	0	Reserved
1	LOOPBACK		Loopback mode. The loopback mode forces internal full-duplex mode regardless of the FULLDUPLEX bit. The loopback bit should be changed only when GMIIEN bit is deasserted.
		0	Loopback mode is disabled.
		1	Loopback mode is enabled.
0	FULLDUPLEX		Full duplex mode.
		0	Half-duplex mode is enabled.
		1	Full-duplex mode is enabled.

19.3.3.30 MAC Status Register (MACSTATUS)

The MAC status register (MACSTATUS) is shown in Figure 19-68 and described in Table 19-67.

Figure 19-68. MAC Status Register (MACSTATUS)

31	30 – 24	23 – 20	19	18 – 16
IDLE	Reserved	TXERRCODE	Rsvd	TXERRCH
R-0	R-0	R-0	R-0	R-0

15 – 12	11	10 – 8
RXERRCODE	Reserved	RXERRCH
R-0	R-0	R-0

7 – 3	2	1	0
Reserved	RXQOSACT	RXFLOWACT	TXFLOWACT
R-0	R-0	R-0	R-0

LEGEND: R = Read only; -*n* = value after reset

Table 19-67. MAC Status Register (MACSTATUS) Field Descriptions

Bit	Field	Value	Description
31	IDLE		EMAC idle bit. This bit is cleared to 0 at reset; one clock after reset, it goes to 1.
		0	The EMAC is not idle.
		1	The EMAC is in the idle state.
30-24	Reserved	0	Reserved
23-20	TXERRCODE	0-Fh	Transmit host error code. These bits indicate that EMAC detected transmit DMA related host errors. The host should read this field after a host error interrupt (HOSTPEND) to determine the error. Host error interrupts require hardware reset in order to recover. A 0 packet length is an error, but it is not detected.
		0	No error
		1h	SOP error; the buffer is the first buffer in a packet, but the SOP bit is not set in software.
		2h	Ownership bit not set in SOP buffer
		3h	Zero next buffer descriptor pointer without EOP
		4h	Zero buffer pointer
		5h	Zero buffer length
		6h	Packet length error (sum of buffers is less than packet length)
		7h-Fh	Reserved
19	Reserved	0	Reserved
18-16	TXERRCH	0-7h	Transmit host error channel. These bits indicate which transmit channel the host error occurred on. This field is cleared to 0 on a host read.
		0	The host error occurred on transmit channel 0
		1h	The host error occurred on transmit channel 1
		2h	The host error occurred on transmit channel 2
		3h	The host error occurred on transmit channel 3
		4h	The host error occurred on transmit channel 4
		5h	The host error occurred on transmit channel 5
		6h	The host error occurred on transmit channel 6
		7h	The host error occurred on transmit channel 7

Table 19-67. MAC Status Register (MACSTATUS) Field Descriptions (continued)

Bit	Field	Value	Description
15-12	RXERRCODE	0-Fh	Receive host error code. These bits indicate that EMAC detected receive DMA related host errors. The host should read this field after a host error interrupt (HOSTPEND) to determine the error. Host error interrupts require hardware reset in order to recover.
		0	No error
		1h	Reserved
		2h	Ownership bit not set in SOP buffer
		3h	Reserved
		4h	Zero buffer pointer
		5h-Fh	Reserved
11	Reserved	0	Reserved
10-8	RXERRCH	0-7h	Receive host error channel. These bits indicate which receive channel the host error occurred on. This field is cleared to 0 on a host read.
		0	The host error occurred on receive channel 0
		1h	The host error occurred on receive channel 1
		2h	The host error occurred on receive channel 2
		3h	The host error occurred on receive channel 3
		4h	The host error occurred on receive channel 4
		5h	The host error occurred on receive channel 5
		6h	The host error occurred on receive channel 6
		7h	The host error occurred on receive channel 7
7-3	Reserved	0	Reserved
2	RXQOSACT		Receive Quality of Service (QOS) active bit. When asserted, indicates that receive quality of service is enabled and that at least one channel freebuffer count (RX*n*FREEBUFFER) is less than or equal to the RXFILTERLOWTHRESH value.
		0	Receive quality of service is disabled.
		1	Receive quality of service is enabled.
1	RXFLOWACT		Receive flow control active bit. When asserted, at least one channel freebuffer count (RX*n*FREEBUFFER) is less than or equal to the channel's corresponding RX*n*FILTERTHRESH value.
		0	Receive flow control is inactive.
		1	Receive flow control is active.
0	TXFLOWACT		Transmit flow control active bit. When asserted, this bit indicates that the pause time period is being observed for a received pause frame. No new transmissions will begin while this bit is asserted, except for the transmission of pause frames. Any transmission in progress when this bit is asserted will complete.
		0	Transmit flow control is inactive.
		1	Transmit flow control is active.

19.3.3.31 Emulation Control Register (EMCONTROL)

The emulation control register (EMCONTROL) is shown in Figure 19-69 and described in Table 19-68.

Figure 19-69. Emulation Control Register (EMCONTROL)

31	16
Reserved	
R-0	

15	2	1	0
Reserved		SOFT	FREE
R-0		R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 19-68. Emulation Control Register (EMCONTROL) Field Descriptions

Bit	Field	Value	Description
31-2	Reserved	0	Reserved
1	SOFT		Emulation soft bit. This bit is used in conjunction with FREE bit to determine the emulation suspend mode. This bit has no effect if FREE = 1.
		0	Soft mode is disabled. EMAC stops immediately during emulation halt.
		1	Soft mode is enabled. During emulation halt, EMAC stops after completion of current operation.
0	FREE		Emulation free bit. This bit is used in conjunction with SOFT bit to determine the emulation suspend mode.
		0	Free-running mode is disabled. During emulation halt, SOFT bit determines operation of EMAC.
		1	Free-running mode is enabled. During emulation halt, EMAC continues to operate.

19.3.3.32 FIFO Control Register (FIFOCONTROL)

The FIFO control register (FIFOCONTROL) is shown in Figure 19-70 and described in Table 19-69.

Figure 19-70. FIFO Control Register (FIFOCONTROL)

31	16
Reserved	
R-0	

15	2	1	0
Reserved		TXCELLTHRESH	
R-0		R/W-2h	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

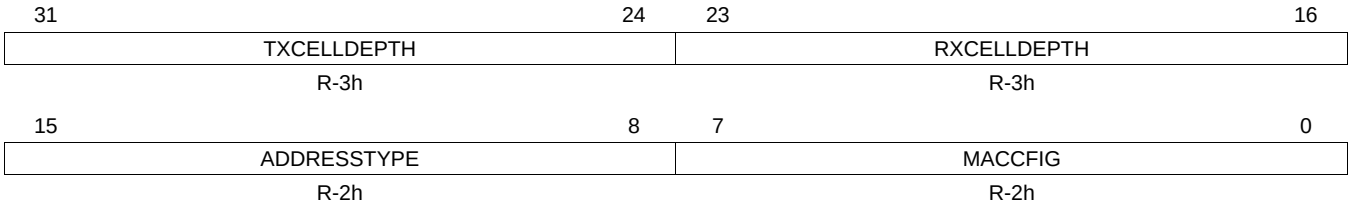
Table 19-69. FIFO Control Register (FIFOCONTROL) Field Descriptions

Bit	Field	Value	Description
31-2	Reserved	0	Reserved
1-0	TXCELLTHRESH	0-3h	Transmit FIFO cell threshold. Indicates the number of 64-byte packet cells required to be in the transmit FIFO before the packet transfer is initiated. Packets with fewer cells will be initiated when the complete packet is contained in the FIFO. The default value is 2, but 3 is also valid. 0 and 1 are not valid values.
		0-1h	Not a valid value.
		2h	Two 64-byte packet cells required to be in the transmit FIFO.
		3h	Three 64-byte packet cells required to be in the transmit FIFO.

19.3.3.33 MAC Configuration Register (MACCONFIG)

The MAC configuration register (MACCONFIG) is shown in Figure 19-71 and described in Table 19-70.

Figure 19-71. MAC Configuration Register (MACCONFIG)



LEGEND: R = Read only; -*n* = value after reset

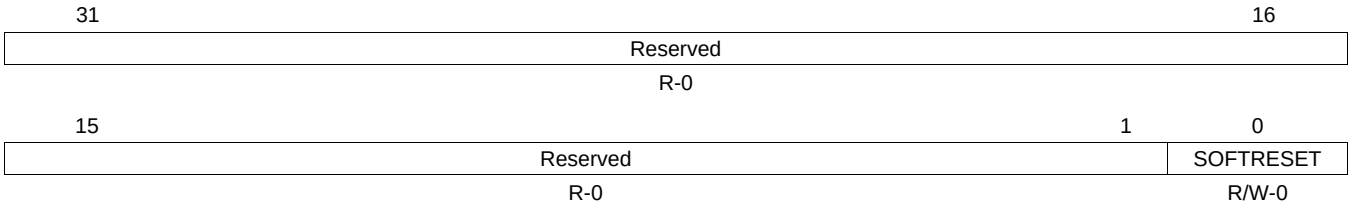
Table 19-70. MAC Configuration Register (MACCONFIG) Field Descriptions

Bit	Field	Value	Description
31-24	TXCELLDEPTH	3h	Transmit cell depth. These bits indicate the number of cells in the transmit FIFO.
23-16	RXCELLDEPTH	3h	Receive cell depth. These bits indicate the number of cells in the receive FIFO.
15-8	ADDRESSTYPE	2h	Address type
7-0	MACCFIG	2h	MAC configuration value

19.3.3.34 Soft Reset Register (SOFTRESET)

The soft reset register (SOFTRESET) is shown in Figure 19-72 and described in Table 19-71.

Figure 19-72. Soft Reset Register (SOFTRESET)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

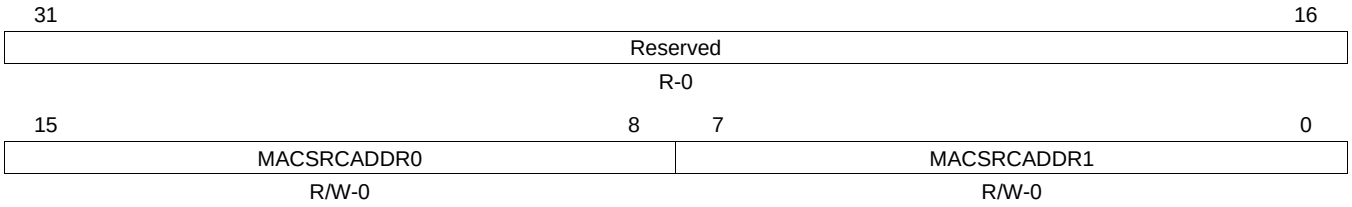
Table 19-71. Soft Reset Register (SOFTRESET) Field Descriptions

Bit	Field	Value	Description
31-1	Reserved	0	Reserved
0	SOFTRESET		Software reset. Writing a 1 to this bit causes the EMAC logic to be reset. Software reset occurs when the receive and transmit DMA controllers are in an idle state to avoid locking up the Configuration bus. After writing a 1 to this bit, it may be polled to determine if the reset has occurred. If a 1 is read, the reset has not yet occurred. If a 0 is read, then a reset has occurred.
		0	A software reset has not occurred.
		1	A software reset has occurred.

19.3.3.35 MAC Source Address Low Bytes Register (MACSRCADDRLO)

The MAC source address low bytes register (MACSRCADDRLO) is shown in Figure 19-73 and described in Table 19-72.

Figure 19-73. MAC Source Address Low Bytes Register (MACSRCADDRLO)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

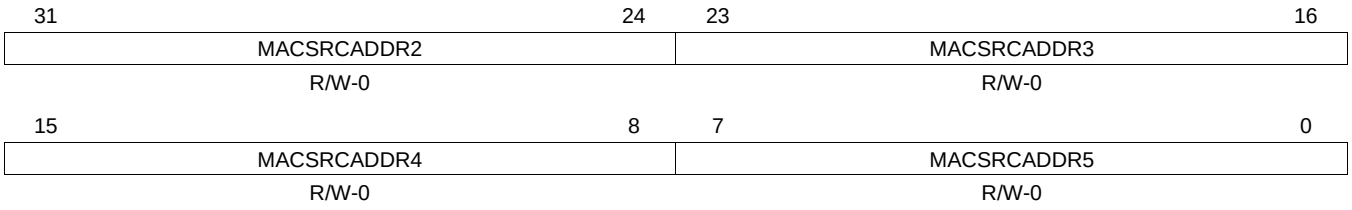
Table 19-72. MAC Source Address Low Bytes Register (MACSRCADDRLO) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	Reserved
15-8	MACSRCADDR0	0-FFh	MAC source address lower 8-0 bits (byte 0)
7-0	MACSRCADDR1	0-FFh	MAC source address bits 15-8 (byte 1)

19.3.3.36 MAC Source Address High Bytes Register (MACSRCADDRHI)

The MAC source address high bytes register (MACSRCADDRHI) is shown in Figure 19-74 and described in Table 19-73.

Figure 19-74. MAC Source Address High Bytes Register (MACSRCADDRHI)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 19-73. MAC Source Address High Bytes Register (MACSRCADDRHI) Field Descriptions

Bit	Field	Value	Description
31-24	MACSRCADDR2	0-FFh	MAC source address bits 23-16 (byte 2)
23-16	MACSRCADDR3	0-FFh	MAC source address bits 31-24 (byte 3)
15-8	MACSRCADDR4	0-FFh	MAC source address bits 39-32 (byte 4)
7-0	MACSRCADDR5	0-FFh	MAC source address bits 47-40 (byte 5)

19.3.3.37 MAC Hash Address Register 1 (MACHASH1)

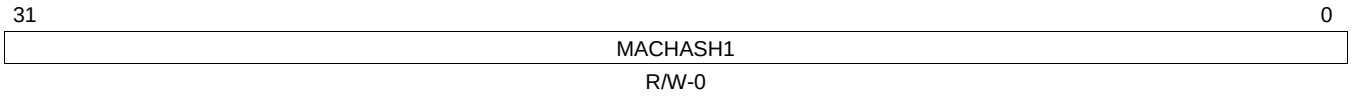
The MAC hash registers allow group addressed frames to be accepted on the basis of a hash function of the address. The hash function creates a 6-bit data value (Hash_fun) from the 48-bit destination address (DA) as follows:

```
Hash_fun(0)=DA(0) XOR DA(6) XOR DA(12) XOR DA(18) XOR DA(24) XOR DA(30) XOR DA(36) XOR DA(42);

Hash_fun(1)=DA(1) XOR DA(7) XOR DA(13) XOR DA(19) XOR DA(25) XOR DA(31) XOR DA(37) XOR DA(43);

Hash_fun(2)=DA(2) XOR DA(8) XOR DA(14) XOR DA(20) XOR DA(26) XOR DA(32) XOR DA(38) XOR DA(44);

Hash_fun(3)=DA(3) XOR DA(9) XOR DA(15) XOR DA(21) XOR DA(27) XOR DA(33) XOR DA(39) XOR DA(45);

Hash_fun(4)=DA(4) XOR DA(10) XOR DA(16) XOR DA(22) XOR DA(28) XOR DA(34) XOR DA(40) XOR DA(46);

Hash_fun(5)=DA(5) XOR DA(11) XOR DA(17) XOR DA(23) XOR DA(29) XOR DA(35) XOR DA(41) XOR DA(47);
```

This function is used as an offset into a 64-bit hash table stored in MACHASH1 and MACHASH2 that indicates whether a particular address should be accepted or not.

The MAC hash address register 1 (MACHASH1) is shown in Figure 19-75 and described in Table 19-74.

Figure 19-75. MAC Hash Address Register 1 (MACHASH1)



LEGEND: R/W = Read/Write; *-n* = value after reset

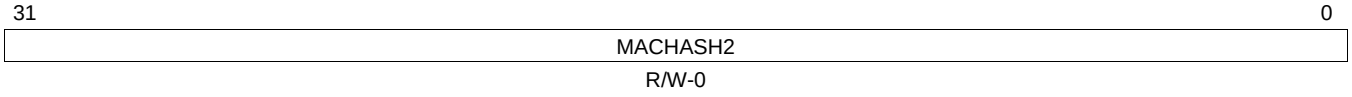
Table 19-74. MAC Hash Address Register 1 (MACHASH1) Field Descriptions

Bit	Field	Value	Description
31-0	MACHASH1	0-FFFF FFFFh	Least-significant 32 bits of the hash table corresponding to hash values 0 to 31. If a hash table bit is set, then a group address that hashes to that bit index is accepted.

19.3.3.38 MAC Hash Address Register 2 (MACHASH2)

The MAC hash address register 2 (MACHASH2) is shown in Figure 19-76 and described in Table 19-75.

Figure 19-76. MAC Hash Address Register 2 (MACHASH2)



LEGEND: R/W = Read/Write; *-n* = value after reset

Table 19-75. MAC Hash Address Register 2 (MACHASH2) Field Descriptions

Bit	Field	Value	Description
31-0	MACHASH2	0-FFFF FFFFh	Most-significant 32 bits of the hash table corresponding to hash values 32 to 63. If a hash table bit is set, then a group address that hashes to that bit index is accepted.

19.3.3.39 Back Off Test Register (BOFFTEST)

The back off test register (BOFFTEST) is shown in Figure 19-77 and described in Table 19-76.

Figure 19-77. Back Off Random Number Generator Test Register (BOFFTEST)

31	26	25	16
Reserved		RNDNUM	
R-0		R-0	

15	12	11	10	9	0
COLLCOUNT		Reserved		TXBACKOFF	
R-0		R-0		R-0	

LEGEND: R = Read only; -*n* = value after reset

Table 19-76. Back Off Test Register (BOFFTEST) Field Descriptions

Bit	Field	Value	Description
31-26	Reserved	0	Reserved
25-16	RNDNUM	0-3FFh	Backoff random number generator. This field allows the Backoff Random Number Generator to be read. Reading this field returns the generator's current value. The value is reset to 0 and begins counting on the clock after the deassertion of reset.
15-12	COLLCOUNT	0-Fh	Collision count. These bits indicate the number of collisions the current frame has experienced.
11-10	Reserved	0	Reserved
9-0	TXBACKOFF	0-3FFh	Backoff count. This field allows the current value of the backoff counter to be observed for test purposes. This field is loaded automatically according to the backoff algorithm, and is decremented by one for each slot time after the collision.

19.3.3.40 Transmit Pacing Algorithm Test Register (TPACETEST)

The transmit pacing algorithm test register (TPACETEST) is shown in Figure 19-78 and described in Table 19-77.

Figure 19-78. Transmit Pacing Algorithm Test Register (TPACETEST)

31	16
Reserved	
R-0	

15	5	4	0
Reserved		PACEVAL	
R-0		R-0	

LEGEND: R = Read only; -*n* = value after reset

Table 19-77. Transmit Pacing Algorithm Test Register (TPACETEST) Field Descriptions

Bit	Field	Value	Description
31-5	Reserved	0	Reserved
4-0	PACEVAL	0-1Fh	Pacing register current value. A nonzero value in this field indicates that transmit pacing is active. A transmit frame collision or deferral causes PACEVAL to be loaded with 1Fh (31); good frame transmissions (with no collisions or deferrals) cause PACEVAL to be decremented down to 0. When PACEVAL is nonzero, the transmitter delays four Inter Packet Gaps between new frame transmissions after each successfully transmitted frame that had no deferrals or collisions. If a transmit frame is deferred or suffers a collision, the IPG time is not stretched to four times the normal value. Transmit pacing helps reduce capture effects, which improves overall network bandwidth.

19.3.3.41 Receive Pause Timer Register (RXPAUSE)

The receive pause timer register (RXPAUSE) is shown in Figure 19-79 and described in Table 19-78.

Figure 19-79. Receive Pause Timer Register (RXPAUSE)

31	16
Reserved	
R-0	

15	0
PAUSETIMER	
R-0	

LEGEND: R = Read only; -*n* = value after reset

Table 19-78. Receive Pause Timer Register (RXPAUSE) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	Reserved
15-0	PAUSETIMER	0-FFh	Receive pause timer value. These bits allow the contents of the receive pause timer to be observed. The receive pause timer is loaded with FF00h when the EMAC sends an outgoing pause frame (with pause time of FFFFh). The receive pause timer is decremented at slot time intervals. If the receive pause timer decrements to 0, then another outgoing pause frame is sent and the load/decrement process is repeated.

19.3.3.42 Transmit Pause Timer Register (TXPAUSE)

The transmit pause timer register (TXPAUSE) is shown in Figure 19-80 and described in Table 19-79.

Figure 19-80. Transmit Pause Timer Register (TXPAUSE)

31	16
Reserved	
R-0	

15	0
PAUSETIMER	
R-0	

LEGEND: R = Read only; -*n* = value after reset

Table 19-79. Transmit Pause Timer Register (TXPAUSE) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	Reserved
15-0	PAUSETIMER	0-FFh	Transmit pause timer value. These bits allow the contents of the transmit pause timer to be observed. The transmit pause timer is loaded by a received (incoming) pause frame, and then decremented at slot time intervals down to 0, at which time EMAC transmit frames are again enabled.

19.3.3.43 MAC Address Low Bytes Register (MACADDRLO)

The MAC address low bytes register used in address matching (MACADDRLO), is shown in Figure 19-81 and described in Table 19-80.

Figure 19-81. MAC Address Low Bytes Register (MACADDRLO)

31	21	20	19	18	16
Reserved		VALID	MATCHFILT	CHANNEL	
R-0		R/W-x	R/W-x	R/W-x	

15	8	7	0
MACADDR0		MACADDR1	
R/W-x		R/W-x	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset; -x = value is indeterminate after reset

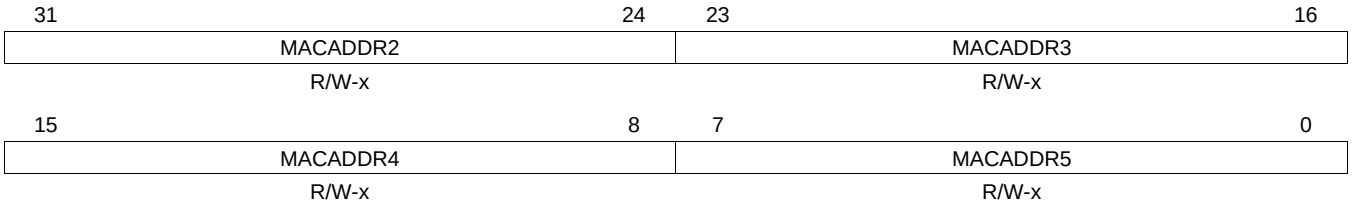
Table 19-80. MAC Address Low Bytes Register (MACADDRLO) Field Descriptions

Bit	Field	Value	Description
31-21	Reserved	0	Reserved
20	VALID		Address valid bit. This bit should be cleared to zero for unused address channels
		0	Address is not valid and will not be used for matching or filtering incoming packets
		1	Address is valid and will be used for matching or filtering incoming packets
19	MATCHFILT		Match or filter bit
		0	The address will be used (if the VALID bit is set) to filter incoming packet addresses
		1	The address will be used (if the VALID bit is set) to match incoming packet addresses
18-16	CHANNEL	0-7h	Channel select. Determines which receive channel a valid address match will be transferred to. The channel is a don't care if MATCHFILT is cleared to 0.
15-8	MACADDR0	0-FFh	MAC address lower 8-0 bits (byte 0)
7-0	MACADDR1	0-FFh	MAC address bits 15-8 (byte 1)

19.3.3.44 MAC Address High Bytes Register (MACADDRHI)

The MAC address high bytes register (MACADDRHI) is shown in Figure 19-82 and described in Table 19-81.

Figure 19-82. MAC Address High Bytes Register (MACADDRHI)



LEGEND: R/W = Read/Write; -x = value is indeterminate after reset

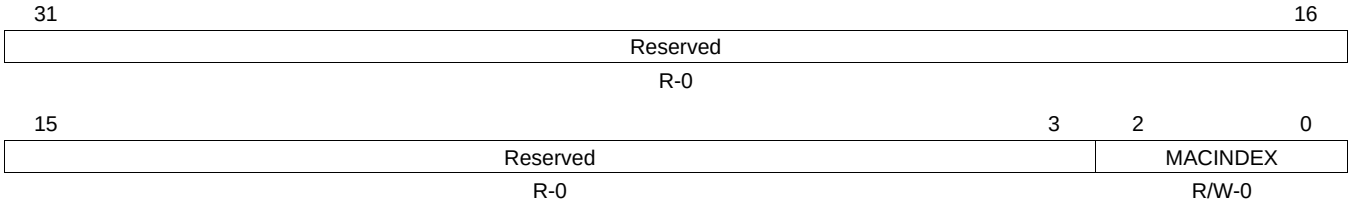
Table 19-81. MAC Address High Bytes Register (MACADDRHI) Field Descriptions

Bit	Field	Value	Description
31-24	MACADDR2	0-FFh	MAC source address bits 23-16 (byte 2)
23-16	MACADDR3	0-FFh	MAC source address bits 31-24 (byte 3)
15-8	MACADDR4	0-FFh	MAC source address bits 39-32 (byte 4)
7-0	MACADDR5	0-FFh	MAC source address bits 47-40 (byte 5). Bit 40 is the group bit. It is forced to 0 and read as 0. Therefore, only unicast addresses are represented in the address table.

19.3.3.45 MAC Index Register (MACINDEX)

The MAC index register (MACINDEX) is shown in Figure 19-83 and described in Table 19-82.

Figure 19-83. MAC Index Register (MACINDEX)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 19-82. MAC Index Register (MACINDEX) Field Descriptions

Bit	Field	Value	Description
31-3	Reserved	0	Reserved
2-0	MACINDEX	0-7h	MAC address index. All eight addresses share the upper 40 bits. Only the lower byte is unique for each address. An address is written by first writing the address number (channel) into the MACINDEX register. The upper 32 bits of the address are then written to the MACADDRHI register, which is followed by writing the lower 16 bits of the address to the MACADDRLO register. Since all eight addresses share the upper 40 bits of the address, the MACADDRHI register only needs to be written the first time.

19.3.3.46 Transmit Channel DMA Head Descriptor Pointer Registers (TX0HDP-TX7HDP)

The transmit channel 0-7 DMA head descriptor pointer register (TX*n*HDP) is shown in Figure 19-84 and described in Table 19-83.

Figure 19-84. Transmit Channel *n* DMA Head Descriptor Pointer Register (TX*n*HDP)

31	0
TX*n*HDP	
R/W-x	

LEGEND: R/W = Read/Write; -*n* = value after reset; -x = value is indeterminate after reset

Table 19-83. Transmit Channel *n* DMA Head Descriptor Pointer Register (TX*n*HDP) Field Descriptions

Bit	Field	Value	Description
31-0	TX*n*HDP	0-FFFF FFFFh	Transmit channel *n* DMA Head Descriptor pointer. Writing a transmit DMA buffer descriptor address to a head pointer location initiates transmit DMA operations in the queue for the selected channel. Writing to these locations when they are nonzero is an error (except at reset). Host software must initialize these locations to 0 on reset.

19.3.3.47 Receive Channel DMA Head Descriptor Pointer Registers (RX0HDP-RX7HDP)

The receive channel 0-7 DMA head descriptor pointer register (RX*n*HDP) is shown in Figure 19-85 and described in Table 19-84.

Figure 19-85. Receive Channel *n* DMA Head Descriptor Pointer Register (RX*n*HDP)

31	0
RX*n*HDP	
R/W-x	

LEGEND: R/W = Read/Write; -*n* = value after reset; -x = value is indeterminate after reset

Table 19-84. Receive Channel *n* DMA Head Descriptor Pointer Register (RX*n*HDP) Field Descriptions

Bit	Field	Value	Description
31-0	RX*n*HDP	0-FFFF FFFFh	Receive channel *n* DMA Head Descriptor pointer. Writing a receive DMA buffer descriptor address to this location allows receive DMA operations in the selected channel when a channel frame is received. Writing to these locations when they are nonzero is an error (except at reset). Host software must initialize these locations to 0 on reset.

19.3.3.48 Transmit Channel Completion Pointer Registers (TX0CP-TX7CP)

The transmit channel 0-7 completion pointer register (TX*n*CP) is shown in Figure 19-86 and described in Table 19-85.

Figure 19-86. Transmit Channel *n* Completion Pointer Register (TX*n*CP)

31	0
TX*n*CP	
R/W-x	

LEGEND: R/W = Read/Write; -*n* = value after reset; -x = value is indeterminate after reset

Table 19-85. Transmit Channel *n* Completion Pointer Register (TX*n*CP) Field Descriptions

Bit	Field	Value	Description
31-0	TX*n*CP	0-FFFF FFFFh	Transmit channel *n* completion pointer register is written by the host with the buffer descriptor address for the last buffer processed by the host during interrupt processing. The EMAC uses the value written to determine if the interrupt should be deasserted.

19.3.3.49 Receive Channel Completion Pointer Registers (RX0CP-RX7CP)

The receive channel 0-7 completion pointer register (RX*n*CP) is shown in Figure 19-87 and described in Table 19-86.

Figure 19-87. Receive Channel *n* Completion Pointer Register (RX*n*CP)

31	0
RX*n*CP	
R/W-x	

LEGEND: R/W = Read/Write; -*n* = value after reset; -x = value is indeterminate after reset

Table 19-86. Receive Channel *n* Completion Pointer Register (RX*n*CP) Field Descriptions

Bit	Field	Value	Description
31-0	RX*n*CP	0-FFFF FFFFh	Receive channel *n* completion pointer register is written by the host with the buffer descriptor address for the last buffer processed by the host during interrupt processing. The EMAC uses the value written to determine if the interrupt should be deasserted.

19.3.3.50 Network Statistics Registers

The EMAC has a set of statistics that record events associated with frame traffic. The statistics values are cleared to zero 38 clocks after the rising edge of reset. When the GMIIEN bit in the MACCONTROL register is set, all statistics registers (see Figure 19-88) are write-to-decrement. The value written is subtracted from the register value with the result stored in the register. If a value greater than the statistics value is written, then zero is written to the register (writing FFFF FFFFh clears a statistics location). When the GMIIEN bit is cleared, all statistics registers are read/write (normal write direct, so writing 0000 0000h clears a statistics location). All write accesses must be 32-bit accesses.

The statistics interrupt (STATPEND) is issued, if enabled, when any statistics value is greater than or equal to 8000 0000h. The statistics interrupt is removed by writing to decrement any statistics value greater than 8000 0000h. The statistics are mapped into internal memory space and are 32-bits wide. All statistics rollover from FFFF FFFFh to 0000 0000h.

Figure 19-88. Statistics Register

31	0
COUNT	
R/WD-0	

LEGEND: R/W = Read/Write; WD = Write to decrement; -*n* = value after reset

19.3.3.50.1 Good Receive Frames Register (RXGOODFRAMES)

The total number of good frames received on the EMAC. A good frame is defined as having all of the following:

- Any data or MAC control frame that matched a unicast, broadcast, or multicast address, or matched due to promiscuous mode
- Was of length 64 to RXMAXLEN bytes inclusive
- Had no CRC error, alignment error, or code error

See **Section 19.2.5.5** for definitions of alignment, code, and CRC errors. Overruns have no effect on this statistic.

19.3.3.50.2 Broadcast Receive Frames Register (RXBCASTFRAMES)

The total number of good broadcast frames received on the EMAC. A good broadcast frame is defined as having all of the following:

- Any data or MAC control frame that was destined for address FF-FF-FF-FF-FF-FFh only
- Was of length 64 to RXMAXLEN bytes inclusive
- Had no CRC error, alignment error, or code error

See Section 19.2.5.5 for definitions of alignment, code, and CRC errors. Overruns have no effect on this statistic.

19.3.3.50.3 Multicast Receive Frames Register (RXMCASTFRAMES)

The total number of good multicast frames received on the EMAC. A good multicast frame is defined as having all of the following:

- Any data or MAC control frame that was destined for any multicast address other than FF-FF-FF-FF-FF-FFh
- Was of length 64 to RXMAXLEN bytes inclusive
- Had no CRC error, alignment error, or code error

See Section 19.2.5.5 for definitions of alignment, code, and CRC errors. Overruns have no effect on this statistic.

19.3.3.50.4 Pause Receive Frames Register (RXPAUSEFRAMES)

The total number of IEEE 802.3X pause frames received by the EMAC (whether acted upon or not). A pause frame is defined as having all of the following:

- Contained any unicast, broadcast, or multicast address
- Contained the length/type field value 88.08h and the opcode 0001h
- Was of length 64 to RXMAXLEN bytes inclusive
- Had no CRC error, alignment error, or code error
- Pause-frames had been enabled on the EMAC (TXFLOWEN bit is set in MACCONTROL).

The EMAC could have been in either half-duplex or full-duplex mode. See Section 19.2.5.5 for definitions of alignment, code, and CRC errors. Overruns have no effect on this statistic.

19.3.3.50.5 Receive CRC Errors Register (RXCRCERRORS)

The total number of frames received on the EMAC that experienced a CRC error. A frame with CRC errors is defined as having all of the following:

- Was any data or MAC control frame that matched a unicast, broadcast, or multicast address, or matched due to promiscuous mode
- Was of length 64 to RXMAXLEN bytes inclusive
- Had no alignment or code error
- Had a CRC error. A CRC error is defined as having all of the following:
  - A frame containing an even number of nibbles
  - Fails the frame check sequence test

See Section 19.2.5.5 for definitions of alignment, code, and CRC errors. Overruns have no effect on this statistic.

19.3.3.50.6 Receive Alignment/Code Errors Register (RXALIGNCODEERRORS)

The total number of frames received on the EMAC that experienced an alignment error or code error. Such a frame is defined as having all of the following:

- Was any data or MAC control frame that matched a unicast, broadcast, or multicast address, or matched due to promiscuous mode
- Was of length 64 to RXMAXLEN bytes inclusive
- Had either an alignment error or a code error
  - An alignment error is defined as having all of the following:
    - A frame containing an odd number of nibbles
    - Fails the frame check sequence test, if the final nibble is ignored
  - A code error is defined as a frame that has been discarded because the EMACs MII_RXER pin is driven with a one for at least one bit-time's duration at any point during the frame's reception.

Overruns have no effect on this statistic.

CRC alignment or code errors can be calculated by summing receive alignment errors, receive code errors, and receive CRC errors.

19.3.3.50.7 Receive Oversized Frames Register (RXOVERSIZED)

The total number of oversized frames received on the EMAC. An oversized frame is defined as having all of the following:

- Was any data or MAC control frame that matched a unicast, broadcast, or multicast address, or matched due to promiscuous mode
- Was greater than RXMAXLEN in bytes
- Had no CRC error, alignment error, or code error

See Section 19.2.5.5 for definitions of alignment, code, and CRC errors. Overruns have no effect on this statistic.

19.3.3.50.8 Receive Jabber Frames Register (RXJABBER)

The total number of jabber frames received on the EMAC. A jabber frame is defined as having all of the following:

- Was any data or MAC control frame that matched a unicast, broadcast, or multicast address, or matched due to promiscuous mode
- Was greater than RXMAXLEN bytes long
- Had a CRC error, alignment error, or code error

See Section 19.2.5.5 for definitions of alignment, code, and CRC errors. Overruns have no effect on this statistic.

19.3.3.50.9 Receive Undersized Frames Register (RXUNDERSIZED)

The total number of undersized frames received on the EMAC. An undersized frame is defined as having all of the following:

- Was any data frame that matched a unicast, broadcast, or multicast address, or matched due to promiscuous mode
- Was less than 64 bytes long
- Had no CRC error, alignment error, or code error

See Section 19.2.5.5 for definitions of alignment, code, and CRC errors. Overruns have no effect on this statistic.

19.3.3.50.10 Receive Frame Fragments Register (RXFRAGMENTS)

The total number of frame fragments received on the EMAC. A frame fragment is defined as having all of the following:

- Any data frame (address matching does not matter)
- Was less than 64 bytes long
- Had a CRC error, alignment error, or code error
- Was not the result of a collision caused by half duplex, collision based flow control

See Section 19.2.5.5 for definitions of alignment, code, and CRC errors. Overruns have no effect on this statistic.

19.3.3.50.11 Filtered Receive Frames Register (RXFILTERED)

The total number of frames received on the EMAC that the EMAC address matching process indicated should be discarded. Such a frame is defined as having all of the following:

- Was any data frame (not MAC control frame) destined for any unicast, broadcast, or multicast address
- Did not experience any CRC error, alignment error, code error
- The address matching process decided that the frame should be discarded (filtered) because it did not match the unicast, broadcast, or multicast address, and it did not match due to promiscuous mode.

To determine the number of receive frames discarded by the EMAC for any reason, sum the following statistics (promiscuous mode disabled):

- Receive fragments
- Receive undersized frames
- Receive CRC errors
- Receive alignment/code errors
- Receive jabbers
- Receive overruns
- Receive filtered frames

This may not be an exact count because the receive overruns statistic is independent of the other statistics, so if an overrun occurs at the same time as one of the other discard reasons, then the above sum double-counts that frame.

19.3.3.50.12 Receive QOS Filtered Frames Register (RXQOSFILTERED)

The total number of frames received on the EMAC that were filtered due to receive quality of service (QOS) filtering. Such a frame is defined as having all of the following:

- Any data or MAC control frame that matched a unicast, broadcast, or multicast address, or matched due to promiscuous mode
- The frame destination channel flow control threshold register (RX*n*FLOWTHRESH) value was greater than or equal to the channel's corresponding free buffer register (RX*n*FREEBUFFER) value
- Was of length 64 to RXMAXLEN
- RXQOSEN bit is set in RXMBPENABLE
- Had no CRC error, alignment error, or code error

See Section 19.2.5.5 for definitions of alignment, code, and CRC errors. Overruns have no effect on this statistic.

19.3.3.50.13 Receive Octet Frames Register (RXOCTETS)

The total number of bytes in all good frames received on the EMAC. A good frame is defined as having all of the following:

- Any data or MAC control frame that matched a unicast, broadcast, or multicast address, or matched due to promiscuous mode
- Was of length 64 to RXMAXLEN bytes inclusive
- Had no CRC error, alignment error, or code error

See Section 19.2.5.5 for definitions of alignment, code, and CRC errors. Overruns have no effect on this statistic.

19.3.3.50.14 Good Transmit Frames Register (TXGOODFRAMES)

The total number of good frames transmitted on the EMAC. A good frame is defined as having all of the following:

- Any data or MAC control frame that was destined for any unicast, broadcast, or multicast address
- Was any length
- Had no late or excessive collisions, no carrier loss, and no underrun

19.3.3.50.15 Broadcast Transmit Frames Register (TXBCASTFRAMES)

The total number of good broadcast frames transmitted on the EMAC. A good broadcast frame is defined as having all of the following:

- Any data or MAC control frame destined for address FF-FF-FF-FF-FF-FFh only
- Was of any length
- Had no late or excessive collisions, no carrier loss, and no underrun

19.3.3.50.16 Multicast Transmit Frames Register (TXMCASTFRAMES)

The total number of good multicast frames transmitted on the EMAC. A good multicast frame is defined as having all of the following:

- Any data or MAC control frame destined for any multicast address other than FF-FF-FF-FF-FF-FFh
- Was of any length
- Had no late or excessive collisions, no carrier loss, and no underrun

19.3.3.50.17 Pause Transmit Frames Register (TXPAUSEFRAMES)

The total number of IEEE 802.3X pause frames transmitted by the EMAC. Pause frames cannot underrun or contain a CRC error because they are created in the transmitting MAC, so these error conditions have no effect on this statistic. Pause frames sent by software are not included in this count. Since pause frames are only transmitted in full-duplex mode, carrier loss and collisions have no effect on this statistic.

Transmitted pause frames are always 64-byte multicast frames so appear in the multicast transmit frames register and 64 octect frames register statistics.

19.3.3.50.18 Deferred Transmit Frames Register (TXDEFERRED)

The total number of frames transmitted on the EMAC that first experienced deferment. Such a frame is defined as having all of the following:

- Was any data or MAC control frame destined for any unicast, broadcast, or multicast address
- Was any size
- Had no carrier loss and no underrun
- Experienced no collisions before being successfully transmitted
- Found the medium busy when transmission was first attempted, so had to wait.

CRC errors have no effect on this statistic.

19.3.3.50.19 Transmit Collision Frames Register (TXCOLLISION)

The total number of times that the EMAC experienced a collision. Collisions occur under two circumstances:

- When a transmit data or MAC control frame has all of the following:
  - Was destined for any unicast, broadcast, or multicast address
  - Was any size
  - Had no carrier loss and no underrun
  - Experienced a collision. A jam sequence is sent for every non-late collision, so this statistic increments on each occasion if a frame experiences multiple collisions (and increments on late collisions).
- When the EMAC is in half-duplex mode, flow control is active, and a frame reception begins.

CRC errors have no effect on this statistic.

19.3.3.50.20 Transmit Single Collision Frames Register (TXSINGLECOLL)

The total number of frames transmitted on the EMAC that experienced exactly one collision. Such a frame is defined as having all of the following:

- Was any data or MAC control frame destined for any unicast, broadcast, or multicast address
- Was any size
- Had no carrier loss and no underrun
- Experienced one collision before successful transmission. The collision was not late.

CRC errors have no effect on this statistic.

19.3.3.50.21 Transmit Multiple Collision Frames Register (TXMULTICOLL)

The total number of frames transmitted on the EMAC that experienced multiple collisions. Such a frame is defined as having all of the following:

- Was any data or MAC control frame destined for any unicast, broadcast, or multicast address
- Was any size
- Had no carrier loss and no underrun
- Experienced 2 to 15 collisions before being successfully transmitted. None of the collisions were late.

CRC errors have no effect on this statistic.

19.3.3.50.22 Transmit Excessive Collision Frames Register (TXEXCESSIVECOLL)

The total number of frames when transmission was abandoned due to excessive collisions. Such a frame is defined as having all of the following:

- Was any data or MAC control frame destined for any unicast, broadcast, or multicast address
- Was any size
- Had no carrier loss and no underrun
- Experienced 16 collisions before abandoning all attempts at transmitting the frame. None of the collisions were late.

CRC errors have no effect on this statistic.

19.3.3.50.23 Transmit Late Collision Frames Register (TXLATECOLL)

The total number of frames when transmission was abandoned due to a late collision. Such a frame is defined as having all of the following:

- Was any data or MAC control frame destined for any unicast, broadcast, or multicast address
- Was any size
- Had no carrier loss and no underrun
- Experienced a collision later than 512 bit-times into the transmission. There may have been up to 15 previous (non-late) collisions that had previously required the transmission to be reattempted. The late collisions statistic dominates over the single, multiple, and excessive collisions statistics. If a late collision occurs, the frame is not counted in any of these other three statistics.

CRC errors, carrier loss, and underrun have no effect on this statistic.

19.3.3.50.24 Transmit Underrun Error Register (TXUNDERRUN)

The number of frames sent by the EMAC that experienced FIFO underrun. Late collisions, CRC errors, carrier loss, and underrun have no effect on this statistic.

19.3.3.50.25 Transmit Carrier Sense Errors Register (TXCARRIERSENSE)

The total number of frames on the EMAC that experienced carrier loss. Such a frame is defined as having all of the following:

- Was any data or MAC control frame destined for any unicast, broadcast, or multicast address
- Was any size
- The carrier sense condition was lost or never asserted when transmitting the frame (the frame is not retransmitted)

CRC errors and underrun have no effect on this statistic.

19.3.3.50.26 Transmit Octet Frames Register (TXOCTETS)

The total number of bytes in all good frames transmitted on the EMAC. A good frame is defined as having all of the following:

- Any data or MAC control frame that was destined for any unicast, broadcast, or multicast address
- Was any length
- Had no late or excessive collisions, no carrier loss, and no underrun

19.3.3.50.27 Transmit and Receive 64 Octet Frames Register (FRAME64)

The total number of 64-byte frames received and transmitted on the EMAC. Such a frame is defined as having all of the following:

- Any data or MAC control frame that was destined for any unicast, broadcast, or multicast address
- Did not experience late collisions, excessive collisions, underrun, or carrier sense error
- Was exactly 64-bytes long. (If the frame was being transmitted and experienced carrier loss that resulted in a frame of this size being transmitted, then the frame is recorded in this statistic).

CRC errors, alignment/code errors, and overruns do not affect the recording of frames in this statistic.

19.3.3.50.28 Transmit and Receive 65 to 127 Octet Frames Register (FRAME65T127)

The total number of 65-byte to 127-byte frames received and transmitted on the EMAC. Such a frame is defined as having all of the following:

- Any data or MAC control frame that was destined for any unicast, broadcast, or multicast address
- Did not experience late collisions, excessive collisions, underrun, or carrier sense error
- Was 65-bytes to 127-bytes long

CRC errors, alignment/code errors, underruns, and overruns do not affect the recording of frames in this statistic.

19.3.3.50.29 Transmit and Receive 128 to 255 Octet Frames Register (FRAME128T255)

The total number of 128-byte to 255-byte frames received and transmitted on the EMAC. Such a frame is defined as having all of the following:

- Any data or MAC control frame that was destined for any unicast, broadcast, or multicast address
- Did not experience late collisions, excessive collisions, underrun, or carrier sense error
- Was 128-bytes to 255-bytes long

CRC errors, alignment/code errors, underruns, and overruns do not affect the recording of frames in this statistic.

19.3.3.50.30 Transmit and Receive 256 to 511 Octet Frames Register (FRAME256T511)

The total number of 256-byte to 511-byte frames received and transmitted on the EMAC. Such a frame is defined as having all of the following:

- Any data or MAC control frame that was destined for any unicast, broadcast, or multicast address
- Did not experience late collisions, excessive collisions, underrun, or carrier sense error
- Was 256-bytes to 511-bytes long

CRC errors, alignment/code errors, underruns, and overruns do not affect the recording of frames in this statistic.

19.3.3.50.31 Transmit and Receive 512 to 1023 Octet Frames Register (FRAME512T1023)

The total number of 512-byte to 1023-byte frames received and transmitted on the EMAC. Such a frame is defined as having all of the following:

- Any data or MAC control frame that was destined for any unicast, broadcast, or multicast address
- Did not experience late collisions, excessive collisions, underrun, or carrier sense error
- Was 512-bytes to 1023-bytes long

CRC errors, alignment/code errors, and overruns do not affect the recording of frames in this statistic.

19.3.3.50.32 Transmit and Receive 1024 to RXMAXLEN Octet Frames Register (FRAME1024TUP)

The total number of 1024-byte to RXMAXLEN-byte frames received and transmitted on the EMAC. Such a frame is defined as having all of the following:

- Any data or MAC control frame that was destined for any unicast, broadcast, or multicast address
- Did not experience late collisions, excessive collisions, underrun, or carrier sense error
- Was 1024-bytes to RXMAXLEN-bytes long

CRC/alignment/code errors, underruns, and overruns do not affect frame recording in this statistic.

19.3.3.50.33 Network Octet Frames Register (NETOCTETS)

The total number of bytes of frame data received and transmitted on the EMAC. Each frame counted has all of the following:

- Was any data or MAC control frame destined for any unicast, broadcast, or multicast address (address match does not matter)
- Was of any size (including less than 64-byte and greater than RXMAXLEN-byte frames)

Also counted in this statistic is:

- Every byte transmitted before a carrier-loss was experienced
- Every byte transmitted before each collision was experienced (multiple retries are counted each time)
- Every byte received if the EMAC is in half-duplex mode until a jam sequence was transmitted to initiate flow control. (The jam sequence is not counted to prevent double-counting).

Error conditions such as alignment errors, CRC errors, code errors, overruns, and underruns do not affect the recording of bytes in this statistic. The objective of this statistic is to give a reasonable indication of Ethernet utilization.

19.3.3.50.34 Receive FIFO or DMA Start of Frame Overruns Register (RXSOFOVERRUNS)

The total number of frames received on the EMAC that had either a FIFO or DMA start of frame (SOF) overrun. An SOF overrun frame is defined as having all of the following:

- Was any data or MAC control frame that matched a unicast, broadcast, or multicast address, or matched due to promiscuous mode
- Was of any size (including less than 64-byte and greater than RXMAXLEN-byte frames)
- The EMAC was unable to receive it because it did not have the resources to receive it (cell FIFO full or no DMA buffer available at the start of the frame).

CRC errors, alignment errors, and code errors have no effect on this statistic.

19.3.3.50.35 Receive FIFO or DMA Middle of Frame Overruns Register (RXMOFOVERRUNS)

The total number of frames received on the EMAC that had either a FIFO or DMA middle of frame (MOF) overrun. An MOF overrun frame is defined as having all of the following:

- Was any data or MAC control frame that matched a unicast, broadcast, or multicast address, or matched due to promiscuous mode
- Was of any size (including less than 64-byte and greater than RXMAXLEN-byte frames)
- The EMAC was unable to receive it because it did not have the resources to receive it (cell FIFO full or no DMA buffer available after the frame was successfully started - no SOF overrun).

CRC errors, alignment errors, and code errors have no effect on this statistic.

19.3.3.50.36 Receive DMA Overruns Register (RXDMAOVERRUNS)

The total number of frames received on the EMAC that had either a DMA start of frame (SOF) overrun or a DMA middle of frame (MOF) overrun. A receive DMA overrun frame is defined as having all of the following:

- Was any data or MAC control frame that matched a unicast, broadcast, or multicast address, or matched due to promiscuous mode
- Was of any size (including less than 64-byte and greater than RXMAXLEN-byte frames)
- The EMAC was unable to receive it because it did not have the DMA buffer resources to receive it (zero head descriptor pointer at the start or during the middle of the frame reception).

CRC errors, alignment errors, and code errors have no effect on this statistic.

External Memory Interface A (EMIFA)

This chapter describes the external memory interface A (EMIFA).

The EMIFA SDRAM interface is not supported on all devices, see your device-specific data manual to see if the EMIFA SDRAM is supported on your device.

Topic **Page**

20.1 Introduction

20.1.1 Purpose of the Peripheral

EMIFA memory controller is complaint with the JESD21-C SDR SDRAM memories utilizing 16-bit data bus of EMIFA memory controller. The purpose of this EMIFA is to provide a means for the CPU to connect to a variety of external devices including:

- Single data rate (SDR) SDRAM
- Asynchronous devices including NOR Flash, NAND Flash, and SRAM

The most common use for the EMIFA is to interface with both a flash device and an SDRAM device simultaneously. Section 20.3 contains an example of operating the EMIFA in this configuration.

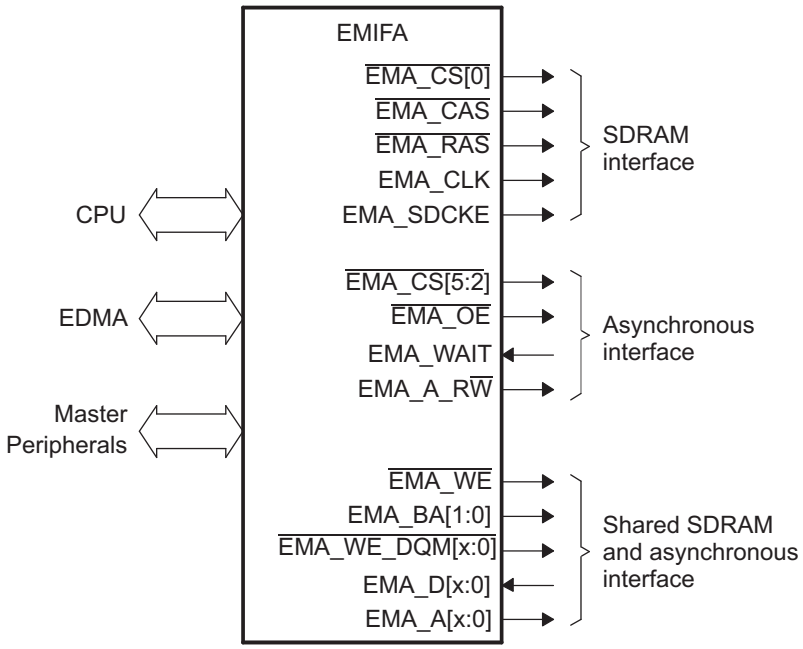
20.1.2 Features

The EMIFA includes many features to enhance the ease and flexibility of connecting to external SDR SDRAM and asynchronous devices. For details on features of EMIFA, see your device-specific data manual.

20.1.3 Functional Block Diagram

Figure 20-1 illustrates the connections between the EMIFA and its internal requesters, along with the external EMIFA pins. Section 20.2.2 contains a description of the entities internal to the SoC that can send requests to the EMIFA, along with their prioritization. Section 20.2.3 describes the EMIFA external pins and summarizes their purpose when interfacing with SDRAM and asynchronous devices.

Figure 20-1. EMIFA Functional Block Diagram



20.2 Architecture

This section provides details about the architecture and operation of the EMIFA. Both, SDRAM and asynchronous interface are covered, along with other system-related issues such as clock control and pin multiplexing.

The EMIFA SDRAM interface is not supported on all devices, see your device-specific data manual to see if the EMIFA SDRAM is supported on your device.

20.2.1 Clock Control

The EMIFA clock is output on the EMA_CLK pin and should be used when interfacing to external memories. The EMIFA clock (EMA_CLK) does not run during device reset. When the RESET pin is released and after the PLL controller releases the device from reset, EMA_CLK begins to oscillate at a frequency determined by the PLL controller.

For details on clock generation and control, see the *Device Clocking* chapter.

20.2.2 EMIFA Requests

Different sources within the SoC can make requests to the EMIFA. These requests consist of accesses to SDRAM memory, asynchronous memory, and EMIFA registers. Because the EMIFA can process only one request at a time, a high performance crossbar switch exists within the SoC to provide prioritized requests from the different sources to the EMIFA. The sources are:

1. CPU
2. EDMA
3. Other master peripherals

If a request is submitted from two or more sources simultaneously, the crossbar switch will forward the highest priority request to the EMIFA first. Upon completion of a request, the crossbar switch again evaluates the pending requests and forwards the highest priority pending request to the EMIFA.

When the EMIFA receives a request, it may or may not be immediately processed. In some cases, the EMIFA will perform one or more auto refresh cycles before processing the request. For details on the EMIFA's internal arbitration between performing requests and performing auto refresh cycles, see Section 20.2.12.

20.2.3 Pin Descriptions

This section describes the function of each of the EMIFA pins.

Table 20-1. EMIFA Pins Used to Access Both SDRAM and Asynchronous Memories

Pins(s)	I/O	Description
EMA_D[x:0]	I/O	**EMIFA data bus.** The number of available data bus pins varies among devices, see your device-specific data manual for details.
EMA_ A[x:0]	O	**EMIFA address bus.** The number of available address pins varies among devices, see your device-specific data manual for details. When interfacing to an SDRAM device, these pins are primarily used to provide the row and column address to the SDRAM. The mapping from the internal program address to the external values placed on these pins can be found in Section 20.2.4.11. EMA_A[10] is also used during the PRE command to select which banks to deactivate. When interfacing to an asynchronous device, these pins are used in conjunction with the EMA_BA pins to form the address that is sent to the device. The mapping from the internal program address to the external values placed on these pins can be found in Section 20.2.5.1.
EMA_BA[1:0]	O	**EMIFA bank address.** When interfacing to an SDRAM device, these pins are used to provide the bank address inputs to the SDRAM. The mapping from the internal program address to the external values placed on these pins can be found in Section 20.2.4.11. When interfacing to an asynchronous device, these pins are used in conjunction with the EMA_A pins to form the address that is sent to the device. The mapping from the internal program address to the external values placed on these pins can be found in Section 20.2.5.1.
$\overline{\text{EMA\_WE\_DQM[x:0]}}$	O	**Active-low byte enables.** When interfacing to SDRAM, these pins are connected to the DQM pins of the SDRAM to individually enable/disable each of the bytes in a data access. When interfacing to an asynchronous device, these pins are connected to byte enables. See Section 20.2.5 for details.
$\overline{\text{EMA\_WE}}$	O	**Active-low write enable.** When interfacing to SDRAM, this pin is connected to the $\overline{\text{WE}}$ pin of the SDRAM and is used to send commands to the device. When interfacing to an asynchronous device, this pin provides a signal which is active-low during the strobe period of an asynchronous write access cycle.

Table 20-2. EMIFA Pins Specific to SDRAM

Pin(s)	I/O	Description
EMA_CS[0]	O	**Active-low chip enable pin for SDRAM devices.** This pin is connected to the chip-select pin of the attached SDRAM device and is used for enabling/disabling commands. By default, the EMIFA keeps this SDRAM chip select active, even if the EMIFA is not interfaced with an SDRAM device. This pin is deactivated when accessing the asynchronous memory bank and is reactivated on completion of the asynchronous assess.
EMA_RAS	O	**Active-low row address strobe pin.** This pin is connected to the RAS pin of the attached SDRAM device and is used for sending commands to the device.
EMA_CAS	O	**Active-low column address strobe pin.** This pin is connected to the CAS pin of the attached SDRAM device and is used for sending commands to the device.
EMA_SDCKE	O	**Clock enable pin.** This pin is connected to the CKE pin of the attached SDRAM device and is used for issuing the SELF REFRESH command which places the device in self refresh mode. See Section 20.2.4.7 for details.
EMA_CLK	O	**SDRAM clock pin.** This pin is connected to the CLK pin of the attached SDRAM device. See Section 20.2.1 for details on the clock signal.

Table 20-3. EMIFA Pins Specific to Asynchronous Memory

Pin(s)	I/O	Description
EMA_CS[5:2]	O	**Active-low chip enable pins for asynchronous devices.** These pins are meant to be connected to the chip-select pins of the attached asynchronous device. These pins are active only during accesses to the asynchronous memory.
EMA_WAIT	I	**Wait input with programmable polarity / NAND Flash ready input.** Not all devices support both EMA_WAIT[1] and EMA_WAIT[0], see your device-specific data manual to determine support on each device. A connected asynchronous device can extend the strobe period of an access cycle by asserting the EMA_WAIT input to the EMIFA as described in Section 20.2.5.7. To enable this functionality, the EW bit in the asynchronous *n* configuration register (CE*n*CFG) must be set to 1. The WP0 and WP1 bits in the asynchronous wait cycle configuration register (AWCC) must be configured to define the polarity of the EMA_WAIT pin. The CS*n*_WAIT bit in AWCC must also be configured to determine which EMA_WAIT[*n*] signal is used for memory accesses. When the CS2NAND/CS3NAND/CS4NAND/CS5NAND bit in the NAND Flash control register (NANDFCR) is set, this pin instead functions as a NAND Flash ready input.
EMA_OE	O	**Active-low pin enable for asynchronous devices.** This pin provides a signal which is active-low during the strobe period of an asynchronous read access cycle.
EMA_A_RW	O	**EMIFA asynchronous read/write control.** This pin stays high during reads and stays low during writes (same duration as CS).

20.2.4 SDRAM Controller and Interface

The EMIFA can gluelessly interface to most standard SDR SDRAM devices and supports such features as self refresh mode and prioritized refresh. In addition, it provides flexibility through programmable parameters such as the refresh rate, CAS latency, and many SDRAM timing parameters. The following sections include details on how to interface and properly configure the EMIFA to perform read and write operations to externally connected SDR SDRAM devices. Also, Section 20.3 provides a detailed example of interfacing the EMIFA to a common SDRAM device.

20.2.4.1 SDRAM Commands

The EMIFA supports the SDRAM commands described in Table 20-4. The truth table for the SDRAM commands is shown in Table 20-5 and an example timing waveform of the PRE command is shown in Figure 20-2. EMA_A[10] is pulled low in this example to deactivate only the bank specified by the EMA_BA pins.

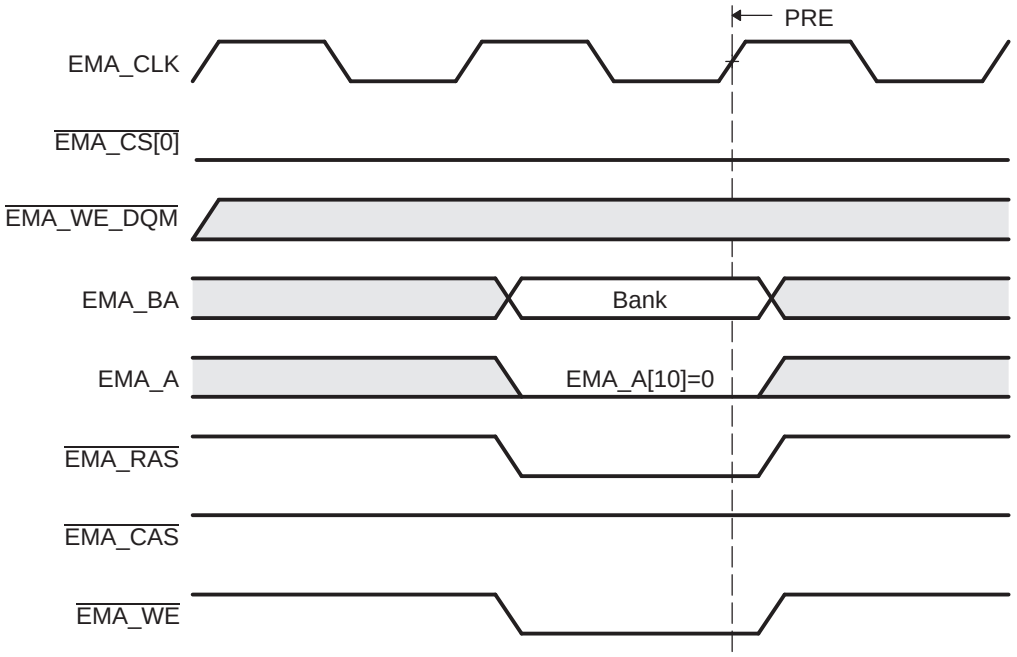
Table 20-4. EMIFA SDRAM Commands

Command	Function
PRE	**Precharge.** Depending on the value of EMA_A[10], the PRE command either deactivates the open row in all banks (EMA_A[10] = 1) or only the bank specified by the EMA_BA[1:0] pins (EMA_A[10] = 0).
ACTV	**Activate**. The ACTV command activates the selected row in a particular bank for the current access.
READ	**Read.** The READ command outputs the starting column address and signals the SDRAM to begin the burst read operation. Address EMA_A[10] is always pulled low to avoid auto precharge. This allows for better bank interleaving performance.
WRT	**Write.** The WRT command outputs the starting column address and signals the SDRAM to begin the burst write operation. Address EMA_A[10] is always pulled low to avoid auto precharge. This allows for better bank interleaving performance.
BT	**Burst terminate**. The BT command is used to truncate the current read or write burst request.
LMR	**Load mode register**. The LMR command sets the mode register of the attached SDRAM devices and is only issued during the SDRAM initialization sequence described in Section 20.2.4.4.
REFR	**Auto refresh**. The REFR command signals the SDRAM to perform an auto refresh according to its internal address.
SLFR	**Self refresh**. The self refresh command places the SDRAM into self refresh mode, during which it provides its own clock signal and auto refresh cycles.
NOP	**No operation**. The NOP command is issued during all cycles in which one of the above commands is not issued.

Table 20-5. Truth Table for SDRAM Commands

SDRAM Pins:	CKE	$\overline{CS}$	$\overline{RAS}$	$\overline{CAS}$	$\overline{WE}$	BA[1:0]	A[12:11]	A[10]	A[9:0]
EMIFA Pins:	**EMA_SDCKE**	**$\overline{EMA\_CS[0]}$**	**$\overline{EMA\_RAS}$**	**$\overline{EMA\_CAS}$**	**$\overline{EMA\_WE}$**	**EMA_BA[1:0]**	**EMA_A[12:11]**	**EMA_A[10]**	**EMA_A[9:0]**
PRE	H	L	L	H	L	Bank/X	X	L/H	X
ACTV	H	L	L	H	H	Bank	Row	Row	Row
READ	H	L	H	L	H	Bank	Column	L	Column
WRT	H	L	H	L	L	Bank	Column	L	Column
BT	H	L	H	H	L	X	X	X	X
LMR	H	L	L	L	L	X	Mode	Mode	Mode
REFR	H	L	L	L	H	X	X	X	X
SLFR	L	L	L	L	H	X	X	X	X
NOP	H	L	H	H	H	X	X	X	X

Figure 20-2. Timing Waveform of SDRAM PRE Command



20.2.4.2 Interfacing to SDRAM

The EMIFA supports a glueless interface to SDRAM devices with the following characteristics:

- Pre-charge bit is A[10]
- The number of column address bits is 8, 9, 10, or 11. See your device-specific data manual for the number of column address bits supported on your device.
- The number of row address bits is 13, 14, 15, or 16. See your device-specific data manual for the number of row address bits supported on your device.
- The number of internal banks is 1, 2, or 4. See your device-specific data manual for the number of internal banks supported on your device.

Figure 20-3 shows an interface between the EMIFA and a 2M × 16 × 4 bank SDRAM device, and Figure 20-4 shows an interface between the EMIFA and a 512K × 16 × 2 bank SDRAM device. For devices supporting 16-bit interface, refer to Table 20-6 for list of commonly-supported SDRAM devices and the required connections for the address pins.

Figure 20-3. EMIFA to 2M × 16 × 4 bank SDRAM Interface

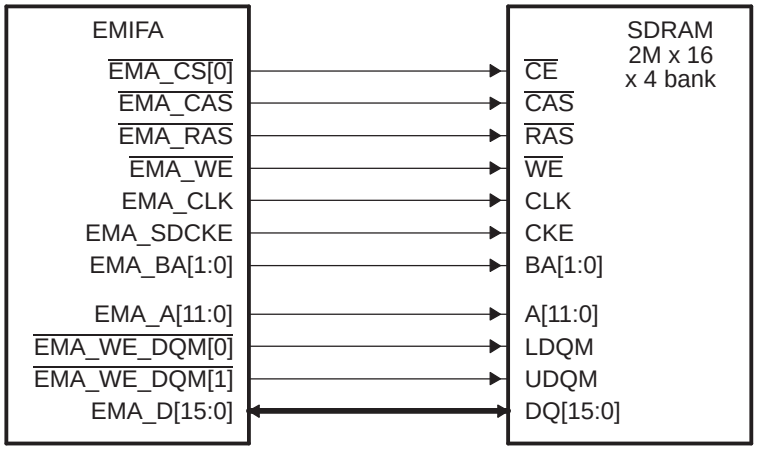


Figure 20-4. EMIFA to 512K × 16 × 2 bank SDRAM Interface

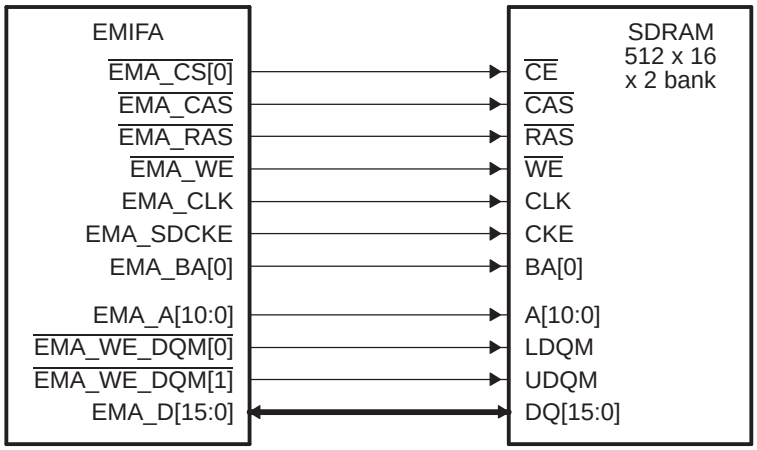


Table 20-6. 16-bit EMIFA Address Pin Connections

SDRAM Size	Width	Banks	Device	Address Pins
16M bits	×16	2	SDRAM	A[10:0]
			EMIFA	EMA_A[10:0]
64M bits	×16	4	SDRAM	A[11:0]
			EMIFA	EMA_A[11:0]
128M bits	×16	4	SDRAM	A[11:0]
			EMIFA	EMA_A[11:0]
256M bits	x16	4	SDRAM	A[12:0]
			EMIFA	EMA_A[12:0]
512M bits	x16	4	SDRAM	A[12:0]
			EMIFA	EMA_A[12:0]

20.2.4.3 SDRAM Configuration Registers

The operation of the EMIFA's SDRAM interface is controlled by programming the appropriate configuration registers. This section describes the purpose and function of each configuration register, but Section 20.4 should be referred for a more detailed description of each register, including the default registers values and bit-field positions. The following tables list the four such configuration registers, along with a description of each of their programmable fields.

NOTE: Writing to any of the fields: NM, CL, IBANK, and PAGESIZE in the SDRAM configuration register (SDCR) causes the EMIFA to abandon whatever it is currently doing and trigger the SDRAM initialization procedure described in Section 20.2.4.4.

Table 20-7. Description of the SDRAM Configuration Register (SDCR)

Parameter	Description
SR	This bit controls entering and exiting of the Self-Refresh mode. The field should be written using a byte-write to the upper byte of SDCR to avoid triggering the SDRAM initialization sequence.
PD	This bit controls entering and exiting of the Power down mode. The field should be written using a byte-write to the upper byte of SDCR to avoid triggering the SDRAM initialization sequence. If both SR and PD bits are set, the EMIFA will go into Self Refresh.
PDWR	Perform refreshes during Power Down. Writing a 1 to this bit will cause the EMIFA to exit the power down state and issue an AUTO REFRESH command every time Refresh May level is set. The field should be written using a byte-write to the upper byte of SDCR to avoid triggering the SDRAM initialization sequence. This bit should be set along with PD when entering power-down mode.
NM	**Narrow Mode.** This bit defines the width of the data bus between the EMIFA and the attached SDRAM device. When set to 1, the data bus is set to 16-bits. When set to 0, the data bus is set to 32-bits. This bit must always be set to 1.
CL	**CAS latency.** This field defines the number of clock cycles between when an SDRAM issues a READ command and when the first piece of data appears on the bus. The value in this field is sent to the attached SDRAM device via the LOAD MODE REGISTER command during the SDRAM initialization procedure as described in Section 20.2.4.4. Only, values of 2h (CAS latency = 2) and 3h (CAS latency = 3) are supported and should be written to this field. A 1 must be simultaneously written to the BIT11_9LOCK bit field of SDCR in order to write to the CL bit field.
IBANK	**Number of Internal SDRAM Banks.** This field defines the number of banks inside the attached SDRAM devices in the following way: • When IBANK = 0, 1 internal bank is used • When IBANK = 1h, 2 internal banks are used • When IBANK = 2h, 4 internal banks are used This field value affects the mapping of logical addresses to SDRAM row, column, and bank addresses. See Section 20.2.4.11 for details.
PAGESIZE	**Page Size.** This field defines the internal page size of the attached SDRAM devices in the following way: • When PAGESIZE = 0, 256-word pages are used • When PAGESIZE = 1h, 512-word pages are used • When PAGESIZE = 2h, 1024-word pages are used • When PAGESIZE = 3h, 2048-word pages are used This field value affects the mapping of logical addresses to SDRAM row, column, and bank addresses. See Section 20.2.4.11 for details.

Table 20-8. Description of the SDRAM Refresh Control Register (SDRCR)

Parameter	Description
RR	**Refresh Rate**. This field controls the rate at which attached SDRAM devices will be refreshed. The following equation can be used to determine the required value of RR for an SDRAM device: • RR = f_{EMA_CLK} / (Required SDRAM Refresh Rate) More information about the operation of the SDRAM refresh controller can be found in Section 20.2.4.6.

Table 20-9. Description of the SDRAM Timing Register (SDTIMR)

Parameter	Description
T_RFC T_RP T_RCD T_WR T_RAS T_RC T_RRD	**SDRAM Timing Parameters.** These fields configure the EMIFA to comply with the AC timing requirements of the attached SDRAM devices. This allows the EMIFA to avoid violating SDRAM timing constraints and to more efficiently schedule its operations. More details about each of these parameters can be found in the register description in Section 20.4.6. These parameters should be set to satisfy the corresponding timing requirements found in the SDRAM's datasheet.

Table 20-10. Description of the SDRAM Self Refresh Exit Timing Register (SDSRETR)

Parameter	Description
T_XS	**Self Refresh Exit Parameter.** The T_XS field of this register informs the EMIFA about the minimum number of EMA_CLK cycles required between exiting Self Refresh and issuing any command. This parameter should be set to satisfy the t_{XSR} value for the attached SDRAM device.

20.2.4.4 SDRAM Auto-Initialization Sequence

The EMIFA automatically performs an SDRAM initialization sequence, regardless of whether it is interfaced to an SDRAM device, when either of the following two events occur:

- The EMIFA comes out of reset. No memory accesses to the SDRAM and Asynchronous interfaces are performed until this auto-initialization is complete.
- A write is performed to any of the three least significant bytes of the SDRAM configuration register (SDCR)

An SDRAM initialization sequence consists of the following steps:

1. If the initialization sequence is activated by a write to SDCR, and if any of the SDRAM banks are open, the EMIFA issues a PRE command with EMA_A[10] held high to indicate all banks. This is done so that the maximum ACTV to PRE timing for an SDRAM is not violated.
2. The EMIFA drives EMA_SDCKE high and begins continuously issuing NOP commands until eight SDRAM refresh intervals have elapsed. An SDRAM refresh interval is equal to the value of the RR field of SDRAM refresh control register (SDRCR), divided by the frequency of EMA_CLK (RR/f_{EMA_CLK}). This step is used to avoid violating the Power-up constraint of most SDRAM devices that requires 200 µs (sometimes 100 µs) between receiving stable Vdd and CLK and the issuing of a PRE command. Depending on the frequency of EMA_CLK, this step may or may not be sufficient to avoid violating the SDRAM constraint. See Section 20.2.4.5 for more information.
3. After the refresh intervals have elapsed, the EMIFA issues a PRE command with EMA_A[10] held high to indicate all banks.
4. The EMIFA issues eight AUTO REFRESH commands.
5. The EMIFA issues the LMR command with the EMA_A[9:0] pins set as described in Table 20-11.
6. Finally, the EMIFA performs a refresh cycle, which consists of the following steps:

   (a) Issuing a PRE command with EMA_A[10] held high if any banks are open

   (b) Issuing an REF command

Table 20-11. SDRAM LOAD MODE REGISTER Command

EMA_A[9:7]	EMA_A[6:4]	EMA_A[3]	EMA_A[2:0]
0 (Write bursts are of the programmed burst length in EMA_A[2:0])	These bits control the CAS latency of the SDRAM and are set according to CL field in the SDRAM configuration register (SDCR) as follows: • If CL = 2, EMA_A[6:4] = 2h (CAS latency = 2) • If CL = 3, EMA_A[6:4] = 3h (CAS latency = 3)	0 (Sequential Burst Type. Interleaved Burst Type not supported)	These bits control the burst length of the SDRAM and are set according to the NM field in the SDRAM configuration register (SDCR) as follows: • If NM = 0, EMA_A[2:0] = 2h (Burst Length = 4) • If NM = 1, EMA_A[2:0] = 3h (Burst Length = 8)

20.2.4.5 SDRAM Configuration Procedure

There are two different SDRAM configuration procedures. Although EMIFA automatically performs the SDRAM initialization sequence described in Section 20.2.4.4 when coming out of reset, it is recommended to follow one of the procedures listed below before performing any EMIFA memory requests. Procedure A should be followed if it is determined that the SDRAM Power-up constraint was not violated during the SDRAM Auto-Initialization Sequence detailed in Section 20.2.4.4 on coming out of Reset. The SDRAM Power-up constraint specifies that 200 µs (sometimes 100 µs) should exits between receiving stable Vdd and CLK and the issuing of a PRE command. Procedure B should be followed if the SDRAM Power-up constraint was violated. The 200 µs (100 µs) SDRAM Power-up constraint will be violated if the frequency of EMA_CLK is greater than 50 MHz (100 MHz for 100 µs SDRAM power-up constraint) during SDRAM Auto-Initialization Sequence. Procedure B should be followed if there is any doubt that the Power-up constraint was met.

Procedure A — Following is the procedure to be followed if the SDRAM Power-up constraint was NOT violated:

1. Place the SDRAM into Self-Refresh Mode by setting the SR bit of SDCR to 1. A byte-write to the upper byte of SDCR should be used to avoid restarting the SDRAM Auto-Initialization Sequence described in Section 20.2.4.4. The SDRAM should be placed into Self-Refresh mode when changing the frequency of EMA_CLK to avoid incurring the 200 µs Power-up constraint again.
2. Program the CPU's PLL Controller to provide the desired EMA_CLK clock frequency. Refer to the device Data Manual for details on programming the PLL Controller. The frequency of the memory clock must meet the timing requirements in the SDRAM manufacturer's documentation and the timing limitations shown in the electrical specifications of the device Data Manual.
3. Remove the SDRAM from Self-Refresh Mode by clearing the SR bit of SDCR to 0. A byte-write to the upper byte of SDCR should be used to avoid restarting the SDRAM Auto-Initialization Sequence described in Section 20.2.4.4.
4. Program SDTIMR and SDSRETR to satisfy the timing requirements for the attached SDRAM device. The timing parameters should be taken from the SDRAM datasheet.
5. Program the RR field of SDRCR to match that of the attached device's refresh interval. See Section 20.2.4.6.1 details on determining the appropriate value.
6. Program SDCR to match the characteristics of the attached SDRAM device. This will cause the auto-initialization sequence in Section 20.2.4.4 to be re-run. This second initialization generally takes much less time due to the increased frequency of EMA_CLK.

Procedure B — Following is the procedure to be followed if the SDRAM Power-up constraint was violated:

1. Program the CPU's PLL Controller to provide the desired EMA_CLK clock frequency. Refer to the device Data Manual for details on programming the PLL Controller. The frequency of the memory clock must meet the timing requirements in the SDRAM manufacturer's documentation and the timing limitations shown in the electrical specifications of the device Data Manual.
2. Program SDTIMR and SDSRETR to satisfy the timing requirements for the attached SDRAM device. The timing parameters should be taken from the SDRAM datasheet.

3. Program the RR field of SDRCR such that the following equation is satisfied: (RR × 8)/(f_{EMA_CLK}) > 200 µs (sometimes 100 µs). For example, an EMA_CLK frequency of 100 MHz would require setting RR to 2501 (9C5h) or higher to meet a 200 µs constraint.
4. Program SDCR to match the characteristics of the attached SDRAM device. This will cause the auto-initialization sequence in Section 20.2.4.4 to be re-run with the new value of RR.
5. Perform a read from the SDRAM to assure that step 5 of this procedure will occur after the initialization process has completed. Alternatively, wait for 200 µs instead of performing a read.
6. Finally, program the RR field to match that of the attached device's refresh interval. See Section 20.2.4.6.1 details on determining the appropriate value.

After following the above procedure, the EMIFA is ready to perform accesses to the attached SDRAM device. See Section 20.3 for an example of configuring the SDRAM interface.

20.2.4.6 EMIFA Refresh Controller

An SDRAM device requires that each of its rows be refreshed at a minimum required rate. The EMIFA can meet this constraint by performing auto refresh cycles at or above this required rate. An auto refresh cycle consists of issuing a PRE command to all banks of the SDRAM device followed by issuing a REFR command. To inform the EMIFA of the required rate for performing auto refresh cycles, the RR field of the SDRAM refresh control register (SDRCR) must be programmed. The EMIFA will use this value along with two internal counters to automatically perform auto refresh cycles at the required rate. The auto refresh cycles cannot be disabled, even if the EMIFA is not interfaced with an SDRAM. The remainder of this section details the EMIFA's refresh scheme and provides an example for determining the appropriate value to place in the RR field of SDRCR.

The two counters used to perform auto-refresh cycles are a 13-bit refresh interval counter and a 4-bit refresh backlog counter. At reset and upon writing to the RR field, the refresh interval counter is loaded with the value from RR field and begins decrementing, by one, each EMIFA clock cycle. When the refresh interval counter reaches zero, the following actions occur:

- The refresh interval counter is reloaded with the value from the RR field and restarts decrementing.
- The 4-bit refresh backlog counter increments unless it has already reached its maximum value.

The refresh backlog counter records the number of auto refresh cycles that the EMIFA currently has outstanding. This counter is decremented by one each time an auto refresh cycle is performed and incremented by one each time the refresh interval counter expires. The refresh backlog counter saturates at the values of 0000b and 1111b. The EMIFA uses the refresh backlog counter to determine the urgency with which an auto refresh cycle should be performed. The four levels of urgency are described in Table 20-12. This refresh scheme allows the required refreshes to be performed with minimal impact on access requests.

Table 20-12. Refresh Urgency Levels

Urgency Level	Refresh Backlog Counter Range	Action Taken
Refresh May	1-3	An auto-refresh cycle is performed only if the EMIFA has no requests pending and none of the SDRAM banks are open.
Refresh Release	4-7	An auto-refresh cycle is performed if the EMIFA has no requests pending, regardless of whether any SDRAM banks are open.
Refresh Need	8-11	An auto-refresh cycle is performed at the completion of the current access unless there are read requests pending.
Refresh Must	12-15	Multiple auto-refresh cycles are performed at the completion of the current access until the Refresh Release urgency level is reached. At that point, the EMIFA can begin servicing any new read or write requests.

20.2.4.6.1 Determining the Appropriate Value for the RR Field

The value that should be programmed into the RR field of SDRCR can be calculated by using the frequency of the EMA_CLK signal (f_{EMA_CLK}) and the required refresh rate of the SDRAM ($f_{Refresh}$). The following formula can be used:

$RR = f_{EMA\_CLK} / f_{Refresh}$

The SDRAM datasheet often communicates the required SDRAM Refresh Rate in terms of the number of REFR commands required in a given time interval. The required SDRAM Refresh Rate in the formula above can therefore be calculated by dividing the number of required cycles per time interval (n_{cycles}) by the time interval given in the datasheet ($t_{Refresh\ Period}$) :

$f_{Refresh} = n_{cycles} / t_{Refresh\ Period}$

Combining these formulas, the value that should be programmed into the RR field can be computed as:

$RR = f_{EMA\_CLK} \times t_{Refresh\ Period} / n_{cycles}$

The following example illustrates calculating the value of RR. Given that:

- f_{EMA_CLK} = 100 MHz (frequency of the EMIFA clock)
- $t_{Refresh\ Period}$ = 64 ms (required refresh interval of the SDRAM)
- n_{cycles} = 8192 (number of cycles in a refresh interval for the SDRAM)

RR can be calculated as:

RR = 100 MHz × 64 ms/8192

RR = 781.25

RR = 782 cycles = 30Eh cycles

20.2.4.7 Self-Refresh Mode

The EMIFA can be programmed to enter the self-refresh state by setting the SR bit of SDCR to 1. This will cause the EMIFA to issue the SLFR command after completing any outstanding SDRAM access requests and clearing the refresh backlog counter by performing one or more auto refresh cycles. This places the attached SDRAM device into self-refresh mode in which it consumes a minimal amount of power while performing its own refresh cycles. The SR bit should be set and cleared using a byte-write to the upper byte of the SDRAM configuration register (SDCR) to avoid triggering the SDRAM initialization sequence.

While in the self-refresh state, the EMIFA continues to service asynchronous bank requests and register accesses as normal, with one caveat. The EMIFA will not park the data bus following a read to asynchronous memory while in the self-refresh state. Instead, the EMIFA tri-states the data bus. Therefore, it is not recommended to perform asynchronous read operations while the EMIFA is in the self-refresh state, in order to prevent floating inputs on the data bus. More information about data bus parking can be found in Section 20.2.6.

The EMIFA will exit from the self-refresh state if either of the following events occur:

- The SR bit of SDCR is cleared to 0.
- An SDRAM accesses is requested.

The EMIFA exits from the self-refresh state by driving EMA_SDCKE high and performing an auto refresh cycle.

The attached SDRAM device should also be placed into Self-Refresh Mode when changing the frequency of EMA_CLK using the PLL Controller. If the frequency of EMA_CLK changes while the SDRAM is not in Self-Refresh Mode, Procedure B in Section 20.2.4.5 should be followed to reinitialize the device.

20.2.4.8 Power Down Mode

To support low-power modes, the EMIFA can be requested to issue a POWER DOWN command to the SDRAM by setting the PD bit in the SDRAM configuration register (SDCR). When this bit is set, the EMIFA will continue normal operation until all outstanding memory access requests have been serviced and the SDRAM refresh backlog (if there is one) has been cleared. At this point the EMIFA will enter the power-down state. Upon entering this state, the EMIFA will issue a POWER DOWN command (same as a NOP command but driving EMA_SDCKE low on the same cycle). The EMIFA then maintains EMA_SDCKE low until it exits the power-down state.

Since the EMIFA services the refresh backlog before it enters the power-down state, all internal banks of the SDRAM are closed (precharged) prior to issuing the POWER DOWN command. Therefore, the EMIFA only supports Precharge Power Down. The EMIFA does not support Active Power Down, where internal banks of the SDRAM are open (active) before the POWER DOWN command is issued.

During the power-down state, the EMIFA services the SDRAM, asynchronous memory, and register accesses as normal, returning to the power-down state upon completion.

The PDWR bit in SDCR indicates whether the EMIFA should perform refreshes in power-down state. If the PDWR bit is set, the EMIFA exits the power-down state every time the Refresh Must level is set, performs AUTO REFRESH commands to the SDRAM, and returns back to the power-down state. This evenly distributes the refreshes to the SDRAM in power-down state. If the PDWR bit is not set, the EMIFA does not perform any refreshes to the SDRAM. Therefore, the data integrity of the SDRAM is not assured upon power down exit if the PDWR bit is not set.

If the PD bit is cleared while in the power-down state, the EMIFA will come out of the power-down state. The EMIFA:

- Drives EMA_SDCKE high.
- Enters its idle state.

20.2.4.9 SDRAM Read Operation

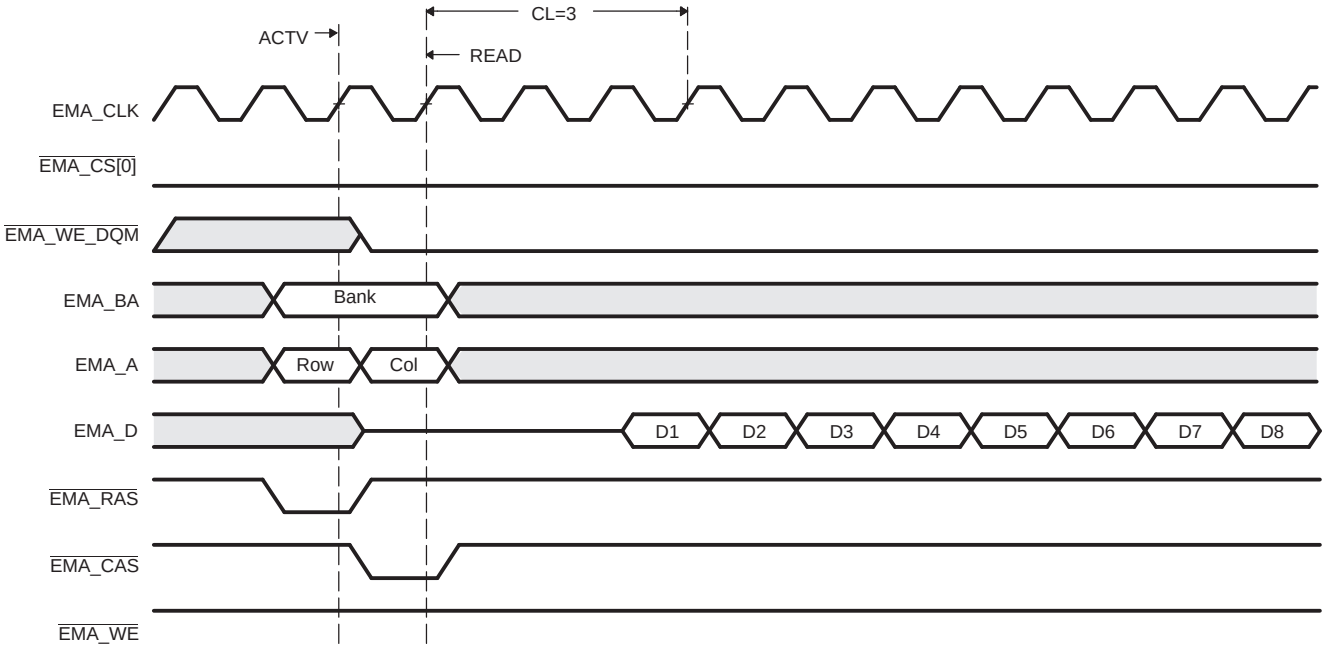
When the EMIFA receives a read request to SDRAM from one of the requesters listed in Section 20.2.2, it performs one or more read access cycles. A read access cycle begins with the issuing of the ACTV command to select the desired bank and row of the SDRAM device. After the row has been opened, the EMIFA proceeds to issue a READ command while specifying the desired bank and column address. EMA_A[10] is held low during the READ command to avoid auto-precharging. The READ command signals the SDRAM device to start bursting data from the specified address while the EMIFA issues NOP commands. Following a READ command, the CL field of the SDRAM configuration register (SDCR) defines how many delay cycles will be present before the read data appears on the data bus. This is referred to as the CAS latency.

Figure 20-5 shows the signal waveforms for a basic SDRAM read operation in which a burst of data is read from a single page. When the EMIFA SDRAM interface is configured to 16 bit by setting the NM bit of the SDRAM configuration register (SDCR) to 1, a burst size of eight is used. Figure 20-5 shows a burst size of eight.

The EMIFA will truncate a series of bursting data if the remaining addresses of the burst are not required to complete the request. The EMIFA can truncate the burst in three ways:

- By issuing another READ to the same page in the same bank.
- By issuing a PRE command in order to prepare for accessing a different page of the same bank.
- By issuing a BT command in order to prepare for accessing a page in a different bank.

Figure 20-5. Timing Waveform for Basic SDRAM Read Operation



Several other pins are also active during a read access. The EMA_WE_DQM[1:0] pins are driven low during the READ commands and are kept low during the NOP commands that correspond to the burst request. The state of the other EMIFA pins during each command can be found in Table 20-5.

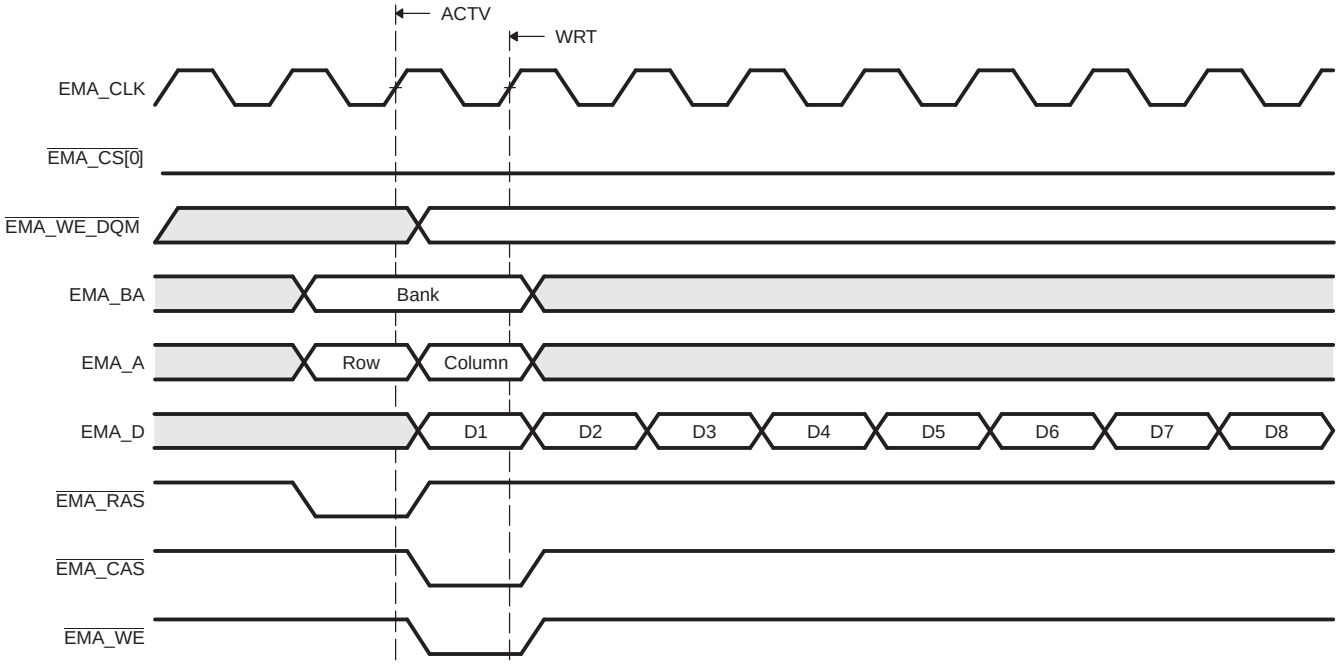
The EMIFA schedules its commands based on the timing information that is provided to it in the SDRAM timing register (SDTIMR). The values for the timing parameters in this register should be chosen to satisfy the timing requirements listed in the SDRAM datasheet. The EMIFA uses this timing information to avoid violating any timing constraints related to issuing commands. This is commonly accomplished by inserting NOP commands between various commands during an access. Refer to the register description of SDTIMR in Section 20.4.6 for more details on the various timing parameters.

20.2.4.10 SDRAM Write Operations

When the EMIFA receives a write request to SDRAM from one of the requesters listed in Section 20.2.2, it performs one or more write-access cycles. A write-access cycle begins with the issuing of the ACTV command to select the desired bank and row of the SDRAM device. After the row has been opened, the EMIFA proceeds to issue a WRT command while specifying the desired bank and column address. EMA_A[10] is held low during the WRT command to avoid auto-precharging. The WRT command signals the SDRAM device to start writing a burst of data to the specified address while the EMIFA issues NOP commands. The associated write data will be placed on the data bus in the cycle concurrent with the WRT command and with subsequent burst continuation NOP commands.

Figure 20-6 shows the signal waveforms for a basic SDRAM write operation in which a burst of data is read from a single page. When the EMIFA SDRAM interface is configured to 16-bit by setting the NM bit of the SDRAM configuration register (SDCR) to 1, a burst size of eight is used. Figure 20-6 shows a burst size of eight.

Figure 20-6. Timing Waveform for Basic SDRAM Write Operation



The EMIFA will truncate a series of bursting data if the remaining addresses of the burst are not part of the write request. The EMIFA can truncate the burst in three ways:

- By issuing another WRT to the same page
- By issuing a PRE command in order to prepare for accessing a different page of the same bank
- By issuing a BT command in order to prepare for accessing a page in a different bank

Several other pins are also active during a write access. The EMA_WE_DQM[1:0] pins are driven to select which bytes of the data word will be written to the SDRAM device. They are also used to mask out entire undesired data words during a burst access. The state of the other EMIFA pins during each command can be found in Table 20-5.

The EMIFA schedules its commands based on the timing information that is provided to it in the SDRAM timing register (SDTIMR). The values for the timing parameters in this register should be chosen to satisfy the timing requirements listed in the SDRAM datasheet. The EMIFA uses this timing information to avoid violating any timing constraints related to issuing commands. This is commonly accomplished by inserting NOP commands during various cycles of an access. Refer to the register description of SDTIMR in Section 20.4.6 for more details on the various timing parameters.

20.2.4.11 Mapping from Logical Address to EMIFA Pins

When the EMIFA receives an SDRAM access request, it must convert the address of the access into the appropriate signals to send to the SDRAM device. The details of this address mapping are shown in Table 20-13 for 16-bit operation. Using the settings of the IBANK and PAGESIZE fields of the SDRAM configuration register (SDCR), the EMIFA determines which bits of the logical address are mapped to the SDRAM row, column, and bank addresses.

As the logical address is incremented by one halfword (16-bit operation), the column address is likewise incremented by one until a page boundary is reached. When the logical address increments across a page boundary, the EMIFA moves into the same page in the next bank of the attached device by incrementing the bank address EMA_BA and resetting the column address. The page in the previous bank is left open until it is necessary to close it. This method of traversal through the SDRAM banks helps maximize the number of open banks inside of the SDRAM and results in an efficient use of the device. There is no limitation on the number of banks that can be open at one time, but only one page within a bank can be open at a time.

The EMIFA uses the $\overline{\text{EMA\_WE\_DQM}}$ pins during a WRT command to mask out selected bytes or entire words. The $\overline{\text{EMA\_WE\_DQM}}$ pins are always low during a READ command.

Table 20-13. Mapping from Logical Address to EMIFA Pins for 16-bit SDRAM

		Logical Address													
IBANK	PAGESIZE	31:27	26	25	24	23	22	21:14	13	12	11	10	9	8:1	0
0	0	-						Row Address						Col Address	$\overline{\text{EMA\_WE\_DQM}}$[0]
1	0	-						Row Address					EMA_BA[0]	Col Address	$\overline{\text{EMA\_WE\_DQM}}$[0]
2	0	-						Row Address				EMA_BA[1:0]		Col Address	$\overline{\text{EMA\_WE\_DQM}}$[0]
0	1	-						Row Address					Column Address		$\overline{\text{EMA\_WE\_DQM}}$[0]
1	1	-						Row Address				EMA_BA[0]	Column Address		$\overline{\text{EMA\_WE\_DQM}}$[0]
2	1	-						Row Address			EMA_BA[1:0]		Column Address		$\overline{\text{EMA\_WE\_DQM}}$[0]
0	2	-						Row Address				Column Address			$\overline{\text{EMA\_WE\_DQM}}$[0]
1	2	-						Row Address			EMA_BA[0]	Column Address			$\overline{\text{EMA\_WE\_DQM}}$[0]
2	2	-						Row Address		EMA_BA[1:0]		Column Address			$\overline{\text{EMA\_WE\_DQM}}$[0]
0	3	-						Row Address			Column Address				$\overline{\text{EMA\_WE\_DQM}}$[0]
1	3	-						Row Address		EMA_BA[0]	Column Address				$\overline{\text{EMA\_WE\_DQM}}$[0]
2	3	-						Row Address		EMA_BA[1:0]	Column Address				$\overline{\text{EMA\_WE\_DQM}}$[0]

NOTE: The upper bit of the Row Address is used only when addressing 256-Mbit and 512-Mbit SDRAM memories.

20.2.5 Asynchronous Controller and Interface

The EMIFA easily interfaces to a variety of asynchronous devices including NOR Flash, NAND Flash, and SRAM. It can be operated in two major modes (see Table 20-14):

- Normal Mode
- Select Strobe Mode

Table 20-14. Normal Mode vs. Select Strobe Mode

Mode	Function of $\overline{\text{EMA\_WE\_DQM}}$ pins	Operation of $\overline{\text{EMA\_CS[5:2]}}$
Normal Mode	Byte enables	Active during the entire asynchronous access cycle
Select Strobe Mode	Byte enables	Active only during the strobe period of an access cycle

The first mode of operation is Normal Mode, in which the $\overline{\text{EMA\_WE\_DQM}}$ pins of the EMIFA function as byte enables. In this mode, the $\overline{\text{EMA\_CS[5:2]}}$ pins behaves as typical chip select signals, remaining active for the duration of the asynchronous access. See Section 20.2.5.1 for an example interface with multiple 8-bit devices.

The second mode of operation is Select Strobe Mode, in which the $\overline{\text{EMA\_CS[5:2]}}$ pins act as a strobe, active only during the strobe period of an access. In this mode, the $\overline{\text{EMA\_WE\_DQM}}$ pins of the EMIFA function as standard byte enables for reads and writes. A summary of the differences between the two modes of operation are shown in Table 20-14. Refer to Section 20.2.5.4 for the details of asynchronous operations in Normal Mode, and to Section 20.2.5.5 for the details of asynchronous operations in Select Strobe Mode. The EMIFA hardware defaults to Normal Mode, but can be manually switched to Select Strobe Mode by setting the SS bit in the asynchronous *m* (m = 1, 2, 3, or 4) configuration register (CE*n*CFG) (*n* = 2, 3, 4, or 5). Throughout the chapter, *m* can hold the values 1, 2, 3 or 4; and *n* can hold the values 2, 3, 4, or 5.

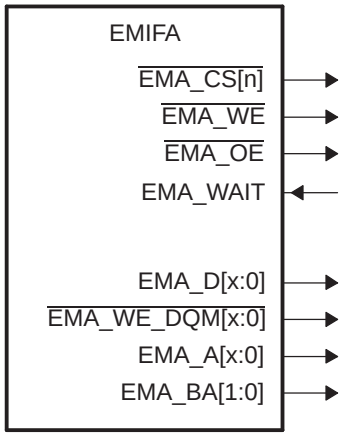
In both Normal Mode and Select Strobe Mode, the EMIFA can be configured to operate in a sub-mode called NAND Flash Mode. In NAND Flash Mode, the EMIFA is able to calculate an error correction code (ECC) for transfers up to 518 bytes.

The EMIFA also provides configurable cycle timing parameters and an Extended Wait Mode that allows the connected device to extend the strobe period of an access cycle. The following sections describe the features related to interfacing with external asynchronous devices.

20.2.5.1 Interfacing to Asynchronous Memory

Figure 20-7 shows the EMIFA's external pins used in interfacing with an asynchronous device. In $\overline{\text{EMA\_CS[n]}}$, n = 2, 3, 4, or 5.

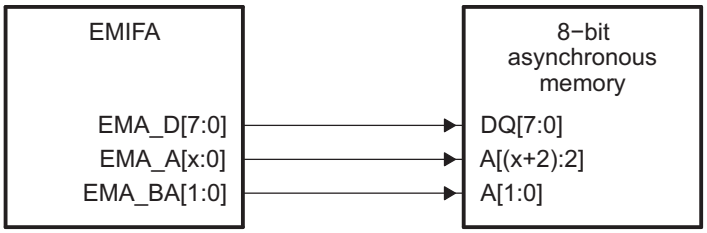
Figure 20-7. EMIFA Asynchronous Interface



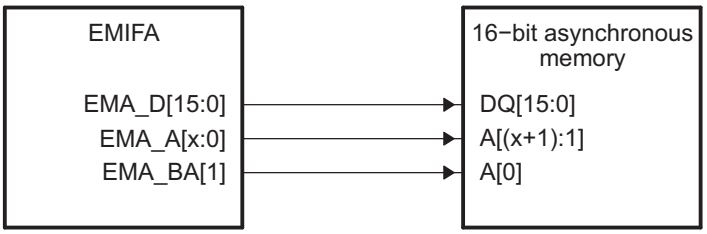
Of special note is the connection between the EMIFA and the external device's address bus. The EMIFA address pin EMA_A[0] always provides the least significant bit of a 32-bit word address. Therefore, when interfacing to a 16-bit or 8-bit asynchronous device, the EMA_BA[1] and EMA_BA[0] pins provide the least-significant bits of the halfword or byte address, respectively. Additionally, when the EMIFA interfaces to a 16-bit asynchronous device, the EMA_BA[0] pin can serve as the upper address line EMA_A[22]. Note that the width of the address bus varies with devices; therefore, see your device-specific data manual for the EMA_A bus width supported. Figure 20-8 and Figure 20-9 show the mapping between the EMIFA and the connected device's data and address pins for various programmed data bus widths. The data bus width may be configured in the asynchronous *n* configuration register (CE*n*CFG).

Figure 20-9 shows a common interface between the EMIFA and external asynchronous memory. Figure 20-9 shows an interface between the EMIFA and an external memory with byte enables. The EMIFA should be operated in either Normal Mode or Select Strobe Mode when using this interface, so that the EMA_WE_DQM signals operate as byte enables.

Figure 20-8. EMIFA to 8-bit/16-bit Memory Interface

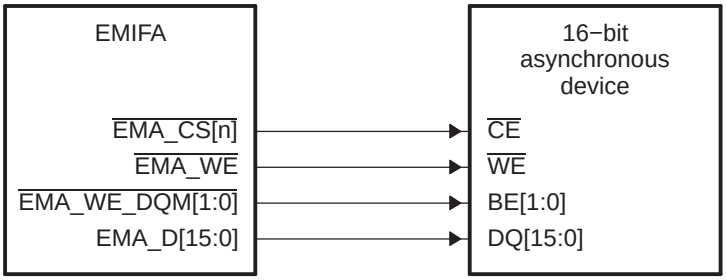


a) EMIF to 8-bit memory interface



b) EMIF to 16-bit memory interface

Figure 20-9. Common Asynchronous Interface



20.2.5.2 Accessing Larger Asynchronous Memories

The device has a limited number of dedicated EMIFA address pins, enough to interface directly to an SDRAM. If a device such as an asynchronous flash needs to be attached to the EMIFA, then GPIO pins may be used to control the flash device's upper address lines. This is sufficient to boot from the flash. Normally, code stored in flash is copied into SDRAM or internal memory before executing because these memories have much faster access times. For details on which device pins are GPIO capable, see your device-specific data manual.

The ROM bootloader can load a secondary bootloader from an attached asynchronous device. The ROM bootloader assumes that any GPIO pins used to control the upper address lines of the boot flash will be pulled to 0 after reset. This means that normally the GPIO pins selected for this function will be either spare or used as outputs only by the application, and therefore can be pulled to 0 at reset with an external pulldown resistor. The GPIO pins chosen should be tri-stated by default on device reset. For details on which GPIO-capable pins are tri-stated on device reset, see your device-specific data manual.

When booting from flash, the ROM bootloader copies a board-specific secondary bootloader from the lower portion of the flash, so it does not need to manipulate the upper address lines. Only the secondary bootloader, which is board-specific and is stored in the external flash, needs to know which GPIO pins have been assigned to the function of upper address lines. Therefore, the secondary bootloader can perform the task of configuring the selected pins as GPIO and loading the remainder of the code from the upper flash memory.

20.2.5.3 Configuring the EMIFA for Asynchronous Accesses

The operation of the EMIFA's asynchronous interface can be configured by programming the appropriate register fields. The reset value and bit position for each register field can be found in Section 20.4, but the Boot ROM documentation should be consulted to determine if the fields are programmed during boot. The following tables list the register fields that can be programmed and describe the purpose of each field. These registers can be programmed prior to accessing the external memory, and the transfer following a write to these registers will use the new configuration.

Table 20-15. Description of the Asynchronous *m* Configuration Register (CE*n*CFG)

Parameter	Description
SS	**Select Strobe mode.** This bit selects the EMIFA's mode of operation in the following way: • SS = 0 selects Normal Mode – $\overline{\text{EMA\_WE\_DQM}}$ pins function as byte enables – $\overline{\text{EMA\_CS}}$[5:2] active for duration of access • SS = 1 selects Select Strobe Mode – $\overline{\text{EMA\_WE\_DQM}}$ pins function as byte enables – $\overline{\text{EMA\_CS}}$[5:2] acts as a strobe.
EW	**Extended Wait Mode enable.** • EW = 0 disables Extended Wait Mode • EW = 1 enables Extended Wait Mode When set to 1, the EMIFA enables its Extended Wait Mode in which the strobe width of an access cycle can be extended in response to the assertion of the EMA_WAIT pin(1). The WP*n* bit in the asynchronous wait cycle configuration register (AWCC) controls to polarity of EMA_WAIT pin. Extended Wait Mode should not be used while in NAND Flash Mode. See Section 20.2.5.7 for more details on this mode of operation.
W_SETUP/R_SETUP	**Read/Write setup widths.** These fields define the number of EMIFA clock cycles of setup time for the address pins (EMA_A and EMA_BA), byte enables ($\overline{\text{EMA\_WE\_DQM}}$), and asynchronous chip enable ($\overline{\text{EMA\_CS}}$[5:2]) before the read strobe pin ($\overline{\text{EMA\_OE}}$) or write strobe pin ($\overline{\text{EMA\_WE}}$) falls, minus one cycle. For writes, the W_SETUP field also defines the setup time for the data pins (EMA_D). Refer to the datasheet of the external asynchronous device to determine the appropriate setting for this field.
W_STROBE/R_STROBE	**Read/Write strobe widths.** These fields define the number of EMIFA clock cycles between the falling and rising of the read strobe pin ($\overline{\text{EMA\_OE}}$) or write strobe pin ($\overline{\text{EMA\_WE}}$), minus one cycle. If Extended Wait Mode is enabled by setting the EW field in the asynchronous *n* configuration register (CE*n*CFG), these fields must be set to a value greater than zero. Refer to the datasheet of the external asynchronous device to determine the appropriate setting for this field.

(1) The EMA_WAIT pin is not available on all devices; therefore, this field is reserved on those devices.

Table 20-15. Description of the Asynchronous *m* Configuration Register (CE*n*CFG) (continued)

Parameter	Description
W_HOLD/R_HOLD	**Read/Write hold widths.** These fields define the number of EMIFA clock cycles of hold time for the address pins (EMA_A and EMA_BA), byte enables (EMA_WE_DQM), and asynchronous chip enable (EMA_CS[5:2]) after the read strobe pin (EMA_OE) or write strobe pin (EMA_WE) rises, minus one cycle. For writes, the W_HOLD field also defines the hold time for the data pins (EMA_D). Refer to the datasheet of the external asynchronous device to determine the appropriate setting for this field.
TA	**Minimum turnaround time.** This field defines the minimum number of EMIFA clock cycles between asynchronous reads and writes, minus one cycle. The purpose of this feature is to avoid contention on the bus. The value written to this field also determines the number of cycles that will be inserted between asynchronous accesses and SDRAM accesses. Refer to the datasheet of the external asynchronous device to determine the appropriate setting for this field. If more turnaround cycles are required than can be programmed into the TA field, additional cycles can be added to the R_HOLD field to compensate.
ASIZE	**Asynchronous Device Bus Width.** This field determines the data bus width of the asynchronous interface in the following way: • ASIZE = 0 selects an 8-bit bus • ASIZE = 1 selects a 16-bit bus The configuration of ASIZE determines the function of the EMA_A and EMA_BA pins as described in Section 20.2.5.1. This field also determines the number of external accesses required to fulfill a request generated by one of the sources mentioned in Section 20.2.2. For example, a request for a 32-bit word would require four external access when ASIZE = 0. Refer to the datasheet of the external asynchronous device to determine the appropriate setting for this field.

Table 20-16. Description of the Asynchronous Wait Cycle Configuration Register (AWCC)[(1)]

Parameter	Description
WP*n*	**EMA_WAIT Polarity.** • WP*n* = 0 selects active-low polarity • WP*n* = 1 selects active-high polarity When set to 1, the EMIFA will wait if the EMA_WAIT pin is high. When cleared to 0, the EMIFA will wait if the EMA_WAIT pin is low. The EMIFA must have the Extended Wait Mode enabled for the EMA_WAIT pin to affect the width of the strobe period. The polarity of the EMA_WAIT signal is not programmable in NAND Flash Mode.
MAX_EXT_WAIT	**Maximum Extended Wait Cycles.** This field configures the number of EMIFA clock cycles the EMIFA will wait for the EMA_WAIT pin to be deactivated during the strobe period of an access cycle. The maximum number of EMIFA clock cycles it will wait is determined by the following formula: Maximum Extended Wait Cycles = (MAX_EXT_WAIT + 1) × 16 If the EMA_WAIT pin is not deactivated within the time specified by this field, the EMIFA resumes the access cycle, registering whatever data is on the bus and proceeding to the hold period of the access cycle. This situation is referred to as an Asynchronous Timeout. An Asynchronous Timeout generates an interrupt, if it has been enabled in the EMIFA interrupt mask set register (INTMSKSET). Refer to Section 20.2.8.1 for more information about the EMIFA interrupts. Extended Wait Mode should not be used while in NAND Flash Mode.

(1) The EMA_WAIT pin is not available on all devices; therefore, this register is reserved on those devices.

Table 20-17. Description of the EMIFA Interrupt Mask Set Register (INTMSKSET)

Parameter	Description
WR_MASK_SET	**Wait Rise Mask Set.** Writing a 1 enables an interrupt to be generated when a rising edge on EMA_WAIT[1] occurs while in NAND Flash Mode
AT_MASK_SET	**Asynchronous Timeout Mask Set.** Writing a 1 to this bit enables an interrupt to be generated when an Asynchronous Timeout occurs.

(1) The EMA_WAIT pin is not available on all devices; therefore, this field is reserved on those devices.

Table 20-18. Description of the EMIFA Interrupt Mast Clear Register (INTMSKCLR)

Parameter	Description
WR_MASK_CLR	**Wait Rise Mask Clear.** Writing a 1 to this bit disables the interrupt, clearing the WR_MASK_SET bit in the EMIFA interrupt mask set register (INTMSKSET).
AT_MASK_CLR	**Asynchronous Timeout Mask Clear.** Writing a 1 to this bit prevents an interrupt from being generated when an Asynchronous Timeout occurs.

20.2.5.4 Read and Write Operations in Normal Mode

Normal Mode is the asynchronous interface's default mode of operation. It is selected when the SS bit in the asynchronous *n* configuration register (CE*n*CFG) is cleared to 0. In this mode, the $\overline{\text{EMA\_WE\_DQM}}$ pins operate as byte enables. Section 20.2.5.4.1 and Section 20.2.5.4.2 explain the details of read and write operations while in Normal Mode.

20.2.5.4.1 Asynchronous Read Operations (Normal Mode)

NOTE: During the entirety of an asynchronous read operation, the $\overline{\text{EMA\_WE}}$ pin is driven high.

An asynchronous read is performed when any of the requesters mentioned in Section 20.2.2 request a read from the attached asynchronous memory. After the request is received, a read operation is initiated once it becomes the EMIFA's highest priority task, according to the priority scheme detailed in Section 20.2.12. In the event that the read request cannot be serviced by a single access cycle to the external device, multiple access cycles will be performed by the EMIFA until the entire request is fulfilled. The details of an asynchronous read operation in Normal Mode are described in Table 20-19. Also, Figure 20-10 shows an example timing diagram of a basic read operation.

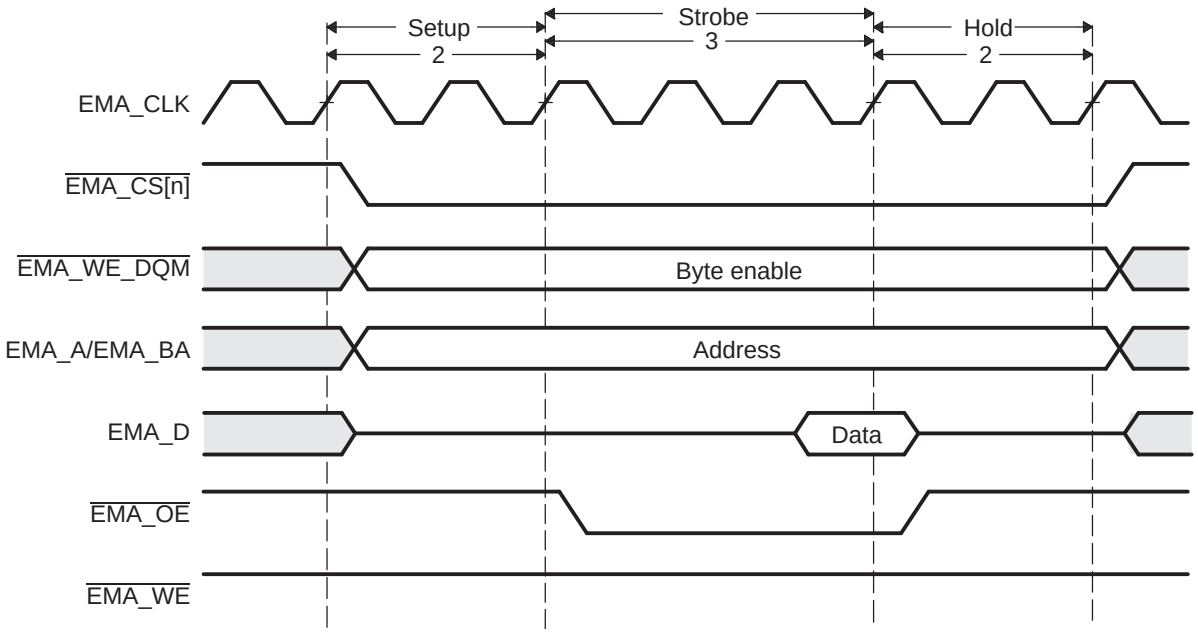
Table 20-19. Asynchronous Read Operation in Normal Mode

Time Interval	Pin Activity in Normal Mode
Turnaround period	Once the read operation becomes the highest priority task for the EMIFA, the EMIFA waits for the programmed number of turn-around cycles before proceeding to the setup period of the operation. The number of wait cycles is taken directly from the TA field of the asynchronous *n* configuration register (CE*n*CFG). There are two exceptions to this rule: • If the current read operation was directly proceeded by another read operation to the same chip select, no turnaround cycles are inserted. After the EMIFA has waited for the turnaround cycles to complete, it again checks to make sure that the read operation is still its highest priority task. If so, the EMIFA proceeds to the setup period of the operation. If it is no longer the highest priority task, the EMIFA terminates the operation.

Table 20-19. Asynchronous Read Operation in Normal Mode (continued)

Time Interval	Pin Activity in Normal Mode
Start of the setup period	The following actions occur at the start of the setup period: • The setup, strobe, and hold values are set according to the R_SETUP, R_STROBE, and R_HOLD values in CE*n*CFG. • The address pins EMA_A and EMA_BA become valid and carry the values described in Section 20.2.5.1. • $\overline{\text{EMA\_CS}}$[5:2] falls to enable the external device (if not already low from a previous operation)
Strobe period	The following actions occur during the strobe period of a read operation: 1. $\overline{\text{EMA\_OE}}$ falls at the start of the strobe period 2. On the rising edge of the clock which is concurrent with the end of the strobe period: • $\overline{\text{EMA\_OE}}$ rises • The data on the EMA_D bus is sampled by the EMIFA. In Figure 20-10, EMA_WAIT is inactive. If EMA_WAIT is instead activated, the strobe period can be extended by the external device to give it more time to provide the data. Section 20.2.5.7 contains more details on using the EMA_WAIT pin.
End of the hold period	At the end of the hold period: • The address pins EMA_A and EMA_BA become invalid • $\overline{\text{EMA\_CS}}$[5:2] rises (if no more operations are required to complete the current request) EMIFA may be required to issue additional read operations to a device with a small data bus width in order to complete an entire word access. In this case, the EMIFA immediately re-enters the setup period to begin another operation without incurring the turn-round cycle delay. The setup, strobe, and hold values are not updated in this case. If the entire word access has been completed, the EMIFA returns to its previous state unless another asynchronous request has been submitted and is currently the highest priority task. If this is the case, the EMIFA instead enters directly into the turnaround period for the pending read or write operation.

Figure 20-10. Timing Waveform of an Asynchronous Read Cycle in Normal Mode



20.2.5.4.2 Asynchronous Write Operations (Normal Mode)

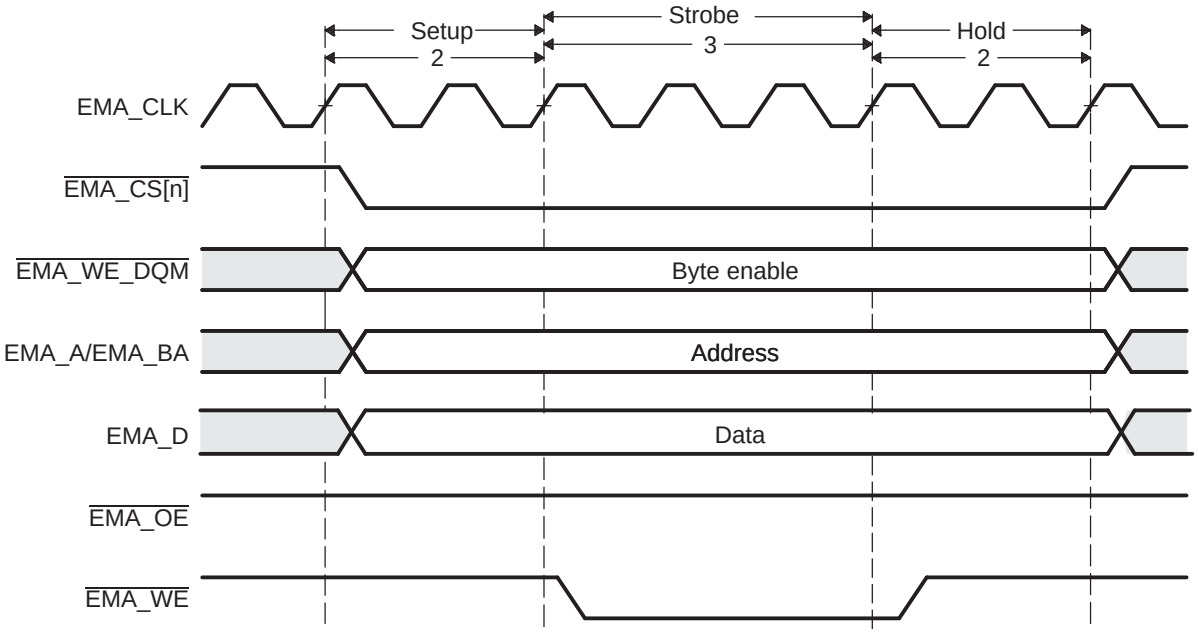
NOTE: During the entirety of an asynchronous write operation, the EMA_OE pin is driven high.

An asynchronous write is performed when any of the requesters mentioned in Section 20.2.2 request a write to memory in the asynchronous bank of the EMIFA. After the request is received, a write operation is initiated once it becomes the EMIFA's highest priority task, according to the priority scheme detailed in Section 20.2.12. In the event that the write request cannot be serviced by a single access cycle to the external device, multiple access cycles will be performed by the EMIFA until the entire request is fulfilled. The details of an asynchronous write operation in Normal Mode are described in Table 20-20. Also, Figure 20-11 shows an example timing diagram of a basic write operation.

Table 20-20. Asynchronous Write Operation in Normal Mode

Time Interval	Pin Activity in Normal Mode
Turnaround period	Once the write operation becomes the highest priority task for the EMIFA, the EMIFA waits for the programmed number of turn-around cycles before proceeding to the setup period of the operation. The number of wait cycles is taken directly from the TA field of the asynchronous *n* configuration register (CE*n*CFG). There are two exceptions to this rule: • If the current write operation was directly proceeded by another write operation to the same chip select, no turn-around cycles are inserted. After the EMIFA has waited for the turn-around cycles to complete, it again checks to make sure that the write operation is still its highest priority task. If so, the EMIFA proceeds to the setup period of the operation. If it is no longer the highest priority task, the EMIFA terminates the operation.
Start of the setup period	The following actions occur at the start of the setup period: • The setup, strobe, and hold values are set according to the W_SETUP, W_STROBE, and W_HOLD values in CE*n*CFG. • The address pins EMA_A and EMA_BA and the data pins EMA_D become valid. The EMA_A and EMA_BA pins carry the values described in Section 20.2.5.1. • EMA_CS[5:2] falls to enable the external device (if not already low from a previous operation).
Strobe period	The following actions occur at the start of the strobe period of a write operation: 1. EMA_WE falls 2. The EMA_WE_DQM pins become valid as byte enables. The following actions occur on the rising edge of the clock which is concurrent with the end of the strobe period: 1. EMA_WE rises 2. The EMA_WE_DQM pins deactivate In Figure 20-11, EMA_WAIT is inactive. If EMA_WAIT is instead activated, the strobe period can be extended by the external device to give it more time to accept the data. Section 20.2.5.7 contains more details on using the EMA_WAIT pin.
End of the hold period	At the end of the hold period: • The address pins EMA_A and EMA_BA become invalid • The data pins become invalid • EMA_CS[n] (n = 2, 3, 4, or 5) rises (if no more operations are required to complete the current request) The EMIFA may be required to issue additional write operations to a device with a small data bus width in order to complete an entire word access. In this case, the EMIFA immediately re-enters the setup period to begin another operation without incurring the turnaround cycle delay. The setup, strobe, and hold values are not updated in this case. If the entire word access has been completed, the EMIFA returns to its previous state unless another asynchronous request has been submitted and is currently the highest priority task. If this is the case, the EMIFA instead enters directly into the turnaround period for the pending read or write operation.

Figure 20-11. Timing Waveform of an Asynchronous Write Cycle in Normal Mode



20.2.5.5 Read and Write Operation in Select Strobe Mode

Select Strobe Mode is the EMIFA's second mode of operation. It is selected when the SS bit of the asynchronous *n* configuration register (CE*n*CFG) is set to 1. In this mode, the EMA_WE_DQM pins operate as byte enables and the EMA_CS[n] (n = 2, 3, 4, or 5) pin is only active during the strobe period of an access cycle. Section 20.2.5.4.1 and Section 20.2.5.4.2 explain the details of read and write operations while in Select Strobe Mode.

20.2.5.5.1 Asynchronous Read Operations (Select Strobe Mode)

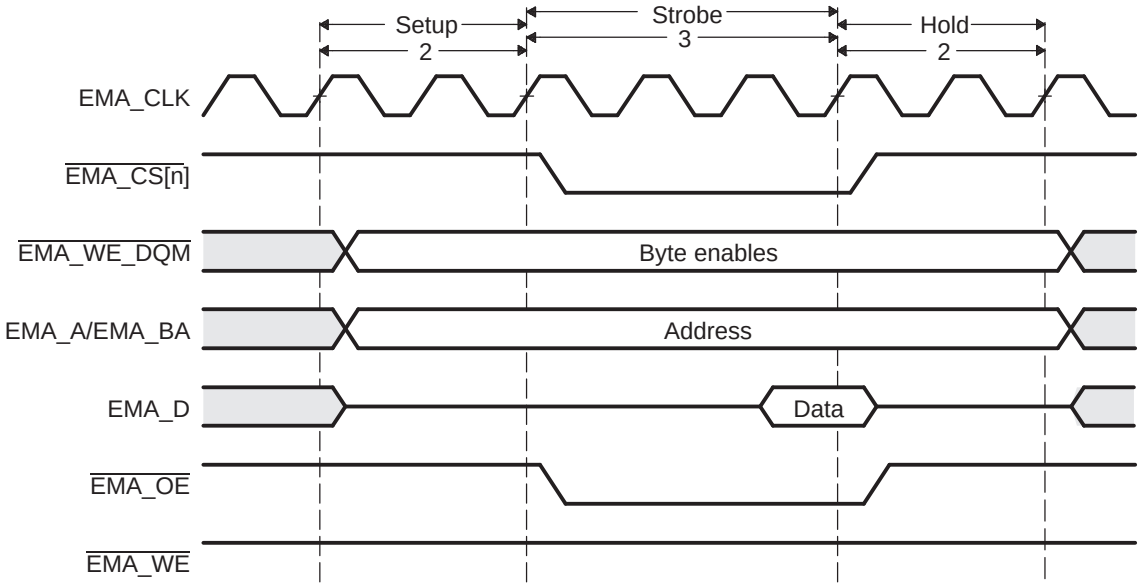
NOTE: During the entirety of an asynchronous read operation, the EMA_WE pin is driven high.

An asynchronous read is performed when any of the requesters mentioned in Section 20.2.2 request a read from the attached asynchronous memory. After the request is received, a read operation is initiated once it becomes the EMIFA's highest priority task, according to the priority scheme detailed in Section 20.2.12. In the event that the read request cannot be serviced by a single access cycle to the external device, multiple access cycles will be performed by the EMIFA until the entire request is fulfilled. The details of an asynchronous read operation in Select Strobe Mode are described in Table 20-21. Also, Figure 20-12 shows an example timing diagram of a basic read operation.

Table 20-21. Asynchronous Read Operation in Select Strobe Mode

Time Interval	Pin Activity in Select Strobe Mode
Turnaround period	Once the read operation becomes the highest priority task for the EMIFA, the EMIFA waits for the programmed number of turn-around cycles before proceeding to the setup period of the operation. The number of wait cycles is taken directly from the TA field of the asynchronous *n* configuration register (CE*n*CFG). There are two exceptions to this rule: • If the current read operation was directly proceeded by another read operation to the same chip select, no turn-around cycles are inserted. After the EMIFA has waited for the turn-around cycles to complete, it again checks to make sure that the read operation is still its highest priority task. If so, the EMIFA proceeds to the setup period of the operation. If it is no longer the highest priority task, the EMIFA terminates the operation.
Start of the setup period	The following actions occur at the start of the setup period: • The setup, strobe, and hold values are set according to the R_SETUP, R_STROBE, and R_HOLD values in CE*n*CFG. • The address pins EMA_A and EMA_BA become valid and carry the values described in Section 20.2.5.1. • The EMA_WE_DQM pins become valid as byte enables.
Strobe period	The following actions occur during the strobe period of a read operation: 1. EMA_CS[n] (n = 2, 3, 4, or 5) and EMA_OE fall at the start of the strobe period 2. On the rising edge of the clock which is concurrent with the end of the strobe period: • EMA_CS[n] (n = 2, 3, 4, or 5) and EMA_OE rise • The data on the EMA_D bus is sampled by the EMIFA. In Figure 20-12, EMA_WAIT is inactive. If EMA_WAIT is instead activated, the strobe period can be extended by the external device to give it more time to provide the data. Section 20.2.5.7 contains more details on using the EMA_WAIT pin.
End of the hold period	At the end of the hold period: • The address pins EMA_A and EMA_BA become invalid • The EMA_EMA_WE_DQM pins become invalid The EMIFA may be required to issue additional read operations to a device with a small data bus width in order to complete an entire word access. In this case, the EMIFA immediately re-enters the setup period to begin another operation without incurring the turnaround cycle delay. The setup, strobe, and hold values are not updated in this case. If the entire word access has been completed, the EMIFA returns to its previous state unless another asynchronous request has been submitted and is currently the highest priority task. If this is the case, the EMIFA instead enters directly into the turnaround period for the pending read or write operation.

Figure 20-12. Timing Waveform of an Asynchronous Read Cycle in Select Strobe Mode



20.2.5.5.2 Asynchronous Write Operations (Select Strobe Mode)

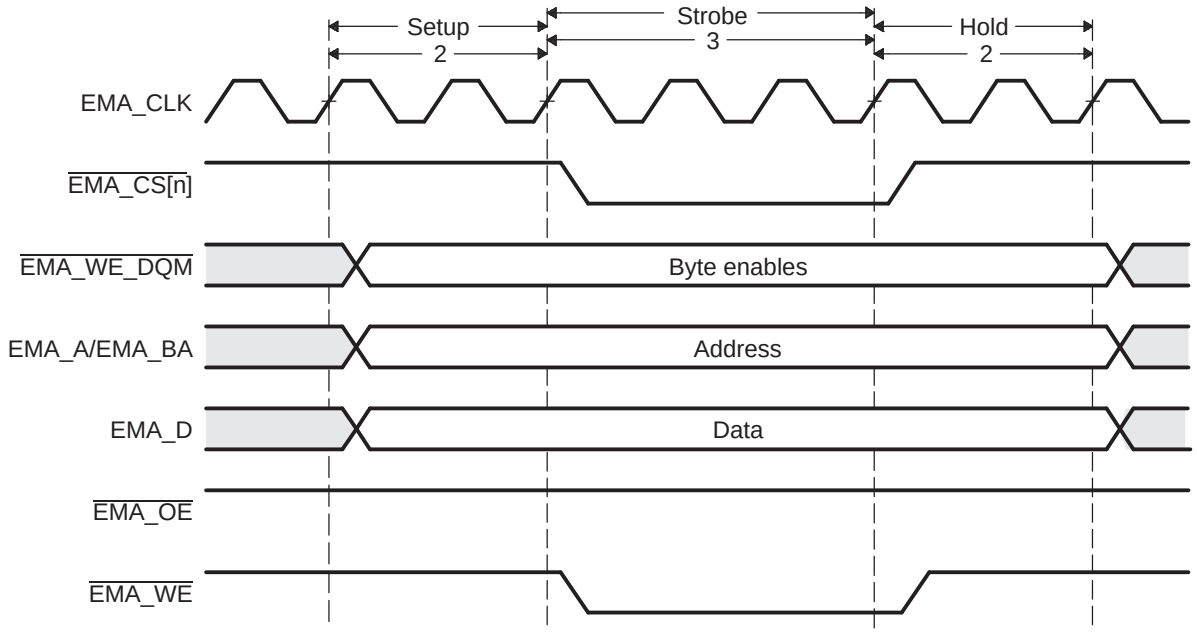
NOTE: During the entirety of an asynchronous write operation, the $\overline{\text{EMA\_OE}}$ pin is driven high.

An asynchronous write is performed when any of the requesters mentioned in Section 20.2.2 request a write to memory in the asynchronous bank of the EMIFA. After the request is received, a write operation is initiated once it becomes the EMIFA's highest priority task, according to the priority scheme detailed in Section 20.2.12. In the event that the write request cannot be serviced by a single access cycle to the external device, multiple access cycles will be performed by the EMIFA until the entire request is fulfilled. The details of an asynchronous write operation in Select Strobe Mode are described in Table 20-22. Also, Figure 20-13 shows an example timing diagram of a basic write operation.

Table 20-22. Asynchronous Write Operation in Select Strobe Mode

Time Interval	Pin Activity in Select Strobe Mode
Turnaround period	Once the write operation becomes the highest priority task for the EMIFA, the EMIFA waits for the programmed number of turn-around cycles before proceeding to the setup period of the operation. The number of wait cycles is taken directly from the TA field of the asynchronous *n* configuration register (CE*n*CFG). There are two exceptions to this rule: • If the current write operation was directly proceeded by another write operation to the same chip select, no turn-around cycles are inserted. After the EMIFA has waited for the turnaround cycles to complete, it again checks to make sure that the write operation is still its highest priority task. If so, the EMIFA proceeds to the setup period of the operation. If it is no longer the highest priority task, the EMIFA terminates the operation.
Start of the setup period	The following actions occur at the start of the setup period: • The setup, strobe, and hold values are set according to the W_SETUP, W_STROBE, and W_HOLD values in CE*n*CFG. • The address pins EMA_A and EMA_BA and the data pins EMA_D become valid. The EMA_A and EMA_BA pins carry the values described in Section 20.2.5.1. • The $\overline{\text{EMA\_WE\_DQM}}$ pins become active as byte enables.
Strobe period	The following actions occur at the start of the strobe period of a write operation: • $\overline{\text{EMA\_CS[n]}}$ (n = 2, 3, 4, or 5) and $\overline{\text{EMA\_WE}}$ fall The following actions occur on the rising edge of the clock which is concurrent with the end of the strobe period: • $\overline{\text{EMA\_CS[n]}}$ (n = 2, 3, 4, or 5) and $\overline{\text{EMA\_WE}}$ rise In Figure 20-13, EMA_WAIT is inactive. If EMA_WAIT is instead activated, the strobe period can be extended by the external device to give it more time to accept the data. Section 20.2.5.7 contains more details on using the EMA_WAIT pin.
End of the hold period	At the end of the hold period: • The address pins EMA_A and EMA_BA become invalid • The data pins become invalid • The $\overline{\text{EMA\_WE\_DQM}}$ pins become invalid The EMIFA may be required to issue additional write operations to a device with a small data bus width in order to complete an entire word access. In this case, the EMIFA immediately re-enters the setup period to begin another operation without incurring the turnaround cycle delay. The setup, strobe, and hold values are not updated in this case. If the entire word access has been completed, the EMIFA returns to its previous state unless another asynchronous request has been submitted and is currently the highest priority task. If this is the case, the EMIFA instead enters directly into the turn-around period for the pending read or write operation.

Figure 20-13. Timing Waveform of an Asynchronous Write Cycle in Select Strobe Mode



20.2.5.6 NAND Flash Mode

NAND Flash Mode is a submode of both Normal Mode and Select Strobe Mode. Chip select $\overline{\text{EMA\_CS}}$[n] (n = 2, 3, 4, or 5) may be placed in NAND Flash mode by setting the CS*n*NAND (*n* = 2, 3, 4, or 5) bit in the NAND Flash control register (NANDFCR). Table 20-23 displays the bit fields present in NANDFCR and briefly describes their use.

When a chip select space is configured to operate in NAND Flash mode, the EMIFA hardware can calculate the error correction code (ECC) for each 518 byte data transfer to that chip select space. The EMIFA hardware will not generate the NAND access cycle, which includes the command, address, and data phases, necessary to complete a transfer to NAND Flash. All NAND Flash operations can be divided into single asynchronous cycles, and with the help of software the EMIFA can execute a complete NAND access cycle.

Table 20-23. Description of the NAND Flash Control Register (NANDFCR)

Parameter	Description
CS5ECC	**NAND Flash ECC state for $\overline{\text{EMA\_CS}}$[5].** • Set to 1 to start an ECC calculation for $\overline{\text{EMA\_CS}}$[5] • Cleared to 0 when NAND Flash 4 ECC register (NANDF4ECC) is read.
CS5NAND	**NAND Flash mode for $\overline{\text{EMA\_CS}}$[5].** • Set to 1 to enable NAND Flash mode for $\overline{\text{EMA\_CS}}$[5]
CS4ECC	**NAND Flash ECC state for $\overline{\text{EMA\_CS}}$[4].** • Set to 1 to start an ECC calculation for $\overline{\text{EMA\_CS}}$[4] • Cleared to 0 when NAND Flash 3 ECC register (NANDF3ECC) is read.
CS4NAND	**NAND Flash mode for $\overline{\text{EMA\_CS}}$[4].** • Set to 1 to enable NAND Flash mode for $\overline{\text{EMA\_CS}}$[4]
CS3ECC	**NAND Flash ECC state for $\overline{\text{EMA\_CS}}$[3].** • Set to 1 to start an ECC calculation for $\overline{\text{EMA\_CS}}$[3] • Cleared to 0 when NAND Flash 2ECC register (NANDF2ECC) is read.
CS3NAND	**NAND Flash mode for $\overline{\text{EMA\_CS}}$[3].** • Set to 1 to enable NAND Flash mode for $\overline{\text{EMA\_CS}}$[3]
CS2ECC	**NAND Flash ECC state for $\overline{\text{EMA\_CS}}$[2].** • Set to 1 to start an ECC calculation for $\overline{\text{EMA\_CS}}$[2] • Cleared to 0 when NAND Flash 1 ECC register (NANDF1ECC) is read.
CS2NAND	**NAND Flash mode for $\overline{\text{EMA\_CS}}$[2].** • Set to 1 to enable NAND Flash mode for $\overline{\text{EMA\_CS}}$[2]

20.2.5.6.1 Configuring for NAND Flash Mode

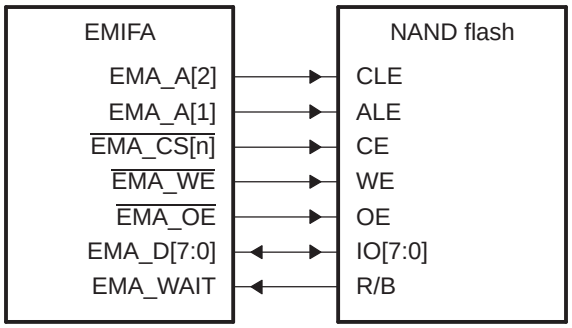
Similar to the asynchronous accesses previously described, the EMIFA's memory-mapped registers must be programmed appropriately to interface to a NAND Flash device. In addition to the fields listed in Table 20-15, the CS*n*NAND (*n* = 2, 3, 4, or 5) bit of the NAND Flash control register (NANDFCR) should be set to 1 to enter NAND Flash Mode. Note that the EW bit of CE*n*CFG should be cleared to avoid enabling the wait feature while in NAND Flash Mode.

20.2.5.6.2 Connecting to NAND Flash

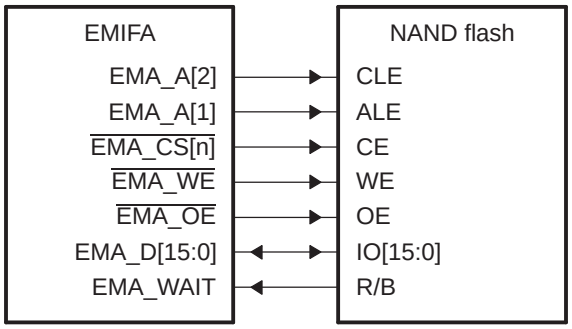
Figure 20-14 shows the EMIFA external pins used to interface with a NAND Flash device. EMIFA address lines are used to drive the NAND Flash device's command latch enable (CLE) and address latch enable (ALE) signals. Any EMIFA address lines may be used to drive the CLE and ALE signals of the NAND Flash.

NOTE: The EMIFA will not control the NAND Flash device's write protect pin. The write protect pin must be controlled outside of the EMIFA.

Figure 20-14. EMIFA to NAND Flash Interface



a) Connection to 8−bit NAND device



b) Connection to 16−bit NAND device

20.2.5.6.3 Driving CLE and ALE

As stated in Section 20.2.5.1, the EMIFA always drives the least significant bit of a 32-bit word address on EMA_A[0]. This functionality must be considered when attempting to drive the offset lines connected to CLE and ALE to the appropriate state.

For example, if using EMA_A[2] and EMA_A[1] to connect to CLE and ALE, respectively, the following offsets should be added to EMIFA base address:

- 0000 0000h to drive CLE and ALE low
- 0000 0010h to drive CLE high and ALE low
- 0000 0008h to drive CLE low and ALE high

20.2.5.6.4 NAND Read and Program Operations

A NAND Flash access cycle is composed of a command, address, and data phase. The EMIFA will not automatically generate these three phases to complete a NAND access with one transfer request. To complete a NAND access cycle, multiple single asynchronous access cycles must be completed by the EMIFA. Software must be used to request the appropriate asynchronous accesses to complete a NAND Flash access cycle. This software must be developed to the specification of the chosen NAND Flash device.

Since NAND operations are divided into single asynchronous access cycles, the chip select signal will not remain activated for the duration of the NAND operation. Instead, the chip select signal will deactivate between each asynchronous access cycle. For this reason, the EMIFA does not support NAND Flash devices that require the chip select signal to remain low during the t_R time for a read. See Section 20.2.5.6.8 for workaround.

Care must be taken when performing a NAND read or write operation via the EDMA controller. See Section 20.2.5.6.5 for more details.

NOTE: The EMIFA does not support NAND Flash devices that require the chip select signal to remain low during the t_R time for a read. See Section 20.2.5.6.8 for workaround.

20.2.5.6.5 NAND Data Read and Write via EDMA Controller

When performing NAND accesses, the EDMA controller is most efficiently used for the data phase of the access. The command and address phases of the NAND access require only a few words of data to be transferred and therefore do not take advantage of the EDMA controller's ability to transfer larger quantities of data with a single request. In this section we will focus on using the EDMA controller for the data phase of a NAND access.

There are two conditions that require care to be taken when performing NAND reads and writes via the EDMA controller. These are:

- The address lines used to drive CLE and ALE signals must be driven low
- The EMIFA does not support constant addressing mode

Since the EMIFA does not support a constant addressing mode, when programming the EDMA, a linear incrementing address mode must be used. When using a linear incrementing address mode, if the CLE and ALE are driven by EMA_A[2] and EMA_A[1], respectively, care must be taken not to increase the address into a range that drives CLE and/or ALE high. To prevent the address from incrementing into a range that drives CLE and/or ALE high, the EDMA ACNT, BCNT, SIDX, DIDX, and synchronization type must be programmed appropriately. Following is an example configuration of EDMA controller when EMA_A[2] is connected to CLE and EMA_A[1] is connected to ALE.

EDMA setup for a NAND Flash data read:

- ACNT ≤ 8 bytes (this can also be set to less than or equal to the external data bus width)
- BCNT = transfer size in bytes/ACNT
- SIDX (source index) = 0
- DIDX (destination index) = ACNT
- AB synchronized

EDMA setup for a NAND Flash data write:

- ACNT ≤ 8 bytes (this can also be set to less than or equal to the external data bus width)
- BCNT = transfer size in bytes/ACNT
- SIDX (source index) = ACNT
- DIDX (destination index) = 0
- AB synchronized

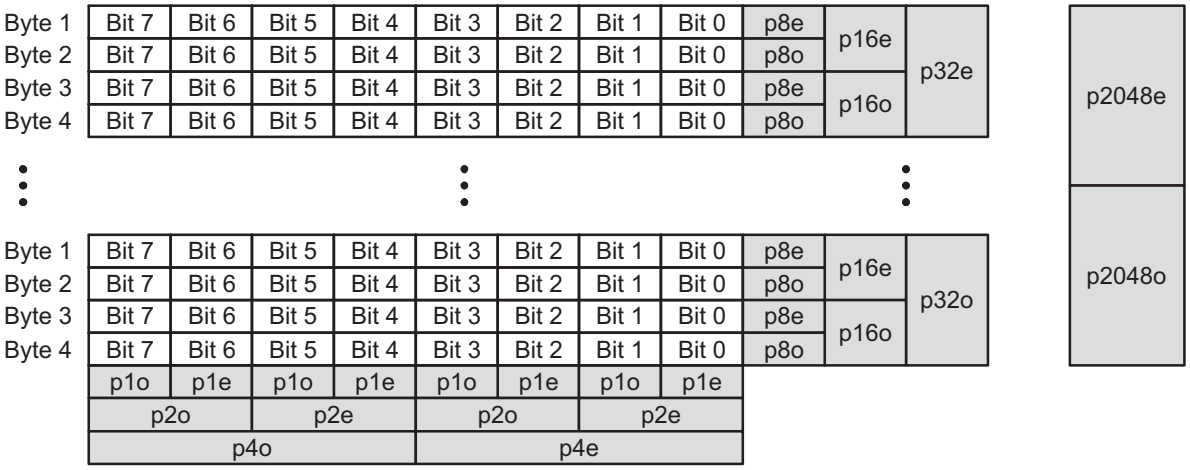
20.2.5.6.6 ECC Generation

20.2.5.6.6.1 1-Bit ECC

If the CS*n*NAND (*n* = 2, 3, 4, or 5) bit in the NAND Flash control register (NANDFCR) is set to 1, the EMIFA supports 1-bit ECC calculation for up to 512 bytes for the corresponding chip select. To perform the ECC calculation, the CS*n*ECC (*n* = 2, 3, 4, or 5) bit in NANDFCR must be set to 1. It is the responsibility of the software to start the ECC calculation by writing to the CS*n*ECC (*n* = 2, 3, 4, or 5) bit prior to issuing a write or read to NAND Flash. It is also the responsibility of the software to read the calculated ECC from the NAND Flash *m* ECC register (NANDF*m*ECC) (*m* = 1, 2, 3, or 4) once the transfer to NAND Flash has completed. If the software writes or reads more than 512 bytes, the ECC will be incorrect. Reading the NAND*m*ECC (*m* = 1, 2, 3, or 4) clears the CS*n*ECC (*n* = 2, 3, 4, or 5) bit in NANDFCR. The NANDF*m*ECC (*m* = 1, 2, 3, or 4) is cleared upon writing a 1 to the CS*n*ECC (*n* = 2, 3, 4, or 5) bit. Figure 20-15 shows the algorithm used to calculate the ECC value for an 8-bit NAND Flash.

For an 8-bit NAND Flash p1o through p4e are column parities and p8e through p2048o are row parities. Similarly, the algorithm can be extended to a 16-bit NAND Flash. For a 16-bit NAND Flash p1o through p8e are column parities and p16e through p2048o are row parities. The software must ignore the unwanted parity bits if ECC is desired for less than 512 bytes of data. For example. p2048e and p2048o are not required for ECC on 256 bytes of data. Similarly, p1024e, p1024o, p2048e, and p2048o are not required for ECC on 128 bytes of data.

Figure 20-15. ECC Value for 8-Bit NAND Flash



20.2.5.6.6.2 4-Bit ECC

The EMIFA supports 4-bit ECC on 8-bit/16-bit NAND Flash. In NAND mode, if the NAND Flash 4-bit ECC start bit (4BITECC_START) in the in the NAND Flash control register (NANDFCR) is set, the EMIFA calculates 4-bit ECC for the selected chip select. Only one chip select can be selected for the 4-bit ECC calculation at one time. The selection of the chip select is done by programming the 4-bit ECC CS select bit field (4BITECCSEL) in the NAND Flash control register (NANDFCR). The calculated parity (for writes) and syndrome (for reads) can be read from the NAND Flash 4-bit ECC 1-4 registers (NAND4BITECC[4:1]). The 4-bit ECC start bit (4BITECC_START) is cleared upon reading any of the NAND Flash 4-bit ECC 1-4 registers (NAND4BITECC[4:1]). The NAND Flash 4-bit ECC 1-4 registers are cleared upon writing one to the 4-bit ECC start bit (4BITECC_START).

The 4-bit ECC algorithm works on a 10-bit data bus, but only the lower eight bits of the data bus actually contain data. When the EMIFA is used in 16-bit mode, the lower and upper 8-bits of the 16-bit data read from the data bus are fed into the ECC engine one at a time, in that order. In all cases, since only 8-bits of data are fed to the ECC engine, the upper two bits of the 10-bit data bus that feeds the ECC engine are always zero. However, the parity and the syndrome value read from the NAND Flash 4-bit ECC 1-4 registers (NAND4BITECC[4:1]) are 10 bits wide. It is the responsibility of software to convert 10-bit parity values to 8 bits before writing to the spare location of the NAND Flash after a write operation. Similarly, it is the responsibility of the software to convert the 8-bit parity values read from the spare location of the NAND Flash after a read operation, to 10 bits before writing the NAND Flash 4-bit ECC load register (NAND4BITECCLOAD).

The 4-bit ECC employed in the EMIFA interface is a Reed-Solomon error correcting code. The symbol size is ten bits (two bits are always zero and eight bits contain data as described above). With eight 10-bit parity words, up to four symbols can be corrected per block read. Though the ECC operation is called 4-bit, it is important to note that correction can actually happen on up to four 10-bit symbols. Only the lower eight bits of each 10-bit symbol actually contain data (see above), so correction can happen on up to four bytes. When bit errors are randomly distributed through the block of data read from the NAND, those errors are not likely to fall into the same bytes of data, so 4-bits of correction is an apt description. Technically speaking, however, more than four bits of error can be corrected if multiple bit errors are confined to four or fewer bytes of the data. If bit errors fall into more than four bytes, the ECC engine will report that there are too many errors to correct.

At the end of the syndrome calculation after read, the error address and the error value can be calculated by setting the address and error value calculation start bit (4BITECC_ADD_CALC_START) in the NAND Flash control register (NANDFCR). The end of address calculation is flagged by the 4-bit ECC correction state field (ECC_STATE) in the NAND Flash status register (NANDFSR). The number of errors can be read from the 4-bit number of errors field (ECC_ERRNUM) in the NAND Flash status register (NANDFSR). The error address value can be read from the NAND Flash error address 1-2 registers (NANDERRADD[2:1]). The error value can be read from the NAND Flash error value 1-2 registers (NANDERRVAL[2:1]). The address and error value start bit (4BITECC_ADD_CALC_START) is cleared upon reading any of the NAND Flash error address 1-2 registers (NANDERRADD[2:1]) or the NAND Flash error value 1-2 registers (NANDERRVAL[2:1]). The EMIFA registers the syndrome value internally before the error address and error value calculation. Therefore, a new read operation can be performed simultaneously with the error address calculation.

The EMIFA supports 4-bit ECC calculation up to 518 bytes. The software needs to follow the following procedure for 4-bit ECC calculation:

For writes:

1. Set the 4BITECC_START bit in the NAND Flash control register (NANDFCR) to 1.
2. Write 518 bytes of data to the NAND Flash.
3. Read the parity from the NAND Flash 4-Bit ECC 1-4 registers (NAND4BITECC[4:1]).
4. Convert the 10-bit parity values to 8-bits. All 10-bit parity values can be concatenated together with ECC value 1 (4BITECCVAL1) as LSB and ECC value 8 (4BITECCVAL8) as MSB. Then the concatenated value can be broken down into ten 8-bit values.
5. Store the parity to spare location in the NAND Flash.

For reads:

1. Set the 4BITECC_START bit in the NAND Flash control register (NANDFCR) to 1.
2. Read 518 bytes of data from the NAND Flash.
3. Clear the 4BITECC_START bit in NANDFCR by reading any of the NAND Flash 4-bit ECC registers.
4. Read the parity stored in the spare location in the NAND Flash.
5. Convert the 8-bit parity values to 10-bits. Reverse of the conversion that was done during writes.
6. Write the parity values in the NAND Flash 4-bit ECC load register (NAND4BITECCLOAD). Write each parity value one at a time starting from 4BITECCVAL8 down to 4BITECCVAL1.
7. Perform a dummy read to the NAND Flash status register (NANDFSR). This is only required to ensure time for syndrome calculation after writing the ECC values in step 6.
8. Read the syndrome from the NAND Flash 4-bit ECC 1-4 registers (NAND4BITECC[4:1]). A syndrome value of 0 means no bit errors. If the syndrome is non-zero, continue with step 9.
9. Set the 4BITECC_ADD_CALC_START bit in the NAND Flash control register (NANDFCR) to 1.
10. Perform a dummy read to any EMIFA registers except the NAND Flash error address 1-2 registers (NANDERRADD[2:1]) or the NAND Flash error value 1-2 registers (NANDERRVAL[2:1]).
11. Start another read from NAND, if required (a new thread from step 1).
12. Wait for the 4-bit ECC correction state field (ECC_STATE) in the NAND Flash status register (NANDFSR) to be equal to 1, 2h, or 3h.
13. The number of errors can be read from the 4-bit number of errors field (ECC_ERRNUM) in the NAND Flash status register (NANDFSR).
14. Read the error address from the NAND Flash error address 1-2 registers (NANDERRADD[2:1]). Address for the error word is equal to (total_words_read + 7 - address_value). For 518 bytes, the address will be equal to (525 - address_value).
15. Read the error value from the NAND Flash error value 1-2 registers (NANDERRVAL[2:1]). Errors can be corrected by XORing the error word with the error value from the NAND Flash error value 1-2 registers (NANDERRVAL[2:1]).

20.2.5.6.7 NAND Flash Status Register (NANDFSR)

The NAND Flash status register (NANDFSR) indicates the raw status of the EMA_WAIT pin while in NAND Flash Mode. The EMA_WAIT pin should be connected to the NAND Flash device's R/$\overline{B}$ signal, so that it indicates whether or not the NAND Flash device is busy. During a read, the R/$\overline{B}$ signal will transition and remain low while the NAND Flash retrieves the data requested. Once the R/$\overline{B}$ signal transitions high, the requested data is ready and should be read by the EMIFA. During a write/program operation, the R/$\overline{B}$ signal transitions and remains low while the NAND Flash is programming the Flash with the data it has received from the EMIFA. Once the R/$\overline{B}$ signal transitions high, the data has been written to the Flash and the next phase of the transaction may be performed. From this explanation, you can see that the NAND Flash status register is useful to the software for indicating the status of the NAND Flash device and determining when to proceed to the next phase of a NAND Flash operation.

When a rising edge occurs on the EMA_WAIT pin, the EMIFA sets the WR (Wait Rise) bit in the EMIFA interrupt raw register (INTRAW). Therefore, the EMIFA Wait Rise interrupt may be used to indicate the status of the NAND Flash device. The WP*n* bit in the asynchronous wait cycle configuration register (AWCC) does not affect the NAND Flash status register (NANDFSR) or the WR bit in INTRAW. See Section 20.2.8 for more a detailed description of the wait rise interrupt.

20.2.5.6.8 Interfacing to a Non-CE Don't Care NAND Flash

As explained in Section 20.2.5.6.4, the EMIFA does not support NAND Flash devices that require the chip select signal to remain low during the t_R time for a read. One way to work around this limitation is to use a GPIO pin to drive the $\overline{CE}$ signal of the NAND Flash device. If this work around is implemented, software will configure the selected GPIO to be low, then begin the NAND Flash operation, starting with the command phase. Once the NAND Flash operation has completed the software can then configure the selected GPIO to be high.

20.2.5.7 Extended Wait Mode and the EMA_WAIT Pin

The EMIFA supports the Extend Wait Mode. This is a mode in which the external asynchronous device may assert control over the length of the strobe period. The Extended Wait Mode can be entered by setting the EW bit in the asynchronous *n* configuration register (CE*n*CFG) (*n* = 2, 3, 4, or 5). When this bit is set, the EMIFA monitors the EMA_WAIT pin to determine if the attached device wishes to extend the strobe period of the current access cycle beyond the programmed number of clock cycles.

When the EMIFA detects that the EMA_WAIT pin has been asserted, it will begin inserting extra strobe cycles into the operation until the EMA_WAIT pin is deactivated by the external device. The EMIFA will then return to the last cycle of the programmed strobe period and the operation will proceed as usual from this point. Please refer to the device data manual for details on the timing requirements of the EMA_WAIT signal.

The EMA_WAIT pin cannot be used to extend the strobe period indefinitely. The programmable MAX_EXT_WAIT field in the asynchronous wait cycle configuration register (AWCC) determines the maximum number of EMA_CLK cycles the strobe period may be extended beyond the programmed length. When the counter expires, the EMIFA proceeds to the hold period of the operation regardless of the state of the EMA_WAIT pin. The EMIFA can also generate an interrupt upon expiration of this counter. See Section 20.2.8.1 for details on enabling this interrupt.

For the EMIFA to function properly in the Extended Wait mode, the WP*n* bit of AWCC must be programmed to match the polarity of the EMA_WAIT pin. In its reset state of 1, the EMIFA will insert wait cycles when the EMA_WAIT pin is sampled high. When set to 0, the EMIFA will insert wait cycles only when EMA_WAIT is sampled low. This programmability allows for a glueless connection to larger variety of asynchronous devices.

Finally, a restriction is placed on the strobe period timing parameters when operating in Extended Wait mode. Specifically, the sum of the W_SETUP and W_STROBE fields must be greater than 4, and the sum of the R_SETUP and R_STROBE fields must be greater than 4 for the EMIFA to recognize the EMA_WAIT pin has been asserted. The W_SETUP, W_STROBE, R_SETUP, and R_STROBE fields are in CE*n*CFG.

20.2.6 Data Bus Parking

The EMIFA always drives the data bus to the previous write data value when it is idle. This feature is called data bus parking. Only when the EMIFA issues a read command to the external memory does it stop driving the data bus. The data bus is released (tri-stated) when the chip enable (EMA_CS[n]) is asserted by EMIFA for the read access. After the read operation is completed, the data bus is driven again by the bus parking feature at the end of the turnaround time. At all other times that the EMIF is enabled but not actively transferring data, the bus parking feature drives the data bus to the last written value.

The one exception to this behavior occurs after performing an asynchronous read operation while the EMIFA is in the self-refresh state. In this situation, the read operation is not followed by the EMIFA parking the data bus. Instead, the EMIFA tri-states the data bus. Therefore, it is not recommended to perform asynchronous read operations while the EMIFA is in the self-refresh state, in order to prevent floating inputs on the data bus. External pull-ups, such as 10kΩ resistors, should be placed on the 16 EMIFA data bus pins (which do not have internal pull-ups) if it is required to perform reads in this situation. The precise resistor value should be chosen so that the worst case combined off-state leakage currents do not cause the voltage levels on the associated pins to drop below the high-level input voltage requirement.

For information about the self-refresh state, see Section 20.2.4.7.

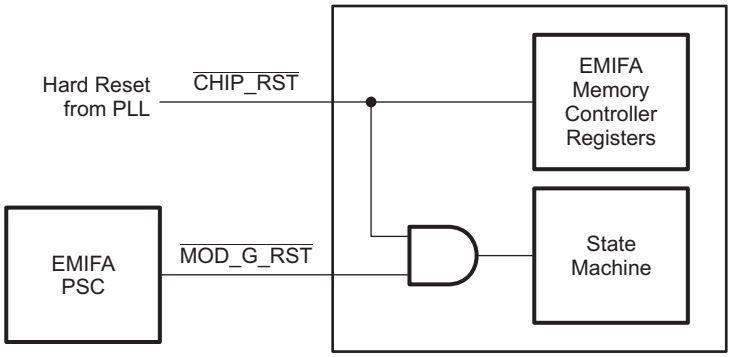
20.2.7 Reset and Initialization Considerations

The EMIFA memory controller has two reset signals, CHIP_RST and MOD_G_RST. The CHIP_RST is a module-level reset that resets both the state machine as well as the EMIFA memory controller's memory-mapped registers. The MOD_G_RST resets the state machine only. If the EMIFA memory controller is reset independently of other peripherals, the user's software should not perform memory, as well as register accesses, while CHIP_RST or MOD_G_RST are asserted. If memory or register accesses are performed while the EMIFA memory controller is in the reset state, other masters may hang. Following the rising edge of CHIP_RST or MOD_G_RST, the EMIFA memory controller immediately begins its initialization sequence. Command and data stored in the EMIFA memory controller FIFOs are lost. Table 20-24 describes the different methods for asserting each reset signal. Figure 20-16 shows the EMIFA memory controller reset diagram.

Table 20-24. Reset Sources

Reset Signal	Reset Source
CHIP_RST	Hardware/ Device Reset
MOD_G_RST	Power and Sleep Controller

Figure 20-16. EMIFA Reset Block Diagram



The EMIFA and its registers are reset when any of the following events occur:

1. The $\overline{\text{RESET}}$ pin on the device is asserted
2. An emulator reset is initiated through the Code Composer Studio™ integrated development environment

In the first case, the EMIFA will exit the reset state when $\overline{\text{RESET}}$ is released and after the PLL controller releases the entire device from reset. In the second case, the EMIFA will exit the reset state immediately after the emulator reset is complete.

In both cases, the EMIFA automatically begins running the SDRAM initialization sequence described in Section 20.2.4.4 after coming out of reset. Even though the initialization procedure is automatic, a special procedure, found in Section 20.2.4.5 must still be followed.

20.2.8 Interrupt Support

The EMIFA supports a single interrupt to the CPU. Section 20.2.8.1 details the generation and internal masking of EMIFA interrupts, and Section 20.2.8.2 describes how the EMIFA interrupts are sent to the CPU.

20.2.8.1 Interrupt Events

There are three conditions that may cause the EMIFA to generate an interrupt to the CPU. These conditions are:

- A rising edge on the EMA_WAIT signal (wait rise interrupt)
- An asynchronous time out
- Usage of unsupported addressing mode (line trap interrupt)

The wait rise interrupt occurs when a rising edge is detected on EMA_WAIT signal. This interrupt generation is not affected by the WP*n* bit in the asynchronous wait cycle configuration register (AWCC). The asynchronous time out interrupt condition occurs when the attached asynchronous device fails to deassert the EMA_WAIT pin within the number of cycles defined by the MAX_EXT_WAIT bit in AWCC (this happens only in extended wait mode). EMIFA supports only linear incrementing and cache line wrap addressing modes . If an access request for an unsupported addressing mode is received, the EMIFA will set the LT bit in the EMIFA interrupt raw register (INTRAW) and treat the request as a linear incrementing request.

Only when the interrupt is enabled by setting the appropriate bit (WR_MASK_SET/AT_MASK_SET/LT_MASK_SET) in the EMIFA interrupt mask set register (INTMSKSET) to 1, will the interrupt be sent to the CPU. Once enabled, the interrupt may be disabled by writing a 1 to the corresponding bit in the EMIFA interrupt mask clear register (INTMSKCLR). The bit fields in both the INTMSKSET and INTMSKCLR may be used to indicate whether the interrupt is enabled. When the interrupt is enabled, the corresponding bit field in both the INTMSKSET and INTMSKCLR will have a value of 1; when the interrupt is disabled, the corresponding bit field will have a value of 0.

The EMIFA interrupt raw register (INTRAW) and the EMIFA interrupt mask register (INTMSK) indicate the status of each interrupt. The appropriate bit (WR/AT/LT) in INTRAW is set when the interrupt condition occurs, whether or not the interrupt has been enabled. However, the appropriate bit (WR_MASKED/AT_MASKED/LT_MASKED) in INTMSK is set only when the interrupt condition occurs and the interrupt is enabled. Writing a 1 to the bit in INTRAW clears the INTRAW bit as well as the corresponding bit in INTMSK. Table 20-25 contains a brief summary of the interrupt status and control bit fields. See Section 20.4 for complete details on the register fields.

Table 20-25. Interrupt Monitor and Control Bit Fields

Register Name	Bit Name	Description
EMIFA interrupt raw register (INTRAW)	WR	This bit is set when an rising edge on the EMA_WAIT signal occurs. Writing a 1 clears the WR bit as well as the WR_MASKED bit in INTMSK.
	AT	This bit is set when an asynchronous timeout occurs. Writing a 1 clears the AT bit as well as the AT_MASKED bit in INTMSK.
	LT	This bit is set when an unsupported addressing mode is used. Writing a 1 clears LT bit as well as the LT_MASKED bit in INTMSK.
EMIFA interrupt mask register (INTMSK)	WR_MASKED	This bit is set only when a rising edge on the EMA_WAIT signal occurs and the interrupt has been enabled by writing a 1 to the WR_MASK_SET bit in INTMSKSET.
	AT_MASKED	This bit is set only when an asynchronous timeout occurs and the interrupt has been enabled by writing a 1 to the AT_MASK_SET bit in INTMSKSET.
	LT_MASKED	This bit is set only when line trap interrupt occurs and the interrupt has been enabled by writing a 1 to the LT_MASK_SET bit in INTMSKSET.
EMIFA interrupt mask set register (INTMSKSET)	WR_MASK_SET	Writing a 1 to this bit enables the wait rise interrupt.
	AT_MASK_SET	Writing a 1 to this bit enables the asynchronous timeout interrupt.
	LT_MASK_SET	Writing a 1 to this bit enables the line trap interrupt.
EMIFA interrupt mask clear register (INTMSKCLR)	WR_MASK_CLR	Writing a 1 to this bit disables the wait rise interrupt.
	AT_MASK_CLR	Writing a 1 to this bit disables the asynchronous timeout interrupt.
	LT_MASK_CLR	Writing a 1 to this bit disables the line trap interrupt.

20.2.8.2 Interrupt Multiplexing

For details on EMIFA interrupt multiplexing, see your device-specific data manual.

20.2.8.3 Interrupt Processing

For details on EMIFA interrupt processing, see the *DSP Subsystem* chapter and the *ARM Interrupt Controller (AINTC)* chapter.

For more details on the CPU's NMI interrupt, see the *DSP Subsystem* chapter and the *TMS320C674x CPU and Instruction Set Reference Guide* (SPRUFE8).

20.2.9 EDMA Event Support

EMIFA memory controller is a DMA slave peripheral and therefore does not generate DMA events. Data read and write requests may be made directly, by masters and the DMA.

20.2.10 Pin Multiplexing

For details on EMIFA pin multiplexing, see your device-specific data manual.

20.2.11 Memory Map

For information describing the device memory-map, see your device-specific data manual.

20.2.12 Priority and Arbitration

Section 20.2.2 describes the external prioritization and arbitration among requests from different sources within the SoC. The result of this external arbitration is that only one request is presented to the EMIFA at a time. Once the EMIFA completes a request, the external arbiter then provides the EMIFA with the next pending request.

Internally, the EMIFA undertakes memory device transactions according to a strict priority scheme. The highest priority events are:

- A device reset.
- A write to any of the three least significant bytes of the SDRAM configuration register (SDCR).

Either of these events will cause the EMIFA to immediately commence its initialization sequence as described in Section 20.2.4.4.

Once the EMIFA has completed its initialization sequence, it performs memory transactions according to the following priority scheme (highest priority listed first):

1. If the EMIFA's backlog refresh counter is at the Refresh Must urgency level, the EMIFA performs multiple SDRAM auto refresh cycles until the Refresh Release urgency level is reached.
2. If an SDRAM or asynchronous read has been requested, the EMIFA performs a read operation.
3. If the EMIFA's backlog refresh counter is at the Refresh Need urgency level, the EMIFA performs an SDRAM auto refresh cycle.
4. If an SDRAM or asynchronous write has been requested, the EMIFA performs a write operation.
5. If the EMIFA's backlog refresh counter is at the Refresh May or Refresh Release urgency level, the EMIFA performs an SDRAM auto refresh cycle.
6. If the value of the SR bit in SDCR has been set to 1, the EMIFA will enter the self-refresh state as described in Section 20.2.4.7.

After taking one of the actions listed above, the EMIFA then returns to the top of the priority list to determine its next action.

Because the EMIFA does not issue auto-refresh cycles when in the self-refresh state, the above priority scheme does not apply when in this state. See Section 20.2.4.7 for details on the operation of the EMIFA when in the self-refresh state.

20.2.13 System Considerations

This section describes various system considerations to keep in mind when operating the EMIFA.

20.2.13.1 Asynchronous Request Times

In a system that interfaces to both SDRAM and asynchronous memory, the asynchronous requests must not take longer than the smaller of the following two values:

- t_{RAS} (typically 120 µs) - to avoid violating the maximum time allowed between issuing an ACTV and PRE command to the SDRAM.
- $t_{Refresh\ Rate}$ × 11 (typically 15.7 µs × 11 = 172.7 µs) - to avoid refresh violations on the SDRAM.

  The length of an asynchronous request is controlled by multiple factors, the primary factor being the number of access cycles required to complete the request. For example, an asynchronous request for 4 bytes will require four access cycles using an 8-bit data bus and only two access cycle using a 16-bit data bus. The maximum request size that the EMIFA can be sent is 16 words, therefore the maximum number of access cycles per memory request is 64 when the EMIFA is configured with an 8-bit data bus. The length of the individual access cycles that make up the asynchronous request is determined by the programmed setup, strobe, hold, and turnaround values, but can also be extended with the assertion of the EMA_WAIT input signal up to a programmed maximum limit. It is up to the user to make sure that an entire asynchronous request does not exceed the timing values listed above when also interfacing to an SDRAM device. This can be done by limiting the asynchronous timing parameters.

20.2.13.2 Cache Fill Requests

The CPU can run code from either internal or external memory. When running code from external memory, the CPU's program cache is periodically filled with eight words (32-bytes) through a dedicated port to the EMIFA. Two system level concerns arise when filling the program cache from the EMIFA.

First, the program cache fills have the possibility of being locked out from accessing the EMIFA by a stream of higher priority requests. Therefore, care should be taken when issuing persistent requests to the EMIFA from a source such which is a high priority requester.

Second, requests to the EMIFA from the other sources risk missing their deadlines while a program cache fill from the EMIFA is in progress. This is because all other EMIFA accesses are held pending while the program cache is filled. The worst-case scenario that can arise is when a requester submits a request immediately after a program cache fill request has begun. The system should be analyzed to make sure that this worst-case request delay is acceptable.

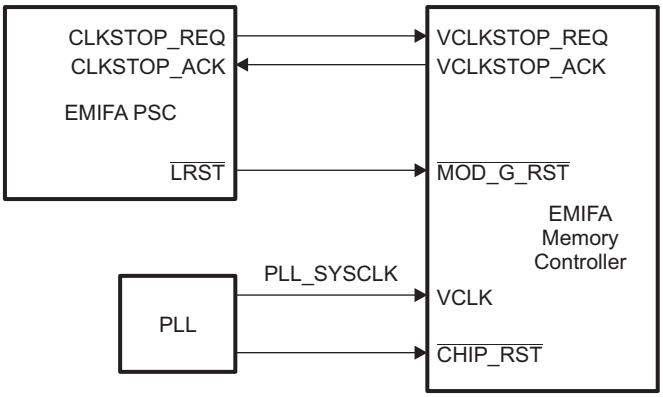
20.2.14 Power Management

Power dissipation from the EMIFA memory controller may be managed by following methods:

- Self-refresh mode
- Power-down mode
- Gating input clocks to the module off

Gating input clocks off to the EMIFA memory controller achieves higher power savings when compared to the power savings of self-refresh or power down mode. The input clocks are turned off outside of the EMIFA memory controller through the use of the Power and Sleep Controller (PSC) and the PLL controller. Figure 20-17 shows the connections between the EMIFA memory controller, PSC, and PLL. Before gating clocks off, the EMIFA memory controller must place the SDR SDRAM memory in self-refresh mode. If the external memory requires a continuous clock, the clock provided by the PLL must not be turned off because this may result in data corruption. See the following subsections for the proper procedures to follow when stopping the EMIFA memory controller clocks.

Figure 20-17. EMIFA PSC Block Diagram



20.2.14.1 Power Management Using Self-Refresh Mode

The EMIFA can be placed into a self-refresh state in order to place the attached SDRAM devices into self-refresh mode, which consumes less power for most SDRAM devices. In this state, the attached SDRAM device uses an internal clock to perform its own auto refresh cycles. This maintains the validity of the data in the SDRAM without the need for any external commands. Refer to Section 20.2.4.7 for more details on placing the EMIFA into the self-refresh state.

20.2.14.2 Power Management Using Power Down Mode

In case of power down, to lower the power consumption, EMIFA drives EMA_SDCKE low. EMA_SDCKE goes high when there is a need to send refresh (REFR) commands, after which EMA_SDCKE is again driven low. EMA_SDCKE remains low until any request arrives. Refer to Section 20.2.4.8 for more details on placing EMIFA in power down mode.

20.2.14.3 Power Management Using Clock Stop

The LPSC of the memory controller can be programmed to be in one of the following states:

- Enable
- Auto Sleep
- Auto Wake
- Sync Reset

After the EMIFA clock is enabled, by default it is in the enable state. EMIFA can be put to auto sleep state, when the clock is to be gated off. Auto Wake brings back EMIFA to the enable state from the auto sleep state.

20.2.14.3.1 Auto Sleep and Auto Wake

To achieve maximum power savings EMIFA core clock should be gated off. EMIFA memory controller can make use of auto sleep and auto wake to achieve clock gating. Following describes the procedure to be followed to put EMIFA memory controller in auto sleep state:

- EMIFA should be put to self-refresh mode before stopping the clock. Refer to Section 20.2.4.7 for details on self-refresh mode. The EMIFA memory controller will complete any outstanding accesses and backlogged refresh cycles and then place the EMIFA memory in self-refresh mode.
- Then, program the LPSC of EMIFA for auto sleep, to gate off the clocks.

Register and memory access requests are honored while EMIFA is in auto sleep state. When EMIFA sees a request while it is in auto sleep state, it automatically returns to enable state, processes the request, and returns back to auto sleep state until further requests come.

On frequent requests, EMIFA switches between auto sleep and enable states. To bring EMIFA back to the enable state, auto wake can be used. Following procedure is followed for performing auto wake.

- Program the LPSC of EMIFA for auto wake.
- Bring EMIFA out of self-refresh. Refer to Section 20.2.4.7 for details on self-refresh mode.

After auto wake, EMIFA is in enable state and clocks run continuously.

20.2.14.3.2 Sync Reset and Enable

Sync reset of EMIFA through the LPSC does not reset the EMIFA registers or memory. Thus EMIFA LPSC sync reset behavior is similar to EMIFA LPSC auto sleep, except that register or memory requests are not honored by EMIFA. Following is the procedure to put EMIFA in sync reset state:

- EMIFA should be put to self-refresh mode before stopping the clock. Refer to Section 20.2.4.7 for details on self-refresh mode. The EMIFA memory controller will complete any outstanding accesses and backlogged refresh cycles and then place the EMIFA memory in self-refresh mode.
- Then, program the LPSC of EMIFA to Sync-Reset state.

On sync reset, requests to EMIFA are not honored. To bring EMIFA back to the enable state, use the following enable procedure:

- Program the LPSC of EMIFA to enter enable state.
- Bring EMIFA out of self-refresh. Refer to Section 20.2.4.7 for details on self-refresh mode.

Now EMIFA memory controller is in the enable state and continues with normal operation.

20.2.15 Emulation Considerations

EMIFA memory controller will remain fully functional during emulation halts, to allow emulation access to external memory.

20.3 Example Configuration

This section presents an example of interfacing the EMIFA to both an SDR SDRAM device and an asynchronous flash device.

20.3.1 Hardware Interface

Figure 20-18 shows the hardware interface between the EMIFA, a Samsung K4S641632H-TC(L)70 64Mb SDRAM device, and two SHARP LH28F800BJE-PTTL90 8Mb Flash memory. The connection between the EMIFA and the SDRAM is straightforward, but the connection between the EMIFA and the flash deserves a detailed look.

The address inputs for the flash are provided by three sources. The A[12:0] address inputs are provided by a combination of the EMA_A and EMA_BA pins according to Section 20.2.5.1. The upper address inputs A[18:13] are provided by GPIO pins. The six GPIO pins are connected to the upper address bits of the flash memory and attached to pulldown resistors so that their value is 0 after reset and before configuring the pins as GPIO. This is necessary if the ROM bootloader is copying the secondary bootloader from the flash. More details on using GPIO pins as upper address pins can be found in Section 20.2.5.2. RD/$\overline{BY}$ signal from one flash is connected to EMA_WAIT pin of EMIFA. A GPIO pin can be made use of to receive the RD/$\overline{BY}$ signal coming from the second flash, as shown in Figure 20-18

Finally, this example configuration connects the $\overline{EMA\_WE}$ pin to the $\overline{WE}$ input of the flash and operates the EMIFA in Normal Mode.

20.3.2 Software Configuration

The following sections describe how to interface the EMIFA to SDRAM, Asynchronous SRAM (ASRAM), or a NAND Flash device.

20.3.2.1 Configuring the SDRAM Interface

This section describes how to configure the EMIFA to interface with the Samsung K4S641632H-TC(L)70 SDRAM with a clock frequency of f_{EMA_CLK} = 100 MHz. Procedure A described in Section 20.2.4.5 is followed which assumes that the SDRAM power-up timing constraint were met during the SDRAM Auto-Initialization sequence after Reset.

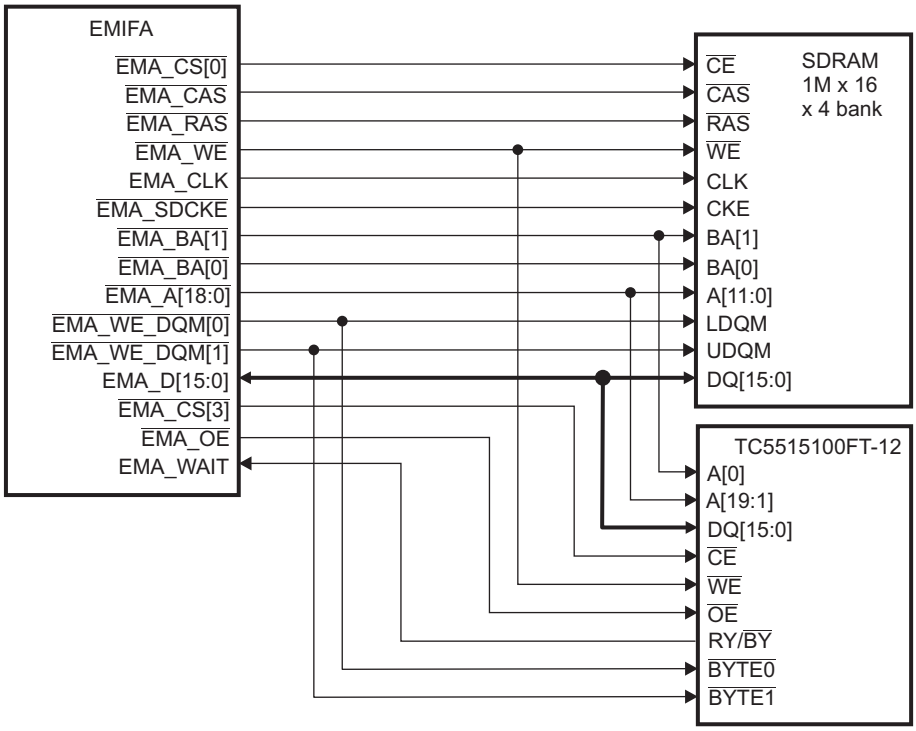
20.3.2.1.1 PLL Programming for the EMIFA to K4S641632H-TC(L)70 Interface

The device PLL Controller should first be programmed to select the desired EMA_CLK frequency. Before doing this, the SDRAM should be placed in Self-Refresh Mode by setting the SR bit in the SDRAM configuration register (SDCR). The SR bit should be set using a byte-write to the upper byte of the SDCR to avoid triggering the SDRAM Initialization Sequence. The EMA_CLK frequency can now be adjusted to the desired value by programming the appropriate SYSCLK domain of the PLL Controller. Once the PLL has been reprogrammed, remove the SDRAM from Self-Refresh by clearing the SR bit in SDCR, again with a byte-write.

Table 20-26. SR Field Value For the EMIFA to K4S641632H-TC(L)70 Interface

Field	Value	Purpose
SR	1 then 0	To place the EMIFA into the self refresh state

Figure 20-18. Example Configuration Interface



20.3.2.1.2 SDRAM Timing Register (SDTIMR) Settings for the EMIFA to K4S641632H-TC(L)70 Interface

The fields of the SDRAM timing register (SDTIMR) should be programmed first as described in Table 20-27 to satisfy the required timing parameters for the K4S641632H-TC(L)70. Based on these calculations, a value of 6111 4610h should be written to SDTIMR. Figure 20-19 shows a graphical description of how SDTIMR should be programmed.

Table 20-27. SDTIMR Field Calculations for the EMIFA to K4S641632H-TC(L)70 Interface

Field Name	Formula	Value from K4S641632H-TC(L)70 Datasheet	Value Calculated for Field
T_RFC	T_RFC >= (t_{RFC} × f_{EMA_CLK}) - 1	t_{RC} = 68 ns (min)(1)	6
T_RP	T_RP >= (t_{RP} × f_{EMA_CLK}) - 1	t_{RP} = 20 ns (min)	1
T_RCD	T_RCD >= (t_{RCD} × f_{EMA_CLK}) - 1	t_{RCD} = 20 ns (min)	1
T_WR	T_WR >= (t_{WR} × f_{EMA_CLK}) - 1	t_{RDL} = 2 CLK = 20 ns (min)(2)	1
T_RAS	T_RAS >= (t_{RAS} × f_{EMA_CLK}) - 1	t_{RAS} = 49 ns (min)	4
T_RC	T_RC >= (t_{RC} × f_{EMA_CLK}) - 1	t_{RC} = 68 ns (min)	6
T_RRD	T_RRD >= (t_{RRD} × f_{EMA_CLK}) - 1	t_{RRD} = 14 ns (min)	1

(1) The Samsung datasheet does not specify a t_{RFC} value. Instead, Samsung specifies t_{RC} as the minimum auto refresh period.
(2) The Samsung datasheet does not specify a t_{WR} value. Instead, Samsung specifies t_{RDL} as last data in to row precharge minimum delay.

Figure 20-19. SDRAM Timing Register (SDTIMR)

31 27	26 24	23	22 20	19	18 16
0 0110	001	0	001	0	001
T_RFC	T_RP	Rsvd	T_RCD	Rsvd	T_WR

15 12	11 8	7	6 4	3 0
0100	0110	0	001	0000
T_RAS	T_RC	Rsvd	T_RRD	Reserved

20.3.2.1.3 SDRAM Self Refresh Exit Timing Register (SDSRETR) Settings for the EMIFA to K4S641632H-TC(L)70 Interface

The SDRAM self refresh exit timing register (SDSRETR) should be programmed second to satisfy the t_{XSR} timing requirement from the K4S641632H-TC(L)70 datasheet. Table 20-28 shows the calculation of the proper value to program into the T_XS field of this register. Based on this calculation, a value of 6h should be written to SDSRETR. Figure 20-20 shows how SDSRETR should be programmed.

Table 20-28. RR Calculation for the EMIFA to K4S641632H-TC(L)70 Interface

Field Name	Formula	Value from K4S641632H-TC(L)70 Datasheet	Value Calculated for Field
T_XS	T_XS >= (t_{XSR} × f_{EMA_CLK}) - 1	t_{RC} = 68 ns (min)[1]	6

[1] The Samsung datasheet does not specify a t_{XSR} value. Instead, Samsung specifies t_{RC} as the minimum required time after CKE going high to complete self refresh exit.

Figure 20-20. SDRAM Self Refresh Exit Timing Register (SDSRETR)

31	16
0000 0000 0000 0000	
Reserved	

15	5	4	0
000 0000 0000		0 0110	
Reserved		T_XS	

20.3.2.1.4 SDRAM Refresh Control Register (SDRCR) Settings for the EMIFA to K4S641632H-TC(L)70 Interface

The SDRAM refresh control register (SDRCR) should next be programmed to satisfy the required refresh rate of the K4S641632H-TC(L)70. Table 20-29 shows the calculation of the proper value to program into the RR field of this register. Based on this calculation, a value of 61Ah should be written to SDRCR. Figure 20-21 shows how SDRCR should be programmed.

Table 20-29. RR Calculation for the EMIFA to K4S641632H-TC(L)70 Interface

Field Name	Formula	Values	Value Calculated for Field
RR	RR ≤ f_{EMA_CLK} × $t_{Refresh\ Period}$ / n_{cycles}	From SDRAM datasheet: $t_{Refresh\ Period}$ = 64 ms; n_{cycles} = 4096 EMIFA clock rate: f_{EMA_CLK} = 100 MHz	RR = 1562 cycles = 61Ah cycles

Figure 20-21. SDRAM Refresh Control Register (SDRCR)

31	19	18	16
0 0000 0000 0000		000	
Reserved		Reserved	

15	13	12	0
000		0 0110 0001 1010 (61Ah)	
Reserved		RR	

20.3.2.1.5 SDRAM Configuration Register (SDCR) Settings for the EMIFA to K4S641632H-TC(L)70 Interface

Finally, the fields of the SDRAM configuration register (SDCR) should be programmed as described in Table 20-30 to properly interface with the K4S641632H-TC(L)70 device. Based on these settings, a value of 4720h should be written to SDCR. Figure 20-22 shows how SDCR should be programmed. The EMIFA is now ready to perform read and write accesses to the SDRAM.

Table 20-30. SDCR Field Values For the EMIFA to K4S641632H-TC(L)70 Interface

Field	Value	Purpose
SR	0	To avoid placing the EMIFA into the self refresh state
NM	1	To configure the EMIFA for a 16-bit data bus
CL	011b	To select a CAS latency of 3
BIT11_9LOCK	1	To allow the CL field to be written
IBANK	010b	To select 4 internal SDRAM banks
PAGESIZE	0	To select a page size of 256 words

Figure 20-22. SDRAM Configuration Register (SDCR)

31	30	29	28				24
0	0	0	0 0000				
SR	Reserved	Reserved	Reserved				

23					18	17	16
00 0000						0	0
Reserved						Reserved	Reserved

15	14	13	12	11		9	8
0	1	0	0	011			1
Reserved	NM	Reserved	Reserved	CL			BIT11_9LOCK

7	6		4	3	2		0
0	010			0	000		
Reserved	IBANK			Reserved	PAGESIZE		

20.3.2.2 Interfacing to Asynchronous SRAM (ASRAM)

The following example describes how to interface the EMIFA to the Toshiba TC55V16100FT-12 device.

20.3.2.2.1 Meeting AC Timing Requirements for ASRAM

When configuring the EMIFA to interface to ASRAM, you must consider the AC timing requirements of the ASRAM as well as the AC timing requirements of the EMIFA. These can be found in the data sheet for each respective device. The read and write asynchronous cycles are programmed separately in the asynchronous configuration register (CE*n*CFG).

For a read access, Table 20-31 to Table 20-33 list the AC timing specifications that must be considered.

Table 20-31. EMIFA Input Timing Requirements

Parameter	Description
t_{SU}	Data Setup time, data valid before $\overline{\text{EMA\_OE}}$ high
t_H	Data Hold time, data valid after $\overline{\text{EMA\_OE}}$ high

Table 20-32. ASRAM Output Timing Characteristics

Parameter	Description
t_{ACC}	Address Access time
t_{OH}	Output data Hold time for address change
t_{COD}	Output Disable time from chip enable

Table 20-33. ASRAM Input Timing Requirement for a Read

Parameter	Description
t_{RC}	Read Cycle time

Figure 20-23 shows an asynchronous read access and describes how the EMIFA and ASRAM AC timing requirements work together to define the values for R_SETUP, R_STROBE, and R_HOLD.

From Figure 20-23, the following equations may be derived. t_{cyc} is the period at which the EMIFA operates. The R_SETUP, R_STROBE, and R_HOLD fields are programmed in terms of EMIFA cycles where as the data sheet specifications are typically given in nanoseconds. This explains the presence of t_{cyc} in the denominator of the following equations. A minus 1 is included in the equations because each field in CE*n*CFG is programmed in terms of EMIFA clock cycles, minus 1 cycle. For example, R_SETUP is equal to R_SETUP width in EMIFA clock cycles minus 1 cycle.

$$\text{R\_SETUP} + \text{R\_STROBE} \geq \frac{t_{ACC}(m) + t_{SU}}{t_{cyc}} - 2$$

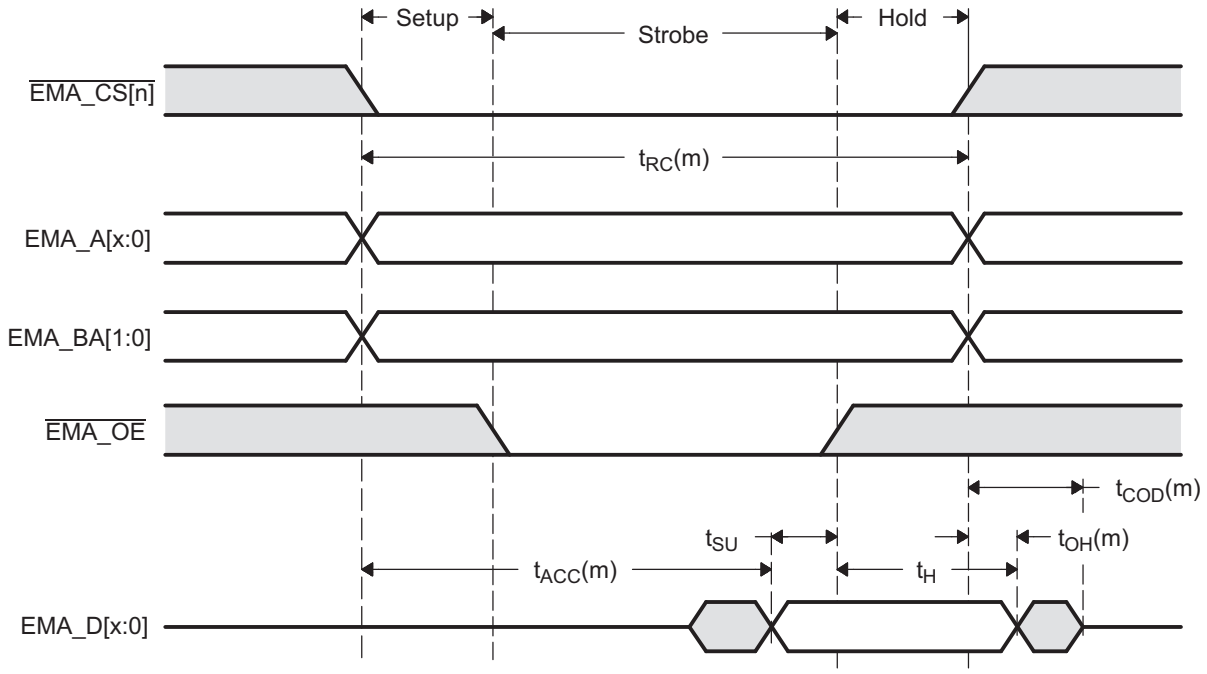
$$\text{R\_SETUP} + \text{R\_STROBE} + \text{R\_HOLD} \geq \frac{t_{RC}(m)}{t_{cyc}} - 3$$

$$\text{R\_HOLD} \geq \frac{\left(t_H - t_{OH}(m)\right)}{t_{cyc}} - 1$$

The EMIFA offers an additional parameter, TA, that defines the turnaround time between read and write cycles. This parameter protects against the situation when the output turn-off time of the memory is longer than the time it takes to start the next write cycle. If this is the case, the EMIFA will drive data at the same time as the memory, causing contention on the bus. By examining Figure 20-23, the equation for TA can be derived as:

$$TA \geq \frac{t_{COD}(m)}{t_{cyc}} - 1$$

Figure 20-23. Timing Waveform of an ASRAM Read



For a write access, Table 20-34 lists the AC timing specifications that must be satisfied.

Table 20-34. ASRAM Input Timing Requirements for a Write

Parameter	Description
t_{WP}	Write Pulse width
t_{AW}	Address valid to end of Write
t_{DS}	Data Setup time
t_{WR}	Write Recovery time
t_{DH}	Data Hold time
t_{WC}	Write Cycle time

Figure 20-24 shows an asynchronous write access and describes how the EMIFA and ASRAM AC timing requirements work together to define values for W_SETUP, W_STROBE, and W_HOLD.

From Figure 20-24, the following equations may be derived. t_{cyc} is the period at which the EMIFA operates. The W_SETUP, W_STROBE, and W_HOLD fields are programmed in terms of EMIFA cycles where as the data sheet specifications are typically given is nano seconds. This is explains the presence of t_{cyc} in the denominator of the following equations. A minus 1 is included in the equations because each field in CE*n*CFG is programmed in terms of EMIFA clock cycles, minus 1 cycle. For example, W_SETUP is equal to W_SETUP width in EMIFA clock cycles minus 1 cycle.≥

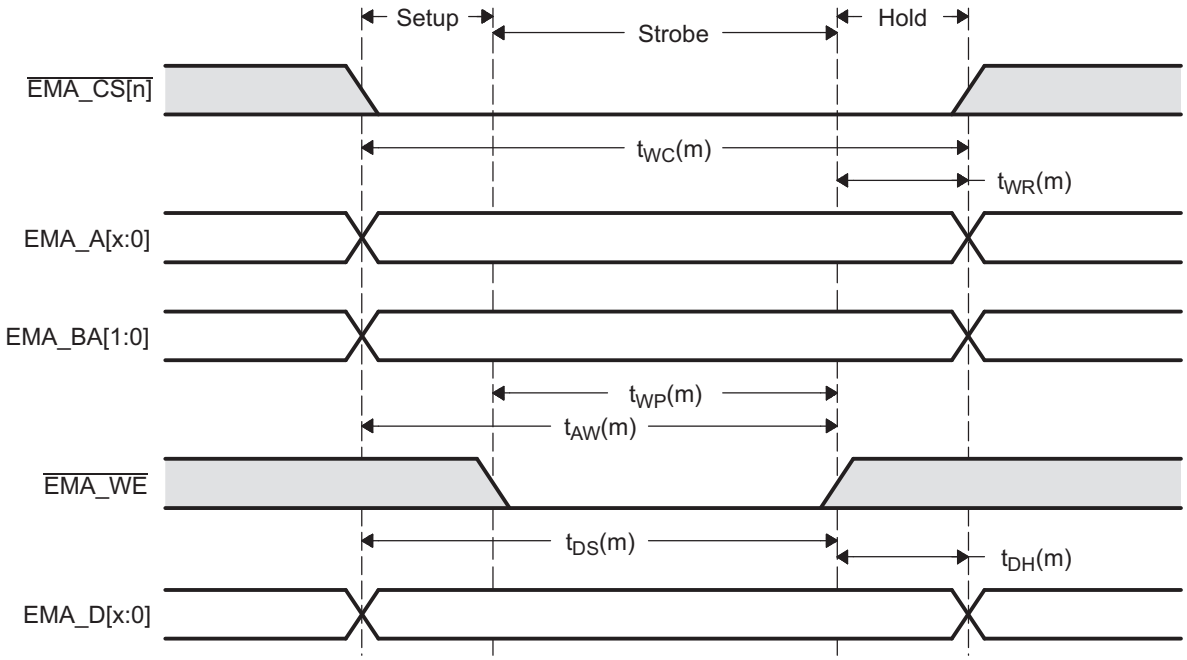
$$\text{W\_STROBE} \geq \frac{t_{WP}(m)}{t_{cyc}} - 1$$

$$\text{W\_SETUP} + \text{W\_STROBE} \geq \max\left(\frac{t_{AW}(m)}{t_{cyc}}, \frac{t_{DS}(m)}{t_{cyc}}\right) - 2$$

$$\text{W\_HOLD} \geq \max\left(\frac{t_{WR}(m)}{t_{cyc}}, \frac{t_{DH}(m)}{t_{cyc}}\right) - 1$$

$$\text{W\_SETUP} + \text{W\_STROBE} + \text{W\_HOLD} \geq \frac{t_{WC}(m)}{t_{cyc}} - 3$$

Figure 20-24. Timing Waveform of an ASRAM Write



20.3.2.2.2 Taking Into Account PCB Delays

The equations described in Section 20.3.2.2.1 are for the ideal case, when board design does not contribute delays. Board characteristics, such as impedance, loading, length, number of nodes, etc., affect how the device driver behaves. Signals driven by the EMIFA will be delayed when they reach the ASRAM and conversely. Table 20-35 lists the delays shown in Figure 20-25 and Figure 20-26 due to PCB affects. The PCB delays are board specific and must be estimated or determined though the use of IBIS modeling. The signals denoted (ASRAM) are the signals seen at the ASRAM. For example, $\overline{\text{EMA\_CS}}$ represents the signal at the EMIFA and $\overline{\text{EMA\_CS}}$ (ASRAM) represents the delayed signal seen at the ASRAM.

Table 20-35. ASRAM Timing Requirements With PCB Delays

Parameter	Description
	Read Access
t_{EM_CS}	Delay on $\overline{\text{EMA\_CS}}$ from EMIFA to ASRAM. $\overline{\text{EMA\_CS}}$ is driven by EMIF.
t_{EM_A}	Delay on EMA_A from EMIFA to ASRAM. EMA_A is driven by EMIF.
t_{EM_OE}	Delay on $\overline{\text{EMA\_OE}}$ from EMIFA to ASRAM. $\overline{\text{EMA\_OE}}$ is driven by EMIF.
t_{EM_D}	Delay on EMA_D from ASRAM to EMIFA. EMA_D is driven by ASRAM.
	Write Access
t_{EM_CS}	Delay on $\overline{\text{EMA\_CS}}$ from EMIFA to ASRAM. $\overline{\text{EMA\_CS}}$ is driven by EMIF.
t_{EM_A}	Delay on EMA_A from EMIFA to ASRAM. EMA_A is driven by EMIF.
t_{EM_WE}	Delay on $\overline{\text{EMA\_WE}}$ from EMIFA to ASRAM. $\overline{\text{EMA\_WE}}$ is driven by EMIF.
t_{EM_D}	Delay on EMA_D from EMIFA to ASRAM. EMA_D is driven by EMIF.

From Figure 20-25, the following equations may be derived. t_{cyc} is the period at which the EMIFA operates. The R_SETUP, R_STROBE, and R_HOLD fields are programmed in terms of EMIFA cycles where as the data sheet specifications are typically given in nano seconds. This is explains the presence of t_{cyc} in the denominator of the following equations. A minus 1 is included in the equations because each field in CE*n*CFG is programmed in terms of EMIFA clock cycles, minus 1 cycle. For example, R_SETUP is equal to R_SETUP width in EMIFA clock cycles minus 1 cycle.

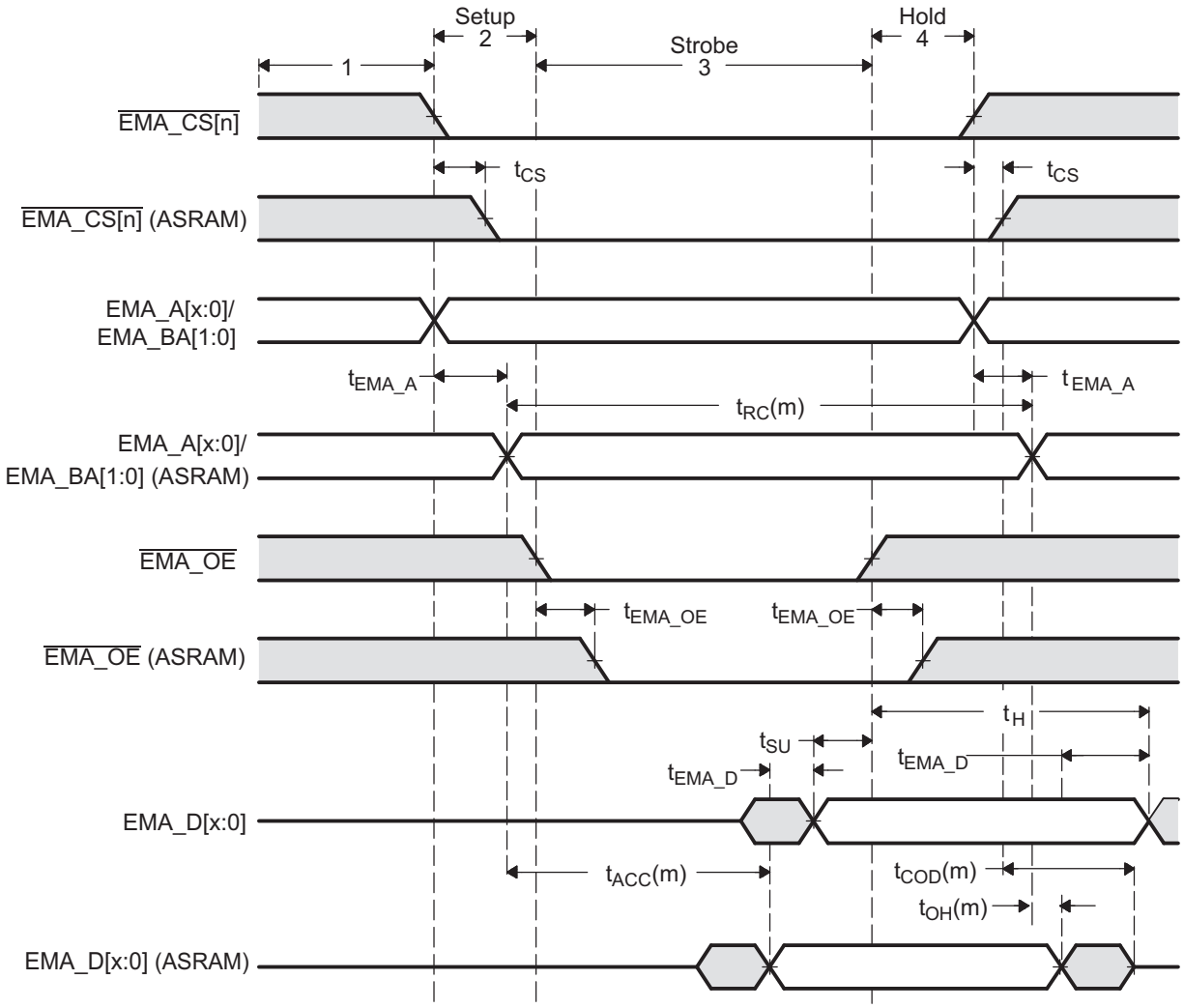
$$\text{R\_SETUP} + \text{R\_STROBE} \geq \frac{(t_{EM\_A} + t_{ACC}(m) + t_{SU} + t_{EM\_D})}{t_{cyc}} - 2$$

$$\text{R\_SETUP} + \text{R\_STROBE} + \text{R\_HOLD} \geq \frac{t_{RC}(m)}{t_{cyc}} - 3$$

$$\text{R\_HOLD} \geq \frac{\left(t_H - t_{EM\_D} - t_{OH}(m) - t_{EM\_A}\right)}{t_{cyc}} - 1$$

$$\text{TA} \geq \frac{\left(t_{EM\_CS} + t_{COD}(m) + t_{EM\_D}\right)}{t_{cyc}} - 1$$

Figure 20-25. Timing Waveform of an ASRAM Read with PCB Delays



From Figure 20-26, the following equations may be derived. t_{cyc} is the period at which the EMIFA operates. The W_SETUP, W_STROBE, and W_HOLD fields are programmed in terms of EMIFA cycles where as the data sheet specifications are typically given is nano seconds. This is explains the presence of t_{cyc} in the denominator of the following equations. A minus 1 is included in the equations because each field in CE*n*CFG is programmed in terms of EMIFA clock cycles, minus 1 cycle. For example, W_SETUP is equal to W_SETUP width in EMIFA clock cycles minus 1 cycle.

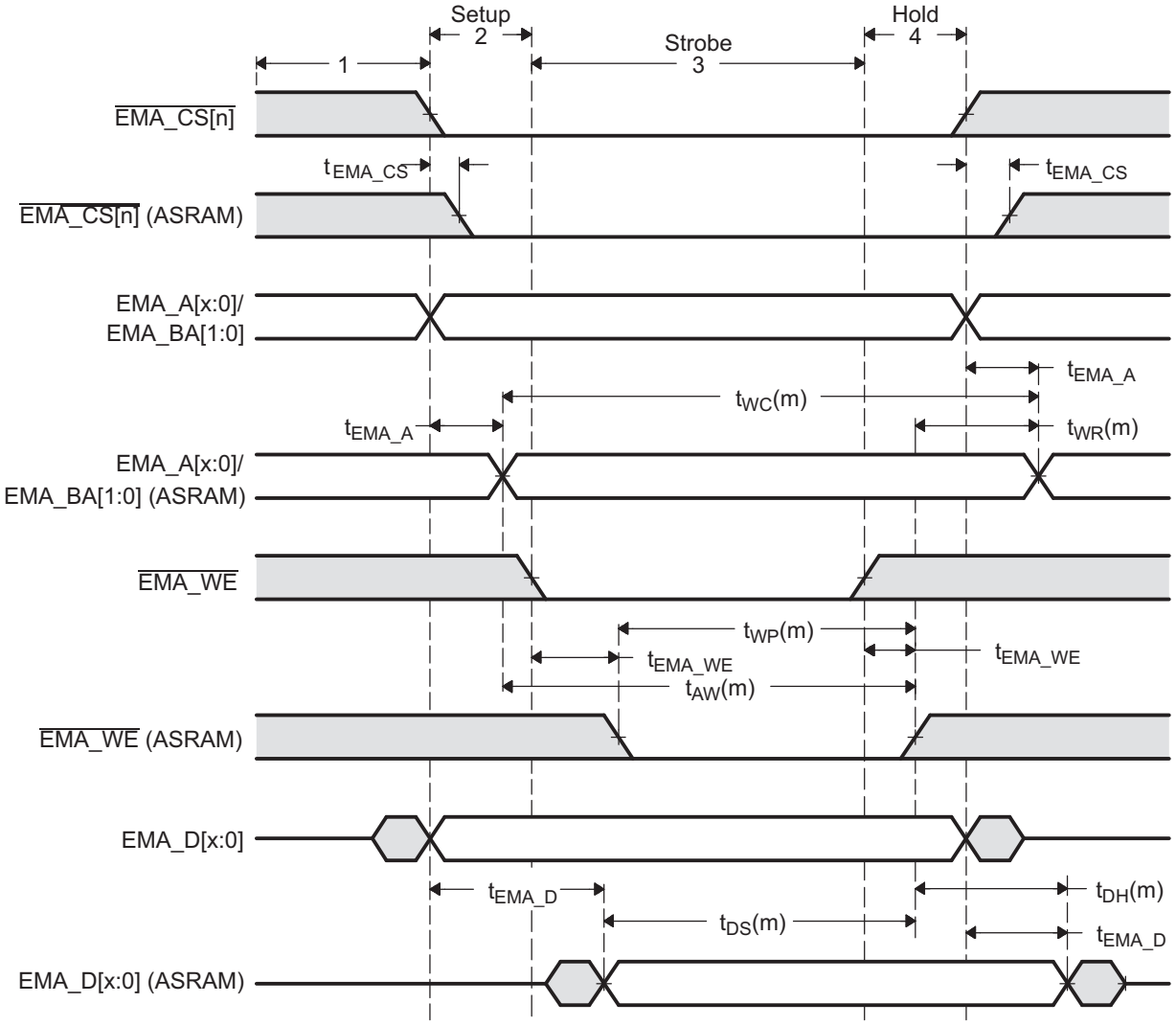
$$W\_STROBE \geq \frac{t_{WP}(m)}{t_{cyc}} - 1$$

$$W\_SETUP + W\_STROBE \geq \max\left(\frac{(t_{EM\_A} + t_{AW}(m) - t_{EM\_WE})}{t_{cyc}}, \frac{(t_{EM\_D} + t_{DS}(m) - t_{EM\_WE})}{t_{cyc}}\right) - 2$$

$$W\_HOLD \geq \max\left(\frac{(t_{EM\_WE} + t_{WR}(m) - t_{EM\_A})}{t_{cyc}}, \frac{(t_{EM\_WE} + t_{DH}(m) - t_{EM\_D})}{t_{cyc}}\right) - 1$$

$$W\_SETUP + W\_STROBE + W\_HOLD \geq \frac{t_{WC}(m)}{t_{cyc}} - 3$$

Figure 20-26. Timing Waveform of an ASRAM Write with PCB Delays



20.3.2.2.3 Example Using TC5516100FT-12

This section takes you through the configuration steps required to implement Toshiba's TC55V1664FT-12 ASRAM with the EMIFA. The following assumptions are made:

- ASRAM is connected to chip select space 3 ($\overline{\text{EMA\_CS[3]}}$)
- EMIFA clock speed is 100 MHz (t_{cyc} = 10 nS)

Table 20-36 lists the data sheet specifications for the EMIFA and Table 20-37 lists the data sheet specifications for the ASRAM.

Table 20-36. EMIFA Timing Requirements for TC5516100FT-12 Example

Parameter	Description	Min	Max	Units
t_{SU}	Data Setup time, data valid before $\overline{\text{EMA\_OE}}$ high	3 to 7 (1)		nS
t_H	Data Hold time, data valid after $\overline{\text{EMA\_OE}}$ high	0		nS

(1) Depending on operating conditions. See your device-specific data manual for the value.

Table 20-37. ASRAM Timing Requirements for TC5516100FT-12 Example

Parameter	Description	Min	Max	Units
t_{ACC}	Address Access time		12	nS
t_{OH}	Output data Hold time for address change	3		nS
t_{RC}	Read cycle time	12		nS
t_{WP}	Write Pulse width	8		nS
t_{AW}	Address valid to end of Write	9		nS
t_{DS}	Data Setup time	7		nS
t_{WR}	Write Recovery time	0		nS
t_{DH}	Data Hold time	0		nS
t_{WC}	Write Cycle time	12		nS
t_{COD}	Output Disable time from chip enable		7	

Table 20-38 lists the values of the PCB board delays. The delays were estimated using the rule that there is 180 pS of delay for every 1 inch of trace.

Table 20-38. Measured PCB Delays for TC5516100FT-12 Example

Parameter	Description	Delay (ns)
	Read Access	
t_{EM_CS}	Delay on $\overline{\text{EMA\_CS}}$ from EMIFA to ASRAM. $\overline{\text{EMA\_CS}}$ is driven by EMIF.	0.36
t_{EM_A}	Delay on EMA_A from EMIFA to ASRAM. EMA_A is driven by EMIF.	0.27
t_{EM_OE}	Delay on $\overline{\text{EMA\_OE}}$ from EMIFA to ASRAM. $\overline{\text{EMA\_OE}}$ is driven by EMIF.	0.36
t_{EM_D}	Delay on EMA_D from ASRAM to EMIFA. EMA_D is driven by ASRAM.	0.45
	Write Access	
t_{EM_CS}	Delay on $\overline{\text{EMA\_CS}}$ from EMIFA to ASRAM. $\overline{\text{EMA\_CS}}$ is driven by EMIF.	0.36
t_{EM_A}	Delay on EMA_A from EMIFA to ASRAM. EMA_A is driven by EMIF.	0.27
t_{EM_WE}	Delay on $\overline{\text{EMA\_WE}}$ from EMIFA to ASRAM. $\overline{\text{EMA\_WE}}$ is driven by EMIF.	0.36
t_{EM_D}	Delay on EMA_D from EMIFA to ASRAM. EMA_D is driven by EMIF.	0.45

Inserting these values into the equations defined above allows you to determine the values for SETUP, STROBE, HOLD, and TA. For a read:

$$R\_SETUP + R\_STROBE \geq \frac{(t_{EM\_A} + t_{ACC}(m) + t_{SU} + t_{EM\_D})}{t_{cyc}} - 2 \geq \frac{(0.27 + 12 + 5 + 0.45)}{10} - 2 \geq -0.23$$

$$R\_SETUP + R\_STROBE + R\_HOLD \geq \frac{t_{RC}(m)}{t_{cyc}} - 3 \geq \left(\frac{12}{10}\right) - 3 \geq -1.8$$

$$R\_HOLD \geq \frac{\left(t_H - t_{EM\_D} - t_{OH}(m) - t_{EM\_A}\right)}{t_{cyc}} - 1 \geq \frac{(0 - 0.45 - 3 - 0.27)}{10} - 1 \geq -1.37$$

$$TA \geq \frac{\left(t_{EM\_CS} + T_{COD}(m) + t_{EM\_D}\right)}{t_{cyc}} - 1 \geq \frac{(0.36 + 7 + 0.45)}{10} - 1 \geq -0.22$$

Therefore if R_SETUP = 0, then R_STROBE = 0, R_HOLD = 0, and TA = 0.

For a write:

$$W\_STROBE \geq \frac{t_{WP}(m)}{t_{cyc}} - 1 \geq \left(\frac{8}{10}\right) - 1 \geq -0.2$$

$$W\_SETUP + W\_STROBE \geq \max\left(\frac{(t_{EM\_A} + t_{AW}(m) - t_{EM\_WE})}{t_{cyc}}, \frac{(t_{EM\_D} + t_{DS}(m) - t_{EM\_WE})}{t_{cyc}}\right) - 2$$

$$\geq \max\left(\frac{(0.36 + 0 - 0.27)}{10}, \frac{(0.36 + 0 - 0.45)}{10}\right) - 2 \geq -2.01$$

$$W\_HOLD \geq \max\left(\frac{\left(t_{EM\_WE} + t_{WR}(m) - t_{EM\_A}\right)}{t_{cyc}}, \frac{\left(t_{EM\_WE} + t_{DH}(m) - t_{EM\_D}\right)}{t_{cyc}}\right) - 1$$

$$\geq \max\left(\frac{(0.27 + 9 - 0.36)}{10}, \frac{(0.45 + 7 - 0.36)}{10}\right) - 1 \geq -0.1$$

$$W\_SETUP + W\_STROBE + W\_HOLD \geq \frac{t_{WC}(m)}{t_{cyc}} - 3 \geq \left(\frac{12}{10}\right) - 3 \geq -1.8$$

Therefore, W_SETUP = 0, W_STROBE = 0, and W_HOLD = 0.

Since the value of the W_SETUP/R_SETUP, W_STROBE/R_STROBE, W_HOLD/R_HOLD, and TA fields are equal to EMIFA clock cycles minus 1 cycle, the CE3CFG should be configured as in Table 20-39. In this example, the EMA_WAIT signal is not implemented; therefore, the asynchronous wait cycle configuration register (AWCC) does not need to be programmed.

Table 20-39. Configuring CE3CFG for TC5516100FT-12 Example

Parameter	Setting
SS	**Select Strobe mode.** • SS = 0. Places EMIFA in Normal Mode.
EW	**Extended Wait mode enable.** • EW = 0. Disabled Extended wait mode.
W_SETUP/R_SETUP	**Read/Write setup widths.** • W_SETUP = 0 • R_SETUP = 0
W_STROBE/R_STROBE	**Read/Write strobe widths.** • W_STROBE = 0 • R_STROBE = 0
W_HOLD/R_HOLD	**Read/Write hold widths.** • W_HOLD = 0 • R_HOLD = 0
TA	**Minimum turnaround time.** • TA = 0
ASIZE	**Asynchronous Device Bus Width.** • ASIZE = 1, select a 16-bit data bus width

20.3.2.3 Interfacing to NAND Flash

The following example explains how to interface the EMIFA to the Hynix HY27UA081G1M NAND Flash device.

20.3.2.3.1 Margin Requirements

The Flash interface is typically a low-performance interface compared to synchronous memory interfaces, high-speed asynchronous memory interfaces, and high-speed FIFO interfaces. For this reason, this example gives little attention to minimizing the amount of margin required when programming the asynchronous timing parameters. The approach used requires approximately 10 ns of margin on all parameters, which is not significant for a 100-ns read or write cycle. For additional details on minimizing the amount of margin, see the ASRAM example given in Section 20.3.2.2.

Table 20-40. Recommended Margins

Timing Parameter	Recommended Margin
Output Setup	10 nS
Output Hold	10 nS
Input Setup	10 nS
Input Hold	10 nS

20.3.2.3.2 Meeting AC Timing Requirements for NAND Flash

When configuring the EMIFA to interface to NAND Flash, you must consider the AC timing requirements of the NAND Flash as well as the AC timing requirements of the EMIFA. These can be found in the data sheet for each respective device. The read and write asynchronous cycles are programmed separately in the asynchronous configuration register (CE*n*CFG).

A NAND Flash access cycle is composed of a command, address, and data phases. The EMIFA will not automatically generate these three phases to complete a NAND access with one transfer request. To complete a NAND access cycle, multiple single asynchronous access cycles must be completed by the EMIFA. The command and address phases of a NAND Flash access cycle are asynchronous writes performed by the EMIFA where as the data phase can be either an asynchronous write or a read depending on whether the NAND Flash is being programmed or read.

Therefore, to determine the required EMIFA configuration to interface to the NAND Flash for a read operation, Table 20-41 and Table 20-42 list the AC timing parameters that must be considered.

Table 20-41. EMIFA Read Timing Requirements

Parameter	Description
t_{SU}	Data Setup time, data valid before $\overline{\text{EMA\_OE}}$ high
t_{H}	Data Hold time, data valid after $\overline{\text{EMA\_OE}}$ high

Table 20-42. NAND Flash Read Timing Requirements

Parameter	Description
t_{RP}	Read Pulse width
t_{REA}	Read Enable Access time
t_{CEA}	Chip Enable low to output valid
t_{CHZ}	Chip Enable high to output High-Z
t_{RC}	Read Cycle time
t_{RHZ}	Read enable high to output High-Z
t_{CLR}	Command Latch low to Read enable low

Figure 20-27 shows an asynchronous read access and describes how the EMIFA and NAND Flash AC timing requirements work together to define the values for R_SETUP, R_STROBE, and R_HOLD.

From Figure 20-27, the following equations may be derived. t_{cyc} is the period at which the EMIFA operates. The R_SETUP, R_STROBE, and R_HOLD fields are programmed in terms of EMIFA cycles where as the data sheet specifications are typically given is nano seconds. This is explains the presence of t_{cyc} in the denominator of the following equations. A minus 1 is included in the equations because each field in CE*n*CFG is programmed in terms of EMIFA clock cycles, minus 1 cycle. For example, R_SETUP is equal to R_SETUP width in EMIFA clock cycles minus 1 cycle.

$$\text{R\_SETUP} \geq \frac{t_{CLR}(m)}{t_{cyc}} - 1$$

$$\text{R\_STROBE} \geq \max\left(\frac{(t_{REA}(m) + t_{SU})}{t_{cyc}}, \frac{t_{RP}(m)}{t_{cyc}}\right) - 1$$

$$\text{R\_SETUP} + \text{R\_STROBE} \geq \frac{(t_{CEA}(m) + t_{SU})}{t_{cyc}} - 2$$

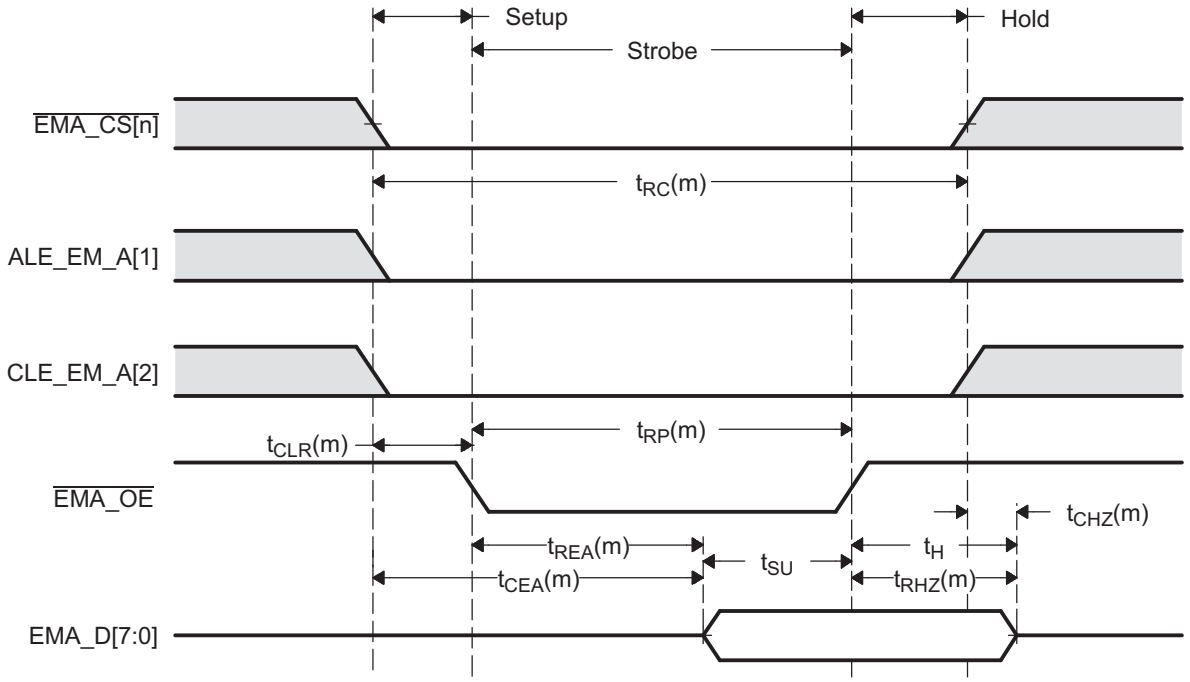
$$\text{R\_HOLD} \geq \frac{(t_H - t_{CHZ}(m))}{t_{cyc}} - 1$$

$$\text{R\_SETUP} + \text{R\_STROBE} + \text{R\_HOLD} \geq \frac{t_{RC}(m)}{t_{cyc}} - 3$$

The EMIFA offers an additional parameter, TA, that defines the turnaround time between read and write cycles. This parameter protects against the situation when the output turn-off time of the memory is longer than the time it takes to start the next write cycle. If this is the case, the EMIFA will drive data at the same time as the memory, causing contention on the bus. By examining Figure 20-27, the equation for TA can be derived as:

$$TA \geq \max\left(\frac{t_{CHZ}(m)}{t_{cyc}}, \frac{t_{RHZ}(m) - (\text{R\_HOLD} + 1)t_{cyc}}{t_{cyc}}\right) - 1$$

Figure 20-27. Timing Waveform of a NAND Flash Read



To determine the required EMIFA configuration to interface to the NAND Flash for a write operation, Table 20-43 lists the NAND AC timing parameters for a command latch, address latch, and data input latch that must be considered.

Table 20-43. NAND Flash Write Timing Requirements

Parameter	Description
t_{WP}	Write Pulse width
t_{CLS}	CLE Setup time
t_{ALS}	ALE Setup time
t_{CS}	$\overline{CS}$ Setup time
t_{DS}	Data Setup time
t_{CLH}	CLE Hold time
t_{ALH}	ALE Hold time
t_{CH}	$\overline{CS}$ Hold time
t_{DH}	Data Hold time
t_{WC}	Write Cycle time

Figure 20-28 to Figure 20-30 show the command latch, address latch, and data input latch of the NAND access.

From Figure 20-28 to Figure 20-30, the following equations may be derived. t_{cyc} is the period at which the EMIFA operates. The W_SETUP, W_STROBE, and W_HOLD fields are programmed in terms of EMIFA cycles where as the data sheet specifications are typically given is nano seconds. This is explains the presence of t_{cyc} in the denominator of the following equations. A minus 1 is included in the equations because each field in CE*n*CFG is programmed in terms of EMIFA clock cycles, minus 1 cycle. For example, W_SETUP is equal to W_SETUP width in EMIFA clock cycles minus 1 cycle.

$$W\_SETUP \geq \max\left(\frac{t_{CLS}(m)}{t_{cyc}}, \frac{t_{ALS}(m)}{t_{cyc}}, \frac{t_{CS}(m)}{t_{cyc}}\right) - 1$$

$$W\_STROBE \geq \frac{t_{WP}(m)}{t_{cyc}} - 1$$

$$W\_SETUP + W\_STROBE \geq \frac{t_{DS}(m)}{t_{cyc}} - 2$$

$$W\_HOLD \geq \max\left(\frac{t_{CLH}(m)}{t_{cyc}}, \frac{t_{ALH}(m)}{t_{cyc}}, \frac{t_{CH}(m)}{t_{cyc}}, \frac{t_{DH}(m)}{t_{cyc}}\right) - 1$$

$$W\_SETUP + W\_STROBE + W\_HOLD \geq \frac{t_{WC}(m)}{t_{cyc}} - 3$$

Figure 20-28. Timing Waveform of a NAND Flash Command Write

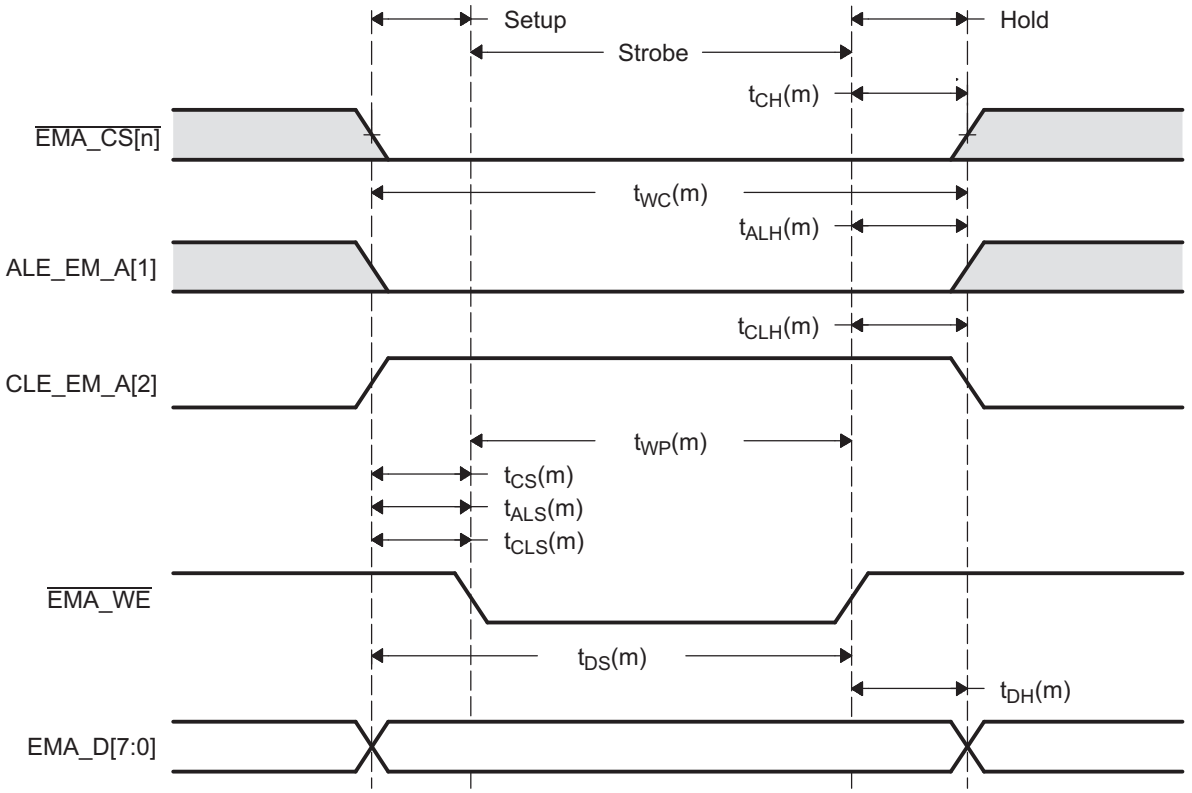


Figure 20-29. Timing Waveform of a NAND Flash Address Write

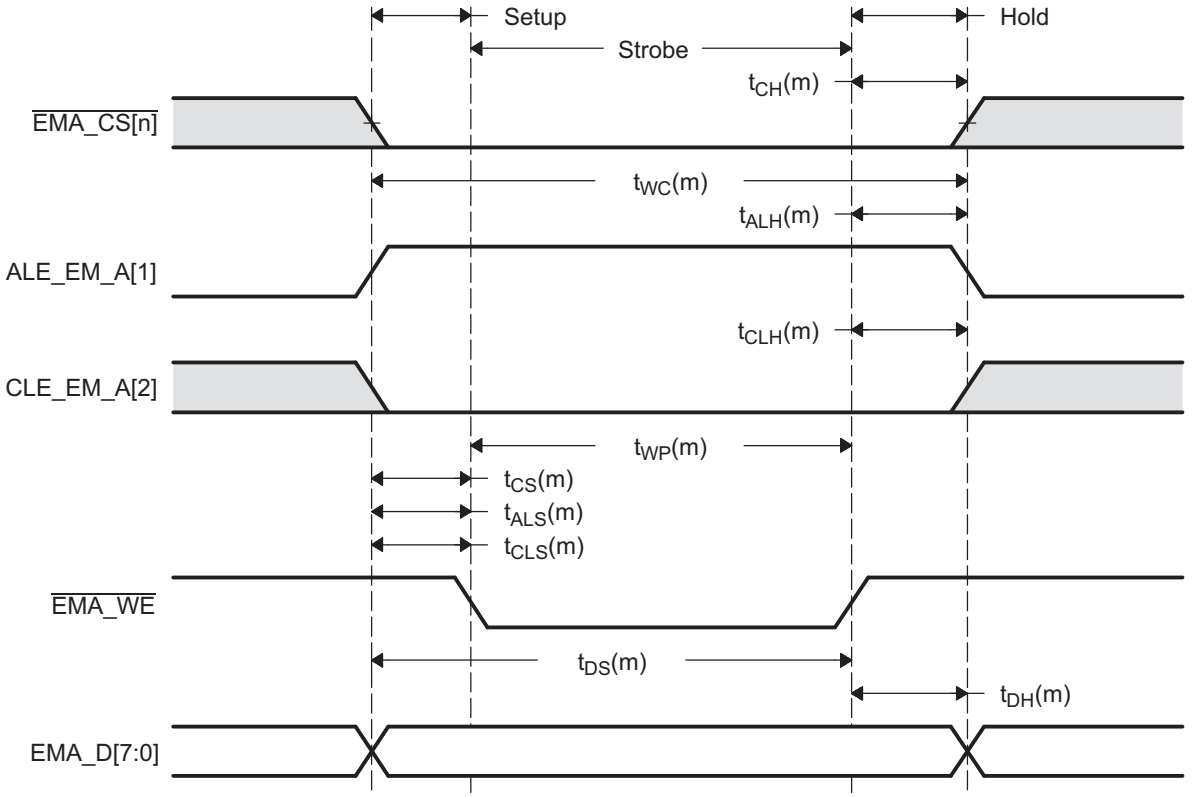
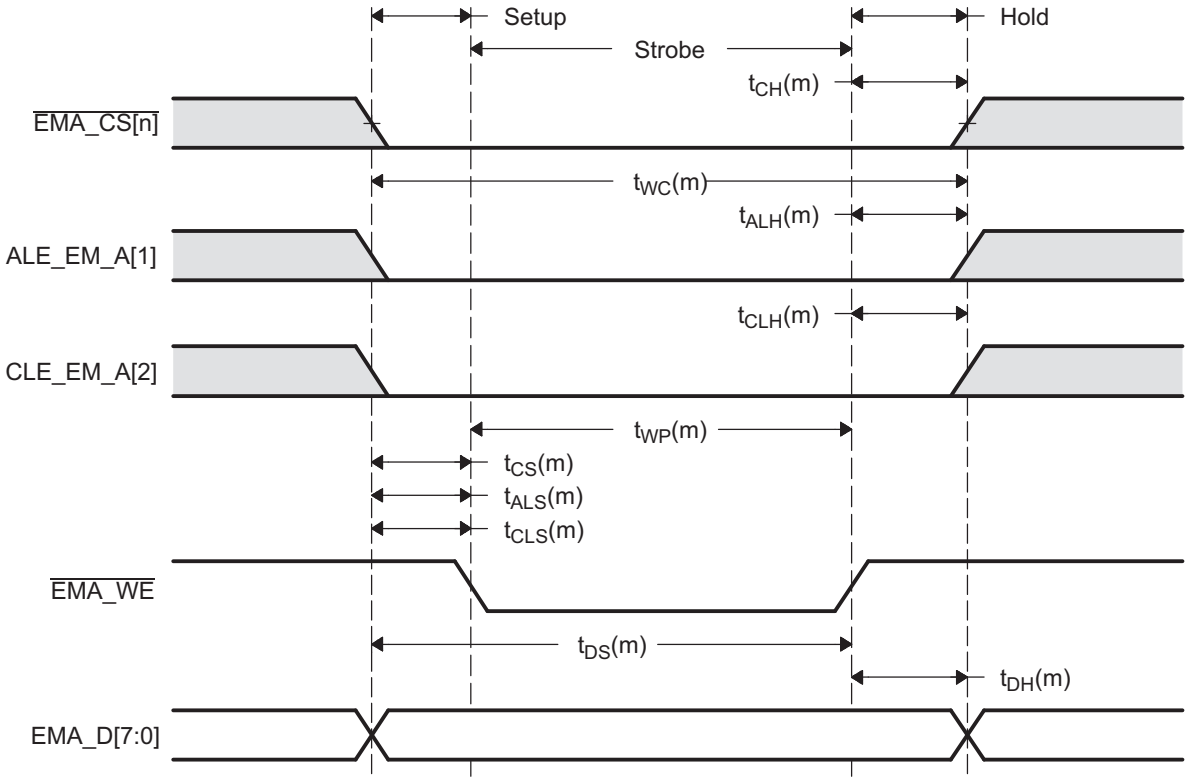


Figure 20-30. Timing Waveform of a NAND Flash Data Write



20.3.2.3.3 Example Using Hynix HY27UA081G1M

This section takes you through the configuration steps required to implement Hynix's HY27UA081G1M NAND Flash with the EMIFA. The following assumptions are made:

- NAND Flash is connected to chip select space 2 ($\overline{\text{EMA\_CS[2]}}$)
- EMIFA clock speed is 100 MHz (t_{cyc} = 10 nS)

Table 20-44 lists the data sheet specifications for the EMIFA and Table 20-45 lists the data sheet specifications for the NAND Flash.

Table 20-44. EMIFA Timing Requirements for HY27UA081G1M Example

Parameter	Description	Min	Max	Units
t_{SU}	Data Setup time, data valid before $\overline{\text{EMA\_OE}}$ high	3 to 7 (1)		nS
t_H	Data Hold time, data valid after $\overline{\text{EMA\_OE}}$ high	0		nS

(1) Depending on operating conditions. See your device-specific data manual for the value.

Table 20-45. NAND Flash Timing Requirements for HY27UA081G1M Example

Parameter	Description	Min	Max	Units
t_{RP}	Read Pulse width	60		nS
t_{REA}	Read Enable Access time		60	nS
t_{CEA}	Chip Enable low to output valid		75	nS
t_{CHZ}	Chip Enable high to output High-Z		20	nS
t_{RC}	Read Cycle time	80		nS
t_{RHZ}	Read Enable high to output High-Z		30	nS
t_{CLR}	Command Latch low to Read enable low	10		nS
t_{WP}	Write Pulse width	60		nS
t_{CLS}	CLE Setup time	0		nS
t_{ALS}	ALE Setup time	0		nS
t_{CS}	$\overline{\text{CS}}$ Setup time	0		nS
t_{DS}	Data Setup time	20		nS
t_{CLH}	CLE Hold time	10		nS
t_{ALH}	ALE Hold time	10		nS
t_{CH}	$\overline{\text{CS}}$ Hold time	10		nS
t_{DH}	Data Hold time	10		nS
t_{WC}	Write Cycle time	80		nS

Inserting these values into the equations defined above allows you to determine the values for SETUP, STROBE, HOLD, and TA. For a read:

$$R\_SETUP \geq \frac{t_{CLR}(m)}{t_{cyc}} - 1 \geq \left(\frac{10}{10}\right) - 1 \geq 0$$

$$R\_STROBE \geq \max\left(\frac{\left(t_{REA}(m) + t_{SU}\right)}{t_{cyc}}, \frac{t_{RP}}{t_{cyc}}\right) - 1 \geq \left(\frac{65}{10}\right) - 1 \geq 5.5$$

$$R\_SETUP + R\_STROBE \geq \frac{\left(t_{CEA} + t_{SU}\right)}{t_{cyc}} - 2 \geq \frac{(75 + 5)}{10} - 2 \geq 6$$

$$R\_HOLD \geq \frac{\left(t_H - t_{CHZ}(m)\right)}{t_{cyc}} - 1 \geq \frac{(0 - 20)}{10} - 1 \geq -3$$

$$R\_SETUP + R\_STROBE + R\_HOLD \geq \frac{t_{RC}(m)}{t_{cyc}} - 3 \geq \left(\frac{80}{10}\right) - 3 \geq 5$$

Therefore with a 10 nS margin added in, R_SETUP ≥ 1.0, R_STROBE ≥ 6.5, and R_HOLD ≥ 0.

After solving for R_HOLD, TA may be calculated:

$$TA \geq \max\left(\frac{t_{CHZ}(m)}{t_{cyc}}, \frac{t_{RHZ}(m) - (R\_HOLD + 1)t_{cyc}}{t_{cyc}}\right) - 1 \geq \left(\frac{20}{10}\right) - 1 \geq 1$$

Adding a 10 ns margin, TA ≥ 2.

For a write:

$$W\_STROBE \geq \frac{t_{WP}(m)}{t_{cyc}} - 1 \geq \left(\frac{60}{10}\right) - 1 \geq 5$$

$$W\_SETUP \geq \max\left(\frac{t_{CLS}(m)}{t_{cyc}}, \frac{t_{ALS}(m)}{t_{cyc}}, \frac{t_{CS}(m)}{t_{cyc}}\right) - 1 \geq \left(\frac{0}{10}\right) - 1 \geq -1$$

$$W\_SETUP + W\_STROBE \geq \frac{t_{DS}(m)}{t_{cyc}} - 2 \geq \frac{20}{10} - 2 \geq 0$$

$$W\_HOLD \geq \max\left(\frac{t_{CLH}(m)}{t_{cyc}}, \frac{t_{ALH}(m)}{t_{cyc}}, \frac{t_{CH}(m)}{t_{cyc}}, \frac{t_{DH}(m)}{t_{cyc}}\right) - 1 \geq \left(\frac{10}{10}\right) - 1 \geq 0$$

$$W\_SETUP + W\_STROBE + W\_HOLD \geq \frac{t_{WC}(m)}{t_{cyc}} - 3 \geq \left(\frac{80}{10}\right) - 3 \geq 5$$

Therefore with a 10 nS margin added in, W_SETUP ≥ 0, W_STROBE ≥ 6, and W_HOLD ≥ 1.

Since the value of the W_SETUP/R_SETUP, W_STROBE/R_STROBE, W_HOLD/R_HOLD, and TA fields are equal to EMIFA clock cycles minus 1 cycle, the CE2CFG should be configured as in Table 20-46. In this example, although the EMA_WAIT signal is connected to the R/$\overline{B}$ signal of the NAND Flash the Extended Wait mode of the EMIFA is not used, therefore the asynchronous wait cycle configuration register (AWCC) does not need to be programmed.

Table 20-46. Configuring CE2CFG for HY27UA081G1M Example

Parameter	Setting
SS	**Select Strobe mode.** • SS = 0. Places EMIFA in Normal Mode.
EW	**Extended Wait mode enable.** • EW = 0. Disabled Extended wait mode.
W_SETUP/R_SETUP	**Read/Write setup widths.** • W_SETUP = 0 • R_SETUP = 2
W_STROBE/R_STROBE	**Read/Write strobe widths.** • W_STROBE = 6 • R_STROBE = 7
W_HOLD/R_HOLD	**Read/Write hold widths.** • W_HOLD = 1 • R_HOLD = 0
TA	**Minimum turnaround time.** • TA = 2
ASIZE	**Asynchronous device bus width.** • ASIZE = 0, select an 8-bit data bus width.

Since this is a NAND Flash example, the EMIFA must be configured for NAND Flash mode. This is accomplished by configuring the NAND Flash control register (NANDFCR) as in Table 20-47. In NANDFCR, chip select space 2 must be configured with NAND Flash mode enabled.

Table 20-47. Configuring NANDFCR for HY27UA081G1M Example

Parameter	Setting
CS5ECC	**NAND Flash ECC start for chip select 5.** • CS5ECC = 0. Not set during configuration. Only set just prior to reading or writing data.
CS4ECC	**NAND Flash ECC start for chip select 4.** • CS4ECC = 0. Not set during configuration. Only set just prior to reading or writing data.
CS3ECC	**NAND Flash ECC start for chip select 3.** • CS3ECC = 0. Not set during configuration. Only set just prior to reading or writing data.
CS2ECC	**NAND Flash ECC start for chip select 2.** • CS2ECC = 0. Not set during configuration. Only set just prior to reading or writing data.
CS5NAND	**NAND Flash mode for chip select 5.** • CS5NAND = 0. NAND Flash mode is disabled.
CS4NAND	**NAND Flash mode for chip select 4.** • CS4NAND = 0. NAND Flash mode is disabled.
CS3NAND	**NAND Flash mode for chip select 3.** • CS3NAND = 0. NAND Flash mode is disabled.
CS2NAND	**NAND Flash mode for chip select 2.** • CS5NAND = 1. NAND Flash mode is enabled.

20.4 Registers

The external memory interface (EMIFA) is controlled by programming its internal memory-mapped registers (MMRs). Table 20-48 lists the memory-mapped registers for the EMIFA.

NOTE: All EMIFA MMRs, except SDCR, support only word (32-bit) accesses. Performing a byte (8-bit) or halfword (16-bit) write to these registers results in undefined behavior. The SDCR is byte writable to allow the setting of the SR, PD and PDWR bits without triggering the SDRAM initialization sequence.

The EMIFA registers must always be accessed using 32-bit accesses (unless otherwise specified in this chapter). For the base address of the memory-mapped registers of EMIFA, see your device-specific data manual.

Table 20-48. External Memory Interface (EMIFA) Registers

Offset	Acronym	Register Description	Section
0h	MIDR	Module ID Register	Section 20.4.1
4h	AWCC	Asynchronous Wait Cycle Configuration Register	Section 20.4.2
8h	SDCR	SDRAM Configuration Register	Section 20.4.3
Ch	SDRCR	SDRAM Refresh Control Register	Section 20.4.4
10h	CE2CFG	Asynchronous 1 Configuration Register	Section 20.4.5
14h	CE3CFG	Asynchronous 2 Configuration Register	Section 20.4.5
18h	CE4CFG	Asynchronous 3 Configuration Register	Section 20.4.5
1Ch	CE5CFG	Asynchronous 4 Configuration Register	Section 20.4.5
20h	SDTIMR	SDRAM Timing Register	Section 20.4.6
3Ch	SDSRETR	SDRAM Self Refresh Exit Timing Register	Section 20.4.7
40h	INTRAW	EMIFA Interrupt Raw Register	Section 20.4.8
44h	INTMSK	EMIFA Interrupt Mask Register	Section 20.4.9
48h	INTMSKSET	EMIFA Interrupt Mask Set Register	Section 20.4.10
4Ch	INTMSKCLR	EMIFA Interrupt Mask Clear Register	Section 20.4.11
60h	NANDFCR	NAND Flash Control Register	Section 20.4.12
64h	NANDFSR	NAND Flash Status Register	Section 20.4.13
70h	NANDF1ECC	NAND Flash 1 ECC Register (CS2 Space)	Section 20.4.14
74h	NANDF2ECC	NAND Flash 2 ECC Register (CS3 Space)	Section 20.4.14
78h	NANDF3ECC	NAND Flash 3 ECC Register (CS4 Space)	Section 20.4.14
7Ch	NANDF4ECC	NAND Flash 4 ECC Register (CS5 Space)	Section 20.4.14
BCh	NAND4BITECCLOAD	NAND Flash 4-Bit ECC Load Register	Section 20.4.15
C0h	NAND4BITECC1	NAND Flash 4-Bit ECC Register 1	Section 20.4.16
C4h	NAND4BITECC2	NAND Flash 4-Bit ECC Register 2	Section 20.4.17
C8h	NAND4BITECC3	NAND Flash 4-Bit ECC Register 3	Section 20.4.18
CCh	NAND4BITECC4	NAND Flash 4-Bit ECC Register 4	Section 20.4.19
D0h	NANDERRADD1	NAND Flash 4-Bit ECC Error Address Register 1	Section 20.4.20
D4h	NANDERRADD2	NAND Flash 4-Bit ECC Error Address Register 2	Section 20.4.21
D8h	NANDERRVAL1	NAND Flash 4-Bit ECC Error Value Register 1	Section 20.4.22
DCh	NANDERRVAL2	NAND Flash 4-Bit ECC Error Value Register 2	Section 20.4.23

20.4.1 Module ID Register (MIDR)

This is a read-only register indicating the module ID of the EMIFA. The MIDR is shown in Figure 20-31 and described in Table 20-49.

Figure 20-31. Module ID Register (MIDR)

31	0
REV	
R-4000 0205h	

LEGEND: R = Read only; -*n* = value after reset

Table 20-49. Module ID Register (MIDR) Field Descriptions

Bit	Field	Value	Description
31-0	REV	4000 0205h	Module ID of EMIFA.

20.4.2 Asynchronous Wait Cycle Configuration Register (AWCC)

The asynchronous wait cycle configuration register (AWCC) is used to configure the parameters for extended wait cycles. Both the polarity of the EMA_WAIT pin(s) and the maximum allowable number of extended wait cycles can be configured. The AWCC is shown in Figure 20-32 and described in Table 20-50. Not all devices support both EMA_WAIT[1] and EMA_WAIT[0], see the device-specific data manual to determine support on each device.

NOTE: The EW bit in the asynchronous *n* configuration register (CE*n*CFG) must be set to allow for the insertion of extended wait cycles.

Figure 20-32. Asynchronous Wait Cycle Configuration Register (AWCCR)

31	30	29	28	27	24	23	22	21	20	19	18	17	16
Reserved		WP1	WP0	Reserved		CS5_WAIT		CS4_WAIT		CS3_WAIT		CS2_WAIT	
R-0		R/W-1	R/W-1	R-0		R/W-0		R/W-0		R/W-0		R/W-0	

15	8	7	0
Reserved		MAX_EXT_WAIT	
R-0		R/W-80h	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 20-50. Asynchronous Wait Cycle Configuration Register (AWCCR) Field Descriptions

Bit	Field	Value	Description
31-30	Reserved	0	Reserved
29	WP1		EMA_WAIT[1] polarity bit. This bit defines the polarity of the EMA_WAIT[1] pin.
		0	Insert wait cycles if EMA_WAIT[1] pin is low.
		1	Insert wait cycles if EMA_WAIT[1] pin is high.
28	WP0		EMA_WAIT[0] polarity bit. This bit defines the polarity of the EMA_WAIT[0] pin.
		0	Insert wait cycles if EMA_WAIT[0] pin is low.
		1	Insert wait cycles if EMA_WAIT[0] pin is high.
27-24	Reserved	0	Reserved
23-22	CS5_WAIT	0-3h	Chip Select 5 WAIT signal selection. This signal determines which EMA_WAIT[*n*] signal will be used for memory accesses to chip select 5 memory space.
		0	EMA_WAIT[0] pin is used to control external wait states.
		1h	EMA_WAIT[1] pin is used to control external wait states.
		2h-3h	Reserved
21-20	CS4_WAIT	0-3h	Chip Select 4 WAIT signal selection. This signal determines which EMA_WAIT[*n*] signal will be used for memory accesses to chip select 4 memory space.
		0	EMA_WAIT[0] pin is used to control external wait states.
		1h	EMA_WAIT[1] pin is used to control external wait states.
		2h-3h	Reserved
19-18	CS3_WAIT	0-3h	Chip Select 3 WAIT signal selection. This signal determines which EMA_WAIT[*n*] signal will be used for memory accesses to chip select 3 memory space.
		0	EMA_WAIT[0] pin is used to control external wait states.
		1h	EMA_WAIT[1] pin is used to control external wait states.
		2h-3h	Reserved
17-16	CS2_WAIT	0-3h	Chip Select 2 WAIT signal selection. This signal determines which EMA_WAIT[*n*] signal will be used for memory accesses to chip select 2 memory space.
		0	EMA_WAIT[0] pin is used to control external wait states..
		1h	EMA_WAIT[1] pin is used to control external wait states.
		2h-3h	Reserved
15-8	Reserved	0	Reserved
7-0	MAX_EXT_WAIT	0-FFh	Maximum extended wait cycles. The EMIFA will wait for a maximum of (MAX_EXT_WAIT + 1) × 16 clock cycles before it stops inserting asynchronous wait cycles and proceeds to the hold period of the access.

20.4.3 SDRAM Configuration Register (SDCR)

The SDRAM configuration register (SDCR) is used to configure various parameters of the SDRAM controller such as the number of internal banks, the internal page size, and the CAS latency to match those of the attached SDRAM device. In addition, this register is used to put the attached SDRAM device into Self-Refresh mode. The SDCR is shown in Figure 20-33 and described in Table 20-51.

NOTE: Writing to the lower three bytes of this register will cause the EMIFA to start the SDRAM initialization sequence described in Section 20.2.4.4.

Figure 20-33. SDRAM Configuration Register (SDCR)

31	30	29	28	24
SR	PD	PDWR	Reserved	
R/W-0	R/W-0	R/W-0	R-0	

23	16
Reserved	
R-0	

15	14	13	12	11	9	8
Reserved	NM(A)	Reserved		CL		BIT11_9LOCK
R-0	R/W-0	R-0		R/W-3h		R/W-0

7	6	4	3	2	0
Reserved	IBANK		Reserved	PAGESIZE	
R-0	R/W-2h		R-0	R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

A. The NM bit must be set to 1 if the EMIFA on your device only has 16 data bus pins.

Table 20-51. SDRAM Configuration Register (SDCR) Field Descriptions

Bit	Field	Value	Description
31	SR		Self-Refresh mode bit. This bit controls entering and exiting of the Self-Refresh mode described in Section 20.2.4.7. The field should be written using a byte-write to the upper byte of SDCR to avoid triggering the SDRAM initialization sequence.
		0	Writing a 0 to this bit will cause connected SDRAM devices and the EMIFA to exit the Self-Refresh mode.
		1	Writing a 1 to this bit will cause connected SDRAM devices and the EMIFA to enter the Self-Refresh mode.
30	PD		Power Down bit. This bit controls entering and exiting of the power-down mode. The field should be written using a byte-write to the upper byte of SDCR to avoid triggering the SDRAM initialization sequence. If both SR and PD bits are set, the EMIFA will go into Self Refresh.
		0	Writing a 0 to this bit will cause connected SDRAM devices and the EMIFA to exit the power-down mode.
		1	Writing a 1 to this bit will cause connected SDRAM devices and the EMIFA to enter the power-down mode.
29	PDWR		Perform refreshes during power down. Writing a 1 to this bit will cause EMIFA to exit power-down state and issue and AUTO REFRESH command every time Refresh May level is set.
28-15	Reserved	0	Reserved. The reserved bit location is always read as 0. If writing to this field, always write the default value of 0.
14	NM		Narrow mode bit. This bit defines whether a 16- or 32-bit-wide SDRAM is connected to the EMIFA. This bit field must always be set to 1. Writing to this field triggers the SDRAM initialization sequence.
		0	32-bit SDRAM data bus is used.
		1	16-bit SDRAM data bus is used.
13-12	Reserved	0	Reserved. The reserved bit location is always read as 0. If writing to this field, always write the default value of 0.

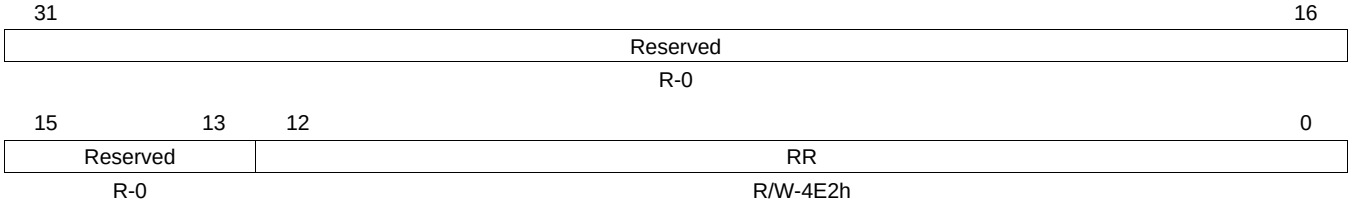
Table 20-51. SDRAM Configuration Register (SDCR) Field Descriptions (continued)

Bit	Field	Value	Description
11-9	CL	0-7h	CAS Latency. This field defines the CAS latency to be used when accessing connected SDRAM devices. A 1 must be simultaneously written to the BIT11_9LOCK bit field of this register in order to write to the CL bit field. Writing to this field triggers the SDRAM initialization sequence.
		0-1h	Reserved
		2h	CAS latency = 2 EMA_CLK cycles
		3h	CAS latency = 3 EMA_CLK cycles
		4h-7h	Reserved
8	BIT11_9LOCK		Bits 11 to 9 lock. CL can only be written if BIT11_9LOCK is simultaneously written with a 1. BIT11_9LOCK is always read as 0. Writing to this field triggers the SDRAM initialization sequence.
		0	CL cannot be written.
		1	CL can be written.
7	Reserved	0	Reserved. The reserved bit location is always read as 0. If writing to this field, always write the default value of 0.
6-4	IBANK	0-7h	Internal SDRAM Bank size. This field defines number of banks inside the connected SDRAM devices. Writing to this field triggers the SDRAM initialization sequence.
		0	1 bank SDRAM devices.
		1	2 bank SDRAM devices.
		2	4 bank SDRAM devices.
		3h-7h	Reserved.
3	Reserved	0	Reserved. The reserved bit location is always read as 0. If writing to this field, always write the default value of 0.
2-0	PAGESIZE	0-7h	Page Size. This field defines the internal page size of connected SDRAM devices. Writing to this field triggers the SDRAM initialization sequence.
		0	8 column address bits (256 elements per row)
		1h	9 column address bits (512 elements per row)
		2h	10 column address bits (1024 elements per row)
		3h	11 column address bits (2048 elements per row)
		4h-7h	Reserved

20.4.4 SDRAM Refresh Control Register (SDRCR)

The SDRAM refresh control register (SDRCR) is used to configure the rate at which connected SDRAM devices will be automatically refreshed by the EMIFA. Refer to Section 20.2.4.6 on the refresh controller for more details. The SDRCR is shown in Figure 20-34 and described in Table 20-52.

Figure 20-34. SDRAM Refresh Control Register (SDRCR)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 20-52. SDRAM Refresh Control Register (SDRCR) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	Reserved. The reserved bit location is always read as 0. If writing to this field, always write the default value of 0.
12-0	RR	0-1FFFh	Refresh Rate. This field is used to define the SDRAM refresh period in terms of EMA_CLK cycles. Writing a value < 0x0020 to this field will cause it to be loaded with (2 × T_RFC) + 1 value from the SDRAM timing register (SDTIMR).

20.4.5 Asynchronous *n* Configuration Registers (CE2CFG-CE5CFG)

The asynchronous *n* configuration registers (CE2CFG, CE3CFG, CE4CFG, and CE5CFG) are used to configure the shaping of the address and control signals during an access to asynchronous memory connected to CS2, CS3, CS4, and CS5, respectively. It is also used to program the width of asynchronous interface and to select from various modes of operation. This register can be written prior to any transfer, and any asynchronous transfer following the write will use the new configuration. The CE*n*CFG is shown in Figure 20-35 and described in Table 20-53.

Figure 20-35. Asynchronous *n* Configuration Register (CE*n*CFG)

31	30	29 26	25 24
SS	EW(A)	W_SETUP	W_STROBE(B)
R/W-0	R/W-0	R/W-Fh	R/W-3Fh

23 20	19 17	16
W_STROBE(B)	W_HOLD	R_SETUP
R/W-3Fh	R/W-7h	R/W-Fh

15 13	12 7	6 4	3 2	1 0
R_SETUP	R_STROBE(B)	R_HOLD	TA	ASIZE
R/W-Fh	R/W-3Fh	R/W-7h	R/W-3h	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

A. The EW bit must be cleared to 0 when operating in NAND Flash mode.

B. This bit field must be cleared to 0 if the EMIFA on your device does not have an EMA_WAIT pin.

Table 20-53. Asynchronous *n* Configuration Register (CE*n*CFG) Field Descriptions

Bit	Field	Value	Description
31	SS		Select Strobe bit. This bit defines whether the asynchronous interface operates in Normal Mode or Select Strobe Mode. See Section 20.2.5 for details on the two modes of operation.
		0	Normal Mode enabled.
		1	Select Strobe Mode enabled.
30	EW		Extend Wait bit. This bit defines whether extended wait cycles will be enabled. See Section 20.2.5.7 on extended wait cycles for details. This bit field must be cleared to 0, if the EMIFA on your device does not have an EMA_WAIT pin. The CS*n*_WAIT bit in the asynchronous wait cycle configuration register (AWCC) must also be configured to determine which EMA_WAIT pin is used for memory accesses.
		0	Extended wait cycles disabled.
		1	Extended wait cycles enabled.
29-26	W_SETUP	0-Fh	Write setup width in EMA_CLK cycles, minus one cycle. See Section 20.2.5.3 for details.
25-20	W_STROBE	0-3Fh	Write strobe width in EMA_CLK cycles, minus one cycle. See Section 20.2.5.3 for details.
19-17	W_HOLD	0-7h	Write hold width in EMA_CLK cycles, minus one cycle. See Section 20.2.5.3 for details.
16-13	R_SETUP	0-Fh	Read setup width in EMA_CLK cycles, minus one cycle. See Section 20.2.5.3 for details.
12-7	R_STROBE	0-3Fh	Read strobe width in EMA_CLK cycles, minus one cycle. See Section 20.2.5.3 for details.
6-4	R_HOLD	0-7h	Read hold width in EMA_CLK cycles, minus one cycle. See Section 20.2.5.3 for details.
3-2	TA	0-3h	Minimum Turn-Around time. This field defines the minimum number of EMA_CLK cycles between reads and writes, minus one cycle. See Section 20.2.5.3 for details.
1-0	ASIZE	0-3h	Asynchronous Data Bus Width. This field defines the width of the asynchronous device's data bus.
		0	8-bit data bus
		1h	16-bit data bus
		2h-3h	Reserved

20.4.6 SDRAM Timing Register (SDTIMR)

The SDRAM timing register (SDTIMR) is used to program many of the SDRAM timing parameters. Consult the SDRAM datasheet for information on the appropriate values to program into each field. The SDTIMR is shown in Figure 20-36 and described in Table 20-54.

Figure 20-36. SDRAM Timing Register (SDTIMR)

31	27	26	24	23	22	20	19	18	16
T_RFC		T_RP		Rsvd	T_RCD		Rsvd	T_WR	
R/W-8h		R/W-2h		R-0	R/W-2h		R-0	R/W-1h	

15	12	11	8	7	6	4	3	0
T_RAS		T_RC		Rsvd	T_RRD		Reserved	
R/W-5h		R/W-8h		R-0	R/W-1h		R-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

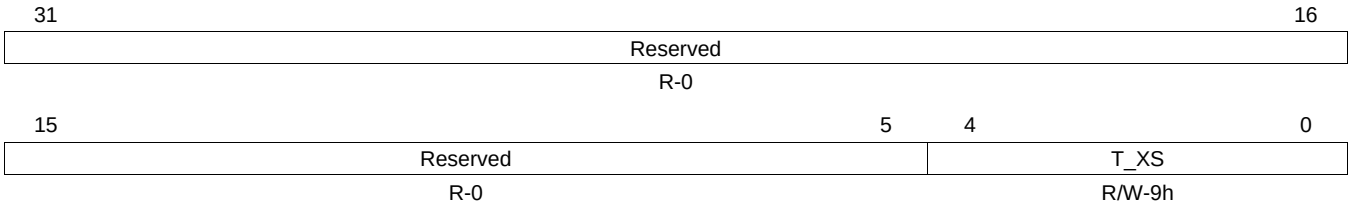
Table 20-54. SDRAM Timing Register (SDTIMR) Field Descriptions

Bit	Field	Value	Description
31-27	T_RFC	0-1Fh	Specifies the Trfc value of the SDRAM. This defines the minimum number of EMA_CLK cycles from Refresh (REFR) to Refresh (REFR), minus 1: T_RFC = (Trfc/t_{EMA_CLK}) - 1
26-24	T_RP	0-7h	Specifies the Trp value of the SDRAM. This defines the minimum number of EMA_CLK cycles from Precharge (PRE) to Activate (ACTV) or Refresh (REFR) command, minus 1: T_RP = (Trp/t_{EMA_CLK}) - 1
23	Reserved	0	Reserved. The reserved bit location is always read as 0. If writing to this field, always write the default value of 0.
22-20	T_RCD	0-7h	Specifies the Trcd value of the SDRAM. This defines the minimum number of EMA_CLK cycles from Active (ACTV) to Read (READ) or Write (WRT), minus 1: T_RCD = (Trcd/t_{EMA_CLK}) - 1
19	Reserved	0	Reserved. The reserved bit location is always read as 0. If writing to this field, always write the default value of 0.
18-16	T_WR	0-7h	Specifies the Twr value of the SDRAM. This defines the minimum number of EMA_CLK cycles from last Write (WRT) to Precharge (PRE), minus 1: T_WR = (Twr/t_{EMA_CLK}) - 1
15-12	T_RAS	0-Fh	Specifies the Tras value of the SDRAM. This defines the minimum number of EMA_CLK clock cycles from Activate (ACTV) to Precharge (PRE), minus 1: T_RAS = (Tras/t_{EMA_CLK}) - 1
11-8	T_RC	0-Fh	Specifies the Trc value of the SDRAM. This defines the minimum number of EMA_CLK clock cycles from Activate (ACTV) to Activate (ACTV), minus 1: T_RC = (Trc/t_{EMA_CLK}) - 1
7	Reserved	0	Reserved. The reserved bit location is always read as 0. If writing to this field, always write the default value of 0.
6-4	T_RRD	0-7h	Specifies the Trrd value of the SDRAM. This defines the minimum number of EMA_CLK clock cycles from Activate (ACTV) to Activate (ACTV) for a different bank, minus 1: T_RRD = (Trrd/t_{EMA_CLK}) - 1
3-0	Reserved	0	Reserved. The reserved bit location is always read as 0. If writing to this field, always write the default value of 0.

20.4.7 SDRAM Self Refresh Exit Timing Register (SDSRETR)

The SDRAM self refresh exit timing register (SDSRETR) is used to program the amount of time between when the SDRAM exits Self-Refresh mode and when the EMIFA issues another command. The SDSRETR is shown in Figure 20-37 and described in Table 20-55.

Figure 20-37. SDRAM Self Refresh Exit Timing Register (SDSRETR)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

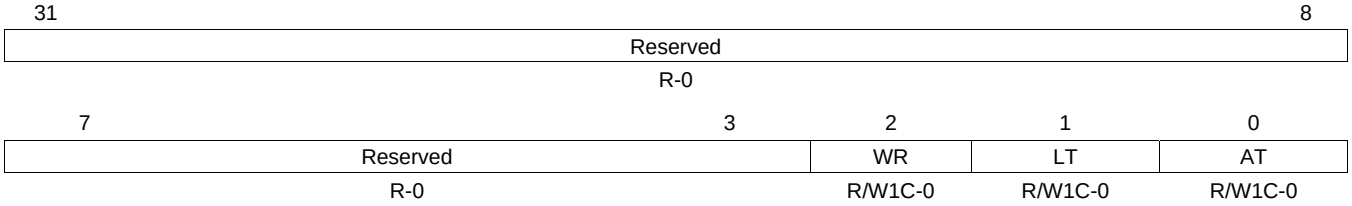
Table 20-55. SDRAM Self Refresh Exit Timing Register (SDSRETR) Field Descriptions

Bit	Field	Value	Description
31-5	Reserved	0	Reserved. The reserved bit location is always read as 0.
4-0	T_XS	0-1Fh	This field specifies the minimum number of ECLKOUT cycles from Self-Refresh exit to any command, minus one. T_XS = Txsr / t_{EMA_CLK} - 1

20.4.8 EMIFA Interrupt Raw Register (INTRAW)

The EMIFA interrupt raw register (INTRAW) is used to monitor and clear the EMIFA's hardware-generated Asynchronous Timeout Interrupt. The AT bit in this register will be set when an Asynchronous Timeout occurs regardless of the status of the EMIFA interrupt mask set register (INTMSKSET) and EMIFA interrupt mask clear register (INTMSKCLR). Writing a 1 to this bit will clear it. The EMIFA on some devices does not have the EMA_WAIT pin; therefore, these registers and fields are reserved on those devices. The INTRAW is shown in Figure 20-38 and described in Table 20-56.

Figure 20-38. EMIFA Interrupt Raw Register (INTRAW)



LEGEND: R/W = Read/Write; R = Read only; W1C = Write 1 to clear (writing 0 has no effect); -*n* = value after reset

Table 20-56. EMIFA Interrupt Raw Register (INTRAW) Field Descriptions

Bit	Field	Value	Description
31-3	Reserved	0	Reserved. The reserved bit location is always read as 0. If writing to this field, always write the default value of 0.
2	WR		Wait Rise. This bit is set to 1 by hardware to indicate that a rising edge on the EMA_WAIT pin has occurred.
		0	Indicates that a rising edge has not occurred on the EMA_WAIT pin. Writing a 0 has no effect.
		1	Indicates that a rising edge has occurred on the EMA_WAIT pin. Writing a 1 will clear this bit and the WR_MASKED bit in the EMIFA interrupt masked register (INTMSK).
1	LT		Line Trap. Set to 1 by hardware to indicate illegal memory access type or invalid cache line size.
		0	Writing a 0 has no effect.
		1	Indicates that a line trap has occurred. Writing a 1 will clear this bit as well as the LT_MASKED bit in the EMIFA interrupt masked register(INTMSK).
0	AT		Asynchronous Timeout. This bit is set to 1 by hardware to indicate that during an extended asynchronous memory access cycle, the EMA_WAIT pin did not go inactive within the number of cycles defined by the MAX_EXT_WAIT field in the asynchronous wait cycle configuration register (AWCC).
		0	Indicates that an Asynchronous Timeout has not occurred. Writing a 0 has no effect.
		1	Indicates that an Asynchronous Timeout has occurred. Writing a 1 will clear this bit as well as the AT_MASKED bit in the EMIFA interrupt masked register (INTMSK).

20.4.9 EMIFA Interrupt Masked Register (INTMSK)

Like the EMIFA interrupt raw register (INTRAW), the EMIFA interrupt masked register (INTMSK) is used to monitor and clear the status of the EMIFA's hardware-generated Asynchronous Timeout Interrupt. The main difference between the two registers is that when the AT_MASKED bit in this register is set, an active-high pulse will be sent to the CPU interrupt controller. Also, the AT_MASKED bit field in INTMSK is only set to 1 if the associated interrupt has been enabled in the EMIFA interrupt mask set register (INTMSKSET). The EMIFA on some devices does not have the EMA_WAIT pin, therefore, these registers and fields are reserved on those devices. The INTMSK is shown in Figure 20-39 and described in Table 20-57.

Figure 20-39. EMIFA Interrupt Mask Register (INTMSK)

31	8
Reserved	
R-0	

7	3	2	1	0
Reserved		WR_MASKED	LT_MASKED	AT_MASKED
R-0		R/W1C-0	R/W1C-0	R/W1C-0

LEGEND: R/W = Read/Write; R = Read only; W1C = Write 1 to clear (writing 0 has no effect); -*n* = value after reset

Table 20-57. EMIFA Interrupt Mask Register (INTMSK) Field Descriptions

Bit	Field	Value	Description
31-3	Reserved	0	Reserved. The reserved bit location is always read as 0. If writing to this field, always write the default value of 0.
2	WR_MASKED		Wait Rise Masked. This bit is set to 1 by hardware to indicate a rising edge has occurred on the EMA_WAIT pin, provided that the WR_MASK_SET bit is set to 1 in the EMIFA interrupt mask set register (INTMSKSET).
		0	Indicates that a wait rise interrupt has not been generated. Writing a 0 has no effect.
		1	Indicates that a wait rise interrupt has been generated. Writing a 1 will clear this bit and the WR bit in the EMIFA interrupt raw register (INTRAW).
1	LT_MASKED		Masked Line Trap. Set to 1 by hardware to indicate illegal memory access type or invalid cache line size, only if the LT_MASK_SET bit in the EMIFA interrupt mask set register (INTMSKSET) is set to 1.
		0	Writing a 0 has no effect.
		1	Writing a 1 will clear this bit as well as the LT bit in the EMIFA interrupt raw register(INTRAW).
0	AT_MASKED		Asynchronous Timeout Masked. This bit is set to 1 by hardware to indicate that during an extended asynchronous memory access cycle, the EMA_WAIT pin did not go inactive within the number of cycles defined by the MAX_EXT_WAIT field in the asynchronous wait cycle configuration register (AWCC), provided that the AT_MASK_SET bit is set to 1 in the EMIFA interrupt mask set register (INTMSKSET).
		0	Indicates that an Asynchronous Timeout Interrupt has not been generated. Writing a 0 has no effect.
		1	Indicates that an Asynchronous Timeout Interrupt has been generated. Writing a 1 will clear this bit as well as the AT bit in the EMIFA interrupt raw register (INTRAW).

20.4.10 EMIFA Interrupt Mask Set Register (INTMSKSET)

The EMIFA interrupt mask set register (INTMSKSET) is used to enable the Asynchronous Timeout Interrupt. If read as 1, the AT_MASKED bit in the EMIFA interrupt masked register (INTMSK) will be set and an interrupt will be generated when an Asynchronous Timeout occurs. If read as 0, the AT_MASKED bit will always read 0 and no interrupt will be generated when an Asynchronous Timeout occurs. Writing a 1 to the AT_MASK_SET bit enables the Asynchronous Timeout Interrupt. The EMIFA on some devices does not have the EMA_WAIT pin; therefore, these registers and fields are reserved on those devices. The INTMSKSET is shown in Figure 20-40 and described in Table 20-58.

Figure 20-40. EMIFA Interrupt Mask Set Register (INTMSKSET)

31	16
Reserved	
R-0	

15	3	2	1	0
Reserved		WR_MASK_SET	Reserved	AT_MASK_SET
R-0		R/W-0	R-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 20-58. EMIFA Interrupt Mask Set Register (INTMSKSET) Field Descriptions

Bit	Field	Value	Description
31-3	Reserved	0	Reserved. The reserved bit location is always read as 0. If writing to this field, always write the default value of 0.
2	WR_MASK_SET		Wait Rise Mask Set. This bit determines whether or not the wait rise Interrupt is enabled. Writing a 1 to this bit sets this bit, sets the WR_MASK_CLR bit in the EMIFA interrupt mask clear register (INTMSKCLR), and enables the wait rise interrupt. To clear this bit, a 1 must be written to the WR_MASK_CLR bit in INTMSKCLR.
		0	Indicates that the wait rise interrupt is disabled. Writing a 0 has no effect.
		1	Indicates that the wait rise interrupt is enabled. Writing a 1 sets this bit and the WR_MASK_CLR bit in the EMIFA interrupt mask clear register (INTMSKCLR).
1	LT_MASK_SET		Mask set for LT_MASKED bit in the EMIFA interrupt mask register (INTMSK).
		0	Indicates that the line trap interrupt is disabled. Writing a 0 has no effect.
		1	Indicates that the line trap interrupt is enabled. Writing a 1 sets this bit and the LT_MASK_CLR bit in the EMIFA interrupt mask clear register (INTMSKCLR).
0	AT_MASK_SET		Asynchronous Timeout Mask Set. This bit determines whether or not the Asynchronous Timeout Interrupt is enabled. Writing a 1 to this bit sets this bit, sets the AT_MASK_CLR bit in the EMIFA interrupt mask clear register (INTMSKCLR), and enables the Asynchronous Timeout Interrupt. To clear this bit, a 1 must be written to the AT_MASK_CLR bit of the EMIFA interrupt mask clear register (INTMSKCLR).
		0	Indicates that the Asynchronous Timeout Interrupt is disabled. Writing a 0 has no effect.
		1	Indicates that the Asynchronous Timeout Interrupt is enabled. Writing a 1 sets this bit and the AT_MASK_CLR bit in the EMIFA interrupt mask clear register (INTMSKCLR).

20.4.11 EMIFA Interrupt Mask Clear Register (INTMSKCLR)

The EMIFA interrupt mask clear register (INTMSKCLR) is used to disable the Asynchronous Timeout Interrupt. If read as 1, the AT_MASKED bit in the EMIFA interrupt masked register (INTMSK) will be set and an interrupt will be generated when an Asynchronous Timeout occurs. If read as 0, the AT_MASKED bit will always read 0 and no interrupt will be generated when an Asynchronous Timeout occurs. Writing a 1 to the AT_MASK_CLR bit disables the Asynchronous Timeout Interrupt. The EMIFA on some devices does not have the EMA_WAIT pin, therefore, these registers and fields are reserved on those devices. The INTMSKCLR is shown in Figure 20-41 and described in Table 20-59.

Figure 20-41. EMIFA Interrupt Mask Clear Register (INTMSKCLR)

31	16
Reserved	
R-0	

15	3	2	1	0
Reserved		WR_MASK_CLR	Reserved	AT_MASK_CLR
R-0		R/W-0	R-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 20-59. EMIFA Interrupt Mask Clear Register (INTMSKCLR) Field Descriptions

Bit	Field	Value	Description
31-3	Reserved	0	Reserved. The reserved bit location is always read as 0. If writing to this field, always write the default value of 0.
2	WR_MASK_CLR		Wait Rise Mask Clear. This bit determines whether or not the wait rise interrupt is enabled. Writing a 1 to this bit clears this bit, clears the WR_MASK_SET bit in the EMIFA interrupt mask set register (INTMSKSET), and disables the wait rise interrupt. To set this bit, a 1 must be written to the WR_MASK_SET bit in INTMSKSET.
		0	Indicates that the wait rise interrupt is disabled. Writing a 0 has no effect.
		1	Indicates that the wait rise interrupt is enabled. Writing a 1 clears this bit and the WR_MASK_SET bit in the EMIFA interrupt mask set register (INTMSKSET).
1	LT_MASK_CLR		Line trap Mask Clear. This bit determines whether or not the line trap interrupt is enabled. Writing a 1 to this bit clears this bit, clears the LT_MASK_SET bit in the EMIFA interrupt mask set register (INTMSKSET), and disables the line trap interrupt. To set this bit, a 1 must be written to the LT_MASK_SET bit in INTMSKSET.
		0	Indicates that the line trap interrupt is disabled. Writing a 0 has no effect.
		1	Indicates that the line trap interrupt is enabled. Writing a 1 clears this bit and the LT_MASK_SET bit in the EMIFA interrupt mask set register (INTMSKSET).
0	AT_MASK_CLR		Asynchronous Timeout Mask Clear. This bit determines whether or not the Asynchronous Timeout Interrupt is enabled. Writing a 1 to this bit clears this bit, clears the AT_MASK_SET bit in the EMIFA interrupt mask set register (INTMSKSET), and disables the Asynchronous Timeout Interrupt. To set this bit, a 1 must be written to the AT_MASK_SET bit of the EMIFA interrupt mask set register (INTMSKSET).
		0	Indicates that the Asynchronous Timeout Interrupt is disabled. Writing a 0 has no effect.
		1	Indicates that the Asynchronous Timeout Interrupt is enabled. Writing a 1 clears this bit and the AT_MASK_SET bit in the EMIFA interrupt mask set register (INTMSKSET).

20.4.12 NAND Flash Control Register (NANDFCR)

The NAND Flash control register (NANDFCR) is shown in Figure 20-42 and described in Table 20-60.

Figure 20-42. NAND Flash Control Register (NANDFCR)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
R-0															

15	14	13	12	11	10	9	8
Reserved		4BITECC_ADD_CALC_START	4BITECC_START	CS5ECC	CS4ECC	CS3ECC	CS2ECC
R-0		R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

7	6	5	4	3	2	1	0
Reserved		4BITECCSEL		CS5NAND	CS4NAND	CS3NAND	CS2NAND
R-0		R/W-0		R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 20-60. NAND Flash Control Register (NANDFCR) Field Descriptions

Bit	Field	Value	Description
31-14	Reserved	0	Reserved
13	4BITECC_ADD_CALC_START		NAND Flash 4-bit ECC address and error value calculation Start. Set to 1 to start 4_bit ECC error address and error value calculation on read syndrome. This bit is cleared when any of the NAND Flash error address registers or NAND Flash error value registers are read.
		1	start 4_bit ECC error address and error value calculation on read syndrome.
12	4BITECC_START		Nand Flash 4-bit ECC start for the selected chip select. Set to 1 to start 4_bit ECC calculation on data for NAND Flash on chip select selected by bit 4BITECCSEL. This bit is cleared when ay of the NAND Flash 4_bit ECC registers are read.
		1	start 4_bit ECC calculation on data for NAND Flash on chip select selected by bit 4BITECCSEL.
11	CS5ECC		NAND Flash ECC start for chip select 5. Set to 1 to start 1_bit ECC calculation on data for NAND Flash for this chip select. This bit is cleared when CS5 1_bit ECC register is read.
		0	Do not start ECC calculation.
		1	Start ECC calculation on data for NAND Flash on $\overline{\text{EMA\_CS5}}$.
10	CS4ECC		NAND Flash ECC start for chip select 4. Set to 1 to start 1_bit ECC calculation on data for NAND Flash for this chip select. This bit is cleared when CS4 1_bit ECC register is read.
		0	Do not start ECC calculation.
		1	Start ECC calculation on data for NAND Flash on $\overline{\text{EMA\_CS4}}$.
9	CS3ECC		NAND Flash ECC start for chip select 3. Set to 1 to start 1_bit ECC calculation on data for NAND Flash for this chip select. This bit is cleared when CS3 1_bit ECC register is read.
		0	Do not start ECC calculation.
		1	Start ECC calculation on data for NAND Flash on $\overline{\text{EMA\_CS3}}$.
8	CS2ECC		NAND Flash ECC start for chip select 2. This bit is cleared when CS2 1_bit ECC register is read.
		0	Do not start ECC calculation.
		1	Start ECC calculation on data for NAND Flash on $\overline{\text{EMA\_CS2}}$.
7-6	Reserved	0	Reserved

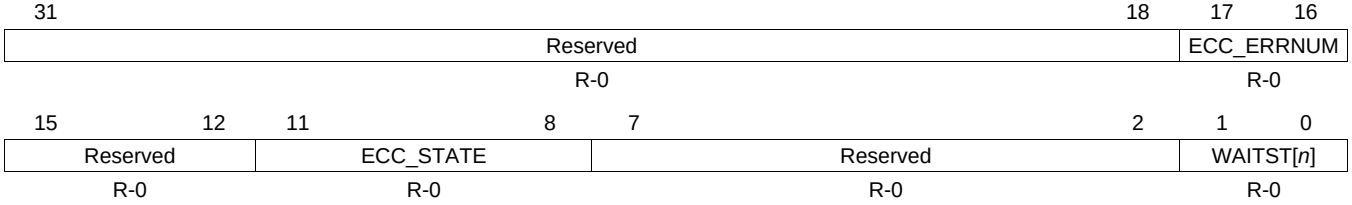
Table 20-60. NAND Flash Control Register (NANDFCR) Field Descriptions (continued)

Bit	Field	Value	Description
5-4	4BITECCSEL	0-3h	4-bit ECC selection. This field selects the chip select on which 4-bit ECC will be calculated.
		0	ECC will be calculated for CS2.
		1h	ECC will be calculated for CS3.
		2h	ECC will be calculated for CS4.
		3h	ECC will be calculated for CS5.
3	CS5NAND		NAND Flash mode for chip select 5.
		0	Not using NAND Flash.
		1	Using NAND Flash on $\overline{\text{EMA\_CS5}}$.
2	CS4NAND		NAND Flash mode for chip select 4.
		0	Not using NAND Flash.
		1	Using NAND Flash on $\overline{\text{EMA\_CS4}}$.
1	CS3NAND		NAND Flash mode for chip select 3.
		0	Not using NAND Flash.
		1	Using NAND Flash on $\overline{\text{EMA\_CS3}}$.
0	CS2NAND		NAND Flash mode for chip select 2.
		0	Not using NAND Flash.
		1	Using NAND Flash on $\overline{\text{EMA\_CS2}}$.

20.4.13 NAND Flash Status Register (NANDFSR)

The NAND Flash status register (NANDFSR) is shown in Figure 20-43 and described in Table 20-61.

Figure 20-43. NAND Flash Status Register (NANDFSR)



LEGEND: R = Read only; -*n* = value after reset

Table 20-61. NAND Flash Status Register (NANDFSR) Field Descriptions

Bit	Field	Value	Description
31-18	Reserved	0	Reserved
17-16	ECC_ERRNUM	0-3h	Number of Errors found after the 4-Bit ECC Error Address and Error Value Calculation.
		0	1 error found.
		1h	2 errors found.
		2h	3 errors found.
		3h	4 errors found.
15-12	Reserved	0	Reserved.
11-8	ECC_STATE	0-Fh	ECC correction state while performing 4-bit ECC Address and Error Value Calculation
		0	No errors detected
		1h	Errors cannot be corrected (5 or more)
		2h	Error correction complete(errors on bit 8 or 9).
		3h	Error correction complete(error exists).
		4h	Reserved.
		5h	Calculating number of errors
		6h-7h	Preparing for error search
		8h	Searching for errors
		9h-Bh	Reserved.
		Ch-Fh	Calculating error value
7-2	Reserved	0	Reserved.
1-0	WAITST[*n*]		Status of the EMA_WAIT[*n*] input pins. Not all devices support both EMA_WAIT[1] and EMA_WAIT[0], see the device-specific data manual to determine support on each device. The WP*n* bit in the asynchronous wait cycle configuration register (AWCC) has no effect on WAITST.
		0	EMA_WAIT[*n*] pin is low.
		1	EMA_WAIT[*n*] pin is high.

20.4.14 NAND Flash *n* ECC Registers (NANDF1ECC-NANDF4ECC)

The NAND Flash *n* ECC register (NANDF*n*ECC) is shown in Figure 20-44 and described in Table 20-62. For 8-bit NAND Flash, the P1 to P4 bits are column parities; the P8 to P2048 bits are row parities. For 16-bit NAND Flash, the P1 to P8 bits are column parities; the P16 to P2048 bits are row parities.

Figure 20-44. NAND Flash *n* ECC Register (NANDF*n*ECC)

31			28	27	26	25	24
Reserved				P2048O	P1024O	P512O	P256O
R-0				R-0	R-0	R-0	R-0
23	22	21	20	19	18	17	16
P128O	P64O	P32O	P16O	P8O	P4O	P2O	P1O
R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0
15			12	11	10	9	8
Reserved				P2048E	P1024E	P512E	P256E
R-0				R-0	R-0	R-0	R-0
7	6	5	4	3	2	1	0
P128E	P64E	P32E	P16E	P8E	P4E	P2E	P1E
R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0

LEGEND: R = Read only; -*n* = value after reset

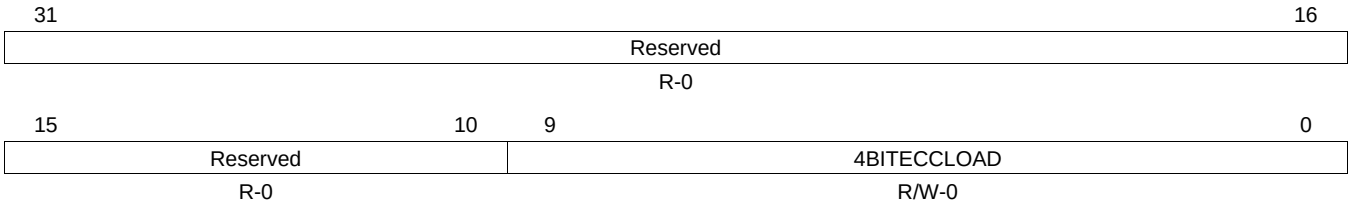
Table 20-62. NAND Flash *n* ECC Register (NANDF*n*ECC) Field Descriptions

Bit	Field	Value	Description
31-28	Reserved	0	Reserved
27	P2048O	0-1	ECC code calculated while reading/writing NAND Flash.
26	P1024O	0-1	ECC code calculated while reading/writing NAND Flash.
25	P512O	0-1	ECC code calculated while reading/writing NAND Flash.
24	P256O	0-1	ECC code calculated while reading/writing NAND Flash.
23	P128O	0-1	ECC code calculated while reading/writing NAND Flash.
22	P64O	0-1	ECC code calculated while reading/writing NAND Flash.
21	P32O	0-1	ECC code calculated while reading/writing NAND Flash.
20	P16O	0-1	ECC code calculated while reading/writing NAND Flash.
19	P8O	0-1	ECC code calculated while reading/writing NAND Flash.
18	P4O	0-1	ECC code calculated while reading/writing NAND Flash.
17	P2O	0-1	ECC code calculated while reading/writing NAND Flash.
16	P1O	0-1	ECC code calculated while reading/writing NAND Flash.
15-12	Reserved	0	Reserved
11	P2948E	0-1	ECC code calculated while reading/writing NAND Flash.
10	P102E	0-1	ECC code calculated while reading/writing NAND Flash.
9	P512E	0-1	ECC code calculated while reading/writing NAND Flash.
8	P256E	0-1	ECC code calculated while reading/writing NAND Flash.
7	P128E	0-1	ECC code calculated while reading/writing NAND Flash.
6	P64E	0-1	ECC code calculated while reading/writing NAND Flash.
5	P32E	0-1	ECC code calculated while reading/writing NAND Flash.
4	P15E	0-1	ECC code calculated while reading/writing NAND Flash.
3	P8E	0-1	ECC code calculated while reading/writing NAND Flash.
2	P4E	0-1	ECC code calculated while reading/writing NAND Flash.
1	P2E	0-1	ECC code calculated while reading/writing NAND Flash.
0	P1E	0-1	ECC code calculated while reading/writing NAND Flash.

20.4.15 NAND Flash 4-Bit ECC LOAD Register (NAND4BITECCLOAD)

The NAND Flash 4-bit ECC load register (NAND4BITECCLOAD) is shown in Figure 20-45 and described in Table 20-63.

Figure 20-45. NAND Flash 4-Bit ECC LOAD Register (NAND4BITECCLOAD)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 20-63. NAND Flash 4-Bit ECC LOAD Register (NAND4BITECCLOAD) Field Descriptions

Bit	Field	Value	Description
31-10	Reserved	0	Reserved
9-0	4BITECCLOAD	0-3FFh	4-bit ECC load. This value is used to load the ECC values when performing the Syndrome calculation during reads.

20.4.16 NAND Flash 4-Bit ECC Register 1 (NAND4BITECC1)

The NAND Flash 4-bit ECC register 1 (NAND4BITECC1) is shown in Figure 20-46 and described in Table 20-64.

Figure 20-46. NAND Flash 4-Bit ECC Register 1 (NAND4BITECC1)

31	26	25	16
Reserved		4BITECCVAL2	
R-0		R/W-0	

15	10	9	0
Reserved		4BITECCVAL1	
R-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 20-64. NAND Flash 4-Bit ECC Register 1 (NAND4BITECC1) Field Descriptions

Bit	Field	Value	Description
31-26	Reserved	0	Reserved
25-16	4BITECCVAL2	0-3FFh	Calculated 4-bit ECC or Syndrom Value2.
15-10	Reserved	0	Reserved
9-0	4BITECCVAL1	0-3FFh	Calculated 4-bit ECC or Syndrom Value1.

20.4.17 NAND Flash 4-Bit ECC Register 2 (NAND4BITECC2)

The NAND Flash 4-bit ECC register 2 (NAND4BITECC2) is shown in Figure 20-47 and described in Table 20-65.

Figure 20-47. NAND Flash 4-Bit ECC Register 2 (NAND4BITECC2)

31	26	25	16
Reserved		4BITECCVAL4	
R-0		R/W-0	

15	10	9	0
Reserved		4BITECCVAL3	
R-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 20-65. NAND Flash 4-Bit ECC Register 2 (NAND4BITECC2) Field Descriptions

Bit	Field	Value	Description
31-26	Reserved	0	Reserved
25-16	4BITECCVAL4	0-3FFh	Calculated 4-bit ECC or Syndrom Value4.
15-10	Reserved	0	Reserved
9-0	4BITECCVAL3	0-3FFh	Calculated 4-bit ECC or Syndrom Value3.

20.4.18 NAND Flash 4-Bit ECC Register 3 (NAND4BITECC3)

The NAND Flash 4-bit ECC register 3 (NAND4BITECC3) is shown in Figure 20-48 and described in Table 20-66.

Figure 20-48. NAND Flash 4-Bit ECC Register 3 (NAND4BITECC3)

31	26	25	16
Reserved		4BITECCVAL6	
R-0		R/W-0	

15	10	9	0
Reserved		4BITECCVAL5	
R-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 20-66. NAND Flash 4-Bit ECC Register 3 (NAND4BITECC3) Field Descriptions

Bit	Field	Value	Description
31-26	Reserved	0	Reserved
25-16	4BITECCVAL6	0-3FFh	Calculated 4-bit ECC or Syndrom Value6.
15-10	Reserved	0	Reserved
9-0	4BITECCVAL5	0-3FFh	Calculated 4-bit ECC or Syndrom Value5.

20.4.19 NAND Flash 4-Bit ECC Register 4 (NAND4BITECC4)

The NAND Flash 4-bit ECC register 4 (NAND4BITECC4) is shown in Figure 20-49 and described in Table 20-67.

Figure 20-49. NAND Flash 4-Bit ECC Register 4 (NAND4BITECC4)

31	26	25	16
Reserved		4BITECCVAL8	
R-0		R/W-0	

15	10	9	0
Reserved		4BITECCVAL7	
R-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 20-67. NAND Flash 4-Bit ECC Register 4 (NAND4BITECC4) Field Descriptions

Bit	Field	Value	Description
31-26	Reserved	0	Reserved
25-16	4BITECCVAL8	0-3FFh	Calculated 4-bit ECC or Syndrom Value8.
15-10	Reserved	0	Reserved
9-0	4BITECCVAL7	0-3FFh	Calculated 4-bit ECC or Syndrom Value7.

20.4.20 NAND Flash 4-Bit ECC Error Address Register 1 (NANDERRADD1)

The NAND Flash 4-bit ECC error register 1 (NANDERRADD1) is shown in Figure 20-50 and described in Table 20-68.

Figure 20-50. NAND Flash 4-Bit ECC Error Address Register 1 (NANDERRADD1)

31	26	25	16
Reserved		4BITECCERRADD2	
R-0		R/W-0	

15	10	9	0
Reserved		4BITECCERRADD1	
R-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 20-68. NAND Flash 4-Bit ECC Error Address Register 1 (NANDERRADD1) Field Descriptions

Bit	Field	Value	Description
31-26	Reserved	0	Reserved
25-16	4BITECCERRADD2	0-3FFh	Calculated 4-bit ECC Error Address 2.
15-10	Reserved	0	Reserved
9-0	4BITECCERRADD1	0-3FFh	Calculated 4-bit ECC Error Address 1.

20.4.21 NAND Flash 4-Bit ECC Error Address Register 2 (NANDERRADD2)

The NAND Flash 4-bit ECC error register 2 (NANDERRADD2) is shown in Figure 20-51and described in Table 20-69.

Figure 20-51. NAND Flash 4-Bit ECC Error Address Register 2 (NANDERRADD2)

31	26	25	16
Reserved		4BITECCERRADD4	
R-0		R/W-0	

15	10	9	0
Reserved		4BITECCERRADD3	
R-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 20-69. NAND Flash 4-Bit ECC Error Address Register 2 (NANDERRADD2) Field Descriptions

Bit	Field	Value	Description
31-26	Reserved	0	Reserved
25-16	4BITECCERRADD4	0-3FFh	Calculated 4-bit ECC Error Address 4.
15-10	Reserved	0	Reserved
9-0	4BITECCERRADD3	0-3FFh	Calculated 4-bit ECC Error Address 3.

20.4.22 NAND Flash 4-Bit ECC Error Value Register 1 (NANDERRVAL1)

The NAND Flash 4-bit ECC error value register 1 (NANDERRVAL1) is shown in Figure 20-52 and described in Table 20-70.

Figure 20-52. NAND Flash 4-Bit ECC Error Value Register 1 (NANDERRVAL1)

31	26	25	16
Reserved		4BITECCERRVAL2	
R-0		R/W-0	

15	10	9	0
Reserved		4BITECCERRVAL1	
R-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 20-70. NAND Flash 4-Bit ECC Error Value Register 1 (NANDERRVAL1) Field Descriptions

Bit	Field	Value	Description
31-26	Reserved	0	Reserved
25-16	4BITECCERRVAL2	0-3FFh	Calculated 4-bit ECC Error Value 2.
15-10	Reserved	0	Reserved
9-0	4BITECCERRVAL1	0-3FFh	Calculated 4-bit ECC Error Value 1.

20.4.23 NAND Flash 4-Bit ECC Error Value Register 2 (NANDERRVAL2)

The NAND Flash 4-bit ECC error value register 2 (NANDERRVAL2) is shown in Figure 20-53 and described in Table 20-71.

Figure 20-53. NAND Flash 4-Bit ECC Error Value Register 2 (NANDERRVAL2)

31	26	25	16
Reserved		4BITECCERRVAL4	
R-0		R/W-0	

15	10	9	0
Reserved		4BITECCERRVAL3	
R-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 20-71. NAND Flash 4-Bit ECC Error Value Register 2 (NANDERRVAL2) Field Descriptions

Bit	Field	Value	Description
31-26	Reserved	0	Reserved
25-16	4BITECCERRVAL4	0-3FFh	Calculated 4-bit ECC Error Value 4.
15-10	Reserved	0	Reserved
9-0	4BITECCERRVAL3	0-3FFh	Calculated 4-bit ECC Error Value 3.

External Memory Interface B (EMIFB)

This chapter describes the external memory interface B (EMIFB).

Topic **Page**

21.1 Introduction

21.1.1 Purpose of the Peripheral

EMIFB memory controller is complaint with the JESD21-C SDR SDRAM memories utilizing either 32-bit or 16-bit of the EMIFB memory controller data bus. The purpose of this EMIFB is to provide a means for the CPU to connect to a variety of external devices including:

- Single data rate (SDR) SDRAM/ mobile SDR SDRAM

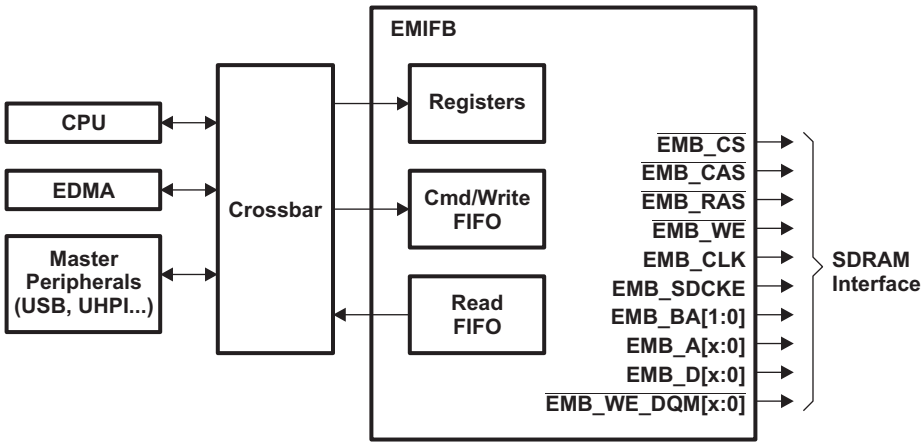
21.1.2 Features

For details on features of EMIFB, see your device-specific data manual.

21.1.3 Functional Block Diagram

Figure 21-1 illustrates a high-level view of the EMIFB and its connections within the device. Multiple requesters have access to EMIFB through a switched central resource(indicated as crossbar in the figure). The EMIFB implements a split transaction internal bus, allowing concurrence between reads and writes from the various requesters. Section 21.2.2 contains further description of the entities internal to the device that can send requests to the EMIFB. Section 21.2.3 describes the EMIFB external pins and summarizes their purpose when interfacing with SDRAM.

Figure 21-1. EMIFB Functional Block Diagram



21.2 Architecture

This section provides details about the architecture and operation of the EMIFB SDRAM interface.

21.2.1 Clock Control

For details on EMIFB clock control, see the *Device Clocking* chapter.

21.2.2 EMIF Requests

Depending on the specific device, different sources (CPU, EDMA, and other master peripherals) within the device can make requests to EMIFB. Some of these sources have multiple master ports to the crossbar (EDMA TPTCs) and some share ports to the crossbar (USB). The requests from these sources consist of accesses to SDRAM memory and EMIFB registers. The EMIFB implements internal data FIFOs and a split transaction internal bus to allow concurrence of read and write operations from multiple masters, in an attempt to fully utilize available throughput of the attached memories.

A high-performance crossbar switch exists within the device to provide prioritized requests from the different requesters to the EMIFB. If a request is submitted from two or more sources simultaneously, the crossbar switch will forward the highest priority request to the EMIFB first. Upon completion of a request, the crossbar switch again evaluates the pending requests and forwards the highest priority pending request to the EMIFB.

When forwarding read and write commands to the EMIFB, the crossbar uses a priority arbitration scheme. When the EMIFB receives a request, it may or may not be immediately processed due to prioritization of pending refresh cycles. In some cases, the EMIFB will perform one or more auto refresh cycles before processing the request. For details on the EMIFB's internal arbitration between performing requests and performing auto refresh cycles, see Section 21.2.6.6. For further details regarding master prioritization within the EMIFB command FIFO, see Section 21.2.6.13.

21.2.3 Pin Descriptions

Table 21-1 describes the function of each EMIFB pin.

Table 21-1. EMIF Pins Used to Access SDRAM

Pins(s)	I/O	Description
EMB_D[x:0]	I/O	**EMIFB data bus.** The number of available data bus pins varies among devices. See your device-specific data manual for details.
EMB_A[x:0]	O	**EMIFB address bus.** When interfacing to an SDRAM device, these pins are primarily used to provide the row and column address to the SDRAM. The number of available address pins depends upon pin multiplexing configuration. See your device-specific data manual for details. The mapping from the internal program address to the external values placed on these pins can be found in Table 21-15 and Table 21-16.
EMB_BA[1:0]	O	**EMIFB bank address.** When interfacing to an SDRAM device, these pins are used to provide the bank address inputs to the SDRAM. The mapping from the internal program address to the external values placed on these pins can be found in Table 21-15 and Table 21-16.
$\overline{\text{EMB\_WE\_DQM[x:0]}}$	O	**Byte enables.** When interfacing to SDRAM, these pins are connected to the DQM pins of the SDRAM to individually enable/disable each of the bytes in a data access.
$\overline{\text{EMB\_WE}}$	O	**Active-low write enable.** When interfacing to SDRAM, this pin is connected to the $\overline{\text{WE}}$ pin of the SDRAM and is used to send commands to the device.
$\overline{\text{EMB\_CS}}$	O	**Active-low chip enable pin for SDRAM devices.** This pin is connected to the chip-select pin of the attached SDRAM device and is used for enabling/disabling commands. By default, the EMIF keeps SDRAM chip select active, even if the EMIF interface is currently idle.
$\overline{\text{EMB\_RAS}}$	O	**Active-low row address strobe pin.** This pin is connected to the $\overline{\text{RAS}}$ pin of the attached SDRAM device and is used for sending commands to the device.

Table 21-1. EMIF Pins Used to Access SDRAM (continued)

Pins(s)	I/O	Description
$\overline{\text{EMB\_CAS}}$	O	**Active-low column address strobe pin.** This pin is connected to the $\overline{\text{CAS}}$ pin of the attached SDRAM device and is used for sending commands to the device.
EMB_SDCKE	O	**Clock enable pin.** This pin is connected to the CKE pin of the attached SDRAM device and is used for issuing the SELF REFRESH command which places the device in self-refresh mode. See Section 21.2.6.7 for details.
EMB_CLK	O	**SDRAM clock pin.** This pin is connected to the CLK pin of the attached SDRAM device. See Section 21.2.1 for details on the clock signal.

21.2.4 Pin Multiplexing

Refer to device-specific data manual for pin multiplexing details.

21.2.5 Memory Map

See your device-specific data manual for information describing the device memory-map.

21.2.6 SDRAM Controller and Interface

The EMIFB can gluelessly interface to most standard SDR SDRAM devices and support such features as self-refresh mode and prioritized refresh. In addition, it provides flexibility through programmable parameters such as the refresh rate, CAS latency, and many SDRAM timing parameters. The following sections include details on how to interface and properly configure the EMIFB to perform read and write operations to externally connected SDR SDRAM devices.

21.2.6.1 SDRAM Commands

The EMIFB supports the SDRAM commands described in Table 21-2. Table 21-3 shows the truth table for the SDRAM commands, and an example timing waveform of the PRE command is shown in Figure 21-2. EMB_A[10] is pulled low in this example to deactivate only the bank specified by the EMB_BA pins.

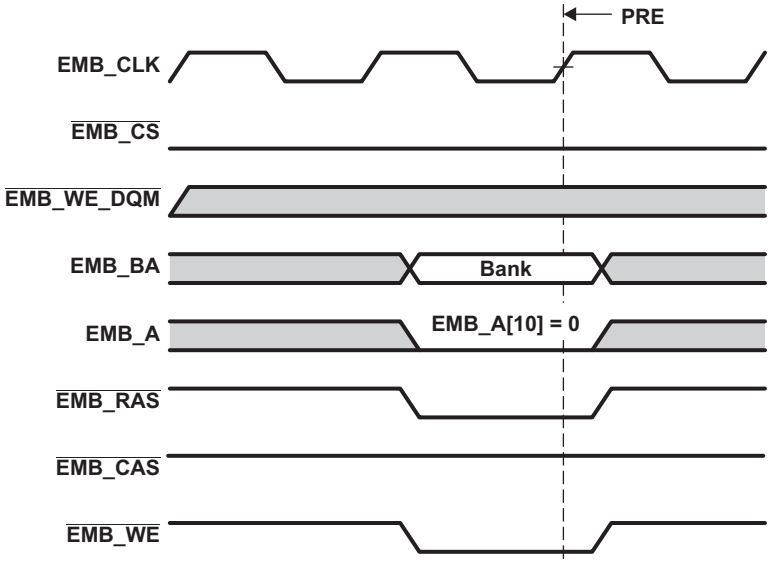
Table 21-2. EMIF SDRAM Commands

Command	Function
PRE	**Precharge.** Depending on the value of EMB_A[10], the PRE command either deactivates the open row in all banks (EMB_A[10] = 1) or only the bank specified by the EMB_BA[1:0] pins (EMB_A[10] = 0).
ACTV	**Activate**. The ACTV command activates the selected row in a particular bank for the current access.
READ	**Read.** The READ command outputs the starting column address and signals the SDRAM to begin the burst read operation. Address EMB_A[10] is always pulled low to avoid auto precharge. This allows for better bank interleaving performance.
WRT	**Write.** The WRT command outputs the starting column address and signals the SDRAM to begin the burst write operation. Address EMB_A[10] is always pulled low to avoid auto precharge. This allows for better bank interleaving performance.
BT	**Burst terminate**. The BT command is used to truncate the current read or write burst request.
LMR	**Load mode register**. The LMR command sets the mode register of the attached SDRAM devices and is only issued during the SDRAM initialization sequence described in Section 21.2.6.4.
REFR	**Auto refresh**. The REFR command signals the SDRAM to perform an auto refresh according to its internal address.
SLFR	**Self refresh**. The self refresh command places the SDRAM into self-refresh mode, during which it provides its own clock signal and auto refresh cycles.
NOP	**No operation**. The NOP command is issued during all cycles in which one of the above commands is not issued.

Table 21-3. Truth Table for SDRAM Commands

SDRAM Pins:	CKE	$\overline{CS}$	$\overline{RAS}$	$\overline{CAS}$	$\overline{WE}$	BA[1:0]	A[12:11]	A[10]	A[9:0]
EMIFB Pins:	EMB_SDCKE	$\overline{EMB\_CS}$	$\overline{EMB\_RAS}$	$\overline{EMB\_CAS}$	$\overline{EMB\_WE}$	EMB_BA[1:0]	EMB_A[12:11]	EMB_A[10]	EMB_A[9:0]
PRE	H	L	L	H	L	Bank/X	X	L/H	X
ACTV	H	L	L	H	H	Bank	Row	Row	Row
READ	H	L	H	L	H	Bank	Column	L	Column
WRT	H	L	H	L	L	Bank	Column	L	Column
BT	H	L	H	H	L	X	X	X	X
LMR	H	L	L	L	L	X	Mode	Mode	Mode
REFR	H	L	L	L	H	X	X	X	X
SLFR	L	L	L	L	H	X	X	X	X
NOP	H	L	H	H	H	X	X	X	X

Figure 21-2. Timing Waveform of SDRAM PRE Command



21.2.6.2 Interfacing to SDRAM

The EMIFB supports a glueless interface to SDRAM devices with the following characteristics:

- Pre-charge bit is A[10]
- The number of column address bits is 8, 9, 10 or 11
- The number of row address bits is 13(in case of mobile SDR, number of row address bits can be 9, 10, 11, 12, or 13)
- The number of internal banks is 1, 2 or 4

Figure 21-3 shows an interface between the EMIFB and a 2M × 16 × 4 bank SDRAM device. In addition, Figure 21-4 shows an interface between the EMIFB and a 2M × 32 × 4 bank SDRAM device and Figure 21-5 shows an interface between the EMIFB and two 4M × 16 × 4 bank SDRAM devices. Refer to Table 21-4, as an example that shows additional list of commonly-supported SDRAM devices and the required connections for the address pins. Note that in Table 21-4, page size/column size (not indicated in the table) is varied to get the required addressability range.

Figure 21-3. EMIFB to 2M × 16 × 4 bank SDRAM Interface

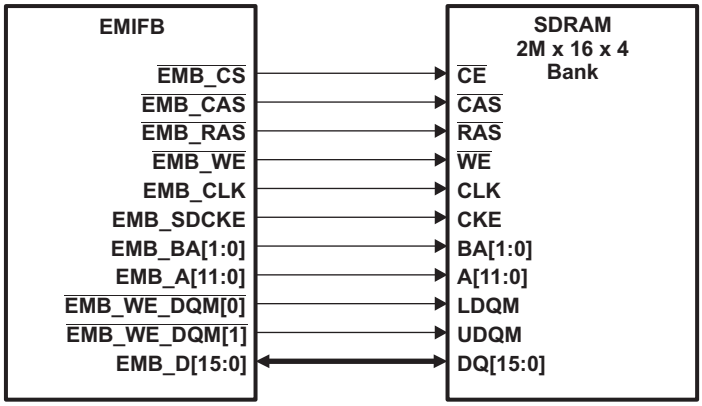


Figure 21-4. EMIFB to 2M × 32 × 4 bank SDRAM Interface

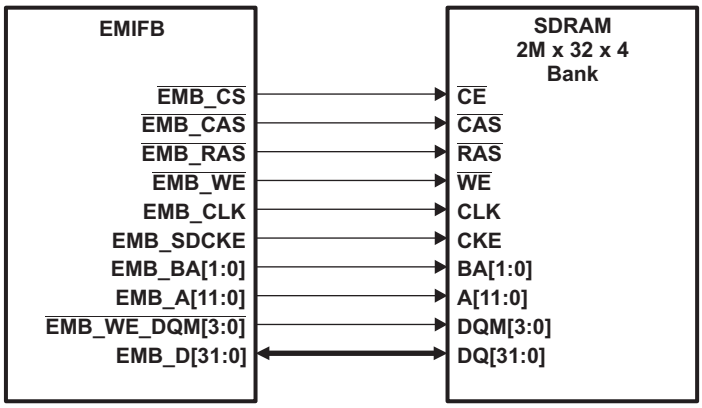


Figure 21-5. EMIFB to Dual 4M × 16 × 4 bank SDRAM Interface

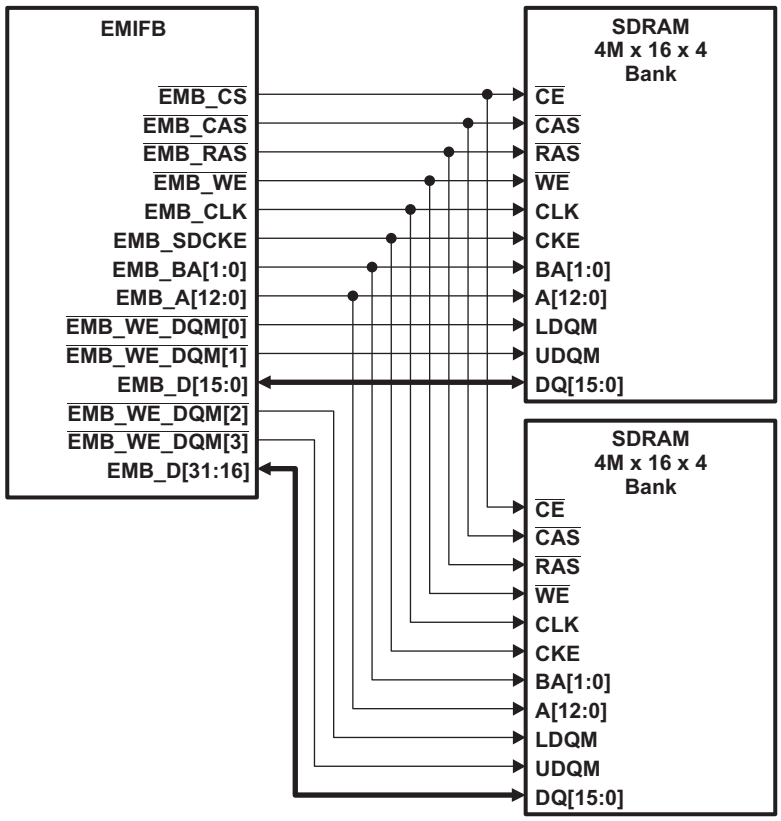


Table 21-4. Example of 32-bit EMIFB Address Pin Connections

SDRAM Size	Width	Banks		Address Pins
64M bits	×16	4	SDRAM	A[11:0]
			EMIFB	EMB_A[11:0]
	×32	4	SDRAM	A[10:0]
			EMIFB	EMB_A[10:0]
128M bits	×16	4	SDRAM	A[11:0]
			EMIFB	EMB_A[11:0]
	×32	4	SDRAM	A[11:0]
			EMIFB	EMB_A[11:0]
256M bits	×16	4	SDRAM	A[12:0]
			EMIFB	EMB_A[12:0]
	×32	4	SDRAM	A[11:0]
			EMIFB	EMB_A[11:0]
512M bits	×16	4	SDRAM	A[12:0]
			EMIFB	EMB_A[12:0]
	×32	4	SDRAM	A[12:0]
			EMIFB	EMB_A[12:0]

Table 21-5. Example of 16-bit EMIFB Address Pin Connections

SDRAM Size	Width	Banks		Address Pins
64M bits	×16	4	SDRAM	A[11:0]
			EMIFB	EMB_A[11:0]
128M bits	×16	4	SDRAM	A[11:0]
			EMIFB	EMB_A[11:0]

21.2.6.3 SDRAM Configuration Registers

The operation of the EMIFB SDRAM interface is controlled by programming the appropriate configuration registers. This section describes the purpose and function of each configuration register, refer to Section 21.4 for a more detailed description of each register. The following tables list the SDRAM configuration registers, along with a description of each of their programmable fields.

NOTE: Writing to any of the fields in SDCFG and SDCFG2 causes the EMIFB to abandon whatever it is currently doing and trigger the SDRAM initialization procedure described in Section 21.2.6.4.

Table 21-6. Description of the SDRAM Configuration Register (SDCFG)

Parameter	Description
IBANK_POS	**Internal bank position.** Set to 1 to assign internal bank address bits from logical address as shown in Table 21-17 (this addressing scheme is normally used in case of mobile SDRAM). Clear to 0 to assign internal bank address bits from logical address as shown in Table 21-15 and Table 21-16 (these addressing schemes are normally used in case of SDR SDRAM) . This bit is writeable only when the BOOT_UNLOCK bit is unlocked.
MSDRAM_ENABLE	**mobile SDR enable.**Both SDREN and MSDRAM_ENABLE should be set to 1 to enable mobile SDR. This bit is writeable only when the BOOT_UNLOCK bit is unlocked.
BOOT_UNLOCK	**Boot Unlock.**Set to 1 to change the values of the fields that are affected by the BOOT_UNLOCK bit.
SDREN	**SDR Enable.** This bit enables EMIFB to interface to SDRAM type memories. This bit is set to 1 by default.
TIMUNLOCK	**Timing Unlock.**Controls the write permission settings for the SDRAM timing 1 register (SDTIM1) and SDRAM timing 2 register (SDTIM2)
NM	**Narrow Mode.** This bit defines the width of the data bus between the EMIF and the attached SDRAM device. When set to 1, the data bus is set to 16-bits; when cleared to 0, the data bus is set to 32-bits.
CL	**CAS latency.** This field defines the number of clock cycles between when an SDRAM issues a READ command and when the first piece of data appears on the bus. The value in this field is sent to the attached SDRAM device via the LOAD MODE REGISTER command during the SDRAM initialization procedure as described in Section 21.2.6.4. Only values of 2h (CAS latency = 2) and 3h (CAS latency = 3) are supported and are written to this field. A 1 must be simultaneously written to the TIMUNLOCK bit field of SDCFG in order to write to the CL bit field.
EBANK	**Number of External SDRAM Banks (or chip selects).** This field defines the number of chip selects are utilized on the SDRAM interface: • When EBANK = 0, CS[0] is used (single external bank). Always write 0 to this field.
IBANK	**Number of Internal SDRAM Banks.** This field defines the number of banks inside the attached SDRAM devices in the following way: • When IBANK = 0, 1 internal bank is used • When IBANK = 1h, 2 internal banks are used • When IBANK = 2h, 4 internal banks are used This field value affects the mapping of logical addresses to SDRAM row, column, and bank addresses. See Section 21.2.6.12 for details.

Table 21-6. Description of the SDRAM Configuration Register (SDCFG) (continued)

Parameter	Description
PAGESIZE	**Page Size.** This field defines the internal page size of the attached SDRAM devices in the following way: • When PAGESIZE = 0, 256-word pages are used, requiring 8 column address bits. • When PAGESIZE = 1h, 512-word pages are used, requiring 9 column address bits. • When PAGESIZE = 2h, 1024-word pages are used, requiring 10 column address bits. • When PAGESIZE = 3h, 2048-word pages are used, requiring 11 column address bits. This field value affects the mapping of logical addresses to SDRAM row, column, and bank addresses. See Section 21.2.6.12 for details.

Table 21-7. Description of the SDRAM Refresh Control Register (SDRFC)

Parameter	Description
LP_MODE	**Low Power Mode**. This bit enables the self-refresh mode of the attached SDRAM devices (which is the lowest power mode).
MCLKSTOP_EN	**mclk stop enable.** mclk can stopped only if this bit is set.
SR_PD	**Self Refresh/ Power Down select.** This bit along with LP_MODE determines if SDRAM is to be placed in self-refresh/power-down mode.
REFRESH_RATE	**Refresh Rate**. This field controls the rate at which attached SDRAM devices will be refreshed. The following equation can be used to determine the required value of REFRESH_RATE for an SDRAM device: • REFRESH_RATE = (EMIFB clock rate)/(Required SDRAM Refresh Rate) More information about the operation of the SDRAM refresh controller can be found in Section 21.2.6.6.

Table 21-8. Description of the SDRAM Timing 1 Register (SDTIM1)

Parameter	Description
T_RFC T_RP T_RCD T_WR T_RAS T_RC T_RRD	**SDRAM Timing Parameters.** These fields configure the EMIFB to comply with the AC timing requirements of the attached SDRAM devices. This allows the EMIFB to avoid violating SDRAM timing constraints and to more efficiently schedule its operations. More details about each of these parameters can be found in the register description in Section 21.4.4. These parameters are set to satisfy the corresponding timing requirements found in the SDRAM's datasheet.

Table 21-9. Description of the SDRAM Timing 2 Register (SDTIM2)

Parameter	Description
T_RAS_MAX	Maximum number of refresh_rate intervals from Activate to Precharge command.
T_XS	**Self Refresh Exit Parameter.** The T_XS field of this register informs the EMIFB about the minimum number of EMB_CLK cycles required between exiting Self Refresh and issuing any command. This parameter is set to satisfy the t_{XSR} value for the attached SDRAM device.
T_CKE	The T_CKE field fixes the minimum time between CKE transitions. This parameter is set to satisfy the t_{RAS} value for the attached SDRAM device.

Table 21-10. Description of the SDRAM Configuration 2 Register (SDCFG2)

Parameter	Description
PASR	**Partial Array Self Refresh.** These bits get loaded into the Extended Mode Register of a mobile SDRAM during initialization. A write to this field will cause the EMIFB to start the SDRAM initialization sequence.
ROWSIZE	**Row Size.** Defines the number of row address bits of connected SDRAM devices. This bit is used only in case of mobile SDRAM. A write to this field will cause the EMIFB to start the SDRAM initialization sequence.

21.2.6.4 SDRAM/mobile SDRAM Auto-Initialization Sequence

The EMIFB automatically performs an SDRAM initialization sequence, regardless of whether it is interfaced to an SDRAM device, when the following event occurs:

- A write is performed to any of the two least significant bytes of the SDRAM configuration register (SDCFG)
- In case of mobile SDR, initialization sequence also starts when a write is performed to SDRAM configuration 2 register (SDCFG2)

An SDRAM/mobile SDR initialization sequence consists of the following steps:

1. First, software must set the SDREN bit (in case of mobile SDRAM, both SDREN and MSDRAM_ENABLE should be set to 1) in the SDRAM configuration register (SDCFG) (assuming clocking and pin multiplexing are already configured accordingly).
2. If the initialization sequence is activated by a write to SDCFG, and if any of the SDRAM banks are open, the EMIFB issues a PRE command with EMB_A[10] held high to indicate all banks. This is done so that the maximum ACTV to PRE timing for an SDRAM is not violated.
3. The EMIFB drives EMB_SDCKE high and begins continuously issuing NOP commands until eight SDRAM refresh intervals have elapsed. An SDRAM refresh interval is equal to the value of the REFRESH_RATE field of the SDRAM refresh control register (SDRFC), divided by the frequency of EMB_CLK (REFRESH_RATE/f_{CLK}). This step is used to avoid violating the Power-up constraint of most SDRAM devices that requires 200 µs (sometimes 100 µs) between receiving stable Vdd and CLK and the issuing of a PRE command. Depending on the frequency of EMB_CLK, this step may or may not be sufficient to avoid violating the SDRAM constraint. See Section 21.2.6.5 for more information.
4. After the refresh intervals have elapsed, the EMIFB issues a PRE command with EMB_A[10] held high to indicate all banks.
5. The EMIFB issues eight AUTO REFRESH commands.
6. If initialization sequence is of mobile SDRAM, EMIFB issues LMR command with EMB_A[6:0] pins set as described in Table 21-11.
7. Then, EMIFB issues the LMR command with the EMB_A[9:0] pins set as described in Table 21-12. This step is executed for both SDRAM/mobile SDRAM.
8. Finally, the EMIFB performs an auto refresh cycle, which consists of the following steps:
   (a) Issuing a PRE command with EMB_A[10] held high if any banks are open
   (b) Issuing a REF command
   (c) Interface is idle (awaiting access)

Table 21-11. mobile SDRAM LOAD MODE REGISTER Command

A[6:5]	A[4:3]	A[2:0]
0 (SDRAM drive strength; 0= full drive strength)	0 (Internal Temperature Compensated Self Refresh)	These bits are set according to the PASR field in the SDRAM configuration 2 register (SDCFG2).

Table 21-12. SDRAM/mobile SDRAM LOAD MODE REGISTER Command

A[9:7]	A[6:4]	A[3]	A[2:0]
0 (Write bursts are of the programmed burst length in EMB_A[2:0])	These bits control the CAS latency of the SDRAM and are set according to CL field in the SDRAM configuration register (SDCFG) as follows: • If CL = 2h, EMB_A[6:4] = 2h (CAS latency = 2) • If CL = 3h, EMB_A[6:4] = 3h (CAS latency = 3)	0 (Sequential Burst Type. Interleaved Burst Type not supported)	These bits control the burst length of the SDRAM and are set according to the NM field in the SDRAM configuration register (SDCFG) as follows: • If NM = 0, EMB_A[2:0] = 2h (Burst Length = 4) • If NM = 1, EMB_A[2:0] = 3h (Burst Length = 8)

21.2.6.5 SDRAM Configuration Procedure

After initial power-on, follow the procedure listed below before performing any EMIFB memory requests. Note that the SDRAM power-up constraint specifies that 200 µs must exist between receiving stable Vdd and CLK and the issuing of a PRE command. Initialization software and system design must ensure that this constraint is met before executing the initialization procedure.

1. Place the SDRAM into Self-Refresh Mode by setting the LP_MODE bit and SR_PD bit of the SDRAM refresh control register (SDRFC) to 1 and 0, respectively. Place the SDRAM into Self-Refresh mode when changing the frequency of EMB_CLK to avoid incurring the 200 µs power-up constraint again.
2. Program the PLL controller and configure the EMIFB clock mux selection (in the System Configuration Module) to attain the desired EMB_CLK clock frequency. Refer to the device data manual for details on programming the PLL controller. The frequency of the memory clock must meet the timing requirements in the SDRAM manufacturer's documentation and the timing limitations shown in the electrical specifications of the device data manual.
3. Enable SDR mode of the EMIFB by writing 1 to the SDREN bit (write 1 to both SDREN and MSDRAM_ENABLE to enable mobile SDR) in the SDRAM configuration register (SDCFG). Also ensure that pin multiplexing is properly configured.
4. Program SDTIM1 and SDTIM2 to satisfy the timing requirements for the attached SDRAM device. Take the timing parameters from the SDRAM datasheet.
5. Program the REFRESH_RATE field of SDRFC to match that of the attached device's refresh interval. See Section 21.2.6.6.1 for details on determining the appropriate value.
6. Program SDCFG to match the characteristics of the attached SDRAM device. This will cause the auto-initialization sequence in Section 21.2.6.4 to be re-run. This second initialization generally takes much less time due to the increased frequency of EMB_CLK.

After following the above procedure, the EMIFB is ready to perform accesses to the attached SDRAM device. If a frequency change is desired after this configuration has been executed, first put the SDRAM into Self-Refresh mode using a byte-write to the upper byte of SDCFG to avoid restarting the SDRAM auto-initialization sequence. Then release the SDRAM from self-refresh mode and repeat steps 4 through 6 of the above procedure.

21.2.6.6 EMIFB Refresh Controller

An SDRAM device requires that each of its rows be refreshed at a minimum required rate. The EMIFB can meet this constraint by performing auto refresh cycles at or above this required rate. An auto refresh cycle consists of issuing a PRE command to all banks of the SDRAM device followed by issuing a REFR command. To inform the EMIFB of the required rate for performing auto refresh cycles, the REFRESH_RATE field of the SDRAM refresh control register (SDRFC) must be programmed. The EMIF will use this value along with two internal counters to automatically perform auto refresh cycles at the required rate. The auto refresh cycles cannot be disabled, even if the EMIFB is not interfaced with an SDRAM. The remainder of this section details the EMIFB's refresh scheme and provides an example for determining the appropriate value to place in the REFRESH_RATE field of SDRFC.

The two counters used to perform auto-refresh cycles are a 13-bit refresh interval counter and a 4-bit refresh backlog counter. After SDREN = 1 and upon writing to the REFRESH_RATE field, the refresh interval counter is loaded with the value from REFRESH_RATE field and begins decrementing, by one, each EMIFB clock cycle. When the refresh interval counter reaches zero, the following actions occur:

- The refresh interval counter is reloaded with the value from the REFRESH_RATE field and restarts decrementing.
- The 4-bit refresh backlog counter increments unless it has already reached its maximum value.

The refresh backlog counter records the number of auto refresh cycles that the EMIFB currently has outstanding. This counter is decremented by one each time an auto refresh cycle is performed and incremented by one each time the refresh interval counter expires. The refresh backlog counter saturates at the values of 0000b and 1111b. The EMIFB uses the refresh backlog counter to determine the urgency with which an auto refresh cycle is to be performed. The four levels of urgency are described in Table 21-13. This refresh scheme allows the required refreshes to be performed with minimal impact on access requests.

Table 21-13. Refresh Urgency Levels

Urgency Level	Refresh Backlog Counter Range	Action Taken
Refresh May	1-3	An auto-refresh cycle is performed only if the EMIFB has no requests pending and none of the SDRAM banks are open.
Refresh Release	4-7	An auto-refresh cycle is performed if the EMIFB has no requests pending, regardless of whether any SDRAM banks are open.
Refresh Need	8-11	An auto-refresh cycle is performed at the completion of the current access unless there are read requests pending.
Refresh Must	12-15	Multiple auto-refresh cycles are performed at the completion of the current access until the Refresh Release urgency level is reached. At that point, the EMIFB can begin servicing any new read or write requests.

21.2.6.6.1 Determining the Appropriate Value for the REFRESH_RATE Field

The value programmed into the REFRESH_RATE field of SDRFC can be calculated by using the frequency of the EMB_CLK signal (f_{CLK}) and the required refresh rate of the SDRAM ($f_{Refresh}$). The following formula can be used:

$REFRESH\_RATE \leq f_{CLK} / f_{Refresh}$

The SDRAM datasheet often communicates the required SDRAM Refresh Rate in terms of the number of REFR commands required in a given time interval. The required SDRAM Refresh Rate in the formula above can be therefore be calculated by dividing the number of required cycles per time interval (n_{cycles}) by the time interval given in the datasheet ($t_{Refresh\ Period}$) :

$f_{Refresh} = n_{cycles} / t_{Refresh\ Period}$

Combining these formulas, the value programmed into the REFRESH_RATE field can be computed as:

$REFRESH\_RATE \leq f_{CLK} \times t_{Refresh\ Period} / n_{cycles}$

The following example illustrates calculating the value of REFRESH_RATE. Given that:

- f_{CLK} = 133 MHz (frequency of the EMIFB clock)
- $t_{Refresh\ Period}$ = 64 ms (required refresh interval of the SDRAM)
- n_{cycles} = 8192 (number of cycles in a refresh interval for the SDRAM)

REFRESH_RATE can be calculated as:

REFRESH_RATE = 133 MHz × 64 ms/8192

REFRESH_RATE = 1039.06

REFRESH_RATE = 1039 cycles = 40Fh cycles

21.2.6.7 Self-Refresh Mode

The EMIFB can be programmed to enter the self-refresh state by setting the LP_MODE bit and SR_PD bit of the SDRAM refresh control register (SDRFC) to 1 and 0, respectively. This will cause the EMIFB to issue the SLFR command after completing any outstanding SDRAM access requests and clearing the refresh backlog counter by performing one or more auto refresh cycles. This places the attached SDRAM device into self-refresh mode in which it consumes a minimal amount of power while performing its own refresh cycles.

While in the self-refresh state, the EMIFB continues to service register accesses as normal.

The EMIFB will exit from the self-refresh state, if any of the following events occur:

- The LP_MODE bit of SDRFC is cleared to 0
- The SR_PD bit is set to 1
- An SDRAM accesses is requested

The EMIFB exits from the self-refresh state by driving EMB_SDCKE high and performing an auto refresh cycle.

The attached SDRAM device must be placed into self-refresh mode when changing the frequency of EMB_CLK using the PLL Controller. If the frequency of EMB_CLK changes while the SDRAM is not in self-refresh mode, the memory must be reinitialized.

During Self- refresh, if memory/register access request is made, EMIFB comes out of self-refresh state (driving EMB_SDCKE high) and executes the requests; after which it again goes back to self-refresh state (driving EMB_SDCKE low).

To use Partial Array Self Refresh for mobile SDR, PASR bits in the SDRAM configuration 2 register must be appropriately programmed. The EMIFB performs bank interleaving. Since the SDRAM is partially refreshed during Partial Array Self Refresh, it is the responsibility of software to move critical data into the banks that are going to be refreshed during Partial Array Self Refresh.

21.2.6.8 Power-Down Mode

To support low-power modes, the EMIFB can be requested to issue a POWERDOWN command to the SDRAM by setting both the LP_MODE and SR_PD bits in the SDRAM refresh control register (SDRFC) to 1. When this bit is set, the EMIFB will continue normal operation until all outstanding memory access requests have been serviced and the SDRAM refresh backlog (if there is one) has been cleared. At this point the EMIFB will enter the power-down state. Upon entering this state the EMIF will issue a POWERDOWN command (same as a NOP command but driving EMB_SDCKE low on the same cycle). The EMIFB then maintains EMB_SDCKE low until it exits the power-down state.

During the power-down state, the EMIFB services synchronous memory and register accesses as normal.

The EMIFB will exit from the power-down state, if any of the following events occur:

- The LP_MODE bit of SDRFC is cleared to 0
- The SR_PD bit is cleared to 0
- An SDRAM accesses is requested
- Refresh (REFR) command is to be sent to SDRAM.

During power-down, if memory/register access request is made, EMIFB comes out of the power-down state (driving EMB_SDCKE high) and executes the requests; after which it again goes back to the power-down state (driving EMB_SDCKE low).

21.2.6.9 Partial Array Self Refresh for mobile SDRAM

This is applicable only to mobile SDRAM, when using the addressing scheme as described in Table 21-17. For additional power savings during self-refresh, the partial array self-refresh (PASR) feature of mobile SDR allows to select the amount of memory that will be refreshed during self-refresh. Use the partial array self-refresh (PASR) bit field in the SDRAM configuration 2 register (SDCFG2) to select the amount of memory to refresh during self-refresh. As shown in Table 21-14 you may select either 4, 2, 1, 1/2, or 1/4 bank(s). The PASR bits are loaded into the extended mode register of the mobile SDR device, during autoinitialization (see Section 21.2.6.4). The EMIFB performs bank interleaving when the internal bank position (IBANKPOS) bit in SDRAM configuration register (SDCFG) is cleared to 0. Since the SDRAM banks are only partially refreshed during partial array self-refresh, it is recommended that you set IBANKPOS to 1 to avoid bank interleaving. Refer to Section 21.2.6.12 for more information on IBANKPOS and addressing mapping in general.

Table 21-14. PASR Bitfield in SDRAM Configuration 2 Register (SDCFG2) Configuration

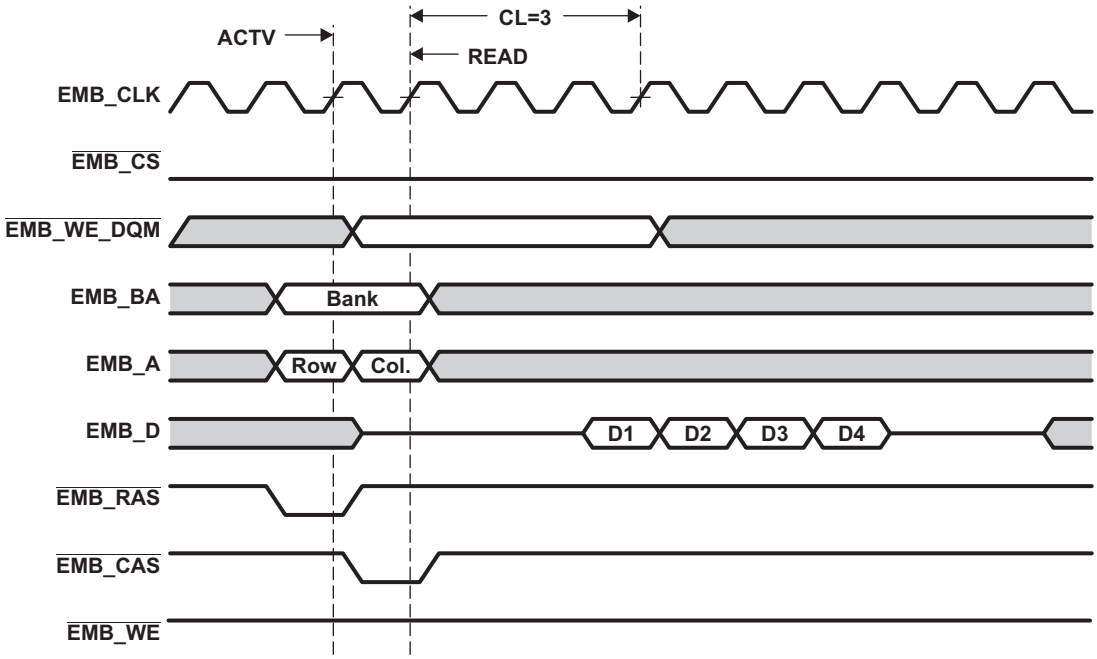
Bit Field	Bit Value	Bit Description
PASR	0	Refresh banks 0, 1, 2, and 3
	1h	Refresh banks 0 and 1
	2h	Refresh bank 0
	3h	Reserved
	4h	Reserved
	5h	Refresh 1/2 of bank 0
	6h	Refresh 1/4 of bank 0
	7h	Reserved

21.2.6.10 SDRAM Read Operation

When the EMIFB receives a read request to SDRAM , it performs one or more read access cycles. A read access cycle begins with the issuing of the ACTV command to select the desired bank and row of the SDRAM device. After the row has been opened, the EMIFB proceeds to issue a READ command while specifying the desired bank and column address. EMB_A[10] is held low during the READ command to avoid auto-precharging. The READ command signals the SDRAM device to start bursting data from the specified address while the EMIFB issues NOP commands. Following a READ command, the CL field of the SDRAM configuration register (SDCFG) defines how many delay cycles will be present before the read data appears on the data bus. This is referred to as the CAS latency.

Figure 21-6 shows the signal waveforms for a basic SDRAM read operation in which a burst of data is read from a single page. When the EMIFB SDRAM interface is configured to 32-bit by clearing the NM bit of the SDRAM configuration register (SDCFG) to 0, a burst size of four is used. When configured to 16-bit by setting NM to 1, a burst size of eight is used. Figure 21-6 shows a burst size of four.

Figure 21-6. Timing Waveform for Basic SDRAM Read Operation



The EMIFB will truncate a series of bursting data if the remaining addresses of the burst are not required to complete the request. The EMIFB can truncate the burst in three ways:

- By issuing another READ to the same page in the same bank.
- By issuing a PRE command in order to prepare for accessing a different page of the same bank.
- By issuing a BT command in order to prepare for accessing a page in a different bank.

Several other pins are also active during a read access. The $\overline{\text{EMB\_WE\_DQM}}$[3:0] pins are driven low during the READ commands and are kept low during the NOP commands that correspond to the burst request. The state of the other EMIFB pins during each command can be found in Table 21-3.

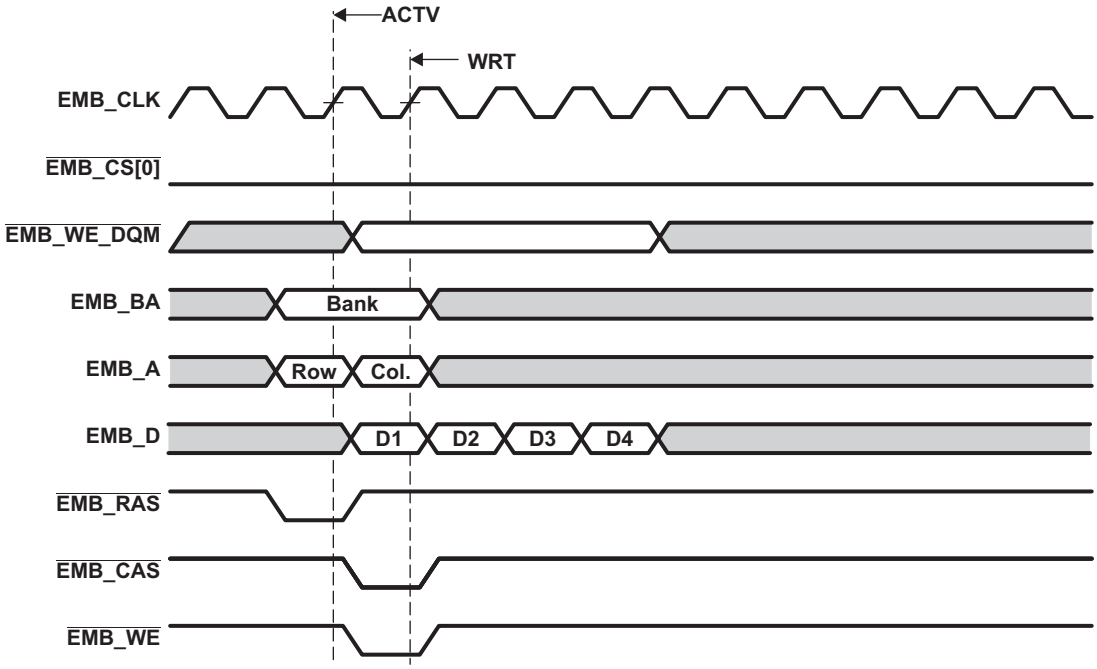
The EMIFB schedules its commands based on the timing information that is provided to it in the SDRAM timing registers (SDTIM1 and SDTIM2). The values for the timing parameters in this register are chosen to satisfy the timing requirements listed in the SDRAM datasheet. The EMIFB uses this timing information to avoid violating any timing constraints related to issuing commands. This is commonly accomplished by inserting NOP commands between various commands during an access. Refer to the register description of SDTIM1 and SDTIM2 for more details on the various timing parameters.

21.2.6.11 SDRAM Write Operations

When the EMIFB receives a write request to SDRAM , it performs one or more write-access cycles. A write-access cycle begins with the issuing of the ACTV command to select the desired bank and row of the SDRAM device. After the row has been opened, the EMIFB proceeds to issue a WRT command while specifying the desired bank and column address. EMB_A[10] is held low during the WRT command to avoid auto-precharging. The WRT command signals the SDRAM device to start writing a burst of data to the specified address while the EMIFB issues NOP commands. The associated write data will be placed on the data bus in the cycle concurrent with the WRT command and with subsequent burst continuation NOP commands.

Figure 21-7 shows the signal waveforms for a basic SDRAM write operation in which a burst of data is read from a single page. When the EMIFB SDRAM interface is configured to 32-bit by clearing the NM bit of the SDRAM configuration register (SDCFG) to 0, a burst size of four is used. When configured to 16-bit by setting NM to 1, a burst size of eight is used. Figure 21-7 shows a burst size of four.

Figure 21-7. Timing Waveform for Basic SDRAM Write Operation



The EMIFB will truncate a series of bursting data if the remaining addresses of the burst are not part of the write request. The EMIFB can truncate the burst in three ways:

- By issuing another WRT to the same page
- By issuing a PRE command in order to prepare for accessing a different page of the same bank
- By issuing a BT command in order to prepare for accessing a page in a different bank

Several other pins are also active during a write access. The EMB_WE_DQM[3:0] pins are driven to select which bytes of the data word will be written to the SDRAM device. They are also used to mask out entire undesired data words during a burst access. The state of the other EMIFB pins during each command can be found in Table 21-3.

EMIFB schedules its commands based on the timing information that is provided to it in the SDRAM timing registers (SDTIM1 and SDTIM2). The values for the timing parameters in this register are chosen to satisfy the timing requirements listed in the SDRAM datasheet. EMIFB uses this timing information to avoid violating any timing constraints related to issuing commands. This is commonly accomplished by inserting NOP commands during various cycles of an access. Refer to the register description of SDTIM1 and SDTIM2 for more details on the various timing parameters.

21.2.6.12 Mapping from Logical Address to EMIFB Pins

When the EMIFB receives an SDRAM access request, it must convert the address of the access into the appropriate signals to send to the SDRAM device. The details of an example address mapping are shown in Table 21-15 for 32-bit operation and in Table 21-16 for 16-bit operation. (In both the examples, a 13-bit row address is used to calculate the maximum reach. See your device-specific data manual to know the possible values of IBANK and PAGESIZE for EMIFB). Using the settings of the IBANK and PAGESIZE fields of the SDRAM configuration register (SDCFG), the EMIFB determines which bits of the logical address will be mapped to the SDRAM row, column, and bank addresses.

As the logical address is incremented by one word (32-bit operation) or one halfword (16-bit operation), the column address is likewise incremented by one until a page boundary is reached. When the logical address increments across a page boundary, the EMIFB moves into the same page in the next bank of the attached device by incrementing the bank address EMB_BA and resetting the column address. The page in the previous bank is left open until it is necessary to close it. This method of traversal through the SDRAM banks helps maximize the number of open banks inside of the SDRAM and results in an efficient use of the device. There is no limitation on the number of banks than can be open at one time, but only one page within a bank can be open at a time. To use such an addressing scheme, clear the internal bank position (IBANK_POS) bit in SDCFG to 0. This addressing scheme is used when EMIFB memory controller is configured to interface with SDR SDRAM.

The EMIFB uses the $\overline{\text{EMB\_WE\_DQM}}$ pins during a WRT command to mask out selected bytes or entire words. The $\overline{\text{EMB\_WE\_DQM}}$ pins are always low during a READ command.

When using mobile SDRAM, set IBANK_POS = 1, and this uses an addressing scheme as described in Table 21-17. See device data manual to know possible values of ROWSIZE, IBANK, and PAGESIZE for EMIFB configured to interface with mobile SDRAM device.

When the IBANK_POS bit is set to 1, the PAGESIZE, ROWSIZE, and IBANK fields control the mapping of the logical source address of the memory controller to the column, row, and bank address bits of the SDRAM device. Table 21-17 shows which source address bits map to the SDRAM column, row, and bank address bits for all combinations of PAGESIZE, ROWSIZE, and IBANK.

When the IBANK_POS bit is set to 1, the effect of the address-mapping scheme is that as the source address increments across an SDRAM page boundary, the memory controller proceeds to the next page in the same bank. This movement along the same bank continues until all the pages have been accessed in the same bank. The memory controller then proceeds to the next bank in the device. Since, in this address mapping scheme, the memory controller can keep only one bank open, this scheme is lower in performance than the case when IBANK_POS is cleared to 0. Therefore, this case is only recommended to be used with Partial Array Self-refresh for mobile SDR SDRAM where performance may be traded-off for power savings.

Table 21-15. Example Mapping from Logical Address to EMIFB Pins for 32-bit SDRAM

REACH (MB)	IBANK	PAGE SIZE	31	30	29	28	27	26	25	24	23	22:15	14	13	12	11	10	9:2	1:0
8	0	0	-									Row Address						Column Address	$\overline{\text{WE\_DQM}}$[3:0]
16	1	0	-									Row Address					BA[0]	Column Address	$\overline{\text{WE\_DQM}}$[3:0]
32	2	0	-									Row Address				BA[1:0]		Column Address	$\overline{\text{WE\_DQM}}$[3:0]
16	0	1	-									Row Address					Column Address		$\overline{\text{WE\_DQM}}$[3:0]
32	1	1	-									Row Address				BA[0]	Column Address		$\overline{\text{WE\_DQM}}$[3:0]
64	2	1	-									Row Address			BA[1:0]		Column Address		$\overline{\text{WE\_DQM}}$[3:0]
32	0	2	-									Row Address				Column Address			$\overline{\text{WE\_DQM}}$[3:0]
64	1	2	-									Row Address			BA[0]	Column Address			$\overline{\text{WE\_DQM}}$[3:0]
128	2	2	-									Row Address		BA[1:0]		Column Address			$\overline{\text{WE\_DQM}}$[3:0]
64	0	3	-									Row Address				Column Address			$\overline{\text{WE\_DQM}}$[3:0]
128	1	3	-									Row Address		BA[0]		Column Address			$\overline{\text{WE\_DQM}}$[3:0]
256	2	3	-									Row Address		BA[1:0]		Column Address			$\overline{\text{WE\_DQM}}$[3:0]

Table 21-16. Example Mapping from Logical Address to EMIFB Pins for 16-bit SDRAM

REACH (MB)	IBANK	PAGE SIZE	31	30	29	28	27	26	25	24	23	22	21:14	13	12	11	10	9	8:1	0
4	0	0	-										Row Address						Column Address	$\overline{WE}$_DQM[1:0]
8	1	0	-										Row Address					BA[0]	Column Address	$\overline{WE}$_DQM[1:0]
16	2	0	-										Row Address				BA[1:0]		Column Address	$\overline{WE}$_DQM[1:0]
8	0	1	-										Row Address					Column Address		$\overline{WE}$_DQM[1:0]
16	1	1	-										Row Address				BA[0]	Column Address		$\overline{WE}$_DQM[1:0]
32	2	1	-										Row Address			BA[1:0]		Column Address		$\overline{WE}$_DQM[1:0]
16	0	2	-										Row Address				Column Address			$\overline{WE}$_DQM[1:0]
32	1	2	-										Row Address			BA[0]	Column Address			$\overline{WE}$_DQM[1:0]
64	2	2	-										Row Address		BA[1:0]		Column Address			$\overline{WE}$_DQM[1:0]
32	0	3	-										Row Address			Column Address				$\overline{WE}$_DQM[1:0]
64	1	3	-										Row Address		BA[0]	Column Address				$\overline{WE}$_DQM[1:0]
128	2	3	-										Row Address		BA[1:0]	Column Address				$\overline{WE}$_DQM[1:0]

NOTE: The upper bit of the Row Address is used only when addressing 256-Mbit and 512-Mbit SDRAM memories.

Table 21-17. Example Mapping from Logical Address to EMIFB Pins for mobile SDRAM

31	N = 1 for 16-bit mobile SDRAM N = 2 for 32-bit mobile SDRAM	N

Bank Address	Row Address	Column Address	Data Mask
# of bits defined by IBANK	# of bits defined by ROWSIZE	# of bits defined by PAGESIZE	$\overline{WE}$_DQM[x:0]
IBANK = 0 => 0 bit	ROWSIZE = 0 => 9 bits	PAGESIZE = 0 => 8 bits	for N = 1, x = 1
IBANK = 1 => 1 bit	ROWSIZE = 1 => 10 bits	PAGESIZE = 1 => 9 bits	for N = 2, x = 3
IBANK = 2 => 2 bits	ROWSIZE = 2 => 11 bits	PAGESIZE = 2 => 10 bits	
	ROWSIZE = 3 => 12 bits	PAGESIZE = 3 => 11 bits	
	ROWSIZE = 4 => 13 bits		

21.2.6.13 SDRAM Memory Controller FIFO and Prioritization Considerations

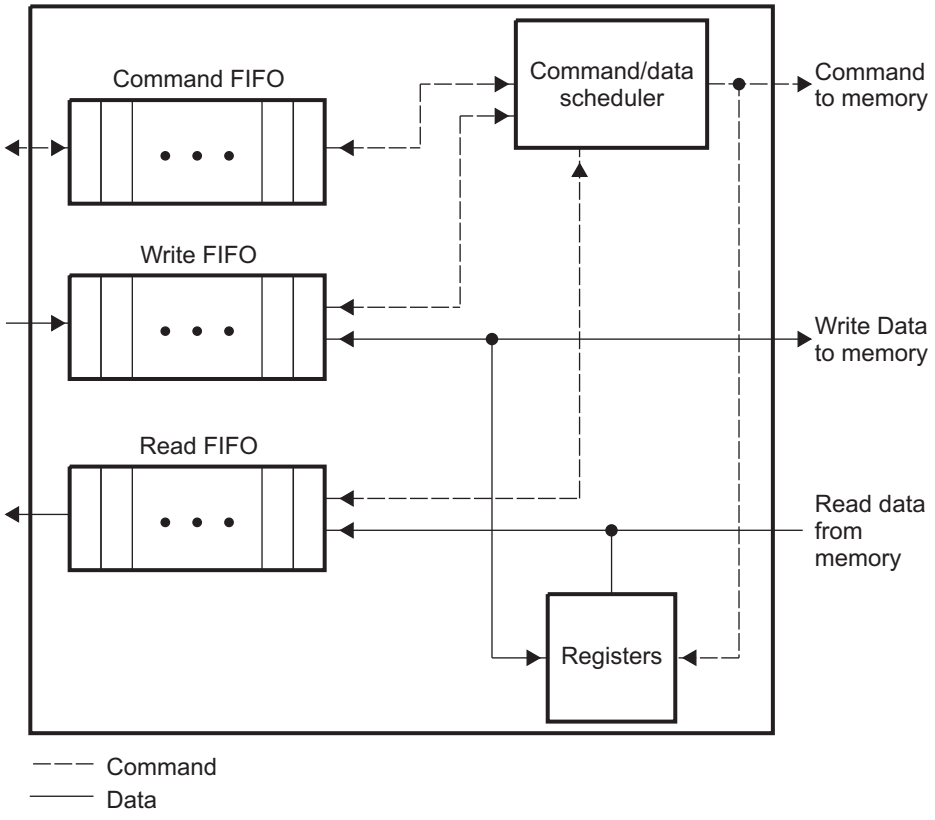
To move data efficiently from on-chip resources to external SDRAM memory, the EMIFB memory controller makes use of a command FIFO, a write FIFO, a read FIFO, and command and data schedulers. Table 21-18 describes the purpose of each FIFO.

Figure 21-8 shows the block diagram of the SDRAM memory controller FIFOs. Commands, write data, and read data arrive at the SDRAM memory controller parallel to each other. The same peripheral bus is used to write and read data from external memory as well as internal memory-mapped registers.

Table 21-18. SDRAM Memory Controller FIFO Description

FIFO	Description	Depth (32-bit words)
Command	Stores all commands coming from on-chip requesters	7
Write	Stores write data coming from on-chip requesters to memory	11
Read	Stores read data coming from memory to on-chip requesters	15

Figure 21-8. EMIFB Memory Controller FIFO Block Diagram



21.2.6.13.1 Command Ordering and Scheduling (Advanced Concept)

The SDRAM memory controller performs command re-ordering and scheduling in an attempt to achieve efficient transfers with maximum throughput. The goal is to maximize the utilization of the data, address, and command buses while hiding the overhead of opening and closing EMIFB SDRAM rows. Command re-ordering takes place within the command FIFO.

Typically, a given master issues commands on a single priority. EDMA transfer controller read and write ports are different masters. The SDRAM memory controller first reorders commands from each master based on the following rules:

- Selects the oldest command (first command in the queue)
- Selects a read before a write if:
  - The read is to a different block address (2048 bytes) than the write
  - The read has greater or equal priority

The second bullet above may be viewed as an exception to the first bullet. This means that for an individual master, all of its commands will complete from oldest to newest, with the exception that a read may be advanced ahead of an older, lower or equal priority write. Following this scheduling, each master may have one command ready for execution.

Next, the SDRAM memory controller examines each of the commands selected by the individual masters and performs the following reordering:

- Among all pending reads, selects reads to rows already open. Among all pending writes, selects writes to rows already open.
- Selects the highest priority command from pending reads and writes to open rows. If multiple commands have the highest priority, then the SDRAM memory controller selects the oldest command.

The SDRAM memory controller may now have a final read and write command. If the Read FIFO is not full, then the read command will be performed before the write command, otherwise the write command will be performed first.

Besides commands received from on-chip resources, the SDRAM memory controller also issues refresh commands. The SDRAM memory controller attempts to delay refresh commands as long as possible to maximize performance while meeting the SDRAM refresh requirements. As the SDRAM memory controller issues read, write, and refresh commands to SDRAM memory, it adheres to the following rules:

1. Refresh request resulting from the Refresh Must level of urgency being reached
2. Read request without a higher priority write (selected from above reordering algorithm)
3. Refresh request resulting from the Refresh Need level of urgency being reached
4. Write request (selected from above reordering algorithm)
5. Refresh request resulting from Refresh May level of urgency being reached
6. Request to enter self-refresh mode

The following results from the above scheduling algorithm:

- All writes from a single master will complete in order
- All reads from a single master will complete in order
- From the same master, any read to the same location (or within 2048 bytes) as a previous write will complete in order

21.2.6.13.2 Command Starvation

The reordering and scheduling rules listed above may lead to command starvation, which is the prevention of certain commands from being processed by the SDRAM memory controller. Command starvation results from the following conditions:

- A continuous stream of high-priority read commands can block a low-priority write command.
- A continuous stream of SDRAM commands to a row in an open bank can block commands to the closed row in the same bank.

To avoid these conditions, the SDRAM memory controller can momentarily raise the priority of the oldest command in the command FIFO after a set number of transfers have been made. The PRIO_RAISE bit field in the peripheral bus burst priority register (BPRIO) sets the number of the transfers that must be made before the SDRAM memory controller will raise the priority of the oldest command.

21.2.6.13.3 Possible Race Condition

A race condition may exist when certain masters write data to the SDRAM memory controller. For example, if master A passes a software message via a buffer in SDRAM memory and does not wait for indication that the write completes, when master B attempts to read the software message it may read stale data and therefore receive an incorrect message. In order to confirm that a write from master A has landed before a read from master B is performed, master A must wait for the write completion status from the SDRAM memory controller before indicating to master B that the data is ready to be read. If master A does not wait for indication that a write is complete, it must perform the following workaround:

1. Perform the required write.
2. Perform a dummy write to the SDRAM memory controller SDRAM status register.
3. Perform a dummy read to the SDRAM memory controller SDRAM status register.
4. Indicate to master B that the data is ready to be read after completion of the read in step 3. The completion of the read in step 3 ensures that the previous write was done.

The EDMA peripheral does not need to implement the above workaround. If a peripheral is not listed here, then the above workaround is required.

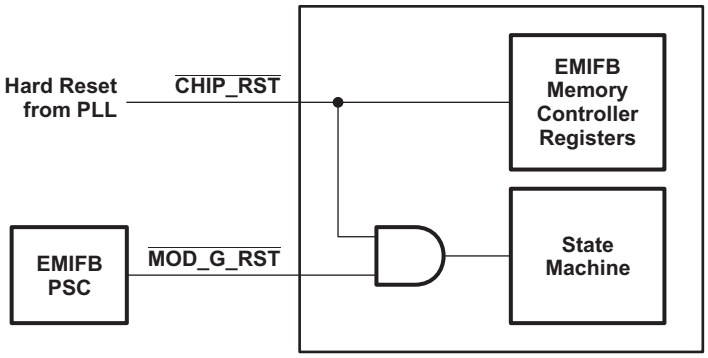
21.2.7 Reset and Initialization Considerations

The EMIFB memory controller has two reset signals, CHIP_RST and MOD_G_RST. The CHIP_RST is a module-level reset that resets both the state machine as well as the EMIFB memory controller memory-mapped registers. The MOD_G_RST resets the state machine only. If the EMIFB memory controller is reset independently of other peripherals, the user's software should not perform memory, as well as register accesses, while CHIP_RST or MOD_G_RST are asserted. If memory or register accesses are performed while the EMIFB memory controller is in the reset state, other masters may hang. Following the rising edge of CHIP_RST or MOD_G_RST, the EMIFB memory controller immediately begins its initialization sequence. Command and data stored in the EMIFB memory controller FIFOs are lost. Table 21-19 describes the different methods for asserting each reset signal. The Power and Sleep Controller (PSC) acts as a master controller for power management for all of the peripherals on the device. Figure 21-9 shows the EMIFB memory controller reset diagram.

Table 21-19. Reset Sources

Reset Signal	Reset Source
CHIP_RST	Hardware/device reset
MOD_G_RST	Power and sleep controller

Figure 21-9. EMIFB Memory Controller Reset Block Diagram



When the RESET pin on the device is asserted or a system reset is issued from Code Composer Studio, EMIFB memory controller's behavior is same as CHIP_RST assertion. In all these cases, the EMIFB will exit the reset state when the reset is released and after the PLL controller releases the entire device from reset. In all cases, EMIFB automatically begins running the SDRAM initialization sequence after coming out of reset. Even though the initialization procedure is automatic, a special procedure, found in Section 21.2.6.5 must still be followed.

21.2.8 Interrupt Support

EMIFB supports Line Trap Interrupt, which is caused by use of unsupported addressing mode. EMIFB supports only linear incrementing and cache line wrap addressing modes . If an access request for an unsupported addressing mode is received, the EMIFB will set the LT bit in the interrupt raw register (IRR) and treat the request as a linear incrementing request. For details on EMIFB interrupt multiplexing, see your device-specific data manual. For details on interrupt support and interrupt events, see the *DSP Subsystem* chapter and the *ARM Interrupt Controller (AINTC)* chapter.

21.2.9 EDMA Event Support

EMIFB memory controller is a DMA slave peripheral and therefore does not generate DMA events. Data read and write requests may be made directly, by masters and the DMA.

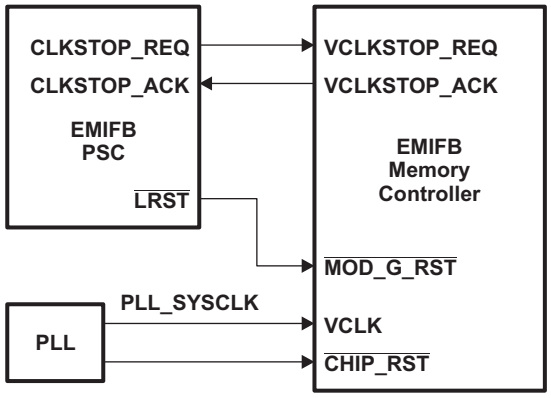
21.2.10 Power Management

Power dissipation from the EMIFB memory controller may be managed by two methods:

- Self-refresh mode (see Section 21.2.6.7)
- Power-down mode
- Gating input clocks to the module off.
- Power management in mobile SDRAM, using partial array self refresh.

Gating input clocks off to the EMIFB memory controller achieves higher power savings when compared to the power savings of self-refresh or power-down mode. The input clocks are turned off outside of the EMIFB memory controller through the use of the Power and Sleep Controller (PSC) and the PLL controller. Figure 21-10 shows the connections between the EMIFB memory controller, PSC, and PLL. Before gating clocks off, the EMIFB memory controller must place the SDR SDRAM memory in self-refresh mode by clearing the SR_PD bit to 0 and setting the LP_MODE bit to 1 in the SDRAM refresh control register (SDRFC). If the external memory requires a continuous clock, the EMIFB memory controller clock provided by PLL must not be turned off because this may result in data corruption. See the following subsections for the proper procedures to follow when stopping the EMIFB memory controller clocks.

Figure 21-10. EMIFB Memory Controller Power and Sleep Controller Diagram



21.2.10.1 Power Management Using Self-Refresh Mode

The EMIFB can be placed into a self-refresh state in order to place the attached SDRAM devices into self-refresh mode, which consumes less power for most SDRAM devices. In this state, the attached SDRAM device uses an internal clock to perform its own auto refresh cycles. This maintains the validity of the data in the SDRAM without the need for any external commands. Refer to Section 21.2.6.7 for more details on placing the EMIFB into the self-refresh state.

21.2.10.2 Power Management Using Power-Down Mode

In case of power-down, to lower the power consumption, EMIFB drives EMB_SDCKE low. EMB_SDCKE goes high when there is a need to send refresh (REFR) commands, after which EMB_SDCKE is again driven low. EMB_SDCKE remains low until any request arrives. Refer to Section 21.2.6.8 for more details on placing EMIFB in power-down mode.

21.2.10.3 Power Management Using Clock Stop

LPSC of EMIFB memory controller can be programmed to be in one of the following states:

- Enable
- Disable
- Auto sleep
- Auto wake
- Sync reset

Each of the states is described in the following sections.

21.2.10.3.1 LPSC Disable and Enable

To achieve maximum power savings VCLK, MCLK and EMB_CLK should be gated off. Perform the following procedure when shutting down clocks to achieve maximum power savings:

- EMIFB should be put to self-refresh mode before stopping the clock. Refer to Section 21.2.6.7 for details on self-refresh mode. The EMIFB memory controller will complete any outstanding accesses and backlogged refresh cycles and then place the EMIFB memory controller in self-refresh mode.
- To enable clock stopping, MCLKSTOP_EN bit in SDRFC must be set to 1. Refer to Section 21.4.3 for details.
- Then, program the LPSC of EMIFB to disable VCLK. For details on how to program the PSC, see the *Power and Sleep Controller (PSC)* chapter.

Clocks should not be stopped while data transfer is in progress. Only after transfer is completed, clock stop request should be issued.

To turn clocks back on and start using EMIFB:

- Program the LPSC of EMIFB to enable VCLK.
- Clear MCLKSTOP_EN bit in SDRFC to 0.
- Bring EMIFB out of self-refresh mode. Refer to Section 21.2.6.7 for details on self-refresh mode.

21.2.10.3.2 LPSC Auto Sleep and Auto Wake

Apart from disable and enable, EMIFB memory controller can make use of auto sleep and auto wake facility. Following describes the procedure to be followed to put EMIFB memory controller in auto sleep state:

- EMIFB should be put to self-refresh mode before stopping the clock. Refer to Section 21.2.6.7 for details on self-refresh mode. The EMIFB memory controller will complete any outstanding accesses and backlogged refresh cycles and then place the 0EMIFB memory controller in self-refresh mode.
- To enable clock stopping, MCLKSTOP_EN bit in SDRFC must be set to 1. Refer to Section 21.4.3 for details.
- Then, program the LPSC of EMIFB for auto sleep, to gate off the clocks.

Register and memory access requests are honored while EMIFB is in auto sleep state. When EMIFB sees a request while it is in auto sleep state, it automatically returns to enable state, processes the request, and returns back to auto sleep state until further requests come.

On frequent requests, EMIFB switches between auto sleep and enable states. To bring EMIFB back to the enable state permanently, auto wake can be used. Following procedure is followed for performing auto wake.

- Program the LPSC of EMIFB for auto wake.
- Clear MCLKSTOP_EN bit in SDRFC to 0.
- Bring EMIFB out of self-refresh mode. Refer to Section 21.2.6.7 for details on self-refresh mode.

After auto wake, EMIFB is in enable state and clocks run continuously.

21.2.10.3.3 LPSC Sync Reset

Sync reset of EMIFB through LPSC doesn't reset the EMIFB registers or memory. Thus EMIFB LPSC sync reset acts similar to EMIFB LPSC disable. Following is the procedure to put EMIFB in sync reset state

- EMIFB should be put to self-refresh mode before stopping the clock. Refer to Section 21.2.6.7 for details on self-refresh mode. The EMIFB memory controller will complete any outstanding accesses and backlogged refresh cycles and then place the EMIFB memory controller in self-refresh mode.
- To enable clock stopping, MCLKSTOP_EN bit in SDRFC must be set to 1. Refer to Section 21.4.3 for details.
- Then, program the LPSC of EMIFB to reset state.

On sync reset, requests to EMIFB are not honored. To bring EMIFB back to enable state, use the enable procedure described in Section 21.2.10.3.1.

21.2.11 Emulation Considerations

The EMIFB memory controller remains fully functional during emulation halts, to allow emulation access to external memory.

21.3 Example Configuration

The EMIFB memory controller allows a high degree of programmability for shaping SDRAM accesses. The programmability inherent to the EMIFB memory controller provides the EMIFB memory controller with the flexibility to interface with a variety of SDRAM devices. By programming the SDRAM configuration register (SDCFG), SDRAM refresh control register (SDRFC), SDRAM timing register 1 (SDTIM1), and SDRAM timing register 2 (SDTIM2), the EMIFB memory controller can be configured to meet the data sheet specification for JESD21-C compliant SDR SDRAM. This section presents an example describing how to interface the EMIFB memory controller to a JESD21-C SDR SDRAM 64MB device. The EMIFB memory controller is assumed to be operating at 133 MHz.

21.3.1 Hardware Configuration

The following figures show how to connect the EMIFB memory controller to an SDR SDRAM device. Figure 21-11 displays a 32-bit interface; therefore, two 16-bit SDR SDRAM devices are connected to the EMIFB memory controller. From Figure 21-11, you can see that the data bus and data mask (byte enable) signals are point-to-point where as all other address, control, and clocks are not. Figure 21-12 displays a 16-bit interface; therefore, all signals are point-to-point.

21.3.2 Software Configuration

Four memory-mapped registers must be programmed to configure the EMIFB memory controller to meet the data sheet specification of the attached SDR SDRAM device. The registers are:

- SDRAM configuration register (SDCFG)
- SDRAM refresh control register (SDRFC)
- SDRAM timing register 1 (SDTIM1)
- SDRAM timing register 2 (SDTIM2)

The following sections describe how to configure each of these registers. See Section 21.4 for more information on the EMIFB memory controller registers.

21.3.2.1 PLL Programming for EMIFB

The device PLL Controller should first be programmed to select the desired EMB_CLK frequency. Before doing this, the SDRAM should be placed into Self-Refresh Mode by setting the SR_PD bit and LP_MODE bit in SDRFC to 0 and 1, respectively. The EMB_CLK frequency can now be adjusted to the desired value by programming the appropriate SYSCLK domain of the PLL Controller. Once the PLL has been reprogrammed, remove the SDRAM from Self-Refresh by clearing the LP_MODE bit in SDRFC.

Figure 21-11. Connecting EMIFB Memory Controller for 32-bit Connection

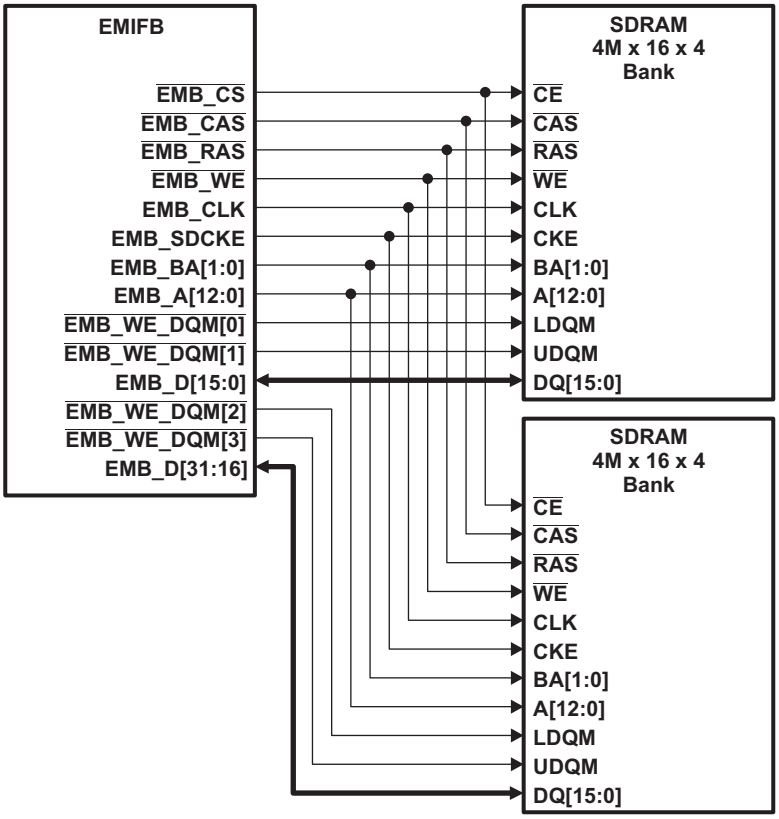
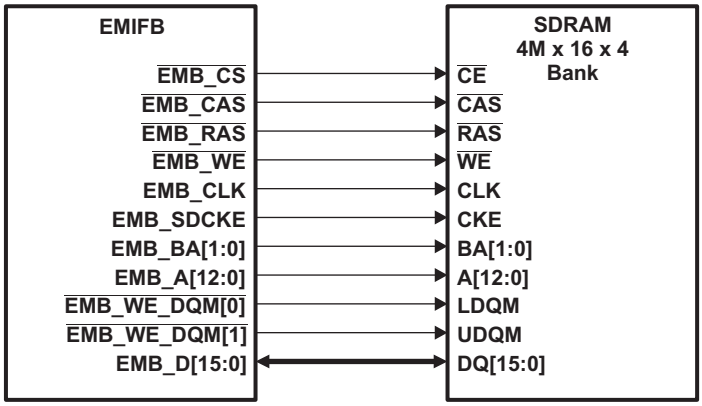


Figure 21-12. Connecting EMIFB Memory Controller for 16-bit Connection



21.3.2.2 Configuring SDRAM Configuration Register (SDCFG)

The SDRAM configuration register (SDCFG) contains register fields that configure the EMIFB memory controller to match the data bus width, CAS latency, number of banks, and page size of the attached SDRAM memory. In this example, we assume the following configuration:

- Data bus width = 32 bits
- CAS latency = 2
- Number of banks = 4
- Page size = 512 words

Table 21-20 shows the resulting SDCFG configuration. Note that the value of the TIMUNLOCK field is dependent on whether or not it is desirable to unlock SDTIM1 and SDTIM2. The TIMUNLOCK bit should only be set to 1 when the SDTIM1 and SDTIM2 need to be updated.

Table 21-20. SDCFG Configuration

Field	Value	Function Selection
TIMUNLOCK	x	Set to 1 to unlock the SDRAM timing register 1 (SDTIM1) and the SDRAM timing register 2 (SDTIM2). Cleared to 0 to lock SDTIM1 and SDTIM2.
NM	0	To configure the EMIFB memory controller for a 32-bit data bus width.
CL	2h	To select a CAS latency of 2.
IBANK	2h	To select 4 internal SDR SDRAM banks.
PAGESIZE	1h	To select 512-word page size.

21.3.2.3 Configuring SDRAM Refresh Control Register (SDRFC)

The SDRAM refresh control register (SDRFC) configures the EMIFB memory controller to meet the refresh requirements of the attached SDRAM device. SDRFC also allows the EMIFB memory controller to enter and exit self-refresh and power-down and enable and disable the MCLK stopping. In this example, we assume that the EMIFB memory controller is not is in self-refresh/power-down mode and that MCLK stopping is disabled. The REFRESH_RATE field in SDRFC is defined as the rate at which the attached SDRAM device is refreshed in SDRAM cycles.

The value of this field may be calculated using the following equation:

REFRESH_RATE = SDRAM clock frequency × SDRAM refresh rate

Assuming 64 ms (tREF), 8192 rows (2^{13}; 13 address lines), SDRAM refresh rate = 64/8192 = 7.8 µs.

Therefore, the following results assuming 133-MHz SDRAM clock frequency.

REFRESH_RATE = 133 MHz × 7.8 µs = 1037.4 Therefore, REFRESH_RATE = 1038 = 40Eh.

Table 21-21 shows the resulting SDRFC configuration.

Table 21-21. SDRFC Configuration

Field	Value	Function Selection
LP_MODE	0	EMIFB memory controller not put in low power mode.
MCLKSTOP_EN	0	MCLK stopping is disabled.
SR_PD	0	This bit is ignored when LP_MODE=0.
REFRESH_RATE	40Eh	Set to 40Eh SDRAM clock cycles to meet the SDRAM memory refresh rate requirement.

21.3.2.4 Configuring SDRAM Timing Registers (SDTIM1 and SDTIM2)

The SDRAM timing register 1 (SDTIM1) and SDRAM timing register 2 (SDTIM2) configure the EMIFB memory controller to meet the data sheet timing parameters of the attached SDRAM device. Each field in SDTIM1 and SDTIM2 corresponds to a timing parameter in the SDRAM data sheet specification. Table 21-22 and Table 21-23 display the register field name and corresponding SDRAM data sheet parameter name along with the data sheet value. These tables also provide a formula to calculate the register field value and displays the resulting calculation. Each of the equations include a minus 1 because the register fields are defined in terms of SDRAM clock cycles minus 1. See Section 21.4.4 and Section 21.4.5 for more information.

Table 21-22. SDTIM1 Configuration

Register Field Name	SDRAM Data Manual Parameter Name	Description	Data Manual Value (ns)	Formula (Register field must be ≥)	Register Value
T_RFC	t_{RFC}	refresh cycle time	66	(t_{RFC}× f_{EMB_CLK}) - 1	8
T_RP	t_{RP}	precharge command to refresh or activate command	20	(t_{RP}× f_{EMB_CLK}) - 1	2
T_RCD	t_{RCD}	activate command to read/write command	20	(t_{RCD}× f_{EMB_CLK}) - 1	2
T_WR	t_{WR}	write recovery time	15	(t_{WR}× f_{EMB_CLK}) - 1	1
T_RAS	t_{RAS}	active to precharge command	44	(t_{RAS}× f_{EMB_CLK}) - 1	5
T_RC	t_{RC}	activate to activate command in the same bank	66	(t_{RC}× f_{EMB_CLK}) - 1	8
T_RRD	t_{RRD}	activate to activate command in a different bank	15	(t_{RRD}× f_{EMB_CLK}) - 1	1

Table 21-23. SDTIM2 Configuration

Register Field Name	SDRAM Data Manual Parameter Name	Description	Data Manual Value (ns)	Formula	Register Value
T_RAS_MAX	t_{RAS_MAX}	refresh cycle time	100K	(t_{RAS_MAX}/ SDRAM refresh rate) - 1 (1)	13
T_XSR	t_{XSR}	self refresh exit to any command other than a read command	75	(t_{XSR}× f_{EMB_CLK}) - 1 (2)	9
T_CKE	t_{CKE}	number of clock cycles between EMB_CKE changes	38	(t_{CKE}× f_{EMB_CLK}) - 1 (2)	5

(1) Register field value must be ≤ the calculated value
(2) Register field value must be ≥ the calculated value

21.4 Registers

The external memory interface (EMIFB) is controlled by programming its internal memory-mapped registers (MMRs). Table 21-24 lists the memory-mapped registers of the EMIFB memory controller.

NOTE: All EMIFB MMRs support only word, that is, 32-bit, accesses. Performing a byte (8-bit) or halfword (16-bit) write to these registers results in undefined behavior.

The EMIFB base controller registers must always be accessed using 32-bit accesses (unless otherwise specified in this document). For the base address of the memory-mapped registers of EMIFB, see your device-specific data manual.

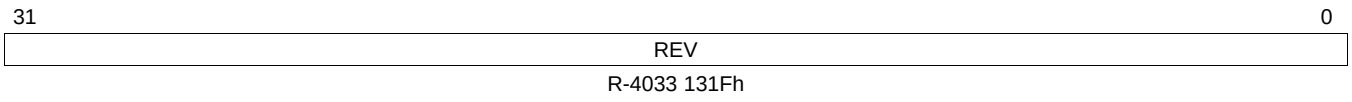
Table 21-24. EMIFB Base Controller Registers

Offset	Acronym	Register	Section
0h	REVID	Revision ID Register	Section 21.4.1
8h	SDCFG	SDRAM Configuration Register	Section 21.4.2
Ch	SDRFC	SDRAM Refresh Control Register	Section 21.4.3
10h	SDTIM1	SDRAM Timing 1 Register	Section 21.4.4
14h	SDTIM2	SDRAM Timing 2 Register	Section 21.4.5
1Ch	SDCFG2	SDRAM Configuration 2 Register	Section 21.4.6
20h	BPRIO	Peripheral Bus Burst Priority Register	Section 21.4.7
40h	PC1	Performance Counter 1 Register	Section 21.4.8
44h	PC2	Performance Counter 2 Register	Section 21.4.9
48h	PCC	Performance Counter Configuration Register	Section 21.4.10
4Ch	PCMRS	Performance Counter Master Region Select Register	Section 21.4.11
50h	PCT	Performance Counter Time Register	Section 21.4.12
C0h	IRR	Interrupt Raw Register	Section 21.4.13
C4h	IMR	Interrupt Mask Register	Section 21.4.14
C8h	IMSR	Interrupt Mask Set Register	Section 21.4.15
CCh	IMCR	Interrupt Mask Clear Register	Section 21.4.16

21.4.1 Revision ID Register (REVID)

This is read-only ID register of EMIFB. The REVID is shown in Figure 21-13 and described in Table 21-25.

Figure 21-13. Revision ID Register (REVID)



LEGEND: R = Read only; -*n* = value after reset

Table 21-25. Revision ID Register (REVID) Field Descriptions

Bit	Field	Value	Description
31-0	REV	4033 131Fh	Revision ID value of EMIFB.

21.4.2 SDRAM Configuration Register (SDCFG)

The SDRAM configuration register (SDCFG) is used to configure various parameters of the SDRAM controller such as the number of internal banks, the internal page size, and the CAS latency to match those of the attached SDRAM device. The SDCFG is shown in Figure 21-14 and described in Table 21-26.

BOOT_UNLOCK bit usage - The following sequence must be followed to change the value of the SDREN and MSDRAM_ENABLE bits.

1. Set the BOOT_UNLOCK bit to 1.
2. Write a 0 to the BOOT_UNLOCK bit along with the desired values for the SDREN/MSDRAM_ENABLE bits. The value of the bits is then updated.

TIMUNLOCK bit usage - The following sequence must be followed to change the value of any field affected by the TIMUNLOCK bit.

1. Write a 1 to the TIMUNLOCK bit along with the desired value for the CL field. The value of the CL field is then updated.
2. Update any of the fields required in the SDRAM timing registers (SDTIM1 and SDTIM2).
3. Clear the TIMUNLOCK bit to 0 to prevent any further changes.

NOTE: Writing to the lower two bytes of this register will cause the EMIF to start the SDRAM initialization sequence.

Figure 21-14. SDRAM Configuration Register (SDCFG)

31	30	29	28	27	26	25	24
Reserved					IBANK_POS	MSDRAM_ENABLE	Reserved
R-0					R/W-0	R/W-0	R-0

23	22	21	20	19	18	17	16
BOOT_UNLOCK	Reserved						SDREN
R/W-0	R-0						R/W-1

15	14	13	12	11	10	9	8
TIMUNLOCK	NM	Reserved		CL			Reserved
R/W-0	R/W-0	R-0		R/W-3h			R-0

7	6	5	4	3	2	1	0
Reserved	IBANK			EBANK	PAGESIZE		
R-0	R/W-2h			R/W-0	R/W-0		

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 21-26. SDRAM Configuration Register (SDCFG) Field Descriptions

Bit	Field	Value	Description
31-27	Reserved	0	All writes to these bit(s) must always have a value of 0.
26	IBANK_POS		Internal bank position. This bit is writeable only when the BOOT_UNLOCK bit is unlocked.
		0	Set to 0 to assign internal bank address bits from logical address as shown in Table 21-15 and Table 21-16. Set this bit to 0 when interfacing with SDR SDRAM.
		1	Set to 1 to assign internal bank address bits from logical address as shown in Table 21-17. Set this bit to 1 when interfacing with mobile SDRAM.
25	MSDRAM_ENABLE		Mobile SDRAM Enable. This bit is writeable only when the BOOT_UNLOCK bit is unlocked. For mobile SDR SDRAM, this bit is only valid when SDREN is set to 1.
		0	mSDR (mobile SDR) is disabled.
		1	When this bit is 1 and SDREN = 1, then mSDR is enabled.
24	Reserved	0	All writes to these bit(s) must always have a value of 0.

Table 21-26. SDRAM Configuration Register (SDCFG) Field Descriptions (continued)

Bit	Field	Value	Description
23	BOOT_UNLOCK		Boot unlock. Set to 1 to change the values of the fields that are affected by the BOOT_UNLOCK bit. See the description of usage of the BOOT_UNLOCK bit.
		0	The SDREN bit in this register may not be changed.
		1	The SDREN bit in this register may be changed.
22-17	Reserved	0	All writes to these bit(s) must always have a value of 0.
16	SDREN		SDRAM Enable. Active high bit which enables the SDRAM mode of the EMIFB controller. This bit is writeable only when the BOOT_UNLOCK bit is unlocked.
		0	SDRAM initialization and refreshes disabled, but SDRAM write/read transactions allowed. This bit must not be cleared to 0 when EMIFB is in self-refresh state.
		1	SDRAM fully enabled.
15	TIMUNLOCK		Timing unlock. Controls the write permission settings for the SDRAM timing register 1 (SDTIM1) and SDRAM timing register 2 (SDTIM2).
		0	CL bit in this register and register fields in SDTIM1 and SDTIM2 may not be changed.
		1	CL bit in this register and register fields in SDTIM1 and SDTIM2 may be changed.
14	NM		NM (Narrow mode). SDRAM data bus width. A write to this field will cause the EMIFB to start the SDRAM initialization sequence.
		0	32-bit SDR SDRAM
		1	16-bit SDR SDRAM
13-12	Reserved	0	All writes to these bit(s) must always have a value of 0.
11-9	CL	0-7h	CAS Latency. The value of this field defines the CAS latency to be used when accessing connected SDRAM devices. A write to this field will cause the EMIFB to start the SDRAM initialization sequence. This field is writeable only when the TIMUNLOCK bit is unlocked.
		0-1h	Reserved
		2h	CAS latency of 2
		3h	CAS latency of 3
		4h-7h	Reserved
8-7	Reserved	0	All writes to these bit(s) must always have a value of 0.
6-4	IBANK	0-7h	Internal SDRAM Bank setup. Defines number of banks inside connected SDRAM devices. A write to this field will cause the EMIFB to start the SDRAM initialization sequence.
		0	1 bank SDRAM devices
		1h	2 bank SDRAM devices
		2h	4 bank SDRAM devices
		3h-7h	Reserved
3	EBANK		External chip select setup. Always write 0 to this field. A write to this field will cause the EMIFB to start the SDRAM initialization sequence.
		0	Use EMB_CS for all SDRAM accesses.
		1	Reserved
2-0	PAGESIZE	0-7h	Page Size. Defines the internal page size of connected SDRAM devices. A write to this field will cause the EMIFB to start the SDRAM initialization sequence.
		0	256-word pages requiring 8 column address bits.
		1h	512-word pages requiring 9 column address bits.
		2h	1024-word pages requiring 10 column address bits.
		3h	2048-word pages requiring 11 column address bits.
		4h-7h	Reserved

21.4.3 SDRAM Refresh Control Register (SDRFC)

The SDRAM refresh control register (SDRFC) is used to configure the rate at which connected SDRAM devices will be automatically refreshed by the EMIFB. In addition, this register is used to put the attached SDRAM device into Self-Refresh/ Power-Down mode. The SDRFC is shown in Figure 21-15 and described in Table 21-27.

Figure 21-15. SDRAM Refresh Control Register (SDRFC)

31	30	29 24	23	22 16
LP_MODE	MCLKSTOP_EN	Reserved	SR_PD	Reserved
R/W-0	R/W-0	R-0	R/W-0	R-0

15 0
REFRESH_RATE
R/W-04E2h

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 21-27. SDRAM Refresh Control Register (SDRFC) Field Descriptions

Bit	Field	Value	Description
31	LP_MODE		Low Power mode (Self Refresh). Writing a 1 to this bit will cause connected SDRAM devices to be place into self-refresh mode and the EMIFB to enter the self-refresh state.
		0	SDRAM is not to be placed in self-refresh/power-down mode.
		1	SDRAM placed in self-refresh/power-down mode depending on the value of SR_PD bit.
30	MCLKSTOP_EN		mclk Stop Enable. Writing a 1 to this bit enables mclk stopping.
		0	mclk stopping disabled.
		1	mclk stopping enabled.
29-24	Reserved	0	Reserved.
23	SR_PD		Self-refresh or power-down select. This bit is ignored when LP_MODE bit is cleared to 0.
		0	When LP_MODE = 1, clear this bit to 0 to cause connected SDRAM devices to be placed into self-refresh mode.
		1	When LP_MODE = 1, set this bit to 1 to cause connected SDRAM devices to be placed into power-down mode.
22-16	Reserved	0	Reserved.
15-0	REFRESH_RATE	0-FFFFh	Refresh Rate. Defines the rate at which connected SDRAM devices will be refreshed.
			SDRAM refresh rate = EMIF rate/REFRESH_RATE
			where EMIF rate is equal to EMIFB SDRAM clock rate.
			Writing a value < 0100h to this field causes it to be loaded with 2 × T_RFC value from SDRAM timing 1 register (SDTIM1).
			The required refresh rate is derived from the SDRAM device data sheet.

21.4.4 SDRAM Timing 1 Register (SDTIM1)

The SDRAM timing 1 register (SDTIM1) configures the SDRAM memory controller to meet many of the AC timing specification of the SDRAM memory. The SDTIM1 is programmable only when the TIMUNLOCK bit is set to 1 in the SDRAM configuration register (SDCFG). Note that EMB_CLK is equal to the period of the EMB_CLK signal. See the SDRAM memory data sheet for information on the appropriate values to program each field. The SDTIM1 is shown in Figure 21-16 and described in Table 21-28.

Figure 21-16. SDRAM Timing 1 Register (SDTIM1)

31–25	24–22	21–19	18–16
T_RFC	T_RP	T_RCD	T_WR
R/W-Ah	R/W-3h	R/W-3h	R/W-1h

15–11	10–6	5–3	2–0
T_RAS	T_RC	T_RRD	Reserved
R/W-7h	R/W-Ah	R/W-2h	R-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 21-28. SDRAM Timing 1 Register (SDTIM1) Field Descriptions

Bit	Field	Value	Description
31-25	T_RFC	0-7Fh	Specifies the minimum number of EMB_CLK cycles from a refresh or load mode command to a refresh or activate command, minus 1. Corresponds to the t_{rfc} AC timing parameter in the SDRAM data sheet. Calculate by: T_RFC = (t_{rfc} /EMB_CLK) - 1
24-22	T_RP	0-7h	Specifies the minimum number of EMB_CLK cycles from a precharge command to a refresh or activate command, minus 1. Corresponds to the t_{rp} AC timing parameter in the SDRAM data sheet. Calculate by: T_RP = (t_{rp} /EMB_CLK) - 1
21-19	T_RCD	0-7h	Specifies the minimum number of EMB_CLK cycles from an activate command to a read or write command, minus 1. Corresponds to the t_{rcd} AC timing parameter in the SDRAM data sheet. Calculate by: T_RCD = (t_{rcd} /EMB_CLK) - 1
18-16	T_WR	0-7h	Specifies the minimum number of EMB_CLK cycles from the last write transfer to a precharge command, minus 1. Corresponds to the t_{wr} AC timing parameter in the SDRAM data sheet. Calculate by: T_WR = (t_{wr} /EMB_CLK) - 1 When the value of this field is changed from its previous value, the initialization sequence will begin.
15-11	T_RAS	0-1Fh	Specifies the minimum number of EMB_CLK cycles from an activate command to a precharge command, minus 1. Corresponds to the t_{ras} AC timing parameter in the SDRAM data sheet. Calculate by: T_RAS = (t_{ras} /EMB_CLK) - 1 T_RAS must be greater than or equal to T_RCD.
10-6	T_RC	0-1Fh	Specifies the minimum number of EMB_CLK cycles from an activate command to an activate command, minus 1. Corresponds to the t_{rc} AC timing parameter in the SDRAM data sheet. Calculate by: T_RC = (t_{rc} /EMB_CLK) - 1
5-3	T_RRD	0-7h	Specifies the minimum number of EMB_CLK cycles from an activate command to an activate command in a different bank, minus 1. Corresponds to the t_{rrd} AC timing parameter in the SDRAM data sheet. Calculate by: T_RRD = (t_{rrd} /EMB_CLK) - 1 Note: for an 8 bank SDRAM device this field must be equal to ((4 × t_{RRD}) + (2 × t_{CK})) / (4 × t_{CK}) - 1.
2-0	Reserved	0	All writes to these bit(s) must always have a value of 0.

21.4.5 SDRAM Timing 2 Register (SDTIM2)

Like SDRAM timing 1 register (SDTIM1), the SDRAM timing register 2 (SDTIM2) also configures the SDRAM memory controller to meet the AC timing specification of the SDRAM memory. The SDTIM2 is programmable only when the TIMUNLOCK bit is set to 1 in the SDRAM configuration register (SDCFG). Note that EMB_CLK is equal to the period of the EMB_CLK signal. See the SDRAM data sheet for information on the appropriate values to program each field. SDTIM2 is shown in Figure 21-17 and described in Table 21-29.

Figure 21-17. SDRAM Timing 2 Register (SDTIM2)

31	30 27	26 23	22 16
Rsvd	T_RAS_MAX	Reserved	T_XSR
R-0	R/W-Eh	R-0	R/W-Ah

15 5	4 0
Reserved	T_CKE
R/W-0	R/W-7h

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 21-29. SDRAM Timing 2 Register (SDTIM2) Field Descriptions

Bit	Field	Value	Description
31	Reserved	0	All writes to these bit(s) must always have a value of 0.
30-27	T_RAS_MAX	0-Fh	Maximum number of refresh_rate intervals from Activate to Precharge command.
26-23	Reserved	0	All writes to these bit(s) must always have a value of 0.
22-16	T_XSR	0-7Fh	Minimum number of EMB_CLK cycles from Self-Refresh exit to any command other than a Read command, minus one. This field must satisfy t_{XSR} for the SDRAM device. T_XSR = (t_{xsr} /EMIF_CLK) - 1
15-5	Reserved	0	All writes to these bit(s) must always have a value of 0.
4-0	T_CKE	0-1Fh	Minimum number of EMB_CLK cycles between EMB_SDCKE changes, minus one. This field must satisfy t_{RAS} for the SDRAM device. T_CKE = (t_{ras} /EMIF_CLK) - 1

21.4.6 SDRAM Configuration 2 Register (SDCFG2)

The SDRAM configuration 2 register (SDCFG2) helps programming the partial array self refresh feature of mobile SDRAM. SDCFG2 is shown in Figure 21-18 and described in Table 21-30.

Figure 21-18. SDRAM Configuration 2 Register (SDCFG2)

31	19	18	16
Reserved		PASR	
R-0		R/W-0	

15	3	2	0
Reserved		ROWSIZE	
R-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 21-30. SDRAM Configuration 2 Register (SDCFG2) Field Description

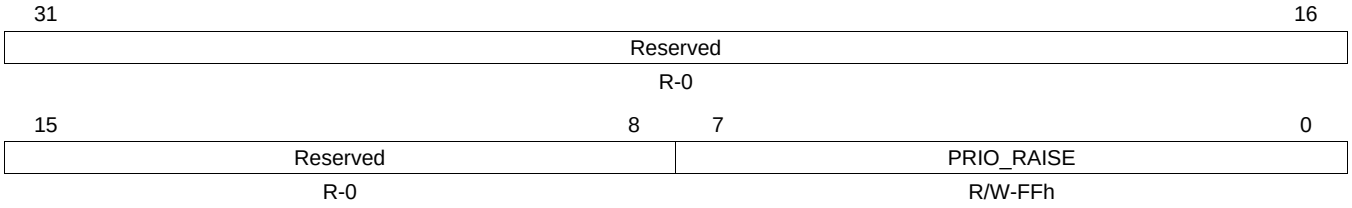
Bit	Field	Value	Description
31-19	Reserved	0	All writes to these bit(s) must always have a value of 0.
18-16	PASR	0-7h	Partial Array Self Refresh. These bits get loaded into the Extended Mode Register of a mobile SDRAM during initialization. A write to this field will cause the EMIFB to start the SDRAM initialization sequence.
		0	4 banks will be refreshed.
		1h	2 banks will be refreshed.
		2h	1 bank will be refreshed.
		3h-4h	Reserved.
		5h	1/2 bank will be refreshed.
		6h	1/4 bank will be refreshed.
		7h	Reserved.
15-3	Reserved	0	All writes to these bit(s) must always have a value of 0.
2-0	ROWSIZE	0-7h	Row Size. Defines the number of row address bits of connected mobile SDRAM devices. This field is only used when IBANK_POS bit in the SDRAM configuration register (SDCFG) is set to 1. A write to this field will cause the EMIFB to start the SDRAM initialization sequence. This bit applicable only when EMIFB controller is configured to interface to mobile SDRAM.
		0h	9 row address bits used.
		1h	10 row address bits used.
		2h	11 row address bits used.
		3h	12 row address bits used.
		4h	13 row address bits used.
		5h	14 row address bits used.
		6h-7h	Reserved

21.4.7 Peripheral Bus Burst Priority Register (BPRIO)

The peripheral bus burst priority register (BPRIO) helps prevent command starvation within the SDRAM memory controller. To avoid command starvation, the SDRAM memory controller momentarily raises the priority of the oldest command in the command FIFO after a set number of 32-bit transfers have been made on the external memory bus. The PRIO_RAISE bit sets the number of transfers that must be made before the SDRAM memory controller raises the priority of the oldest command. The BPRIO is shown in Figure 21-19 and described in Table 21-31.

Proper configuration of the BPRIO is critical to correct system operation. The EMIFB controller always prioritizes accesses to open rows as highest if there is any bank conflict regardless of master priority. This is done to allow most efficient utilization of the SDRAM. However, it could lead to excessive blocking of high priority masters. If the PRIO_RAISE bits are cleared to 00h, then the EMIFB controller always honors the master priority, regardless of open row/bank status. For most systems, the BPRIO should be set to a moderately low value to provide an acceptable balance of SDRAM efficiency and latency for high priority masters (for example, 10h or 20h).

Figure 21-19. Peripheral Bus Burst Priority Register (BPRIO)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 21-31. Peripheral Bus Burst Priority Register (BPRIO) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	All writes to these bit(s) must always have a value of 0.
7-0	PRIO_RAISE	0-FFh	Priority raise old counter. Specifies the number of 32-bit memory transfers after which the SDRAM memory controller will elevate the priority of the oldest command in the command FIFO. Clearing to 00h will ensure master priority is strictly honored (at the cost of decreased EMIFB efficiency, as open row will always be closed immediately if any bank conflict occurs). Recommended setting for typical system operation is between 10h and 20h.

21.4.8 Performance Counter 1 Register (PC1)

For debug or gathering performance statistics, the PC1 and PC2 counters and associated configuration registers are provided. These are intended for debug and analysis only. By configuring the performance counter configuration register (PCC) to define the type of statistics to gather and configuring the performance counter master region select register (PCMRS) to filter accesses only to specific chip select regions, performing system applications and then reading these counters, different statistics can be gathered. To reset the counters, you must reset (SYNC RESET) the EMIFB module through the PSC (for details on the PSC, see the *Power and Sleep Controller (PSC)* chapter.

The performance counter 1 register (PC1) is shown in Figure 21-20 and described in Table 21-32.

Figure 21-20. Performance Counter 1 Register (PC1)

31	0
Counter1	
R-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 21-32. Performance Counter 1 Register (PC1) Field Descriptions

Bit	Field	Value	Description
31-0	Counter1	0-FFFF FFFFh	32-bit counter that can be configured as specified in the performance counter configuration register (PCC) and the performance counter master region select register.

21.4.9 Performance Counter 2 Register (PC2)

The performance counter 2 register (PC2) is shown in Figure 21-21 and described in Table 21-33.

Figure 21-21. Performance Counter 2 Register (PC2)

31	0
Counter2	
R-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 21-33. Performance Counter 2 Register (PC2) Field Descriptions

Bit	Field	Value	Description
31-0	Counter2	0-FFFF FFFFh	32-bit counter that can be configured as specified in the performance counter configuration register (PCC) and the performance counter master region select register.

21.4.10 Performance Counter Configuration Register (PCC)

The performance counter configuration register (PCC) is shown in Figure 21-22 and described in Table 21-34.

Table 21-35 shows the possible filter configurations for the two performance counters. These filter configurations can be used in conjunction with a Master ID and/or an external chip select to obtain performance statistics for a particular master and/or an external chip select.

Figure 21-22. Performance Counter Configuration Register (PCC)

31	30	29 20	19 16
CNTR2_MSTID_EN	CNTR2_REGION_EN	Reserved	CNTR2_CFG
R/W-0	R/W-0	R-0	R/W-1

15	14	13 4	3 0
CNTR1_MSTID_EN	CNTR1_REGION_EN	Reserved	CNTR1_CFG
R/W-0	R/W-0	R-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 21-34. Performance Counter Configuration Register (PCC) Field Descriptions

Bit	Field	Value	Description
31	CNTR2_MSTID_EN		Master ID filter enable for performance counter 2 register (PC2). Refer to Table 21-35 for details.
		0	Master ID filter is disabled. PC2 counts accesses from all masters to SDRAM.
		1	Master ID filter is enabled. PC2 counts accesses from the master, corresponding to the Master ID value in the MST_ID2 bit field of the performance counter master region select register (PCMRS).
30	CNTR2_REGION_EN		Chip select filter enable for performance counter 2 register (PC2). Refer to Table 21-35 for details.
		0	Chip select filter is disabled. PC2 counts total number of accesses (SDRAM + EMIFB memory-mapped register accesses). The REGION_SEL2 bit field value in the performance counter master region select register (PCMRS) is a don't care.
		1	Chip select filter is enabled. If the REGION_SEL2 bit field value in the performance counter master region select register (PCMRS) is:
			REGION_SEL2 = 0: PC2 counts accesses to SDRAM memory.
			REGION_SEL2 = 7h: PC2 counts accesses to EMIFB memory-mapped registers.
29-20	Reserved	0	Any writes to these bit(s) must always have a value of 0.
19-16	CNTR2_CFG	0-Fh	Filter configuration for performance counter 2 register (PC2). Refer to Table 21-35 for details.
15	CNTR1_MSTID_EN		Master ID filter enable for performance counter 1 register (PC1). Refer to Table 21-35 for details.
		0	Master ID filter is disabled. PC1 counts accesses from all masters to SDRAM.
		1	Master ID filter is enabled. PC1 counts accesses from the master, corresponding to the Master ID value in the MST_ID1 bit field of the performance counter master region select register (PCMRS).
14	CNTR1_REGION_EN		Chip select filter enable for performance counter 1 register (PC1). Refer to Table 21-35 for details.
		0	Chip select filter is disabled. PC1 counts total number of accesses (SDRAM + EMIFB memory-mapped register accesses). The REGION_SEL1 bit field value in the performance counter master region select register (PCMRS) is a don't care.
		1	Chip select filter is enabled. If the REGION_SEL1 bit field value in the performance counter master region select register (PCMRS) is:
			REGION_SEL1 = 0: PC1 counts accesses to SDRAM memory.
			REGION_SEL1 = 7h: PC1 counts accesses to EMIFB memory-mapped registers.
13-4	Reserved	0	Any writes to these bit(s) must always have a value of 0.
3-0	CNTR1_CFG	0-Fh	Filter configuration for performance counter 1 register (PC1). Refer to Table 21-35 for details.

Table 21-35. Performance Counter Filter Configuration

Performance Counter Configuration Register (PCC) Bit			
CNTR*n*_CFG	**CNTR*n*_REGION_EN**	**CNTR*n*_MSTID_EN**	**Description**
0	0	0 or 1	**Counts the total number of READ/WRITE commands the external memory controller receives.** The size of counter increments are determines by the size of the transfer and the default burst size (DBS). The counter breaks up transfers into sizes according to DBS. Therefore, counter increments for transfers aligned to DBS are equal to the transfer size divided by the DBS.
1h	0	0 or 1	**Counts the total number of ACTIVATE commands the external memory controller issues to SDRAM memory.** The counter increments by a value of 1 for every request to read/write data to a closed bank in SDRAM memory by the external memory controller.
2h	0 or 1	0 or 1	**Counts the total number of READ commands (read accesses) the EMIFB receives.** Counter increments for transfers aligned to the default burst size (DBS) are equal to the transfer size divided by the DBS.
3h	0 or 1	0 or 1	**Counts the total number of WRITE commands the EMIFB receives.** Counter increments for transfers aligned to the default burst size (DBS) are equal to the transfer size of data written to the DDR2 memory controller divided by the DBS.
4h	0	0	**Counts the number of external memory controller cycles (EMB_CLK cycles) that the command FIFO is full.** Use the following to calculate the counter value as a percentage: *% = counter value / total EMB_CLK cycles in a sample period* As the value of this counter approaches 100%, the EMIFB memory controller is approaching a congestion point where the command FIFO is full 100% of the time and a command will have to wait at the SCR to be accepted in the command FIFO.
5h-7h	0	0	Reserved
8h	0 or 1	0 or 1	**Counts the number of commands (requests) in the command FIFO that require a priority elevation.** To avoid command starvation, the EMIFB memory controller can momentarily raise the priority of the oldest command in the command FIFO after a set number of transfers have been made. The PRIO_RAISE bit field in the peripheral bus burst priority register (BPRIO) sets the number of the transfers that must be made before the EMIFB memory controller will raise the priority of the oldest command.
9h	0	0	**Counts the number of EMIFB memory controller cycles (EMB_CLK cycles) that a command is pending in the command FIFO.** This counter increments every cycle the command FIFO is not empty. Use the following to calculate the counter value as a percentage: *% = counter value / total EMB_CLK cycles in sample period* As the value of this counter approaches 100%, the number of cycles the EMIFB has a command in the command FIFO to service approaches 100%.
Ah-Fh	0	0	Reserved

21.4.11 Performance Counter Master Region Select Register (PCMRS)

The performance counter master region select register (PCMRS) is shown in Figure 21-23 and described in Table 21-36.

Figure 21-23. Performance Counter Master Region Select Register (PCMRS)

31	24	23	20	19	16
MST_ID2		Reserved		REGION_SEL2	
R/W-0		R-0		R/W-0	

15	8	7	4	3	0
MST_ID1		Reserved		REGION_SEL1	
R/W-0		R-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 21-36. Performance Counter Master Region Select Register (PCMRS) Field Descriptions

Bit	Field	Value	Description
31-24	MST_ID2	0-FFh	Master ID for performance counter 2 register (PC2). For the Master ID value for master peripherals in the device, see the *System Configuration (SYSCFG) Module* chapter.
23-20	Reserved	0	Any writes to these bit(s) must always have a value of 0.
19-16	REGION_SEL2	0-Fh	Region select for performance counter 2 register (PC2).
		0	PC2 counts total SDRAM accesses.
		1h-6h	Reserved
		7h	PC2 counts total EMIFB memory-mapped register accesses.
		8h-Fh	Reserved
15-8	MST_ID1	0-FFh	Master ID for performance counter 1 register (PC1). For the Master ID value for master peripherals in the device, see the *System Configuration (SYSCFG) Module* chapter.
7-4	Reserved	0	Any writes to these bit(s) must always have a value of 0.
3-0	REGION_SEL1	0-Fh	Region select for performance counter 1 register (PC1).
		0	PC1 counts total SDRAM accesses.
		1h-6h	Reserved
		7h	PC1 counts total EMIFB memory-mapped register accesses.
		8h-Fh	Reserved

21.4.12 Performance Counter Time Register (PCT)

The performance counter time register (PCT) is shown in Figure 21-24 and described in Table 21-37.

Figure 21-24. Performance Counter Time Register (PCT)

31	0
TOTAL_TIME	
R-0	

LEGEND: R = Read only; -*n* = value after reset

Table 21-37. Performance Counter Time Register (PCT) Field Description

Bit	Field	Value	Description
31-0	TOTAL_TIME	0-FFFF FFFFh	32-bit counter that continuously counts number for EMB_CLK cycles elapsed after EMIFB is brought out of reset.

21.4.13 Interrupt Raw Register (IRR)

The interrupt raw register (IRR) displays the raw status of the interrupt. If the interrupt condition occurs, the corresponding bit in IRR is set independent of whether or not the interrupt is enabled. The IRR is shown in Figure 21-25 and described in Table 21-38.

Figure 21-25. Interrupt Raw Register (IRR)

31	8
Reserved	
R-0	

7	3	2	1	0
Reserved		LT	Reserved	
R-0		R/W-0	R-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 21-38. Interrupt Raw Register (IRR) Field Descriptions

Bit	Field	Value	Description
31-3	Reserved	0	All writes to these bit(s) must always have a value of 0.
2	LT		Line Trap. Set to 1 by hardware to indicate illegal memory access type. Writing a 1 will clear this bit as well as the LTM bit in the interrupt mask register (IMR). Writing a 0 has no effect.
		0	Line trap hasn't occurred.
		1	Line trap has occurred due to use of unsupported addressing mode. EMIFB supports linear incrementing and cache line wrap addressing modes.
1-0	Reserved	0	All writes to these bit(s) must always have a value of 0.

21.4.14 Interrupt Mask Register (IMR)

The interrupt mask register (IMR) displays the status of the interrupt when it is enabled. If the interrupt condition occurs and the corresponding bit in the interrupt mask set register (IMSR) is set, then the IMR bit is set. The IMR bit is not set if the interrupt is not enabled in IMSR. The IMR is shown in Figure 21-26 and described in Table 21-39.

Figure 21-26. Interrupt Mask Register (IMR)

31	8
Reserved	
R-0	

7	3	2	1	0
Reserved		LTM	Reserved	
R-0		R/W-0	R-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

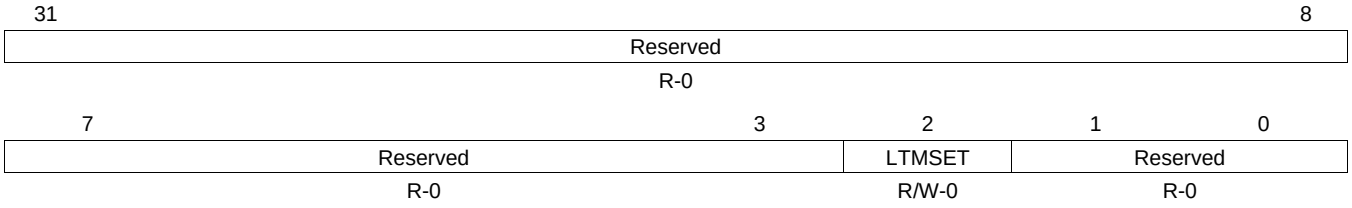
Table 21-39. Interrupt Mask Register (IMR) Field Descriptions

Bit	Field	Value	Description
31-3	Reserved	0	All writes to these bit(s) must always have a value of 0.
2	LTM		Masked Line Trap. Set to 1 by hardware to indicate illegal memory access type, only if the LTMSET bit in the interrupt mask set register (IMSR) is set to 1. Writing a 1 will clear this bit as well as the LT bit in the interrupt raw register (IRR). Writing a 0 has no effect.
		0	Line trap has not occurred.
		1	Line trap occurred due to use of unsupported addressing mode (only set if the LTMSET bit in IMSR is set).
1-0	Reserved	0	All writes to these bit(s) must always have a value of 0.

21.4.15 Interrupt Mask Set Register (IMSR)

The interrupt mask set register (IMSR) enables the memory controller interrupt. The IMSR is shown in Figure 21-27 and described in Table 21-40.

Figure 21-27. Interrupt Mask Set Register (IMSR)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

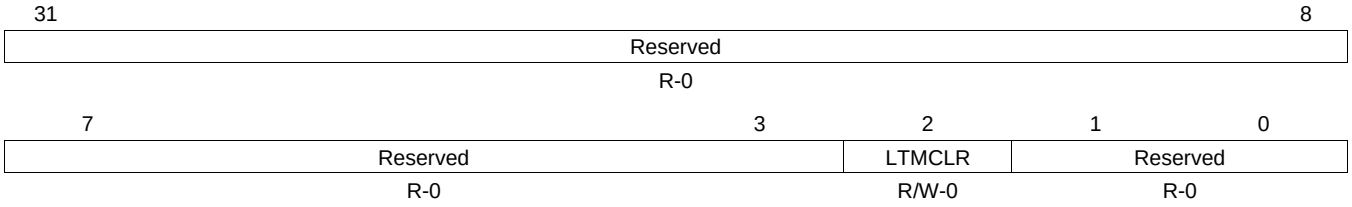
Table 21-40. Interrupt Mask Set Register (IMSR) Field Descriptions

Bit	Field	Value	Description
31-3	Reserved	0	All writes to these bit(s) must always have a value of 0.
2	LTMSET		Mask set for LTM bit in the interrupt mask register (IMR). Writing a 1 will enable the interrupt, and set this bit as well as the LTMCLR bit in the interrupt mask clear register (IMCR). The interrupt will not be enabled, and this bit as well as the LTMCLR bit will not be set if a 1 is written to this bit and the LTMCLR bit at the same time. Writing a 0 has no effect.
		0	Line trap interrupt is not enabled; a write of 1 to the LTMCLR bit in IMCR occurred.
		1	Line trap interrupt is enabled.
1-0	Reserved	0	All writes to these bit(s) must always have a value of 0.

21.4.16 Interrupt Mask Clear Register (IMCR)

The interrupt mask clear register (IMCR) disables the memory controller interrupt. Once an interrupt is enabled, it may be disabled by writing a 1 to the IMCR bit. The IMCR is shown in Figure 21-28 and described in Table 21-41.

Figure 21-28. Interrupt Mask Clear Register (IMCR)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 21-41. Interrupt Mask Clear Register (IMCR) Field Descriptions

Bit	Field	Value	Description
31-3	Reserved	0	All writes to these bit(s) must always have a value of 0.
2	LTMCLR		Mask clear for LTM bit in the interrupt mask register (IMR). Writing a 1 will disable the interrupt, and clear this bit as well as the LTMSET bit in the interrupt mask set register (IMSR). Writing a 0 has no effect.
		0	Line trap interrupt is not enabled.
		1	Line trap interrupt is enabled; a write of 1 to the LTMSET bit in IMSR occurred.
1-0	Reserved	0	All writes to these bit(s) must always have a value of 0.

General-Purpose Input/Output (GPIO)

The GPIO peripheral provides dedicated general-purpose pins that can be configured as either inputs or outputs. When configured as an output, you can write to an internal register to control the state driven on the output pin. When configured as an input, you can detect the state of the input by reading the state of an internal register. This chapter describes the GPIO.

Topic **Page**

22.1 Introduction

22.1.1 Purpose of the Peripheral

Most system-on-chip (SoC) devices require some general-purpose input/output (GPIO) functionality in order to interact with other components in the system using low-speed interface pins. The control and use of the GPIO capability on this device is grouped together in the GPIO peripheral and is described in the following sections.

22.1.2 Features

The GPIO peripheral consists of the following features.

- Output set/clear functionality through separate data set and clear registers allows multiple software processes to control GPIO signals without critical section protection.
- Set/clear functionality through writing to a single output data register is also supported.
- Separate input/output registers
  - Output register can be read to reflect output drive status.
  - Input register can be read to reflect pin status.
- All GPIO signals can be used as interrupt sources with configurable edge detection.
- All GPIO signals can be used to generate events to the EDMA.

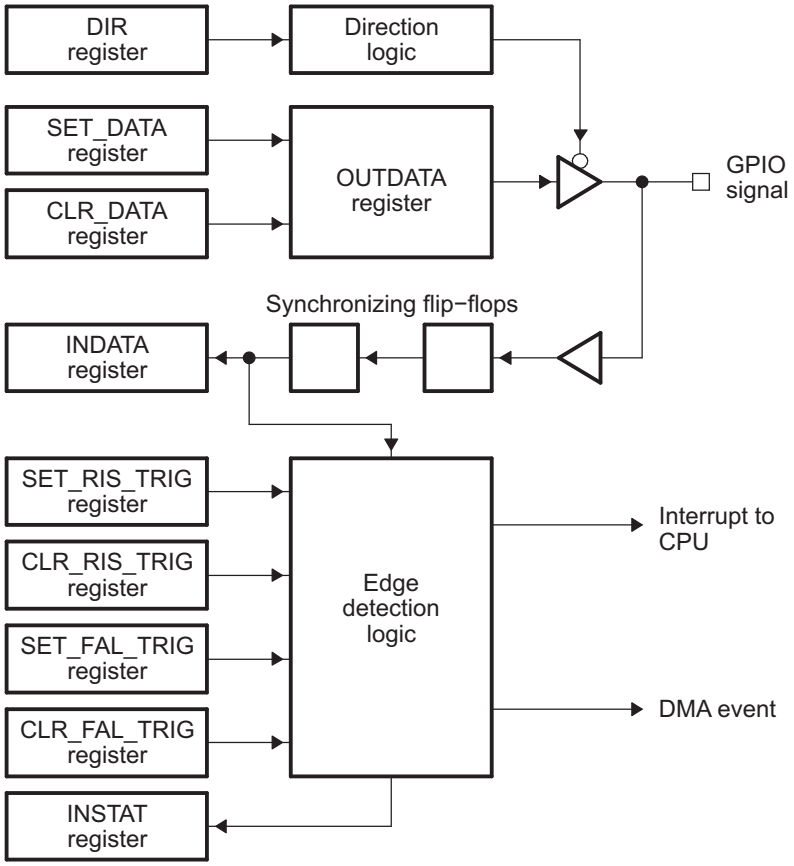
22.1.3 Functional Block Diagram

Figure 22-1 shows a block diagram of the GPIO peripheral.

22.1.4 Industry Standard(s) Compliance Statement

The GPIO peripheral connects to external devices. While it is possible that the software implements some standard connectivity protocol over GPIO, the GPIO peripheral itself is not compliant with any such standards.

Figure 22-1. GPIO Block Diagram



22.2 Architecture

The following sections describe the GPIO peripheral.

22.2.1 Clock Control

The input clock to the GPIO peripheral is indicated in the device datasheet. The maximum operating speed of the GPIO peripheral is limited by system-level latencies. More specifically, how quickly the GPIO registers can be written to or read from.

22.2.2 Signal Descriptions

The number of GPIO signals supported will vary between devices. For information on the number of signals supported and the package pinout of each GPIO signal, see your device-specific data manual.

22.2.3 Pin Multiplexing

Extensive pin multiplexing is used to accommodate the largest number of peripheral functions in the smallest possible package. Pin multiplexing is controlled using a combination of hardware configuration at device reset and software programmable register settings. Refer to the device-specific data manual to determine how pin multiplexing affects the GPIO module.

22.2.4 Endianness Considerations

The GPIO operation is independent of endianness; therefore, there are no endianness considerations for the GPIO module.

22.2.5 GPIO Register Structure

The GPIO signals are grouped by banks of 16 signals per bank. Each bank of GPIO signals has several registers with various control fields for each GPIO signal. Each 32-bit GPIO control register controls a pair of GPIO banks.

The register names for each bank of control registers (or pair of banks of GPIO bits) are all of the form *register_nameXY*, where *X* and *Y* are the two banks of GPIO bits controlled, such as 01, 23, 45, etc. The register fields associated with each GPIO are all of the form B*k*P*j*, where *k* is the GPIO bank and *j* is the pin number within the GPIO bank. For example, for GP2[5], which is located in GPIO bank 2, the control register names are of the form *register_name*23, and the register field associated with GP2[5] is GP2P5.

Table 22-1 shows the banks and register control bit information associated with each GPIO pin for up to 144 supportable pins. The table is not indicative of how many GPIO pins are supported on a device; it is only a reference for what register and field mappings look like for the first 144 supportable GPIO pins. For devices with less than 144 GPIO pins, assume that the extraneous fields and registers listed in the table are Reserved with no function. For devices with more than 144 GPIO pins, additional control registers and fields should be appended using the same numbering scheme in the table. Detailed information regarding the specific register names for each bank and the contents and function of these registers is presented in Section 22.3.

Table 22-1. GPIO Register Bits and Banks Associated With GPIO Signals

GPIO Pin Number	GPIO Signal Name	Bank Number	Control Registers	Register Bit	Register Field
1	GP0[0]	0	*register_name*01	Bit 0	GP0P0
2	GP0[1]	0	*register_name*01	Bit 1	GP0P1
3	GP0[2]	0	*register_name*01	Bit 2	GP0P2
4	GP0[3]	0	*register_name*01	Bit 3	GP0P3
5	GP0[4]	0	*register_name*01	Bit 4	GP0P4
6	GP0[5]	0	*register_name*01	Bit 5	GP0P5
7	GP0[6]	0	*register_name*01	Bit 6	GP0P6
8	GP0[7]	0	*register_name*01	Bit 7	GP0P7
9	GP0[8]	0	*register_name*01	Bit 8	GP0P8
10	GP0[9]	0	*register_name*01	Bit 9	GP0P9
11	GP0[10]	0	*register_name*01	Bit 10	GP0P10
12	GP0[11]	0	*register_name*01	Bit 11	GP0P11
13	GP0[12]	0	*register_name*01	Bit 12	GP0P12
14	GP0[13]	0	*register_name*01	Bit 13	GP0P13
15	GP0[14]	0	*register_name*01	Bit 14	GP0P14
16	GP0[15]	0	*register_name*01	Bit 15	GP0P15
17	GP1[0]	1	*register_name*01	Bit 16	GP1P0
18	GP1[1]	1	*register_name*01	Bit 17	GP1P1
19	GP1[2]	1	*register_name*01	Bit 18	GP1P2
20	GP1[3]	1	*register_name*01	Bit 19	GP1P3
21	GP1[4]	1	*register_name*01	Bit 20	GP1P4
22	GP1[5]	1	*register_name*01	Bit 21	GP1P5
23	GP1[6]	1	*register_name*01	Bit 22	GP1P6
24	GP1[7]	1	*register_name*01	Bit 23	GP1P7
25	GP1[8]	1	*register_name*01	Bit 24	GP1P8
26	GP1[9]	1	*register_name*01	Bit 25	GP1P9
27	GP1[10]	1	*register_name*01	Bit 26	GP1P10
28	GP1[11]	1	*register_name*01	Bit 27	GP1P11
29	GP1[12]	1	*register_name*01	Bit 28	GP1P12
30	GP1[13]	1	*register_name*01	Bit 29	GP1P13

Table 22-1. GPIO Register Bits and Banks Associated With GPIO Signals (continued)

GPIO Pin Number	GPIO Signal Name	Bank Number	Control Registers	Register Bit	Register Field
31	GP1[14]	1	*register_name*01	Bit 30	GP1P14
32	GP1[15]	1	*register_name*01	Bit 31	GP1P15
33	GP2[0]	2	*register_name*23	Bit 0	GP2P0
34	GP2[1]	2	*register_name*23	Bit 1	GP2P1
35	GP2[2]	2	*register_name*23	Bit 2	GP2P2
36	GP2[3]	2	*register_name*23	Bit 3	GP2P3
37	GP2[4]	2	*register_name*23	Bit 4	GP2P4
38	GP2[5]	2	*register_name*23	Bit 5	GP2P5
39	GP2[6]	2	*register_name*23	Bit 6	GP2P6
40	GP2[7]	2	*register_name*23	Bit 7	GP2P7
41	GP2[8]	2	*register_name*23	Bit 8	GP2P8
42	GP2[9]	2	*register_name*23	Bit 9	GP2P9
43	GP2[10]	2	*register_name*23	Bit 10	GP2P10
44	GP2[11]	2	*register_name*23	Bit 11	GP2P11
45	GP2[12]	2	*register_name*23	Bit 12	GP2P12
46	GP2[13]	2	*register_name*23	Bit 13	GP2P13
47	GP2[14]	2	*register_name*23	Bit 14	GP2P14
48	GP2[15]	2	*register_name*23	Bit 15	GP2P15
49	GP3[0]	3	*register_name*23	Bit 16	GP3P0
50	GP3[1]	3	*register_name*23	Bit 17	GP3P1
51	GP3[2]	3	*register_name*23	Bit 18	GP3P2
52	GP3[3]	3	*register_name*23	Bit 19	GP3P3
53	GP3[4]	3	*register_name*23	Bit 20	GP3P4
54	GP3[5]	3	*register_name*23	Bit 21	GP3P5
55	GP3[6]	3	*register_name*23	Bit 22	GP3P6
56	GP3[7]	3	*register_name*23	Bit 23	GP3P7
57	GP3[8]	3	*register_name*23	Bit 24	GP3P8
58	GP3[9]	3	*register_name*23	Bit 25	GP3P9
59	GP3[10]	3	*register_name*23	Bit 26	GP3P10
60	GP3[11]	3	*register_name*23	Bit 27	GP3P11
61	GP3[12]	3	*register_name*23	Bit 28	GP3P12
62	GP3[13]	3	*register_name*23	Bit 29	GP3P13
63	GP3[14]	3	*register_name*23	Bit 30	GP3P14
64	GP3[15]	3	*register_name*23	Bit 31	GP3P15
65	GP4[0]	4	*register_name*45	Bit 0	GP4P0
66	GP4[1]	4	*register_name*45	Bit 1	GP4P1
67	GP4[2]	4	*register_name*45	Bit 2	GP4P2
68	GP4[3]	4	*register_name*45	Bit 3	GP4P3
69	GP4[4]	4	*register_name*45	Bit 4	GP4P4
70	GP4[5]	4	*register_name*45	Bit 5	GP4P5
71	GP4[6]	4	*register_name*45	Bit 6	GP4P6
72	GP4[7]	4	*register_name*45	Bit 7	GP4P7
73	GP4[8]	4	*register_name*45	Bit 8	GP4P8
74	GP4[9]	4	*register_name*45	Bit 9	GP4P9
75	GP4[10]	4	*register_name*45	Bit 10	GP4P10
76	GP4[11]	4	*register_name*45	Bit 11	GP4P11
77	GP4[12]	4	*register_name*45	Bit 12	GP4P12

Table 22-1. GPIO Register Bits and Banks Associated With GPIO Signals (continued)

GPIO Pin Number	GPIO Signal Name	Bank Number	Control Registers	Register Bit	Register Field
78	GP4[13]	4	*register_name*45	Bit 13	GP4P13
79	GP4[14]	4	*register_name*45	Bit 14	GP4P14
80	GP4[15]	4	*register_name*45	Bit 15	GP4P15
81	GP5[0]	5	*register_name*45	Bit 16	GP5P0
82	GP5[1]	5	*register_name*45	Bit 17	GP5P1
83	GP5[2]	5	*register_name*45	Bit 18	GP5P2
84	GP5[3]	5	*register_name*45	Bit 19	GP5P3
85	GP5[4]	5	*register_name*45	Bit 20	GP5P4
86	GP5[5]	5	*register_name*45	Bit 21	GP5P5
87	GP5[6]	5	*register_name*45	Bit 22	GP5P6
88	GP5[7]	5	*register_name*45	Bit 23	GP5P7
89	GP5[8]	5	*register_name*45	Bit 24	GP5P8
90	GP5[9]	5	*register_name*45	Bit 25	GP5P9
91	GP5[10]	5	*register_name*45	Bit 26	GP5P10
92	GP5[11]	5	*register_name*45	Bit 27	GP5P11
93	GP5[12]	5	*register_name*45	Bit 28	GP5P12
94	GP5[13]	5	*register_name*45	Bit 29	GP5P13
95	GP5[14]	5	*register_name*45	Bit 30	GP5P14
96	GP5[15]	5	*register_name*45	Bit 31	GP5P15
97	GP6[0]	6	*register_name*67	Bit 0	GP6P0
98	GP6[1]	6	*register_name*67	Bit 1	GP6P1
99	GP6[2]	6	*register_name*67	Bit 2	GP6P2
100	GP6[3]	6	*register_name*67	Bit 3	GP6P3
101	GP6[4]	6	*register_name*67	Bit 4	GP6P4
102	GP6[5]	6	*register_name*67	Bit 5	GP6P5
103	GP6[6]	6	*register_name*67	Bit 6	GP6P6
104	GP6[7]	6	*register_name*67	Bit 7	GP6P7
105	GP6[8]	6	*register_name*67	Bit 8	GP6P8
106	GP6[9]	6	*register_name*67	Bit 9	GP6P9
107	GP6[10]	6	*register_name*67	Bit 10	GP6P10
108	GP6[11]	6	*register_name*67	Bit 11	GP6P11
109	GP6[12]	6	*register_name*67	Bit 12	GP6P12
110	GP6[13]	6	*register_name*67	Bit 13	GP6P13
111	GP6[14]	6	*register_name*67	Bit 14	GP6P14
112	GP6[15]	6	*register_name*67	Bit 15	GP6P15
113	GP7[0]	7	*register_name*67	Bit 16	GP7P0
114	GP7[1]	7	*register_name*67	Bit 17	GP7P1
115	GP7[2]	7	*register_name*67	Bit 18	GP7P2
116	GP7[3]	7	*register_name*67	Bit 19	GP7P3
117	GP7[4]	7	*register_name*67	Bit 20	GP7P4
118	GP7[5]	7	*register_name*67	Bit 21	GP7P5
119	GP7[6]	7	*register_name*67	Bit 22	GP7P6
120	GP7[7]	7	*register_name*67	Bit 23	GP7P7
121	GP7[8]	7	*register_name*67	Bit 24	GP7P8
122	GP7[9]	7	*register_name*67	Bit 25	GP7P9
123	GP7[10]	7	*register_name*67	Bit 26	GP7P10
124	GP7[11]	7	*register_name*67	Bit 27	GP7P11

Table 22-1. GPIO Register Bits and Banks Associated With GPIO Signals (continued)

GPIO Pin Number	GPIO Signal Name	Bank Number	Control Registers	Register Bit	Register Field
125	GP7[12]	7	*register_name*67	Bit 28	GP7P12
126	GP7[13]	7	*register_name*67	Bit 29	GP7P13
127	GP7[14]	7	*register_name*67	Bit 30	GP7P14
128	GP7[15]	7	*register_name*67	Bit 31	GP7P15
129	GP8[0]	8	*register_name*8	Bit 0	GP8P0
130	GP8[1]	8	*register_name*8	Bit 1	GP8P1
131	GP8[2]	8	*register_name*8	Bit 2	GP8P2
132	GP8[3]	8	*register_name*8	Bit 3	GP8P3
133	GP8[4]	8	*register_name*8	Bit 4	GP8P4
134	GP8[5]	8	*register_name*8	Bit 5	GP8P5
135	GP8[6]	8	*register_name*8	Bit 6	GP8P6
136	GP8[7]	8	*register_name*8	Bit 7	GP8P7
137	GP8[8]	8	*register_name*8	Bit 8	GP8P8
138	GP8[9]	8	*register_name*8	Bit 9	GP8P9
139	GP8[10]	8	*register_name*8	Bit 10	GP8P10
140	GP8[11]	8	*register_name*8	Bit 11	GP8P11
141	GP8[12]	8	*register_name*8	Bit 12	GP8P12
142	GP8[13]	8	*register_name*8	Bit 13	GP8P13
143	GP8[14]	8	*register_name*8	Bit 14	GP8P14
144	GP8[15]	8	*register_name*8	Bit 15	GP8P15

22.2.6 Using a GPIO Signal as an Output

GPIO signals are configured to operate as inputs or outputs by writing the appropriate value to the GPIO direction register (DIR). This section describes using the GPIO signal as an output signal.

22.2.6.1 Configuring a GPIO Output Signal

To configure a given GPIO signal as an output, clear the bit in DIR that is associated with the desired GPIO signal. For detailed information on DIR, see Section 22.3.

22.2.6.2 Controlling the GPIO Output Signal State

There are three registers that control the output state driven on a GPIO signal configured as an output:

1. GPIO set data register (SET_DATA) controls driving GPIO signals high.
2. GPIO clear data register (CLR_DATA) controls driving GPIO signals low.
3. GPIO output data register (OUT_DATA) contains the current state of the output signals.

Reading SET_DATA, CLR_DATA, and OUT_DATA returns the output state, not necessarily the actual signal state (since some signals may be configured as inputs). The actual signal state is read using the GPIO input data register (IN_DATA) associated with the desired GPIO signal. IN_DATA contains the actual logic state on the external signal.

For detailed information on these registers, see Section 22.3.

22.2.6.2.1 Driving a GPIO Output Signal High

To drive a GPIO signal high, use one of the following methods:

- Write a logic 1 to the bit in SET_DATA associated with the desired GPIO signal(s) to be driven high. Bit positions in SET_DATA containing logic 0 do not affect the state of the associated output signals.
- Modify the bit in OUT_DATA associated with the desired GPIO signal by using a read-modify-write operation. The logic states driven on the GPIO output signals match the logic values written to all bits in OUT_DATA.

For GPIO signals configured as inputs, the values written to the associated SET_DATA, CLR_DATA, and OUT_DATA bits have no effect.

22.2.6.2.2 Driving a GPIO Output Signal Low

To drive a GPIO signal low, use one of the following methods:

- Write a logic 1 to the bit in CLR_DATA associated with the desired GPIO signal(s) to be driven low. Bit positions in CLR_DATA containing logic 0 do not affect the state of the associated output signals.
- Modify the bit in OUT_DATA associated with the desired GPIO signal by using a read-modify-write operation. The logic states driven on the GPIO output signals match the logic values written to all bits in OUT_DATA.

For GPIO signals configured as inputs, the values written to the associated SET_DATA, CLR_DATA, and OUT_DATA bits have no effect.

22.2.7 Using a GPIO Signal as an Input

GPIO signals are configured to operate as inputs or outputs by writing the appropriate value to the GPIO direction register (DIR). This section describes using the GPIO signal as an input signal.

22.2.7.1 Configuring a GPIO Input Signal

To configure a given GPIO signal as an input, set the bit in DIR that is associated with the desired GPIO signal. For detailed information on DIR, see Section 22.3.

22.2.7.2 Reading a GPIO Input Signal

The current state of the GPIO signals is read using the GPIO input data register (IN_DATA).

- For GPIO signals configured as inputs, reading IN_DATA returns the state of the input signal synchronized to the GPIO peripheral clock.
- For GPIO signals configured as outputs, reading IN_DATA returns the output value being driven by the device.

Some signals may utilize open-drain output buffers for wired-logic operations. For open-drain GPIO signals, reading IN_DATA returns the wired-logic value on the signal (which will not be driven by the device alone). Information on any signals using open-drain outputs is available in your device-specific data manual.

To use GPIO input signals as interrupt sources, see Section 22.2.10.

22.2.8 Reset Considerations

The GPIO peripheral has two reset sources: software reset and hardware reset.

22.2.8.1 Software Reset Considerations

A software reset (such as a reset initiated through the emulator) does not modify the configuration and state of the GPIO signals. A reset invoked via the Power and Sleep Controller (PSC) (GPIO clock disable, PSC reset, followed by GPIO clock enable) will result in the default configuration register settings. For details on the PSC, see the *Power and Sleep Controller (PSC)* chapter.

22.2.8.2 Hardware Reset Considerations

A hardware reset does reset the GPIO configuration and data registers to their default states; therefore, affecting the configuration and state of the GPIO signals.

22.2.9 Initialization

The following steps are required to configure the GPIO module after a hardware reset:

1. Perform the necessary device pin multiplexing setup (see your device-specific data manual).
2. Program the Power and Sleep Controller (PSC) to enable the GPIO module. For details on the PSC, see the *Power and Sleep Controller (PSC)* chapter.
3. Program the direction, data, and interrupt control registers to set the configuration of the desired GPIO pins (described in this chapter).

The GPIO module is now ready to perform data transactions.

22.2.10 Interrupt Support

The GPIO peripheral can send an interrupt event to the CPU.

22.2.10.1 Interrupt Events and Requests

All GPIO signals can be configured to generate interrupts. The device supports interrupts from single GPIO signals, interrupts from banks of GPIO signals, or both.

Note that the GPIO interrupts may also be used to provide synchronization events to the DMA controller.

22.2.10.2 Enabling GPIO Interrupt Events

GPIO interrupt events are enabled in banks of 16 by setting the appropriate bit(s) in the GPIO interrupt per-bank enable register (BINTEN). For example, to enable bank 0 interrupts (events from GP0[15-0]), set bit 0 in BINTEN; to enable bank 3 interrupts (events from GP3[15-0]), set bit 3 in BINTEN.

For detailed information on BINTEN, see Section 22.3.

22.2.10.3 Configuring GPIO Interrupt Edge Triggering

Each GPIO interrupt source can be configured to generate an interrupt on the GPIO signal rising edge, falling edge, both edges, or neither edge (no event). The edge detection is synchronized to the GPIO peripheral module clock.

The following four registers control the configuration of the GPIO interrupt edge detection:

1. The GPIO set rising edge interrupt register (SET_RIS_TRIG) enables GPIO interrupts on the occurrence of a rising edge on the GPIO signal.
2. The GPIO clear rising edge interrupt register (CLR_RIS_TRIG) disables GPIO interrupts on the occurrence of a rising edge on the GPIO signal.
3. The GPIO set falling edge interrupt register (SET_FAL_TRIG) enables GPIO interrupts on the occurrence of a falling edge on the GPIO signal.
4. The GPIO clear falling edge interrupt register (CLR_FAL_TRIG) disables GPIO interrupts on the occurrence of a falling edge on the GPIO signal.

To configure a GPIO interrupt to occur only on rising edges of the GPIO signal:

- Write a logic 1 to the associated bit in SET_RIS_TRIG.
- Write a logic 1 to the associated bit in CLR_FAL_TRIG.

To configure a GPIO interrupt to occur only on falling edges of the GPIO signal:

- Write a logic 1 to the associated bit in SET_FAL_TRIG.
- Write a logic 1 to the associated bit in CLR_RIS_TRIG.

To configure a GPIO interrupt to occur on both the rising and falling edges of the GPIO signal:

- Write a logic 1 to the associated bit in SET_RIS_TRIG.
- Write a logic 1 to the associated bit in SET_FAL_TRIG.

To disable a specific GPIO interrupt:

- Write a logic 1 to the associated bit in CLR_RIS_TRIG.
- Write a logic 1 to the associated bit in CLR_FAL_TRIG.

For detailed information on these registers, see Section 22.3.

Note that the direction of the GPIO signal does not have to be an input for the interrupt event generation to work. When a GPIO signal is configured as an output, the software can change the GPIO signal state and, in turn, generate an interrupt. This can be useful for debugging interrupt signal connectivity.

22.2.10.4 GPIO Interrupt Status

The status of GPIO interrupt events can be monitored by reading the GPIO interrupt status register (INTSTAT). Pending GPIO interrupts are indicated with a logic 1 in the associated bit position; interrupts that are not pending are indicated with a logic 0.

For individual GPIO interrupts that are directly routed to the DSP subsystem, the interrupt status can be read by reading the associated interrupt flag in the CPU. For the GPIO bank interrupts, INTSTAT can be used to determine which GPIO interrupt occurred. It is the responsibility of software to ensure that all pending GPIO interrupts are appropriately serviced.

Pending GPIO interrupt flags can be cleared by writing a logic 1 to the associated bit position in INTSTAT.

For detailed information on INTSTAT, see Section 22.3.

22.2.10.5 Interrupt Multiplexing

GPIO interrupts may be multiplexed with other interrupt functions on the device.

22.2.11 EDMA Event Support

The GPIO peripheral may provide synchronization events to the DMA controller.

22.2.12 Power Management

The GPIO peripheral can be placed in reduced-power modes to conserve power during periods of low activity. The power management of the GPIO peripheral is controlled by the processor Power and Sleep Controller (PSC). The PSC acts as a master controller for power management for all of the peripherals on the device. For detailed information on power management procedures using the PSC, see the *Power and Sleep Controller (PSC)* chapter.

When the GPIO peripheral is placed in a low-power state by the PSC, the interrupt generation capability is suspended until the GPIO peripheral is removed from the low-power state. While in the low-power state, the GPIO signals configured as outputs are maintained at their state prior to the GPIO peripheral entering the low-power state.

22.2.13 Emulation Considerations

The GPIO peripheral is not affected by emulation suspend events (such as halts and breakpoints).

22.3 Registers

Table 22-2 lists the memory-mapped registers for the general-purpose input/output (GPIO). The table enumerates the registers required to support 144 GPIO pins, however not all devices will support 144 GPIO pins. For devices with less than 144 GPIO pins, assume that the extraneous fields and registers are Reserved and serve no function. For devices with more than 144 GPIO pins, append registers and fields as necessary using the address offset scheme in the table. See your device-specific data manual for the number of GPIO pins supported and the base memory address for these registers.

Table 22-2. GPIO Registers

Offset	Acronym	Register Description	Section
0h	REVID	Revision ID Register	Section 22.3.1
8h	BINTEN	GPIO Interrupt Per-Bank Enable Register	Section 22.3.2
		GPIO Banks 0 and 1	
10h	DIR01	GPIO Banks 0 and 1 Direction Register	Section 22.3.3
14h	OUT_DATA01	GPIO Banks 0 and 1 Output Data Register	Section 22.3.4
18h	SET_DATA01	GPIO Banks 0 and 1 Set Data Register	Section 22.3.5
1Ch	CLR_DATA01	GPIO Banks 0 and 1 Clear Data Register	Section 22.3.6
20h	IN_DATA01	GPIO Banks 0 and 1 Input Data Register	Section 22.3.7
24h	SET_RIS_TRIG01	GPIO Banks 0 and 1 Set Rising Edge Interrupt Register	Section 22.3.8
28h	CLR_RIS_TRIG01	GPIO Banks 0 and 1 Clear Rising Edge Interrupt Register	Section 22.3.9
2Ch	SET_FAL_TRIG01	GPIO Banks 0 and 1 Set Falling Edge Interrupt Register	Section 22.3.10
30h	CLR_FAL_TRIG01	GPIO Banks 0 and 1 Clear Falling Edge Interrupt Register	Section 22.3.11
34h	INTSTAT01	GPIO Banks 0 and 1 Interrupt Status Register	Section 22.3.12
		GPIO Banks 2 and 3	
38h	DIR23	GPIO Banks 2 and 3 Direction Register	Section 22.3.3
3Ch	OUT_DATA23	GPIO Banks 2 and 3 Output Data Register	Section 22.3.4
40h	SET_DATA23	GPIO Banks 2 and 3 Set Data Register	Section 22.3.5
44h	CLR_DATA23	GPIO Banks 2 and 3 Clear Data Register	Section 22.3.6
48h	IN_DATA23	GPIO Banks 2 and 3 Input Data Register	Section 22.3.7
4Ch	SET_RIS_TRIG23	GPIO Banks 2 and 3 Set Rising Edge Interrupt Register	Section 22.3.8
50h	CLR_RIS_TRIG23	GPIO Banks 2 and 3 Clear Rising Edge Interrupt Register	Section 22.3.9
54h	SET_FAL_TRIG23	GPIO Banks 2 and 3 Set Falling Edge Interrupt Register	Section 22.3.10
58h	CLR_FAL_TRIG23	GPIO Banks 2 and 3 Clear Falling Edge Interrupt Register	Section 22.3.11
5Ch	INTSTAT23	GPIO Banks 2 and 3 Interrupt Status Register	Section 22.3.12
		GPIO Banks 4 and 5	
60h	DIR45	GPIO Banks 4 and 5 Direction Register	Section 22.3.3
64h	OUT_DATA45	GPIO Banks 4 and 5 Output Data Register	Section 22.3.4
68h	SET_DATA45	GPIO Banks 4 and 5 Set Data Register	Section 22.3.5
6Ch	CLR_DATA45	GPIO Banks 4 and 5 Clear Data Register	Section 22.3.6
70h	IN_DATA45	GPIO Banks 4 and 5 Input Data Register	Section 22.3.7
74h	SET_RIS_TRIG45	GPIO Banks 4 and 5 Set Rising Edge Interrupt Register	Section 22.3.8
78h	CLR_RIS_TRIG45	GPIO Banks 4 and 5 Clear Rising Edge Interrupt Register	Section 22.3.9
7Ch	SET_FAL_TRIG45	GPIO Banks 4 and 5 Set Falling Edge Interrupt Register	Section 22.3.10
80h	CLR_FAL_TRIG45	GPIO Banks 4 and 5 Clear Falling Edge Interrupt Register	Section 22.3.11
84h	INTSTAT45	GPIO Banks 4 and 5 Interrupt Status Register	Section 22.3.12

Table 22-2. GPIO Registers (continued)

Offset	Acronym	Register Description	Section
		GPIO Banks 6 and 7	
88h	DIR67	GPIO Banks 6 and 7 Direction Register	Section 22.3.3
8Ch	OUT_DATA67	GPIO Banks 6 and 7 Output Data Register	Section 22.3.4
90h	SET_DATA67	GPIO Banks 6 and 7 Set Data Register	Section 22.3.5
94h	CLR_DATA67	GPIO Banks 6 and 7 Clear Data Register	Section 22.3.6
98h	IN_DATA67	GPIO Banks 6 and 7 Input Data Register	Section 22.3.7
9Ch	SET_RIS_TRIG67	GPIO Banks 6 and 7 Set Rising Edge Interrupt Register	Section 22.3.8
A0h	CLR_RIS_TRIG67	GPIO Banks 6 and 7 Clear Rising Edge Interrupt Register	Section 22.3.9
A4h	SET_FAL_TRIG67	GPIO Banks 6 and 7 Set Falling Edge Interrupt Register	Section 22.3.10
A8h	CLR_FAL_TRIG67	GPIO Banks 6 and 7 Clear Falling Edge Interrupt Register	Section 22.3.11
ACh	INTSTAT67	GPIO Banks 6 and 7 Interrupt Status Register	Section 22.3.12
		GPIO Bank 8	
B0h	DIR8	GPIO Bank 8 Direction Register	Section 22.3.3
B4h	OUT_DATA8	GPIO Bank 8 Output Data Register	Section 22.3.4
B8h	SET_DATA8	GPIO Bank 8 Set Data Register	Section 22.3.5
BCh	CLR_DATA8	GPIO Bank 8 Clear Data Register	Section 22.3.6
C0h	IN_DATA8	GPIO Bank 8 Input Data Register	Section 22.3.7
C4h	SET_RIS_TRIG8	GPIO Bank 8 Set Rising Edge Interrupt Register	Section 22.3.8
C8h	CLR_RIS_TRIG8	GPIO Bank 8 Clear Rising Edge Interrupt Register	Section 22.3.9
CCh	SET_FAL_TRIG8	GPIO Bank 8 Set Falling Edge Interrupt Register	Section 22.3.10
D0h	CLR_FAL_TRIG8	GPIO Bank 8 Clear Falling Edge Interrupt Register	Section 22.3.11
D4h	INTSTAT8	GPIO Bank 8 Interrupt Status Register	Section 22.3.12

22.3.1 Revision ID Register (REVID)

The revision ID register (REVID) contains the peripheral version information. REVID is shown in Figure 22-2 and described in Table 22-3.

Figure 22-2. Revision ID Register (REVID)

31	0
REV	
R-4483 0105h	

LEGEND: R = Read only; -*n* = value after reset

Table 22-3. Revision ID Register (REVID) Field Descriptions

Bit	Field	Value	Description
31-0	REV	4483 0105h	Peripheral Revision

22.3.2 GPIO Interrupt Per-Bank Enable Register (BINTEN)

The GPIO interrupt per-bank enable register (BINTEN) is shown in Figure 22-3 and described in Table 22-4. For information on which GPIO signals are associated with each bank, see Table 22-1. Note that the bits in BINTEN control both the interrupt and EDMA events.

Figure 22-3. GPIO Interrupt Per-Bank Enable Register (BINTEN)

31	16
Reserved	
R-0	

15	9	8	7	6	5	4	3	2	1	0
Reserved		EN8	EN7	EN6	EN5	EN4	EN3	EN2	EN1	EN0
R-0		R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 22-4. GPIO Interrupt Per-Bank Enable Register (BINTEN) Field Descriptions

Bit	Field	Value	Description
31-9	Reserved	0	Reserved
8	EN8		Bank 8 interrupt enable is used to disable or enable the bank 8 interrupts (events from GP8[15-0]).
		0	Bank 8 interrupts are disabled.
		1	Bank 8 interrupts are enabled.
7	EN7		Bank 7 interrupt enable is used to disable or enable the bank 7 interrupts (events from GP7[15-0]).
		0	Bank 7 interrupts are disabled.
		1	Bank 7 interrupts are enabled.
6	EN6		Bank 6 interrupt enable is used to disable or enable the bank 6 interrupts (events from GP6[15-0]).
		0	Bank 6 interrupts are disabled.
		1	Bank 6 interrupts are enabled.
5	EN5		Bank 5 interrupt enable is used to disable or enable the bank 5 interrupts (events from GP5[15-0]).
		0	Bank 5 interrupts are disabled.
		1	Bank 5 interrupts are enabled.
4	EN4		Bank 4 interrupt enable is used to disable or enable the bank 4 interrupts (events from GP4[15-0]).
		0	Bank 4 interrupts are disabled.
		1	Bank 4 interrupts are enabled.
3	EN3		Bank 3 interrupt enable is used to disable or enable the bank 3 interrupts (events from GP3[15-0])
		0	Bank 3 interrupts are disabled.
		1	Bank 3 interrupts are enabled.
2	EN2		Bank 2 interrupt enable is used to disable or enable the bank 2 interrupts (events from GP2[15-0]).
		0	Bank 2 interrupts are disabled.
		1	Bank 2 interrupts are enabled.
1	EN1		Bank 1 interrupt enable is used to disable or enable the bank 1 interrupts (events from GP1[15-0]).
		0	Bank 1 interrupts are disabled.
		1	Bank 1 interrupts are enabled.
0	EN0		Bank 0 interrupt enable is used to disable or enable the bank 0 interrupts (events from GP0[15-0]).
		0	Bank 0 interrupts are disabled.
		1	Bank 0 interrupts are enabled.

22.3.3 GPIO Direction Registers (DIR*n*)

The GPIO direction register (DIR*n*) determines if GPIO pin *j* in GPIO bank *k* is an input or an output. Each of the GPIO banks may have up to 16 GPIO pins. By default, all the GPIO pins are configured as inputs (bit value = 1). The GPIO direction register (DIR01) is shown in Figure 22-4, DIR23 is shown in Figure 22-5, DIR45 is shown in Figure 22-6, DIR67 is shown in Figure 22-7, DIR8 is shown in Figure 22-8, and described in Table 22-5. See Table 22-1 to determine the DIR*n* bit associated with each GPIO bank and pin number.

Figure 22-4. GPIO Banks 0 and 1 Direction Register (DIR01)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
GP1P15	GP1P14	GP1P13	GP1P12	GP1P11	GP1P10	GP1P9	GP1P8	GP1P7	GP1P6	GP1P5	GP1P4	GP1P3	GP1P2	GP1P1	GP1P0
R/W-1															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP0P15	GP0P14	GP0P13	GP0P12	GP0P11	GP0P10	GP0P9	GP0P8	GP0P7	GP0P6	GP0P5	GP0P4	GP0P3	GP0P2	GP0P1	GP0P0
R/W-1															

LEGEND: R/W = Read/Write; -*n* = value after reset

Figure 22-5. GPIO Banks 2 and 3 Direction Register (DIR23)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
GP3P15	GP3P14	GP3P13	GP3P12	GP3P11	GP3P10	GP3P9	GP3P8	GP3P7	GP3P6	GP3P5	GP3P4	GP3P3	GP3P2	GP3P1	GP3P0
R/W-1															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP2P15	GP2P14	GP2P13	GP2P12	GP2P11	GP2P10	GP2P9	GP2P8	GP2P7	GP2P6	GP2P5	GP2P4	GP2P3	GP2P2	GP2P1	GP2P0
R/W-1															

LEGEND: R/W = Read/Write; -*n* = value after reset

Figure 22-6. GPIO Banks 4 and 5 Direction Register (DIR45)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
GP5P15	GP5P14	GP5P13	GP5P12	GP5P11	GP5P10	GP5P9	GP5P8	GP5P7	GP5P6	GP5P5	GP5P4	GP5P3	GP5P2	GP5P1	GP5P0
R/W-1															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP4P15	GP4P14	GP4P13	GP4P12	GP4P11	GP4P10	GP4P9	GP4P8	GP4P7	GP4P6	GP4P5	GP4P4	GP4P3	GP4P2	GP4P1	GP4P0
R/W-1															

LEGEND: R/W = Read/Write; -*n* = value after reset

Figure 22-7. GPIO Banks 6 and 7 Direction Register (DIR67)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
GP7P15	GP7P14	GP7P13	GP7P12	GP7P11	GP7P10	GP7P9	GP7P8	GP7P7	GP7P6	GP7P5	GP7P4	GP7P3	GP7P2	GP7P1	GP7P0
R/W-1															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP6P15	GP6P14	GP6P13	GP6P12	GP6P11	GP6P10	GP6P9	GP6P8	GP6P7	GP6P6	GP6P5	GP6P4	GP6P3	GP6P2	GP6P1	GP6P0
R/W-1															

LEGEND: R/W = Read/Write; -*n* = value after reset

Figure 22-8. GPIO Bank 8 Direction Register (DIR8)

31															16
Reserved															
R/W-1															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP8P15	GP8P14	GP8P13	GP8P12	GP8P11	GP8P10	GP8P9	GP8P8	GP8P7	GP8P6	GP8P5	GP8P4	GP8P3	GP8P2	GP8P1	GP8P0
R/W-1															

LEGEND: R/W = Read/Write; -*n* = value after reset

Table 22-5. GPIO Direction Register (DIR*n*) Field Descriptions

Bit	Field	Value	Description
31-0	GP*k*P*j*		Direction of pin GP*k*[*j*]. The GP*k*P*j* bit is used to control the direction (output = 0, input = 1) of pin *j* in GPIO bank*k*.
		0	GP*k*[*j*] is an output.
		1	GP*k*[*j*] is an input.

22.3.4 GPIO Output Data Registers (OUT_DATA*n*)

The GPIO output data register (OUT_DATA*n*) determines the value driven on the corresponding GPIO pin *j* in GPIO bank *k*, if the pin is configured as an output (DIR*n* = 0). Writes do not affect pins not configured as GPIO outputs. The bits in OUT_DATA*n* are set or cleared by writing directly to this register. A read of OUT_DATA*n* returns the value of the register not the value at the pin (that might be configured as an input). The GPIO output data register (OUT_DATA01) is shown in Figure 22-9, OUT_DATA23 is shown in Figure 22-10, OUT_DATA45 is shown in Figure 22-11, OUT_DATA67 is shown in Figure 22-12, OUT_DATA8 is shown in Figure 22-13, and described in Table 22-6. See Table 22-1 to determine the OUT_DATA*n* bit associated with each GPIO bank and pin number.

Figure 22-9. GPIO Banks 0 and 1 Output Data Register (OUT_DATA01)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
GP1P15	GP1P14	GP1P13	GP1P12	GP1P11	GP1P10	GP1P9	GP1P8	GP1P7	GP1P6	GP1P5	GP1P4	GP1P3	GP1P2	GP1P1	GP1P0
R/W-0															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP0P15	GP0P14	GP0P13	GP0P12	GP0P11	GP0P10	GP0P9	GP0P8	GP0P7	GP0P6	GP0P5	GP0P4	GP0P3	GP0P2	GP0P1	GP0P0
R/W-0															

LEGEND: R/W = Read/Write; -*n* = value after reset

Figure 22-10. GPIO Banks 2 and 3 Output Data Register (OUT_DATA23)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
GP3P15	GP3P14	GP3P13	GP3P12	GP3P11	GP3P10	GP3P9	GP3P8	GP3P7	GP3P6	GP3P5	GP3P4	GP3P3	GP3P2	GP3P1	GP3P0
R/W-0															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP2P15	GP2P14	GP2P13	GP2P12	GP2P11	GP2P10	GP2P9	GP2P8	GP2P7	GP2P6	GP2P5	GP2P4	GP2P3	GP2P2	GP2P1	GP2P0
R/W-0															

LEGEND: R/W = Read/Write; -*n* = value after reset

Figure 22-11. GPIO Banks 4 and 5 Output Data Register (OUT_DATA45)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
GP5P15	GP5P14	GP5P13	GP5P12	GP5P11	GP5P10	GP5P9	GP5P8	GP5P7	GP5P6	GP5P5	GP5P4	GP5P3	GP5P2	GP5P1	GP5P0
R/W-0															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP4P15	GP4P14	GP4P13	GP4P12	GP4P11	GP4P10	GP4P9	GP4P8	GP4P7	GP4P6	GP4P5	GP4P4	GP4P3	GP4P2	GP4P1	GP4P0
R/W-0															

LEGEND: R/W = Read/Write; -*n* = value after reset

Figure 22-12. GPIO Banks 6 and 7 Output Data Register (OUT_DATA67)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
GP7P15	GP7P14	GP7P13	GP7P12	GP7P11	GP7P10	GP7P9	GP7P8	GP7P7	GP7P6	GP7P5	GP7P4	GP7P3	GP7P2	GP7P1	GP7P0
R/W-0															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP6P15	GP6P14	GP6P13	GP6P12	GP6P11	GP6P10	GP6P9	GP6P8	GP6P7	GP6P6	GP6P5	GP6P4	GP6P3	GP6P2	GP6P1	GP6P0
R/W-0															

LEGEND: R/W = Read/Write; -*n* = value after reset

Figure 22-13. GPIO Bank 8 Output Data Register (OUT_DATA8)

31															16
Reserved															
R/W-0															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP8P15	GP8P14	GP8P13	GP8P12	GP8P11	GP8P10	GP8P9	GP8P8	GP8P7	GP8P6	GP8P5	GP8P4	GP8P3	GP8P2	GP8P1	GP8P0
R/W-0															

LEGEND: R/W = Read/Write; -*n* = value after reset

Table 22-6. GPIO Output Data Register (OUT_DATA*n*) Field Descriptions

Bit	Field	Value	Description
31-0	GP*k*P*j*		Output drive state of GP*k*[*j*]. The GP*k*P*j* bit is used to drive the output (low = 0, high = 1) of pin *j* in GPIO bank*k*. The GP*k*P*j* bit is ignored when GP*k*[*j*] is configured as an input.
		0	GP*k*[*j*] is driven low.
		1	GP*k*[*j*] is driven high.

22.3.5 GPIO Set Data Registers (SET_DATA*n*)

The GPIO set data register (SET_DATA*n*) controls driving high of the corresponding GPIO pin *j* in GPIO bank *k*, if the pin is configured as an output (DIR*n* = 0). Writes do not affect pins not configured as GPIO outputs. Writing a 1 to a specific bit in SET_DATA*n* sets the corresponding GPIO pin *j* in GPIO bank *k*. A read of the B*k*P*j* bit returns the output drive state of the corresponding pin GPIO*k*[*j*]. The GPIO set data register (SET_DATA01) is shown in Figure 22-14, SET_DATA23 is shown in Figure 22-15, SET_DATA45 is shown in Figure 22-16, SET_DATA67 is shown in Figure 22-17, SET_DATA8 is shown in Figure 22-18, and described in Table 22-7. See Table 22-1 to determine the SET_DATA*n* bit associated with each GPIO bank and pin number.

Figure 22-14. GPIO Banks 0 and 1 Set Data Register (SET_DATA01)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
GP1P15	GP1P14	GP1P13	GP1P12	GP1P11	GP1P10	GP1P9	GP1P8	GP1P7	GP1P6	GP1P5	GP1P4	GP1P3	GP1P2	GP1P1	GP1P0
R/W-0															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP0P15	GP0P14	GP0P13	GP0P12	GP0P11	GP0P10	GP0P9	GP0P8	GP0P7	GP0P6	GP0P5	GP0P4	GP0P3	GP0P2	GP0P1	GP0P0
R/W-0															

LEGEND: R/W = Read/Write; -*n* = value after reset

Figure 22-15. GPIO Banks 2 and 3 Set Data Register (SET_DATA23)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
GP3P15	GP3P14	GP3P13	GP3P12	GP3P11	GP3P10	GP3P9	GP3P8	GP3P7	GP3P6	GP3P5	GP3P4	GP3P3	GP3P2	GP3P1	GP3P0
R/W-0															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP2P15	GP2P14	GP2P13	GP2P12	GP2P11	GP2P10	GP2P9	GP2P8	GP2P7	GP2P6	GP2P5	GP2P4	GP2P3	GP2P2	GP2P1	GP2P0
R/W-0															

LEGEND: R/W = Read/Write; -*n* = value after reset

Figure 22-16. GPIO Banks 4 and 5 Set Data Register (SET_DATA45)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
GP5P15	GP5P14	GP5P13	GP5P12	GP5P11	GP5P10	GP5P9	GP5P8	GP5P7	GP5P6	GP5P5	GP5P4	GP5P3	GP5P2	GP5P1	GP5P0
R/W-0															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP4P15	GP4P14	GP4P13	GP4P12	GP4P11	GP4P10	GP4P9	GP4P8	GP4P7	GP4P6	GP4P5	GP4P4	GP4P3	GP4P2	GP4P1	GP4P0
R/W-0															

LEGEND: R/W = Read/Write; -*n* = value after reset

Figure 22-17. GPIO Banks 6 and 7 Set Data Register (SET_DATA67)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
GP7P15	GP7P14	GP7P13	GP7P12	GP7P11	GP7P10	GP7P9	GP7P8	GP7P7	GP7P6	GP7P5	GP7P4	GP7P3	GP7P2	GP7P1	GP7P0
R/W-0															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP6P15	GP6P14	GP6P13	GP6P12	GP6P11	GP6P10	GP6P9	GP6P8	GP6P7	GP6P6	GP6P5	GP6P4	GP6P3	GP6P2	GP6P1	GP6P0
R/W-0															

LEGEND: R/W = Read/Write; -*n* = value after reset

Figure 22-18. GPIO Bank 8 Set Data Register (SET_DATA8)

31															16
Reserved															
R/W-0															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP8P15	GP8P14	GP8P13	GP8P12	GP8P11	GP8P10	GP8P9	GP8P8	GP8P7	GP8P6	GP8P5	GP8P4	GP8P3	GP8P2	GP8P1	GP8P0
R/W-0															

LEGEND: R/W = Read/Write; -*n* = value after reset

Table 22-7. GPIO Set Data Register (SET_DATA*n*) Field Descriptions

Bit	Field	Value	Description
31-0	GP*k*P*j*		Set the output drive state of GP*k*[*j*] to logic high. The GP*k*P*j* bit is used to drive the output high on pin *j* in GPIO bank*k*. The GP*k*P*j* bit is ignored when GP*k*[*j*] is configured as an input. Reading the GP*k*P*j* bit returns the output drive state of GP*k*[*j*].
		0	No effect.
		1	GP*k*[*j*] is set to output logic high.

22.3.6 GPIO Clear Data Registers (CLR_DATA*n*)

The GPIO clear data register (CLR_DATA*n*) controls clearing low of the corresponding GPIO pin *j* in GPIO bank *k*, if the pin is configured as an output (DIR*n* = 0). Writes do not affect pins not configured as GPIO outputs. Writing a 1 to a specific bit in CLR_DATA*n* resets the corresponding GPIO pin *j* in GPIO bank *k*. A read of the B*k*P*j* bit returns the output drive state of the corresponding pin GPIO*k*[*j*]. The GPIO clear data register (CLR_DATA01) is shown in Figure 22-19, CLR_DATA23 is shown in Figure 22-20, CLR_DATA45 is shown in Figure 22-21, CLR_DATA67 is shown in Figure 22-22, CLR_DATA8 is shown in Figure 22-23, and described in Table 22-8. See Table 22-1 to determine the CLR_DATA*n* bit associated with each GPIO bank and pin number.

Figure 22-19. GPIO Banks 0 and 1 Clear Data Register (CLR_DATA01)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
GP1P15	GP1P14	GP1P13	GP1P12	GP1P11	GP1P10	GP1P9	GP1P8	GP1P7	GP1P6	GP1P5	GP1P4	GP1P3	GP1P2	GP1P1	GP1P0
R/W-0															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP0P15	GP0P14	GP0P13	GP0P12	GP0P11	GP0P10	GP0P9	GP0P8	GP0P7	GP0P6	GP0P5	GP0P4	GP0P3	GP0P2	GP0P1	GP0P0
R/W-0															

LEGEND: R/W = Read/Write; -*n* = value after reset

Figure 22-20. GPIO Banks 2 and 3 Clear Data Register (CLR_DATA23)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
GP3P15	GP3P14	GP3P13	GP3P12	GP3P11	GP3P10	GP3P9	GP3P8	GP3P7	GP3P6	GP3P5	GP3P4	GP3P3	GP3P2	GP3P1	GP3P0
R/W-0															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP2P15	GP2P14	GP2P13	GP2P12	GP2P11	GP2P10	GP2P9	GP2P8	GP2P7	GP2P6	GP2P5	GP2P4	GP2P3	GP2P2	GP2P1	GP2P0
R/W-0															

LEGEND: R/W = Read/Write; -*n* = value after reset

Figure 22-21. GPIO Banks 4 and 5 Clear Data Register (CLR_DATA45)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
GP5P15	GP5P14	GP5P13	GP5P12	GP5P11	GP5P10	GP5P9	GP5P8	GP5P7	GP5P6	GP5P5	GP5P4	GP5P3	GP5P2	GP5P1	GP5P0
R/W-0															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP4P15	GP4P14	GP4P13	GP4P12	GP4P11	GP4P10	GP4P9	GP4P8	GP4P7	GP4P6	GP4P5	GP4P4	GP4P3	GP4P2	GP4P1	GP4P0
R/W-0															

LEGEND: R/W = Read/Write; -*n* = value after reset

Figure 22-22. GPIO Banks 6 and 7 Clear Data Register (CLR_DATA67)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
GP7P15	GP7P14	GP7P13	GP7P12	GP7P11	GP7P10	GP7P9	GP7P8	GP7P7	GP7P6	GP7P5	GP7P4	GP7P3	GP7P2	GP7P1	GP7P0
R/W-0															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP6P15	GP6P14	GP6P13	GP6P12	GP6P11	GP6P10	GP6P9	GP6P8	GP6P7	GP6P6	GP6P5	GP6P4	GP6P3	GP6P2	GP6P1	GP6P0
R/W-0															

LEGEND: R/W = Read/Write; -*n* = value after reset

Figure 22-23. GPIO Bank 8 Clear Data Register (CLR_DATA8)

31															16
Reserved															
R/W-0															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP8P15	GP8P14	GP8P13	GP8P12	GP8P11	GP8P10	GP8P9	GP8P8	GP8P7	GP8P6	GP8P5	GP8P4	GP8P3	GP8P2	GP8P1	GP8P0
R/W-0															

LEGEND: R/W = Read/Write; -*n* = value after reset

Table 22-8. GPIO Clear Data Register (CLR_DATA*n*) Field Descriptions

Bit	Field	Value	Description
31-0	GP*k*P*j*		Clear the output drive state of GP*k*[*j*] to logic low. The GP*k*P*j* bit is used to drive the output low on pin *j* in GPIO bank*k*. The GP*k*P*j* bit is ignored when GP*k*[*j*] is configured as an input. Reading the GP*k*P*j* bit returns the output drive state of GP*k*[*j*].
		0	No effect.
		1	GP*k*[*j*] is set to output logic low.

22.3.7 GPIO Input Data Registers (IN_DATA*n*)

The current state of the GPIO signals is read using the GPIO input data register (IN_DATA*n*).

- For GPIO signals configured as inputs, reading IN_DATA*n* returns the state of the input signal synchronized to the GPIO peripheral clock.
- For GPIO signals configured as outputs, reading IN_DATA*n* returns the output value being driven by the device.

The GPIO input data register (IN_DATA01) is shown in Figure 22-24, IN_DATA23 is shown in Figure 22-25, IN_DATA45 is shown in Figure 22-26, IN_DATA67 is shown in Figure 22-27, IN_DATA8 is shown in Figure 22-28, and described in Table 22-9. See Table 22-1 to determine the IN_DATA*n* bit associated with each GPIO bank and pin number.

Figure 22-24. GPIO Banks 0 and 1 Input Data Register (IN_DATA01)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
GP1P15	GP1P14	GP1P13	GP1P12	GP1P11	GP1P10	GP1P9	GP1P8	GP1P7	GP1P6	GP1P5	GP1P4	GP1P3	GP1P2	GP1P1	GP1P0
R-0															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP0P15	GP0P14	GP0P13	GP0P12	GP0P11	GP0P10	GP0P9	GP0P8	GP0P7	GP0P6	GP0P5	GP0P4	GP0P3	GP0P2	GP0P1	GP0P0
R-0															

LEGEND: R = Read only; -*n* = value after reset

Figure 22-25. GPIO Banks 2 and 3 Input Data Register (IN_DATA23)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
GP3P15	GP3P14	GP3P13	GP3P12	GP3P11	GP3P10	GP3P9	GP3P8	GP3P7	GP3P6	GP3P5	GP3P4	GP3P3	GP3P2	GP3P1	GP3P0
R-0															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP2P15	GP2P14	GP2P13	GP2P12	GP2P11	GP2P10	GP2P9	GP2P8	GP2P7	GP2P6	GP2P5	GP2P4	GP2P3	GP2P2	GP2P1	GP2P0
R-0															

LEGEND: R = Read only; -*n* = value after reset

Figure 22-26. GPIO Banks 4 and 5 Input Data Register (IN_DATA45)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
GP5P15	GP5P14	GP5P13	GP5P12	GP5P11	GP5P10	GP5P9	GP5P8	GP5P7	GP5P6	GP5P5	GP5P4	GP5P3	GP5P2	GP5P1	GP5P0
R-0															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP4P15	GP4P14	GP4P13	GP4P12	GP4P11	GP4P10	GP4P9	GP4P8	GP4P7	GP4P6	GP4P5	GP4P4	GP4P3	GP4P2	GP4P1	GP4P0
R-0															

LEGEND: R = Read only; -*n* = value after reset

Figure 22-27. GPIO Banks 6 and 7 Input Data Register (IN_DATA67)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
GP7P15	GP7P14	GP7P13	GP7P12	GP7P11	GP7P10	GP7P9	GP7P8	GP7P7	GP7P6	GP7P5	GP7P4	GP7P3	GP7P2	GP7P1	GP7P0
R-0															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP6P15	GP6P14	GP6P13	GP6P12	GP6P11	GP6P10	GP6P9	GP6P8	GP6P7	GP6P6	GP6P5	GP6P4	GP6P3	GP6P2	GP6P1	GP6P0
R-0															

LEGEND: R = Read only; -*n* = value after reset

Figure 22-28. GPIO Bank 8 Input Data Register (IN_DATA8)

31															16
Reserved															
R-0															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP8P15	GP8P14	GP8P13	GP8P12	GP8P11	GP8P10	GP8P9	GP8P8	GP8P7	GP8P6	GP8P5	GP8P4	GP8P3	GP8P2	GP8P1	GP8P0
R-0															

LEGEND: R = Read only; -*n* = value after reset

Table 22-9. GPIO Input Data Register (IN_DATA*n*) Field Descriptions

Bit	Field	Value	Description
31-0	GP*k*P*j*		Status of pin GP*k*[*j*]. Reading the GP*k*P*j* bit returns the state of pin *j* in GPIO bank *k*.
		0	GP*k*[*j*] is logic low.
		1	GP*k*[*j*] is logic high.

22.3.8 GPIO Set Rising Edge Interrupt Registers (SET_RIS_TRIG*n*)

The GPIO set rising edge trigger interrupt register (SET_RIS_TRIG*n*) enables a rising edge trigger on the GPIO pin to generate a GPIO interrupt. The GPIO set rising edge interrupt register (SET_RIS_TRIG01) is shown in Figure 22-29, SET_RIS_TRIG23 is shown in Figure 22-30, SET_RIS_TRIG45 is shown in Figure 22-31, SET_RIS_TRIG67 is shown in Figure 22-32, SET_RIS_TRIG8 is shown in Figure 22-33, and described in Table 22-10. See Table 22-1 to determine the SET_RIS_TRIG*n* bit associated with each GPIO bank and pin number.

Figure 22-29. GPIO Banks 0 and 1 Set Rise Trigger Register (SET_RIS_TRIG01)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
GP1P15	GP1P14	GP1P13	GP1P12	GP1P11	GP1P10	GP1P9	GP1P8	GP1P7	GP1P6	GP1P5	GP1P4	GP1P3	GP1P2	GP1P1	GP1P0
R/W-0															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP0P15	GP0P14	GP0P13	GP0P12	GP0P11	GP0P10	GP0P9	GP0P8	GP0P7	GP0P6	GP0P5	GP0P4	GP0P3	GP0P2	GP0P1	GP0P0
R/W-0															

LEGEND: R/W = Read/Write; -*n* = value after reset

Figure 22-30. GPIO Banks 2 and 3 Set Rise Trigger Register (SET_RIS_TRIG23)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
GP3P15	GP3P14	GP3P13	GP3P12	GP3P11	GP3P10	GP3P9	GP3P8	GP3P7	GP3P6	GP3P5	GP3P4	GP3P3	GP3P2	GP3P1	GP3P0
R/W-0															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP2P15	GP2P14	GP2P13	GP2P12	GP2P11	GP2P10	GP2P9	GP2P8	GP2P7	GP2P6	GP2P5	GP2P4	GP2P3	GP2P2	GP2P1	GP2P0
R/W-0															

LEGEND: R/W = Read/Write; -*n* = value after reset

Figure 22-31. GPIO Banks 4 and 5 Set Rise Trigger Register (SET_RIS_TRIG45)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
GP5P15	GP5P14	GP5P13	GP5P12	GP5P11	GP5P10	GP5P9	GP5P8	GP5P7	GP5P6	GP5P5	GP5P4	GP5P3	GP5P2	GP5P1	GP5P0
R/W-0															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP4P15	GP4P14	GP4P13	GP4P12	GP4P11	GP4P10	GP4P9	GP4P8	GP4P7	GP4P6	GP4P5	GP4P4	GP4P3	GP4P2	GP4P1	GP4P0
R/W-0															

LEGEND: R/W = Read/Write; -*n* = value after reset

Figure 22-32. GPIO Banks 6 and 7 Set Rise Trigger Register (SET_RIS_TRIG67)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
GP7P15	GP7P14	GP7P13	GP7P12	GP7P11	GP7P10	GP7P9	GP7P8	GP7P7	GP7P6	GP7P5	GP7P4	GP7P3	GP7P2	GP7P1	GP7P0
R/W-0															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP6P15	GP6P14	GP6P13	GP6P12	GP6P11	GP6P10	GP6P9	GP6P8	GP6P7	GP6P6	GP6P5	GP6P4	GP6P3	GP6P2	GP6P1	GP6P0
R/W-0															

LEGEND: R/W = Read/Write; -*n* = value after reset

Figure 22-33. GPIO Bank 8 Set Rise Trigger Register (SET_RIS_TRIG8)

31															16
Reserved															
R/W-0															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP8P15	GP8P14	GP8P13	GP8P12	GP8P11	GP8P10	GP8P9	GP8P8	GP8P7	GP8P6	GP8P5	GP8P4	GP8P3	GP8P2	GP8P1	GP8P0
R/W-0															

LEGEND: R/W = Read/Write; -*n* = value after reset

Table 22-10. GPIO Set Rising Edge Trigger Interrupt Register (SET_RIS_TRIG*n*) Field Descriptions

Bit	Field	Value	Description
31-0	GP*j*P*k*		Enable rising edge trigger interrupt detection on GP*k*[*j*]. Reading the GP*k*P*j* bit in either SET_RIS_TRIG*n* or CLR_RIS_TRIG*n* always returns an indication of whether the rising edge interrupt generation function is enabled for pin GP*k*[*j*]. Therefore, this bit will be one in both registers if the function is enabled, and zero in both registers if the function is disabled.
		0	No effect.
		1	Interrupt is caused by a low-to-high transition on GP*k*[*j*].

22.3.9 GPIO Clear Rising Edge Interrupt Registers (CLR_RIS_TRIG*n*)

The GPIO clear rising edge trigger interrupt register (CLR_RIS_TRIG*n*) disables the rising edge trigger on the GPIO pin to generate a GPIO interrupt. The GPIO clear rising edge interrupt register (CLR_RIS_TRIG01) is shown in Figure 22-34, CLR_RIS_TRIG23 is shown in Figure 22-35, CLR_RIS_TRIG45 is shown in Figure 22-36, CLR_RIS_TRIG67 is shown in Figure 22-37, CLR_RIS_TRIG8 is shown in Figure 22-38, and described in Table 22-11. See Table 22-1 to determine the CLR_RIS_TRIG*n* bit associated with each GPIO bank and pin number.

Figure 22-34. GPIO Banks 0 and 1 Clear Rise Trigger Register (CLR_RIS_TRIG01)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
GP1P15	GP1P14	GP1P13	GP1P12	GP1P11	GP1P10	GP1P9	GP1P8	GP1P7	GP1P6	GP1P5	GP1P4	GP1P3	GP1P2	GP1P1	GP1P0
R/W-0															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP0P15	GP0P14	GP0P13	GP0P12	GP0P11	GP0P10	GP0P9	GP0P8	GP0P7	GP0P6	GP0P5	GP0P4	GP0P3	GP0P2	GP0P1	GP0P0
R/W-0															

LEGEND: R/W = Read/Write; -*n* = value after reset

Figure 22-35. GPIO Banks 2 and 3 Clear Rise Trigger Register (CLR_RIS_TRIG23)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
GP3P15	GP3P14	GP3P13	GP3P12	GP3P11	GP3P10	GP3P9	GP3P8	GP3P7	GP3P6	GP3P5	GP3P4	GP3P3	GP3P2	GP3P1	GP3P0
R/W-0															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP2P15	GP2P14	GP2P13	GP2P12	GP2P11	GP2P10	GP2P9	GP2P8	GP2P7	GP2P6	GP2P5	GP2P4	GP2P3	GP2P2	GP2P1	GP2P0
R/W-0															

LEGEND: R/W = Read/Write; -*n* = value after reset

Figure 22-36. GPIO Banks 4 and 5 Clear Rise Trigger Register (CLR_RIS_TRIG45)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
GP5P15	GP5P14	GP5P13	GP5P12	GP5P11	GP5P10	GP5P9	GP5P8	GP5P7	GP5P6	GP5P5	GP5P4	GP5P3	GP5P2	GP5P1	GP5P0
R/W-0															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP4P15	GP4P14	GP4P13	GP4P12	GP4P11	GP4P10	GP4P9	GP4P8	GP4P7	GP4P6	GP4P5	GP4P4	GP4P3	GP4P2	GP4P1	GP4P0
R/W-0															

LEGEND: R/W = Read/Write; -*n* = value after reset

Figure 22-37. GPIO Banks 6 and 7 Clear Rise Trigger Register (CLR_RIS_TRIG67)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
GP7P15	GP7P14	GP7P13	GP7P12	GP7P11	GP7P10	GP7P9	GP7P8	GP7P7	GP7P6	GP7P5	GP7P4	GP7P3	GP7P2	GP7P1	GP7P0
R/W-0															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP6P15	GP6P14	GP6P13	GP6P12	GP6P11	GP6P10	GP6P9	GP6P8	GP6P7	GP6P6	GP6P5	GP6P4	GP6P3	GP6P2	GP6P1	GP6P0
R/W-0															

LEGEND: R/W = Read/Write; -*n* = value after reset

Figure 22-38. GPIO Bank 8 Clear Rise Trigger Register (CLR_RIS_TRIG8)

31															16
Reserved															
R/W-0															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP8P15	GP8P14	GP8P13	GP8P12	GP8P11	GP8P10	GP8P9	GP8P8	GP8P7	GP8P6	GP8P5	GP8P4	GP8P3	GP8P2	GP8P1	GP8P0
R/W-0															

LEGEND: R/W = Read/Write; -*n* = value after reset

Table 22-11. GPIO Clear Rising Edge Interrupt Register (CLR_RIS_TRIG*n*) Field Descriptions

Bit	Field	Value	Description
31-0	GP*k*P*j*		Disable rising edge interrupt detection on GP*k*[*j*]. Reading the GP*k*P*j* bit in either SET_RIS_TRIG*n* or CLR_RIS_TRIG*n* always returns an indication of whether the rising edge interrupt generation function is enabled for GP*k*[*j*]. Therefore, this bit will be one in both registers if the function is enabled, and zero in both registers if the function is disabled.
		0	No effect.
		1	No interrupt is caused by a low-to-high transition on GP*k*[*j*].

22.3.10 GPIO Set Falling Edge Interrupt Registers (SET_FAL_TRIG*n*)

The GPIO set falling edge trigger interrupt register (SET_FAL_TRIG*n*) enables a falling edge trigger on the GPIO pin to generate a GPIO interrupt. The GPIO set falling edge interrupt register (SET_FAL_TRIG01) is shown in Figure 22-39, SET_FAL_TRIG23 is shown in Figure 22-40, SET_FAL_TRIG45 is shown in Figure 22-41, SET_FAL_TRIG67 is shown in Figure 22-42, SET_FAL_TRIG8 is shown in Figure 22-43, and described in Table 22-12. See Table 22-1 to determine the SET_FAL_TRIG*n* bit associated with each GPIO bank and pin number.

Figure 22-39. GPIO Banks 0 and 1 Set Rise Trigger Register (SET_FAL_TRIG01)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
GP1P15	GP1P14	GP1P13	GP1P12	GP1P11	GP1P10	GP1P9	GP1P8	GP1P7	GP1P6	GP1P5	GP1P4	GP1P3	GP1P2	GP1P1	GP1P0
R/W-0															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP0P15	GP0P14	GP0P13	GP0P12	GP0P11	GP0P10	GP0P9	GP0P8	GP0P7	GP0P6	GP0P5	GP0P4	GP0P3	GP0P2	GP0P1	GP0P0
R/W-0															

LEGEND: R/W = Read/Write; -*n* = value after reset

Figure 22-40. GPIO Banks 2 and 3 Set Rise Trigger Register (SET_FAL_TRIG23)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
GP3P15	GP3P14	GP3P13	GP3P12	GP3P11	GP3P10	GP3P9	GP3P8	GP3P7	GP3P6	GP3P5	GP3P4	GP3P3	GP3P2	GP3P1	GP3P0
R/W-0															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP2P15	GP2P14	GP2P13	GP2P12	GP2P11	GP2P10	GP2P9	GP2P8	GP2P7	GP2P6	GP2P5	GP2P4	GP2P3	GP2P2	GP2P1	GP2P0
R/W-0															

LEGEND: R/W = Read/Write; -*n* = value after reset

Figure 22-41. GPIO Banks 4 and 5 Set Rise Trigger Register (SET_FAL_TRIG45)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
GP5P15	GP5P14	GP5P13	GP5P12	GP5P11	GP5P10	GP5P9	GP5P8	GP5P7	GP5P6	GP5P5	GP5P4	GP5P3	GP5P2	GP5P1	GP5P0
R/W-0															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP4P15	GP4P14	GP4P13	GP4P12	GP4P11	GP4P10	GP4P9	GP4P8	GP4P7	GP4P6	GP4P5	GP4P4	GP4P3	GP4P2	GP4P1	GP4P0
R/W-0															

LEGEND: R/W = Read/Write; -*n* = value after reset

Figure 22-42. GPIO Banks 6 and 7 Set Rise Trigger Register (SET_FAL_TRIG67)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
GP7P15	GP7P14	GP7P13	GP7P12	GP7P11	GP7P10	GP7P9	GP7P8	GP7P7	GP7P6	GP7P5	GP7P4	GP7P3	GP7P2	GP7P1	GP7P0
R/W-0															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP6P15	GP6P14	GP6P13	GP6P12	GP6P11	GP6P10	GP6P9	GP6P8	GP6P7	GP6P6	GP6P5	GP6P4	GP6P3	GP6P2	GP6P1	GP6P0
R/W-0															

LEGEND: R/W = Read/Write; -*n* = value after reset

Figure 22-43. GPIO Bank 8 Set Rise Trigger Register (SET_FAL_TRIG8)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
R/W-0															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP8P15	GP8P14	GP8P13	GP8P12	GP8P11	GP8P10	GP8P9	GP8P8	GP8P7	GP8P6	GP8P5	GP8P4	GP8P3	GP8P2	GP8P1	GP8P0
R/W-0															

LEGEND: R/W = Read/Write; -*n* = value after reset

Table 22-12. GPIO Set Falling Edge Trigger Interrupt Register (SET_FAL_TRIG*n*) Field Descriptions

Bit	Field	Value	Description
31-0	GP*k*P*j*		Enable falling edge trigger interrupt detection on GP*k*[*j*]. Reading the GP*k*P*j* bit in either SET_FAL_TRIG*n* or CLR_FAL_TRIG*n* always returns an indication of whether the falling edge interrupt generation function is enabled for pin GP*k*[*j*]. Therefore, this bit will be one in both registers if the function is enabled, and zero in both registers if the function is disabled.
		0	No effect.
		1	Interrupt is caused by a high-to-low transition on GP*k*[*j*].

22.3.11 GPIO Clear Falling Edge Interrupt Registers (CLR_FAL_TRIG*n*)

The GPIO clear falling edge trigger interrupt register (CLR_FAL_TRIG*n*) disables the falling edge trigger on the GPIO pin to generate a GPIO interrupt. The GPIO clear falling edge interrupt register (CLR_FAL_TRIG01) is shown in Figure 22-44, CLR_FAL_TRIG23 is shown in Figure 22-45, CLR_FAL_TRIG45 is shown in Figure 22-46, CLR_FAL_TRIG67 is shown in Figure 22-47, CLR_FAL_TRIG8 is shown in Figure 22-48, and described in Table 22-13. See Table 22-1 to determine the CLR_FAL_TRIG*n* bit associated with each GPIO bank and pin number.

Figure 22-44. GPIO Banks 0 and 1 Clear Rise Trigger Register (CLR_FAL_TRIG01)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
GP1P15	GP1P14	GP1P13	GP1P12	GP1P11	GP1P10	GP1P9	GP1P8	GP1P7	GP1P6	GP1P5	GP1P4	GP1P3	GP1P2	GP1P1	GP1P0
R/W-0															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP0P15	GP0P14	GP0P13	GP0P12	GP0P11	GP0P10	GP0P9	GP0P8	GP0P7	GP0P6	GP0P5	GP0P4	GP0P3	GP0P2	GP0P1	GP0P0
R/W-0															

LEGEND: R/W = Read/Write; -*n* = value after reset

Figure 22-45. GPIO Banks 2 and 3 Clear Rise Trigger Register (CLR_FAL_TRIG23)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
GP3P15	GP3P14	GP3P13	GP3P12	GP3P11	GP3P10	GP3P9	GP3P8	GP3P7	GP3P6	GP3P5	GP3P4	GP3P3	GP3P2	GP3P1	GP3P0
R/W-0															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP2P15	GP2P14	GP2P13	GP2P12	GP2P11	GP2P10	GP2P9	GP2P8	GP2P7	GP2P6	GP2P5	GP2P4	GP2P3	GP2P2	GP2P1	GP2P0
R/W-0															

LEGEND: R/W = Read/Write; -*n* = value after reset

Figure 22-46. GPIO Banks 4 and 5 Clear Rise Trigger Register (CLR_FAL_TRIG45)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
GP5P15	GP5P14	GP5P13	GP5P12	GP5P11	GP5P10	GP5P9	GP5P8	GP5P7	GP5P6	GP5P5	GP5P4	GP5P3	GP5P2	GP5P1	GP5P0
R/W-0															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP4P15	GP4P14	GP4P13	GP4P12	GP4P11	GP4P10	GP4P9	GP4P8	GP4P7	GP4P6	GP4P5	GP4P4	GP4P3	GP4P2	GP4P1	GP4P0
R/W-0															

LEGEND: R/W = Read/Write; -*n* = value after reset

Figure 22-47. GPIO Banks 6 and 7 Clear Rise Trigger Register (CLR_FAL_TRIG67)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
GP7P15	GP7P14	GP7P13	GP7P12	GP7P11	GP7P10	GP7P9	GP7P8	GP7P7	GP7P6	GP7P5	GP7P4	GP7P3	GP7P2	GP7P1	GP7P0
R/W-0															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP6P15	GP6P14	GP6P13	GP6P12	GP6P11	GP6P10	GP6P9	GP6P8	GP6P7	GP6P6	GP6P5	GP6P4	GP6P3	GP6P2	GP6P1	GP6P0
R/W-0															

LEGEND: R/W = Read/Write; -*n* = value after reset

Figure 22-48. GPIO Bank 8 Clear Rise Trigger Register (CLR_FAL_TRIG8)

31															16
Reserved															
R/W-0															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP8P15	GP8P14	GP8P13	GP8P12	GP8P11	GP8P10	GP8P9	GP8P8	GP8P7	GP8P6	GP8P5	GP8P4	GP8P3	GP8P2	GP8P1	GP8P0
R/W-0															

LEGEND: R/W = Read/Write; -*n* = value after reset

Table 22-13. GPIO Clear Falling Edge Interrupt Register (CLR_FAL_TRIG*n*) Field Descriptions

Bit	Field	Value	Description
31-0	GP*k*P*j*		Disable falling edge interrupt detection on GP*k*[*j*]. Reading the GP*k*P*j* bit in either SET_FAL_TRIG*n* or CLR_FAL_TRIG*n* always returns an indication of whether the falling edge interrupt generation function is enabled for GP*k*[*j*]. Therefore, this bit will be one in both registers if the function is enabled, and zero in both registers if the function is disabled.
		0	No effect.
		1	No interrupt is caused by a high-to-low transition on GP*k*[*j*].

22.3.12 GPIO Interrupt Status Registers (INTSTAT*n*)

The status of GPIO interrupt events can be monitored by reading the GPIO interrupt status register (INTSTAT*n*). In the associated bit position, pending GPIO interrupts are indicated with a logic 1 and GPIO interrupts that are not pending are indicated with a logic 0. The GPIO interrupt status register (INTSTAT01) is shown in Figure 22-49, INTSTAT23 is shown in Figure 22-50, INTSTAT45 is shown in Figure 22-51, INTSTAT67 is shown in Figure 22-52, INTSTAT8 is shown in Figure 22-53, and described in Table 22-14. See Table 22-1 to determine the INTSTAT*n* bit associated with each GPIO bank and pin number.

Figure 22-49. GPIO Banks 0 and 1 Interrupt Status Register (INTSTAT01)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
GP1P15	GP1P14	GP1P13	GP1P12	GP1P11	GP1P10	GP1P9	GP1P8	GP1P7	GP1P6	GP1P5	GP1P4	GP1P3	GP1P2	GP1P1	GP1P0
R/W1C-0															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP0P15	GP0P14	GP0P13	GP0P12	GP0P11	GP0P10	GP0P9	GP0P8	GP0P7	GP0P6	GP0P5	GP0P4	GP0P3	GP0P2	GP0P1	GP0P0
R/W1C-0															

LEGEND: R/W = Read/Write; W1C = Write 1 to clear bit (writing 0 has no effect); -*n* = value after reset

Figure 22-50. GPIO Banks 2 and 3 Interrupt Status Register (INTSTAT23)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
GP3P15	GP3P14	GP3P13	GP3P12	GP3P11	GP3P10	GP3P9	GP3P8	GP3P7	GP3P6	GP3P5	GP3P4	GP3P3	GP3P2	GP3P1	GP3P0
R/W1C-0															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP2P15	GP2P14	GP2P13	GP2P12	GP2P11	GP2P10	GP2P9	GP2P8	GP2P7	GP2P6	GP2P5	GP2P4	GP2P3	GP2P2	GP2P1	GP2P0
R/W1C-0															

LEGEND: R/W = Read/Write; W1C = Write 1 to clear bit (writing 0 has no effect); -*n* = value after reset

Figure 22-51. GPIO Banks 4 and 5 Interrupt Status Register (INTSTAT45)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
GP5P15	GP5P14	GP5P13	GP5P12	GP5P11	GP5P10	GP5P9	GP5P8	GP5P7	GP5P6	GP5P5	GP5P4	GP5P3	GP5P2	GP5P1	GP5P0
R/W1C-0															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP4P15	GP4P14	GP4P13	GP4P12	GP4P11	GP4P10	GP4P9	GP4P8	GP4P7	GP4P6	GP4P5	GP4P4	GP4P3	GP4P2	GP4P1	GP4P0
R/W1C-0															

LEGEND: R/W = Read/Write; W1C = Write 1 to clear bit (writing 0 has no effect); -*n* = value after reset

Figure 22-52. GPIO Banks 6 and 7 Interrupt Status Register (INTSTAT67)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
GP7P15	GP7P14	GP7P13	GP7P12	GP7P11	GP7P10	GP7P9	GP7P8	GP7P7	GP7P6	GP7P5	GP7P4	GP7P3	GP7P2	GP7P1	GP7P0
R/W1C-0															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP6P15	GP6P14	GP6P13	GP6P12	GP6P11	GP6P10	GP6P9	GP6P8	GP6P7	GP6P6	GP6P5	GP6P4	GP6P3	GP6P2	GP6P1	GP6P0
R/W1C-0															

LEGEND: R/W = Read/Write; W1C = Write 1 to clear bit (writing 0 has no effect); -*n* = value after reset

Figure 22-53. GPIO Bank 8 Interrupt Status Register (INTSTAT8)

31															16
Reserved															
R/W1C-0															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GP8P15	GP8P14	GP8P13	GP8P12	GP8P11	GP8P10	GP8P9	GP8P8	GP8P7	GP8P6	GP8P5	GP8P4	GP8P3	GP8P2	GP8P1	GP8P0
R/W1C-0															

LEGEND: R/W = Read/Write; W1C = Write 1 to clear bit (writing 0 has no effect); -*n* = value after reset

Table 22-14. GPIO Interrupt Status Register (INTSTAT*n*) Field Descriptions

Bit	Field	Value	Description
31-0	GP*k*P*j*		Interrupt status of GP*k*[*j*]. The GP*k*P*j* bit is used to monitor pending GPIO interrupts on pin *j* of GPIO bank *k*. Write a 1 to the GP*k*P*j* bit to clear the status bit; a write of 0 has no effect.
		0	No pending interrupt on GP*k*[*j*].
		1	Pending interrupt on GP*k*[*j*].

Host Port Interface (HPI)

This chapter describes the host port interface (HPI).

Topic **Page**

23.1 Introduction

The host port interface (HPI) provides a parallel port interface through which an external host processor can directly access the processor's resources (configuration and program/data memories). The external host device is asynchronous to the CPU clock and functions as a master to the HPI interface. The HPI enables a host device and the processor to exchange information via internal or external memory. Dedicated address (HPIA) and data (HPID) registers within the HPI provide the data path between the external host interface and the processor resources. An HPI control register (HPIC) is available to the host and the CPU for various configuration and interrupt functions.

23.1.1 Purpose of the Peripheral

The HPI enables an external host processor (host) to directly access program/data memory on the processor using a parallel interface. The primary purpose is to provide a mechanism to move data to and from the processor. In addition to data transfer, the host can also use the HPI to bootload the processor by downloading program and data information to the processor's memory after power-up.

23.1.2 Features

The HPI supports the following features:

- Multiplexed address/data
- Dual 16-bit halfword cycle access (internal data word is 32-bits wide)
- 16-bit-wide host data bus interface
- Internal data bursting using 8-word read and write first-in, first-out (FIFO) buffers
- HPI control register (HPIC) accessible by both the DSP CPU and the external host
- HPI address register (HPIA) accessible by both the DSP CPU and the external host
- Separate HPI address registers for read (HPIAR) and write (HPIAW) with configurable option for operating as a single HPI address register
- HPI data register (HPID)/FIFOs providing data-path between external host interface and CPU resources
- Multiple strobes and control signals to allow flexible host connection
- Asynchronous UHPI_HRDY output to allow the HPI to insert wait states to the host
- Software control of data prefetching to the HPID/FIFOs
- Processor-to-Host interrupt output signal controlled by HPIC accesses
- Host-to-Processor interrupt controlled by HPIC accesses
- Register controlled HPIA and HPIC ownership and FIFO timeout
- Memory-mapped peripheral identification register (PID)
- Bus holders on host data and address buses (these are actually external to HPI module)

23.1.3 Functional Block Diagram

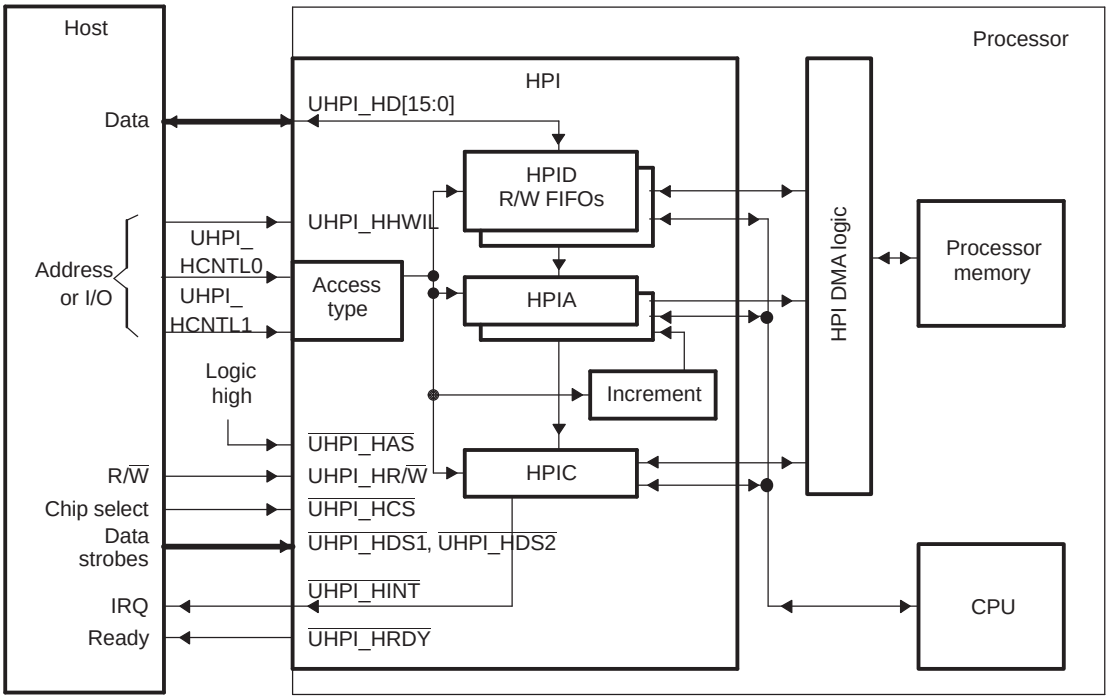
Figure 23-1 is a high-level block diagram showing how the HPI connects a host (left side of figure) and the processor internal memory (right side of figure). Host activity is asynchronous to the internal processor clock that drives the HPI. The host functions as a master to the HPI. When HPI resources are temporarily busy or unavailable, the HPI communicates this to the host by deasserting the HPI ready ($\overline{\text{UHPI\_HRDY}}$) output signal.

The HPI supports multiplexed operation meaning the data bus is used for both address and data. Each host cycle consists of two consecutive 16-bit transfers. When the host drives an address on the bus, the address is stored in a 32-bit address register (HPIA) in the HPI, so that the bus can then be used for data. The HPI contains two address registers (HPIAR and HPIAW), which can be used as separate address registers for read accesses and write accesses (for details, see Section 23.2.6.1).

A control register (HPIC) is accessible by the CPU and the host. The CPU uses HPIC to send an interrupt request to the host, to clear an interrupt request from the host, and to monitor the HPI. The host uses HPIC to configure and monitor the HPI, to send an interrupt request to the CPU, and to clear an interrupt request from the CPU.

Data flow between the host and the HPI uses a temporary storage register, the 32-bit data register (HPID). Data arriving from the host is held in HPID until the data can be stored elsewhere in the processor. Data to be sent to the host is held in HPID until the HPI is ready to perform the transfer. When address autoincrementing is used, read and write FIFOs are used to store burst data. If autoincrementing is not used, the FIFO memory acts as a single register (only one location is used).

Figure 23-1. HPI Block Diagram



23.1.4 Industry Standard(s) Compliance Statement

The HPI is not an industry standard interface that is developed and monitored by an international organization. It is a generic parallel interface that can be configured to gluelessly interface to a variety of parallel devices.

23.1.5 Terminology Used in This Document

The following is a brief explanation of some terms used in this document:

Term	Meaning
CPU	DSP CPU
host	External host device
HPI DMA logic	Logic used to communicate between the HPI and the DMA system that moves data to and from memory. This is independent of the EDMA system on the processor
processor	Entire system-on-chip

23.2 Architecture

23.2.1 Clock Control

For detailed information on the PLLs and clock distribution on the processor, see the *Phase-Locked Loop Controller (PLLC)* chapter.

23.2.2 Memory Map

The HPI can be used by the host to access on-chip device memory, peripheral, and memory-mapped registers. See your device-specific data manual for more detailed information.

23.2.3 Signal Descriptions

Table 23-1 shows the a description of the HPI signals.

Table 23-1. HPI Pins

Pin	Type	Host Connection	Function
UHPI_HCNTL[1:0]	I	Address or control pins	**HPI access control inputs**. The HPI latches the logic levels of these pins on the falling edge of internal $\overline{\text{HSTRB}}$ (for details about internal $\overline{\text{HSTRB}}$, see Section 23.2.6.4). The four binary states of these pins determine the access type of the current transfer (HPIC, HPIA, HPID with and without autoincrementing).
$\overline{\text{UHPI\_HCS}}$	I	Chip select pin	**HPI chip select**. $\overline{\text{UHPI\_HCS}}$ must be low for the HPI to be selected by the host. $\overline{\text{UHPI\_HCS}}$ can be kept low between accesses. $\overline{\text{UHPI\_HCS}}$ normally precedes an active $\overline{\text{UHPI\_HDS}}$ (data strobe) signal, but can be connected to a $\overline{\text{UHPI\_HDS}}$ pin for simultaneous select and strobe activity.
UHPI_HR/$\overline{\text{W}}$	I	R/W strobe pin	**HPI read/write**. On the falling edge of internal $\overline{\text{HSTRB}}$, UHPI_HR/$\overline{\text{W}}$ indicates whether the current access is to be a read or write operation. Driving UHPI_HR/$\overline{\text{W}}$ high indicates the transfer is a read from the HPI, while driving UHPI_HR/$\overline{\text{W}}$ low indicates a write to the HPI.
UHPI_HHWIL	I	Address or control pins	**Halfword identification line**. The host uses UHPI_HHWIL to identify the first and second halfwords of the host cycle. UHPI_HHWIL must be driven low for the first halfword and high for the second halfword.
$\overline{\text{UHPI\_HAS}}$	I	None	**Address strobe**. Connect to logic high.
$\overline{\text{UHPI\_HINT}}$	O/Z	Interrupt pin	**Host Interrupt**. The CPU can interrupt the host processor by writing a 1 to the HINT bit of HPIC. Before subsequent $\overline{\text{UHPI\_HINT}}$ interrupts can occur, the host must acknowledge interrupts by writing a 1 to the HINT bit. This pin is active-low (that is, when an interrupt is asserted from the host, the state of this signal is low) and inverted from the HINT bit value in HPIC.
$\overline{\text{UHPI\_HDS1}}$ and $\overline{\text{UHPI\_HDS2}}$	I	Read strobe and write strobe pins or any data strobe pin	**HPI data strobe pins**. These pins are used for strobing data in and out of the HPI (for data strobing details, see Section 23.2.6.4). The direction of the data transfer depends on the logic level of the UHPI_HR/$\overline{\text{W}}$ signal. The $\overline{\text{UHPI\_HDS}}$ signals are also used to latch control information on the falling edge. During an HPID write access, data is latched into the HPID register on the rising edge of $\overline{\text{UHPI\_HDS}}$. During read operations, these pins act as output-enable pins of the host data bus.
UHPI_HD[15:0]	I/O/Z	Data bus	**HPI data bus**. The HPI data bus carries the address and data to/from the HPI.
$\overline{\text{UHPI\_HRDY}}$	O/Z	Asynchronous ready pin	**HPI-ready signal**. When the HPI drives $\overline{\text{UHPI\_HRDY}}$ low, the host has permission to complete the current host cycle. When the HPI drives $\overline{\text{UHPI\_HRDY}}$ high, the HPI is not ready for the current host cycle to complete.

23.2.4 Pin Multiplexing and General-Purpose I/O Control Blocks

Extensive pin multiplexing is used to accommodate the largest number of peripheral functions in the smallest possible package. Pin multiplexing is controlled using a combination of hardware configuration at device reset and software programmable register settings. See your device-specific data manual to determine how pin multiplexing affects the HPI.

The HPI supports general-purpose I/O (GPIO) capability on all pins. All HPI pins may be enabled for GPIO mode when the HPI is disabled via the HPIENA bit in the chip configuration 1 register (CFGCHIP1) in the *System Configuration (SYSCFG) Module* chapter.

When the HPI is enabled, the pins not being used for host accesses may be configured as general-purpose I/O.

23.2.4.1 Treatment of Optional Pins when Configured as General-Purpose I/O

Certain pins are optional, but if used to interface to the external hosts, the pins are inputs to the HPI. For the purpose of host accesses, the HPI treats these pins as if they were driven to the values listed in Table 23-2.

Table 23-2. Value on Optional Pins when Configured as General-Purpose I/O

Pin	GPIO Enable Bit(s)	When Enabled as GPIO, Treated as Driven:
UHPI_HD[15:8]	GPIOEN8	0
UHPI_HD[7:0]	GPIOEN7	0
UHPI_HCNTL0	GPIOEN1	1
UHPI_HCNTL1	GPIOEN1	1
$\overline{\text{UHPI\_HAS}}$	GPIOEN2	1

23.2.4.2 General-Purpose I/O Programmer's Model

For each HPI pin, there are three bits that control this pin as general-purpose I/O (GPIO):

- Enable: GPIO_EN.GPIOEN[xx]
- Direction: GPIO_DIR*n*.DIR[yy]
- Data: GPIO_DAT*n*.DIR[yy]

For example, the $\overline{\text{UHPI\_HAS}}$ pin is enabled with the GPIO_EN.GPIOEN2 bit. In the default setting, the GPIO_EN.GPIOEN2 bit is cleared to 0; therefore, the $\overline{\text{UHPI\_HAS}}$ pin functions as the host address strobe.

Enabling this pin for GPIO, by setting the GPIO_EN.GPIOEN2 bit to 1 does two things:

- Transfers control of the $\overline{\text{UHPI\_HAS}}$ pin to GPIO direction and data bits.
- Drives a 1 into the $\overline{\text{UHPI\_HAS}}$ pin input of the external host interface block (regardless of the actual pin value).

Once enabled as GPIO, the direction of the $\overline{\text{UHPI\_HAS}}$ pin is controlled by the GPIO_DIR2.HASZ bit. If this bit is set to 1, the pin will be driven as an output; if this bit is cleared to 0, the pin will be an input.

Once the direction of the $\overline{\text{UHPI\_HAS}}$ pin is set, the data value is either written to or read from the GPIO_DAT2.HASZ bit. If the pin was configured as an output, then writing to this bit determines the value to drive out the pin. Reading from this bit will return the value written.

When the GPIO_DIR2.HASZ bit is cleared to 0, configuring the $\overline{\text{UHPI\_HAS}}$ pin as an input, writing to the GPIO_DAT2.HASZ bit has no effect. Reading from this bit will return the value on the $\overline{\text{UHPI\_HAS}}$ pin.

NOTE: Note that you cannot preload a value into the DAT field before configuring the pin as an output. This means that when switching the pin from input to output, the pin will initially drive the last value input back out on the pin. Then the DAT bit can be written to change the value on the pin. If the intermediate value between writing to DIR and writing to DAT will cause a problem at the system level, it is suggested to use another general-purpose I/O pin on the device.

23.2.5 Protocol Description

The HPI does not conform to any industry standard protocol.

23.2.6 Operation

23.2.6.1 Using the Address Registers

The HPI contains two 32-bit address registers: one for read operations (HPIAR) and one for write operations (HPIAW). These roles are unchanging from the viewpoint of the HPI logic. The HPI DMA logic gets the address from HPIAR when reading from processor resources (see Section 23.2.2) and gets the address from HPIAW when writing to processor resources (see Section 23.2.2).

However, unlike the HPI logic, the host can choose how to interact with the two HPI address registers. Using the DUALHPIA bit in the HPI control register (HPIC), the host determines whether HPIAR and HPIAW act as a single 32-bit register (single-HPIA mode) or as two independent 32-bit registers (dual-HPIA mode).

Note that the addresses loaded into the HPI address registers must be byte addresses, and must be 32-bit word aligned (with the least-significant two bits equal to zero), for use in addressing memory space within the DSP.

23.2.6.1.1 Single-HPIA Mode

When DUALHPIA = 0 in HPIC, HPIAR and HPIAW become a single HPI address register (HPIA) from the perspective of the host. In this mode:

- A host HPIA write cycle (UHPI_HCNTL[1:0] = 10b, UHPI_HR/$\overline{W}$ = 0) updates HPIAR and HPIAW with the same value.
- Both HPI address registers are incremented during autoincrement read/write cycles (UHPI_HCNTL[1:0] = 01b).
- An HPIA read cycle (UHPI_HCNTL[1:0] = 10b, UHPI_HR/$\overline{W}$ = 1) returns the content of HPIAR, which should be identical to the content of HPIAW.

To maintain consistency between the contents of HPIAR and HPIAW, the host should always reinitialize the HPI address registers after changing the state of the DUALHPIA bit. In addition, when DUALHPIA = 0, the host must always reinitialize the HPI address registers when it changes the data direction (from an HPID read cycle to an HPID write cycle, or conversely). Otherwise, the memory location accessed by the HPI DMA logic might not be the location intended by the host.

23.2.6.1.2 Dual-HPIA Mode

When DUALHPIA = 1 in HPIC, HPIAR and HPIAW are two independent HPI address registers from the perspective of the host. In this mode:

- A host HPIA access (UHPI_HCNTL[1:0] = 10b) reads/updates either HPIAR or HPIAW, depending on the value of the HPIA read/write select (HPIASEL) bit in HPIC. This bit is programmed by the host. While HPIASEL = 1, only HPIAR is read or updated by the host. While HPIASEL = 0, only HPIAW is read or updated by the host. The HPIASEL bit is only meaningful in the dual-HPIA mode.

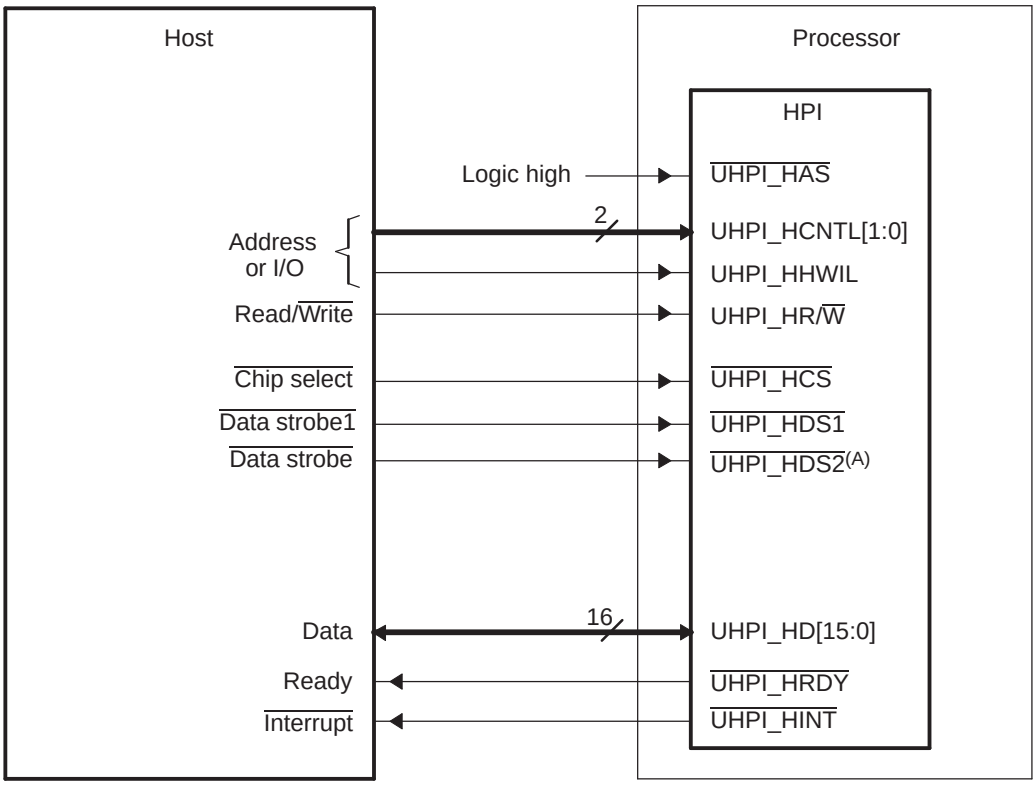
NOTE: The HPIASEL bit does not affect the HPI DMA logic. Regardless of the value of HPIASEL, the HPI DMA logic uses HPIAR when reading from memory and HPIAW when writing to memory.

- A host HPID access with autoincrementing (UHPI_HCNTL[1:0] = 01b) causes only the relevant HPIA value to be incremented to the next consecutive memory address. In an autoincrement read cycle, HPIAR is incremented after it has been used to perform the current read from memory. In an autoincrement write cycle, HPIAW is incremented after it has been used for the write operation.

23.2.6.2 Host-HPI Signal Connections

Figure 23-2 shows an example of a signal connection between the HPI and a host.

Figure 23-2. Example of Host-Processor Signal Connections



A Data strobing options are given in Section 23.2.6.4

23.2.6.3 HPI Configuration and Data Flow

The host accomplishes a multiplexed access in the following manner:

1. The host writes to the HPI control register (HPIC) to properly configure the HPI. Typically, this means programming the halfword order bit (HWOB) and the HPIA-related bits (DUALHPIA and HPIASEL). This step is normally performed once before the initial data access.
2. The host writes the desired internal processor memory address to an address register (HPIAR and/or HPIAW). For an introduction to the two HPI address registers and the two ways the host can interact with them, see Section 23.2.6.1.
3. The host reads from or writes to the data register (HPID). Data transfers between HPID and the internal memory of the processor are handled by the HPI DMA logic and are transparent to the CPU.

Each step of the access uses the same bus. Therefore, the host must drive the appropriate levels on the UHPI_HCNTL1 and UHPI_HCNTL0 signals to indicate which register is to be accessed. The host must also drive the appropriate level on the UHPI_HR/$\overline{W}$ signal to indicate the data direction (read or write) and must drive other control signals as appropriate. When HPI resources are temporarily busy or unavailable, the HPI can communicate this to the host by deasserting the HPI-ready ($\overline{UHPI\_HRDY}$) output signal.

When performing an access, the HPI first latches the levels on UHPI_HCNTL[1:0], UHPI_HR/$\overline{W}$, and other control signals. This latching can occur on the falling edge of the internal strobe signal (for details, see Section 23.2.6.4). After the control information is latched, the HPI initiates an access based on the control signals.

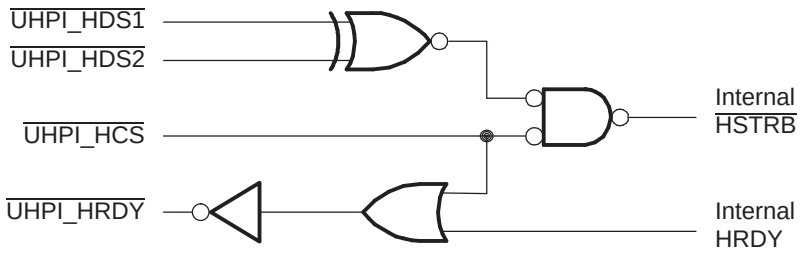
If the host wants to read data from processor resources (see Section 23.2.2), the HPI DMA logic reads the resource address from HPIAR and retrieves the data from the addressed memory location. When the data has been placed in HPID, the HPI drives the data onto its UHPI_HD bus. The $\overline{UHPI\_HRDY}$ signal informs the host whether the data on the UHPI_HD bus is valid ($\overline{UHPI\_HRDY}$ low) or not valid yet ($\overline{UHPI\_HRDY}$ high). When the data is valid, the host should latch the data and drive the connected data strobe ($\overline{UHPI\_HDS1}$ or $\overline{UHPI\_HDS2}$) inactive, which, in turn, will cause the internal strobe (internal $\overline{HSTRB}$) signal to transition from low to high.

If the host wants to write data to processor resources (see Section 23.2.2), the operation is similar. After the host determines that the HPI is ready to latch the data ($\overline{UHPI\_HRDY}$ is low), it must cause internal $\overline{HSTRB}$ to transition from low to high, which causes the data to be latched into HPID. Once the data is in HPID, the HPI DMA logic reads the memory address from HPIAW and transfers the data from HPID to the addressed memory location.

23.2.6.4 UHPI_HDS2, UHPI_HDS1, and UHPI_HCS: Data Strobing and Chip Selection

As shown in Figure 23-3, the strobing logic is a function of three key inputs: the chip select pin (UHPI_HCS) and two data strobe signals (UHPI_HDS1 and UHPI_HDS2). The internal strobe signal, which is referred to as internal HSTRB throughout this document, functions as the actual strobe signal inside the HPI. UHPI_HCS must be low (HPI selected) during strobe activity on the UHPI_HDS pins. If UHPI_HCS remains high (HPI not selected), activity on the UHPI_HDS pins is ignored.

Figure 23-3. HPI Strobe and Select Logic



Strobe connections between the host and the HPI depend in part on the number and types of strobe pins available on the host. Table 23-3 describes some options for connecting to the UHPI_HDS pins.

Notice in Figure 23-3 that UHPI_HRDY is also gated by UHPI_HCS. If UHPI_HCS goes high (HPI not selected), UHPI_HRDY goes low, regardless of whether the current internal transfer is completed in the processor.

NOTE: The UHPI_HCS input and one UHPI_HDS strobe input can be tied together and driven with a single strobe signal from the host. This technique selects the HPI and provides the strobe, simultaneously. When using this method, be aware that UHPI_HRDY is gated by UHPI_HCS as previously described.

It is not recommended to tie both UHPI_HDS1 and UHPI_HDS2 to static logic levels and use UHPI_HCS as a strobe.

Table 23-3. Options for Connecting Host and HPI Data Strobe Pins

Available Host Data Strobe Pins	Connections to HPI Data Strobe Pins
Host has separate read and write strobe pins, both active-low	Connect one strobe pin to UHPI_HDS1 and the other to UHPI_HDS2 (1). Since such a host might not provide a R/W line, take care to satisfy UHPI_HR/W timings as stated in your device-specific data manual. This could possibly be done using a host address line.
Host has separate read and write strobe pins, both active-high	Connect one strobe pin to UHPI_HDS1 and the other to UHPI_HDS2 (1). Since such a host might not provide a R/W line, take care to satisfy UHPI_HR/W timings as stated in your device-specific data manual. This could possibly be done using a host address line.
Host has one active-low strobe pin	Connect the strobe pin to UHPI_HDS1 or UHPI_HDS2, and connect the other pin to logic-level 1.
Host has one active-high strobe pin	Connect the strobe pin to UHPI_HDS1 or UHPI_HDS2, and connect the other strobe pin to logic-level 0.

(1) The UHPI_HR/W signal could be driven by a host address line in this case.

23.2.6.5 UHPI_HCNTL[1:0] and UHPI_HR/$\overline{W}$: Indicating the Cycle Type

The cycle type consists of:

- The access type that the host selects by driving the appropriate levels on the UHPI_HCNTL[1:0] pins of the HPI. Table 23-4 describes the four available access types.
- The transfer direction that the host selects with the UHPI_HR/$\overline{W}$ pin. The host must drive the UHPI_HR/$\overline{W}$ signal high (read) or low (write).

A summary of cycle types is in Table 23-5. The HPI samples the UHPI_HCNTL levels at the falling edge of the internal strobe signal $\overline{HSTRB}$.

Table 23-4. Access Types Selectable With the UHPI_HCNTL Signals

UHPI_HCNTL1	UHPI_HCNTL0	Access Type
0	0	**HPIC access.** The host requests to access the HPI control register (HPIC).
0	1	**HPID access with autoincrementing.** The host requests to access the HPI data register (HPID) and to have the appropriate HPI address register (HPIAR and/or HPIAW) automatically incremented by 1 after the access.
1	0	**HPIA access.** The host requests to access the appropriate HPI address register (HPIAR and/or HPIAW).
1	1	**HPID access without autoincrementing.** The host requests to access the HPI data register (HPID) but requests no automatic post-increment of the HPI address register.

Table 23-5. Cycle Types Selectable With the UHPI_HCNTL and UHPI_HR/$\overline{W}$ Signals

UHPI_HCNTL1	UHPI_HCNTL0	UHPI_HR/$\overline{W}$	Cycle Type
0	0	0	HPIC write cycle
0	0	1	HPIC read cycle
0	1	0	HPID write cycle with autoincrementing
0	1	1	HPID read cycle with autoincrementing
1	0	0	HPIA write cycle
1	0	1	HPIA read cycle
1	1	0	HPID write cycle without autoincrementing
1	1	1	HPID read cycle without autoincrementing

23.2.6.6 UHPI_HHWIL: Identifying the First and Second Halfwords in Multiplexed Mode Transfers

Each host cycle consists of two consecutive halfword transfers. For each transfer, the host must specify the cycle type with UHPI_HCNTL[1:0] and UHPI_HR/$\overline{W}$, and the host must use UHPI_HHWIL to indicate whether the first or second halfword is being transferred. For HPID and HPIA accesses, UHPI_HHWIL must always be driven low for the first halfword transfer and high for the second halfword transfer. Results are undefined if the sequence is broken. For examples of using UHPI_HHWIL, see Section 23.2.6.7.

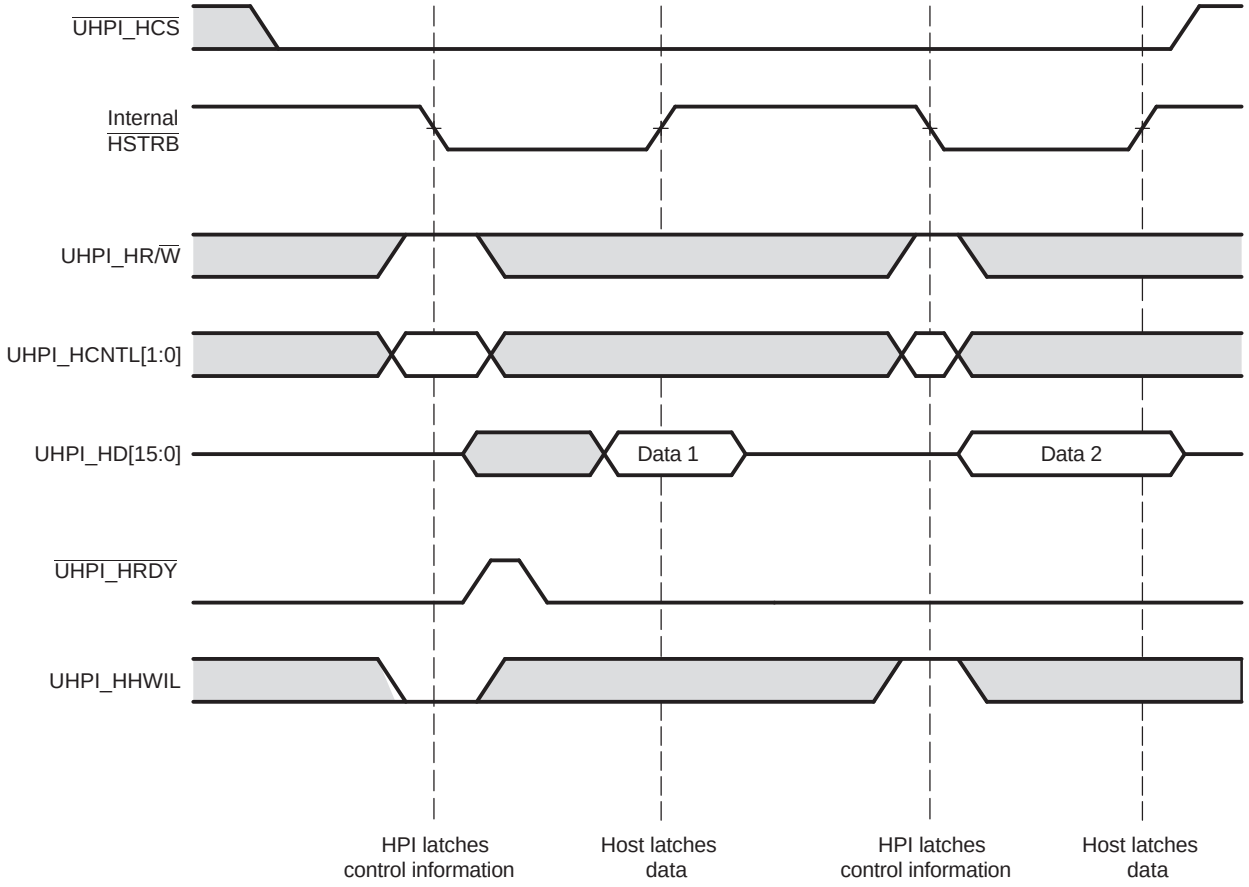
When the host sends the two halfwords of a 32-bit word in this manner, the host can send the most-significant and the least-significant halfwords of the word in either order (most-significant halfword first or most-significant halfword second). However, the host must inform the HPI of the selected order before beginning the host cycle. This is done by programming the halfword order (HWOB) bit in HPIC. Although HWOB is written at bit 0 in HPIC, its current value is readable at both bit 0 and bit 8 (HWOBSTAT). Thus, the host can determine the current halfword order configuration by checking the least-significant bit of either half of HPIC.

There is one case when the HPI does not require a dual halfword access with UHPI_HHWIL low for the first halfword and UHPI_HHWIL high for the second halfword. This is the case when accessing the HPIC register. When accessing HPIC, the state of UHPI_HHWIL is ignored and the same 16-bit HPIC register is accessed regardless of whether the host performs a single or dual access. For an example timing diagram of this case, see Section 23.2.6.8.

23.2.6.7 Performing a Multiplexed Access

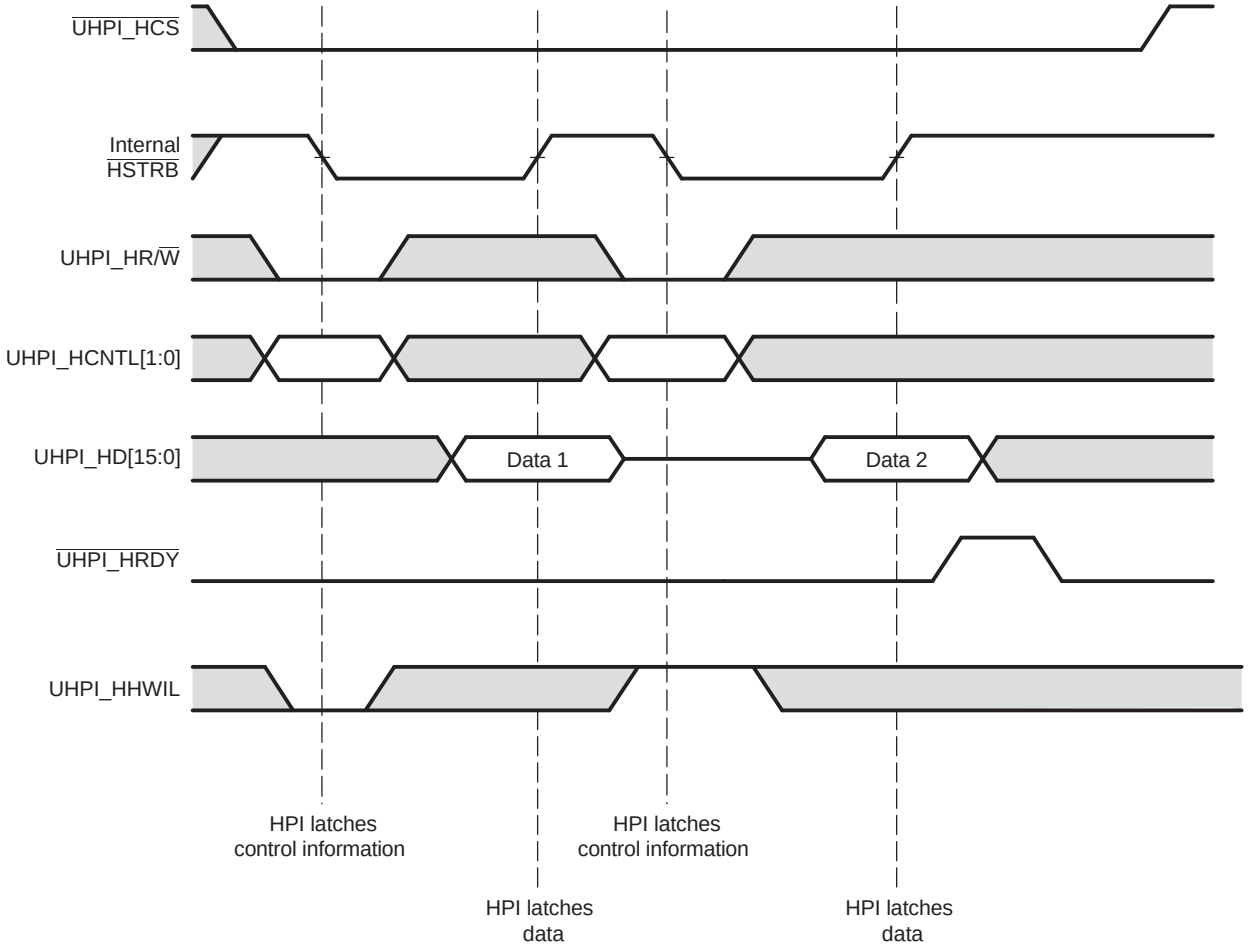
Figure 23-2 shows an example of signal connections for multiplexed transfers. Figure 23-4 and Figure 23-5 show typical HPI signal activity when performing a read and write transfer, respectively. In these cases, the falling edge of internal $\overline{\text{HSTRB}}$ is used to latch the UHPI_HCNTL[1:0], UHPI_HR/$\overline{\text{W}}$, and UHPI_HHWIL states into the HPI. Internal $\overline{\text{HSTRB}}$ is derived from $\overline{\text{UHPI\_HCS}}$, $\overline{\text{UHPI\_HDS1}}$, and $\overline{\text{UHPI\_HDS2}}$ as described in Section 23.2.6.4.

Figure 23-4. Multiplexed-Mode Host Read Cycle



NOTE: Depending on the type of write operation (HPID without autoincrementing, HPIA, HPIC, or HPID with autoincrementing) and the state of the FIFO, transitions on $\overline{\text{UHPI\_HRDY}}$ may or may not occur. For more information, see Section 23.2.6.9.

Figure 23-5. Multiplexed-Mode Host Write Cycle

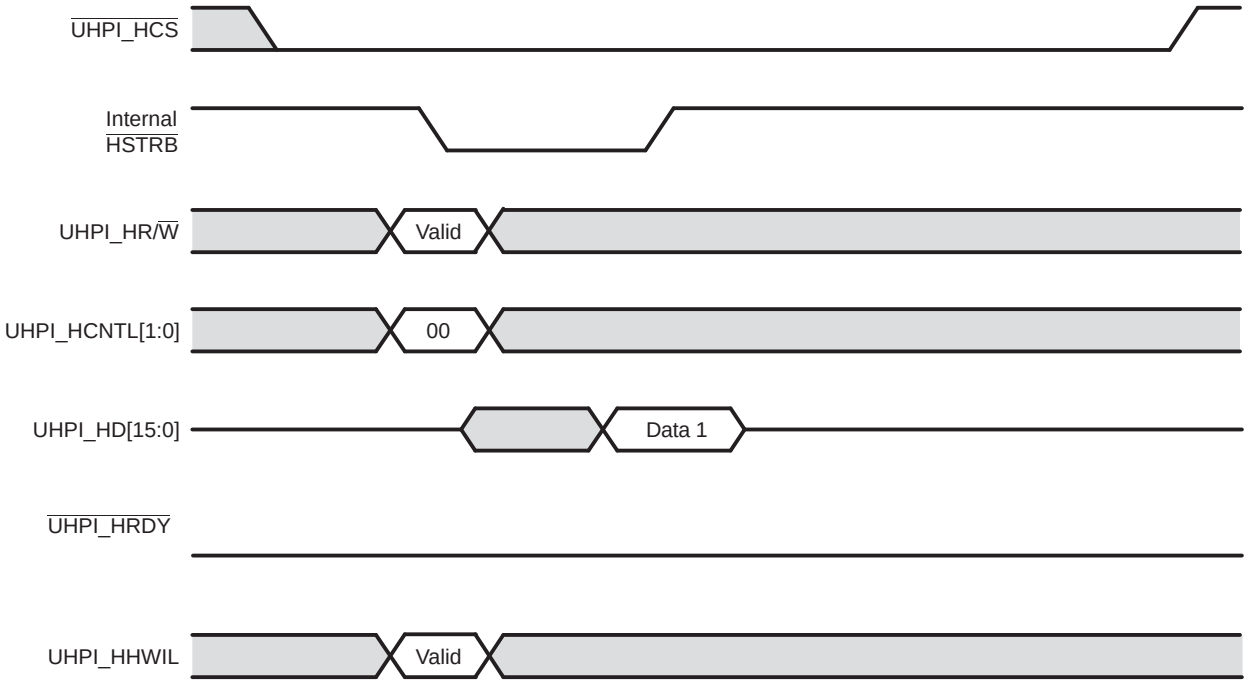


NOTE: Depending on the type of write operation (HPID without autoincrementing, HPIA, HPIC, or HPID with autoincrementing) and the state of the FIFO, transitions on UHPI_HRDY may or may not occur. For more information, see Section 23.2.6.9.

23.2.6.8 Single-Halfword HPIC Cycle

Figure 23-6 shows the special case (see Section 23.2.6.6) when the host performs a single-halfword cycle to access the HPIC. The state of UHPI_HHWIL is ignored and if a dual-halfword access is performed, then the same HPIC register is accessed twice.

Figure 23-6. Multiplexed-Mode Single-Halfword HPIC Cycle (Read or Write)



23.2.6.9 Hardware Handshaking Using the HPI-Ready (UHPI_HRDY) Signal

The HPI uses its ready signal, UHPI_HRDY, to tell the host whether it is ready to complete an access. During a read cycle, the HPI is ready (UHPI_HRDY is low) when it has data available for the host. During a write cycle, the HPI is ready (UHPI_HRDY is low) when it is ready to latch data from the host. If the HPI is not ready, it can drive UHPI_HRDY high to insert wait states. These wait states indicate to the host that read data is not yet valid (read cycle) or that the HPI is not ready to latch write data (write cycle). The number of wait states that must be inserted by the HPI is dependent upon the state of the resource that is being accessed.

When the HPI is not ready to complete the current cycle (UHPI_HRDY is high), the host can begin a new host cycle by forcing the HPI to latch new control information. However, once the cycle has been initiated, the host must wait until UHPI_HRDY goes low before causing a rising edge on the internal strobe signal (internal HSTRB) to complete the cycle. If internal HSTRB goes high when the HPI is not ready, the cycle will be terminated with invalid data being returned (read cycle) or written (write cycle).

One reason the HPI may drive UHPI_HRDY high is a not-ready condition in one of its first-in, first-out buffers (FIFOs). For example, any HPID access that occurs while the write FIFO is full or the read FIFO is empty may result in some number of wait states being inserted by the HPI. The FIFOs are explained in Section 23.2.6.10.

The following sections describe the behavior of UHPI_HRDY during HPI register accesses. In all cases, the chip select signal, UHPI_HCS, must be asserted for UHPI_HRDY to go low.

23.2.6.9.1 UHPI_HRDY Behavior During Multiplexed-Mode Read Operations

Figure 23-7 shows an HPIC (UHPI_HCNTL[1:0] = 00b) or HPIA (UHPI_HCNTL[1:0] = 10b) read cycle. Neither an HPIC read cycle nor an HPIA read cycle causes UHPI_HRDY to go high. For this type of access, the state of UHPI_HHWIL is ignored, so if a dual halfword access is performed, the same register will be accessed twice.

Figure 23-7. UHPI_HRDY Behavior During an HPIC or HPIA Read Cycle in the Multiplexed Mode

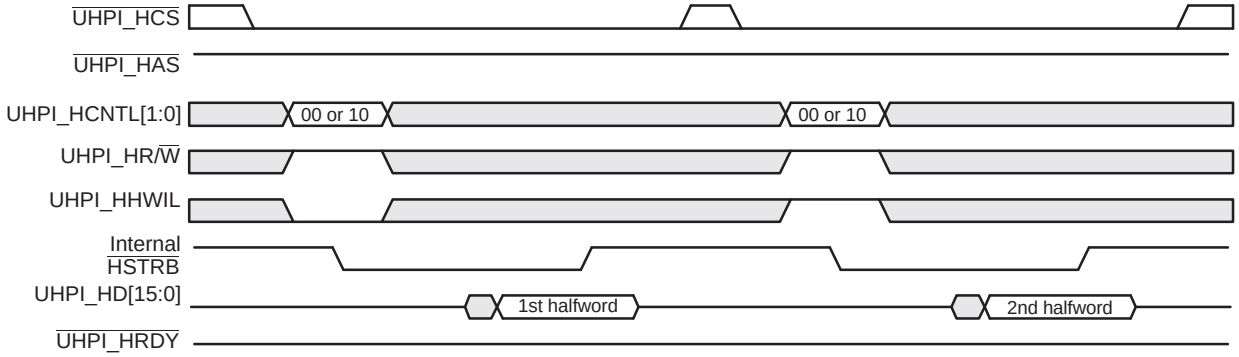


Figure 23-8 includes an HPID read cycle without autoincrementing. The host writes the memory address during the HPIA (UHPI_HCNTL[1:0] = 10b) write cycle, and the host reads the data during the HPID (UHPI_HCNTL[1:0] = 11b) read cycle. UHPI_HRDY goes high for each HPIA halfword access, but UHPI_HRDY goes high for only the first halfword access in each HPID read cycle.

Figure 23-8. UHPI_HRDY Behavior During a Data Read Operation in the Multiplexed Mode (Case 1: HPIA Write Cycle Followed by Nonautoincrement HPID Read Cycle)

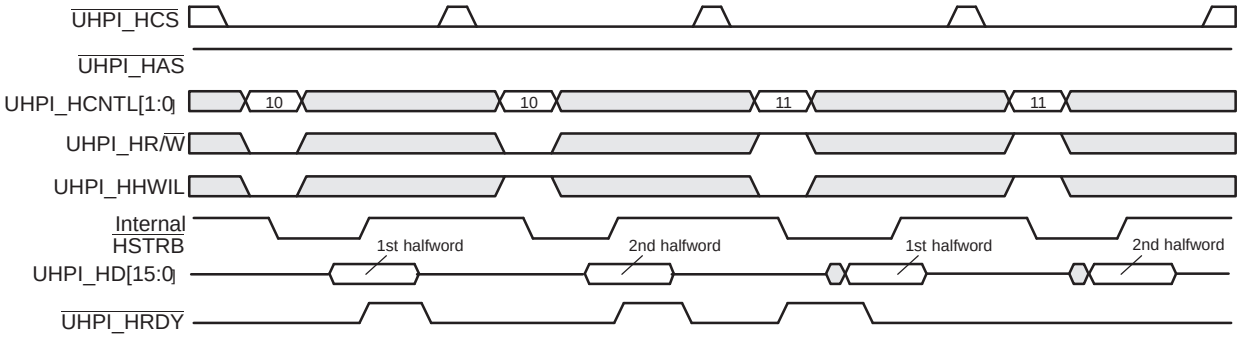
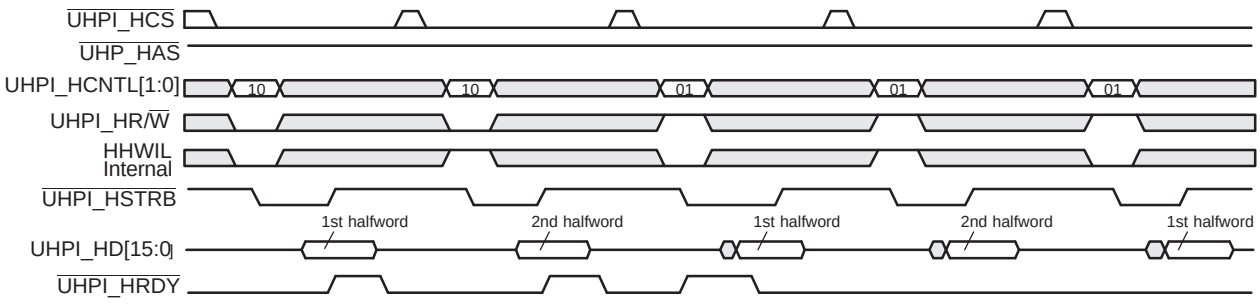


Figure 23-9 includes an autoincrement HPID read cycle. The host writes the memory address while asserting UHPI_HCNTL[1:0] = 10b and reads the data while asserting UHPI_HCNTL[1:0] = 01b. During the first HPID read cycle, UHPI_HRDY goes high for only the first halfword access, and subsequent HPID read cycles do not cause UHPI_HRDY to go high.

Figure 23-9. UHPI_HRDY Behavior During a Data Read Operation in the Multiplexed Mode (Case 2: HPIA Write Cycle Followed by Autoincrement HPID Read Cycles)



23.2.6.9.2 UHPI_HRDY Behavior During Multiplexed-Mode Write Operations

Figure 23-10 shows an HPIC (UHPI_HCNTL[1:0] = 00b) write cycle operation. An HPIC write cycle does not cause UHPI_HRDY to go high and the state of UHPI_HHWIL is ignored. Firmware is not required to perform a dual access to access HPIC.

Figure 23-10. UHPI_HRDY Behavior During an HPIC Write Cycle in the Multiplexed Mode

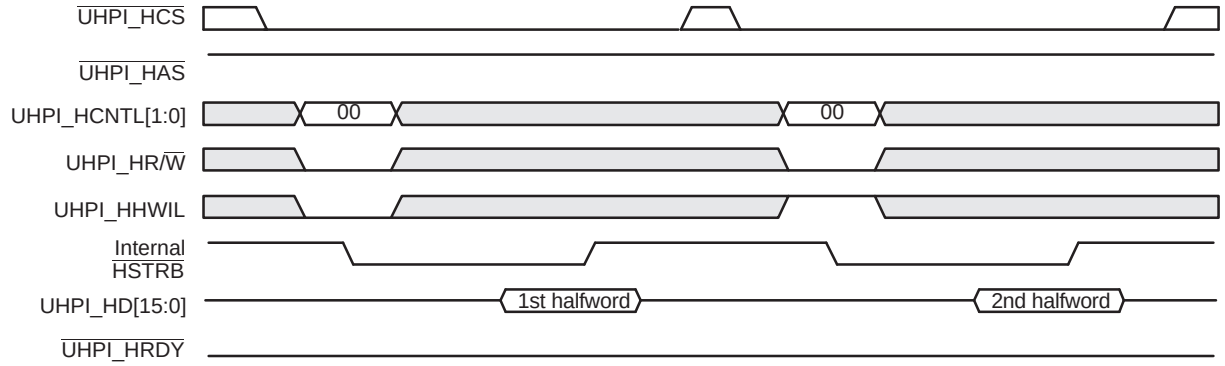


Figure 23-11 includes a HPID write cycle without autoincrementing. The host writes the memory address while UHPI_HCNTL[1:0] = 10b and writes the data while UHPI_HCNTL[1:0] = 11b. During the HPID write cycle, UHPI_HRDY goes high only for the second halfword access.

Figure 23-11. UHPI_HRDY Behavior During a Data Write Operation in the Multiplexed Mode (Case 1: No Autoincrementing)

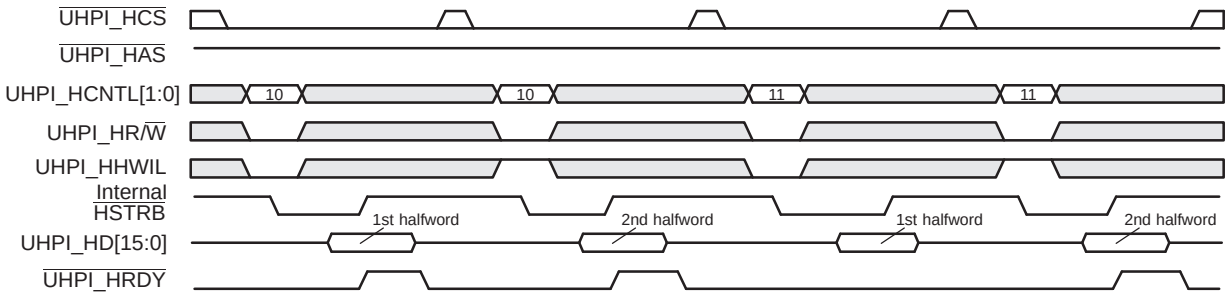


Figure 23-12 shows autoincrement HPID write cycles when the write FIFO is empty prior to the HPIA write. The host writes the memory address while UHPI_HCNTL[1:0] = 10b and writes the data while UHPI_HCNTL[1:0] = 01b. UHPI_HRDY does not go high during any of the HPID write cycles until the FIFO is full.

Figure 23-12. UHPI_HRDY Behavior During a Data Write Operation in the Multiplexed Mode (Case 2: Autoincrementing Selected, FIFO Empty Before Write)

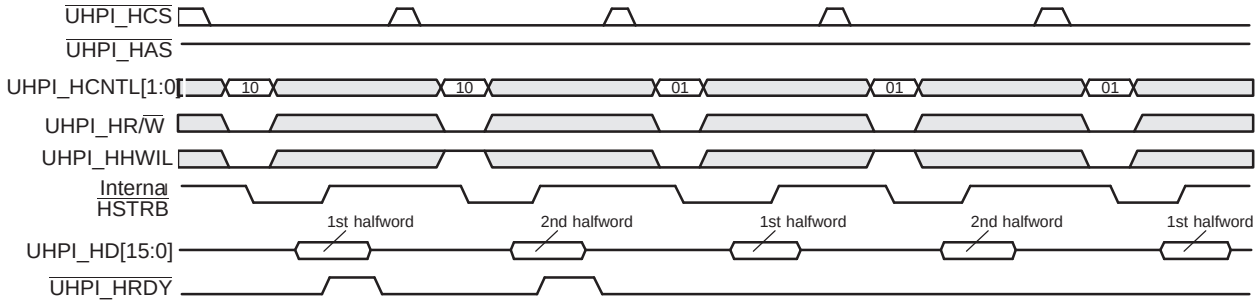
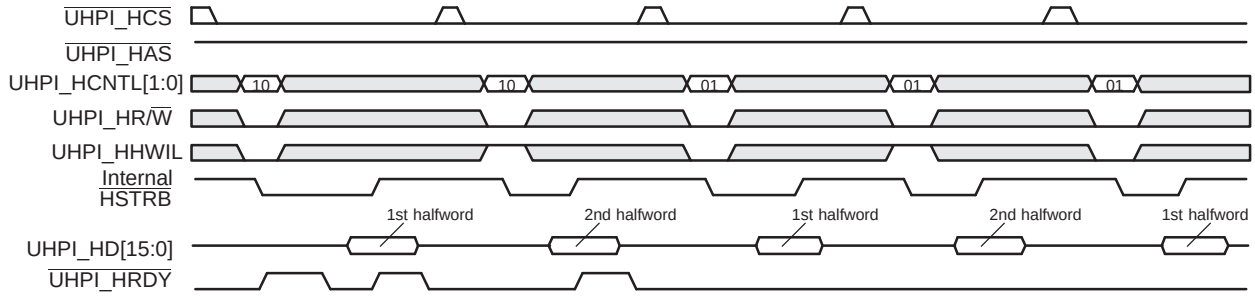


Figure 23-13 shows a case similar to that of Figure 23-12. However, in the case of Figure 23-13, the write FIFO is not empty when the HPIA access is made. UHPI_HRDY goes high twice for the first halfword access of the HPIA write cycle. The first UHPI_HRDY high period is due to the nonempty FIFO. The data currently in the FIFO must first be written to the memory. This results in UHPI_HRDY going high immediately after the falling edge of the data strobe (HSTRB). The second and third UHPI_HRDY high periods occur for the writes to the HPIA. UHPI_HRDY remains low for the HPID accesses.

Figure 23-13. UHPI_HRDY Behavior During a Data Write Operation in the Multiplexed Mode (Case 3: Autoincrementing Selected, FIFO Not Empty Before Write)

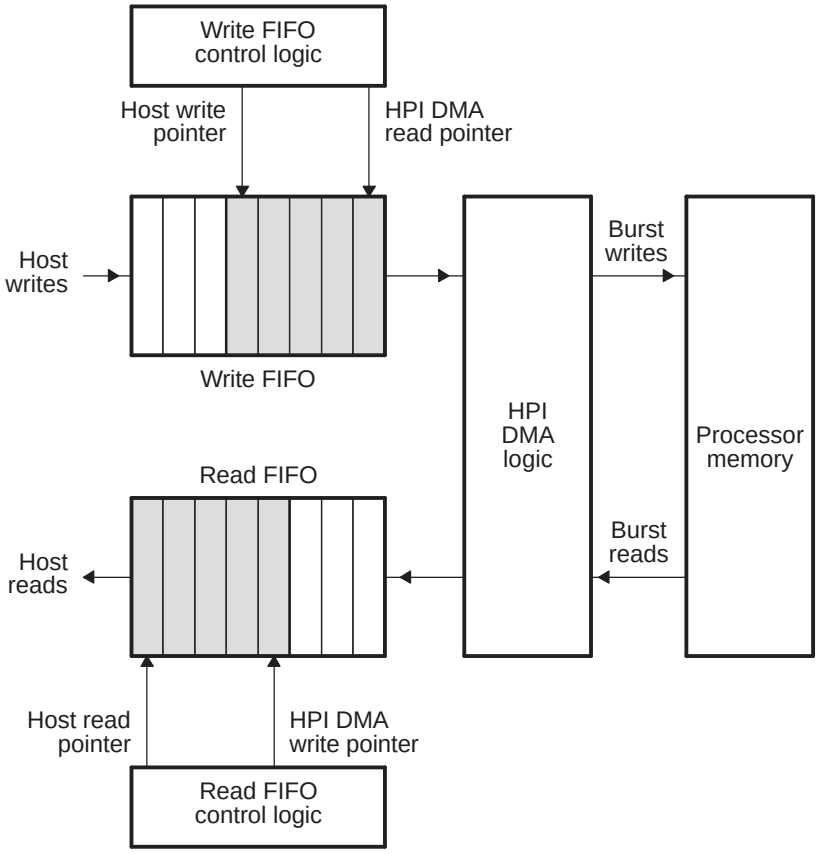


23.2.6.10 FIFOs and Bursting

The HPI data register (HPID) is a port through which the host accesses two first-in, first-out buffers (FIFOs). As shown in Figure 23-14, a read FIFO supports host read cycles, and a write FIFO supports host write cycles. Both read and write FIFOs are 8-words deep (each word is 32 bits). If the host is performing multiple reads or writes to consecutive memory addresses (autoincrement HPID cycles), the FIFOs are used for bursting. The HPI DMA logic reads or writes a burst of four words at a time when accessing one of the FIFOs.

Bursting is essentially invisible to the host because the host interface signaling is not affected. Its benefit to the host is that the $\overline{\text{UHPI\_HRDY}}$ signal is deasserted less often when there are multiple reads or writes to consecutive addresses.

Figure 23-14. FIFOs in the HPI



23.2.6.10.1 Read Bursting

When the host writes to the read address register (HPIAR), the read FIFO is flushed. Any host read data that was in the read FIFO is discarded (the read FIFO pointers are reset). If an HPI DMA write to the read FIFO is in progress at the time of a flush request, the HPI allows this write to complete and then performs the flush.

Read bursting can begin in one of two ways: the host initiates an HPID read cycle with autoincrementing, or the host initiates issues a FETCH command (writes 1 to the FETCH bit in HPIC).

If the host initiates an HPID read cycle with autoincrementing, the HPI DMA logic performs two 4-word burst operations to fill the read FIFO. The host is initially held off by the deassertion of the $\overline{\text{UHPI\_HRDY}}$ signal until data is available to be read from the read FIFO. Once data is available in the read FIFO, the host can read data from the read FIFO by performing subsequent reads of HPID with autoincrementing. Once the initial read has been performed, the HPI DMA logic continues to perform 4-word burst operations to consecutive memory addresses every time there are four empty word locations in the read FIFO. The HPI DMA logic continues to prefetch data to keep the read FIFO full, until the occurrence of an event that causes a read FIFO flush (see Section 23.2.6.10.3).

As mentioned, the second way that read bursting may begin is with a FETCH command. The host should always precede the FETCH command with the initialization of the HPIAR register or a nonautoincrement access, so that the read FIFO is flushed beforehand. When the host initiates a FETCH command, the HPI DMA logic begins to prefetch data to keep the read FIFO full, as described in the previous paragraph. The FETCH bit in HPIC does not actually store the value that is written to it; rather, the decoding of a host write of 1 to this bit is considered a FETCH command.

The FETCH command can be helpful if the host wants to minimize a stall condition on the interface. The host can initiate prefetching by writing 1 to the FETCH bit and later perform a read. The host can make use of the time it takes to load the read FIFO with read data, during which the HPI was not ready, by using the CPU to service other tasks.

Both types of continuous or burst reads described in the previous paragraphs begin with a write to the HPI address register, which causes a read FIFO flush. This is the typical way of initiating read cycles, because the initial read address needs to be specified.

NOTE: An HPID read cycle without autoincrementing does not initiate any prefetching activity. Instead, it causes the read FIFO to be flushed and causes the HPI DMA logic to perform a single-word read from the processor memory. As soon as the host activates a read cycle without autoincrementing, prefetching activity ceases until the occurrence of a FETCH command or an autoincrement read cycle.

23.2.6.10.2 Write Bursting

A write to the write address register (HPIAW) causes the write FIFO to be flushed. This means that any write data in the write FIFO is forced to its destination in the processor memory (the HPI DMA logic performs burst operations until the write FIFO is empty). When the FIFO has been flushed, the only action that will cause the HPI DMA logic to perform burst writes is a host write to HPID with autoincrementing. The initial host-write data is stored in the write FIFO. An HPI DMA write is not requested until there are four words in the write FIFO. As soon as four words have been written to the FIFO via HPID write cycles with autoincrementing, the HPI DMA logic performs a 4-word burst operation to the processor memory. The burst operations continue as long as there are at least four words in the FIFO. If the FIFO becomes full (eight words are waiting in the FIFO), the HPI holds off the host by deasserting $\overline{\text{UHPI\_HRDY}}$ until at least one empty word location is available in the FIFO.

Because excessive time might pass between consecutive burst operations, the HPI has a time-out counter. If there are fewer than four words in the write FIFO and the time-out counter expires, the HPI DMA logic empties the FIFO immediately by performing a 2-word or 3-word burst, or a single-word write, as necessary. Every time new data is written to the write FIFO, the time-out counter is automatically reset to begin its count again. The time-out period is set to a value of 160. For more detailed information about the time-out period, see your device-specific data manual.

NOTE: An HPID write cycle without autoincrementing does not initiate any bursting activity. Instead, it causes the write FIFO to be flushed and causes the HPI DMA logic to perform a single-word write to the processor memory. As soon as the host activates a write cycle without autoincrementing, bursting activity ceases until the occurrence of an autoincrement write cycle. A nonautoincrement write cycle always should be preceded by the initialization of HPIAW or by another nonautoincrement access, so that the write FIFO is flushed beforehand.

23.2.6.10.3 FIFO Flush Conditions

When specific conditions occur within the HPI, the read or write FIFO must be flushed to prevent the reading of stale data from the FIFOs. When a read FIFO flush condition occurs, all current host accesses and direct memory accesses (DMAs) to the read FIFO are allowed to complete. This includes DMAs that have been requested but not yet initiated. The read FIFO pointers are then reset, causing any read data to be discarded.

Similarly, when a write FIFO flush condition occurs, all current host accesses and DMAs to the write FIFO are allowed to complete. This includes DMAs that have been requested but not yet initiated. All posted writes in the FIFO are then forced to completion with a final burst or single-word write, as necessary.

If the host initiates an HPID host cycle during a FIFO flush, the cycle is held off with the deassertion of $\overline{\text{UHPI\_HRDY}}$ until the flush is complete and the FIFO is ready to be accessed.

The following conditions cause the read and write FIFOs to be flushed:

- Read FIFO flush conditions:
  - A value from the host is written to the read address register (HPIAR).
  - The host performs an HPID read cycle without autoincrementing.
- Write FIFO flush conditions:
  - A value from the host is written to the write address register (HPIAW).
  - The host performs an HPID write cycle without autoincrementing.
  - The write-burst time-out counter expires.

When operating with DUALHPIA = 0, any read or write flush condition causes both read and write FIFOs to be flushed. In addition, the following scenarios cause both FIFOs to be flushed when DUALHPIA = 0:

- The host performs a write to the HPIA register.
- The host performs an HPID write cycle with autoincrementing while the read FIFO is not empty (the read FIFO still contains data from prefetching or an HPID read cycle with autoincrementing).
- The host performs an HPID read cycle with autoincrementing while the write FIFO is not empty (there is still posted write data in the write FIFO).

This is useful in providing protection against reading stale data by reading a memory address when a previous write cycle has not been completed at the same address. Similarly, this protects against overwriting data at a memory address when a previous read cycle has not been completed at the same address.

When operating with DUALHPIA = 1 (HPIAR and HPIAW are independent), there is no such protection. However, when DUALHPIA = 1, data flow can occur in both directions without flushing both FIFOs simultaneously, thereby improving HPI bandwidth.

23.2.6.10.4 FIFO Behavior When a Hardware Reset or Software Reset Occurs

A hardware reset (RESET pin driven low) or an HPI software reset causes the FIFOs to be reset. The FIFO pointers are cleared, so that all data in the FIFOs are discarded. In addition, all associated FIFO logic is reset.

If a host cycle is active when a hardware or HPI software reset occurs, the $\overline{\text{UHPI\_HRDY}}$ signal is asserted (driven low), allowing the host to complete the cycle. When the cycle is complete, $\overline{\text{UHPI\_HRDY}}$ is deasserted (driven high). Any access interrupted by a reset may result in corrupted read data or a lost write data (if the write does not actually update the intended memory or register). Although data may be lost, the host interface protocol is not violated. While either of reset condition is true, and the host is idle (internal $\overline{\text{HSTRB}}$ is held high), the FIFOs are held in reset, and host transactions are held off with an inactive $\overline{\text{UHPI\_HRDY}}$ signal.

23.2.7 Reset Considerations

The HPI has two reset sources: software reset and hardware reset.

23.2.7.1 Software Reset Considerations

The HPI is not affected by a software reset issued by the emulator.

23.2.7.2 Hardware Reset Considerations

When the entire processor is reset with the RESET pin:

- If the internal strobe signal, internal $\overline{\text{HSTRB}}$, is high (host is inactive), $\overline{\text{UHPI\_HRDY}}$ is driven low and remains low until the reset condition is over.
- If internal $\overline{\text{HSTRB}}$ is low (host cycle is active), $\overline{\text{UHPI\_HRDY}}$ is driven high, allowing the host to complete the cycle. When internal $\overline{\text{HSTRB}}$ goes high (cycle is complete), $\overline{\text{UHPI\_HRDY}}$ is driven low and remains low until the reset condition is over. If the active cycle was a write cycle, the memory or register may not have been correctly updated. If the active cycle was a read cycle, the fetched value may not be valid.
- The HPI registers are reset to their default values (see Section 23.3).
- The read and write FIFOs and the associated FIFO logic are reset (this includes a flush of the FIFOs).
- Host-to-CPU and CPU-to-host interrupts are cleared.

23.2.8 Initialization

The following steps are required to configure the HPI after a hardware reset:

1. Perform the necessary device pin multiplexing setup (see your device-specific data manual).
2. Configure the HPIENA and HPIBYTEAD bits in the chip configuration 1 register (CFGCHIP1) in the *System Configuration (SYSCFG) Module* chapter.
3. Choose how HPIAR and HPIAW will be controlled by configuring the DUALHPIA bit in HPIC.
4. Choose how halfword ordering will be handled by configuring the HWOB bit in HPIC.
5. Choose how the HPI will respond to emulation suspend events by configuring the FREE and SOFT bits in PWREMU_MGMT.
6. Choose the desired initial addresses and write the addresses to HPIAW and HPIAR, appropriately.
7. Release the HPI logic from reset by clearing the HPIRST bit in HPIC.

The HPI is now ready to perform data transactions.

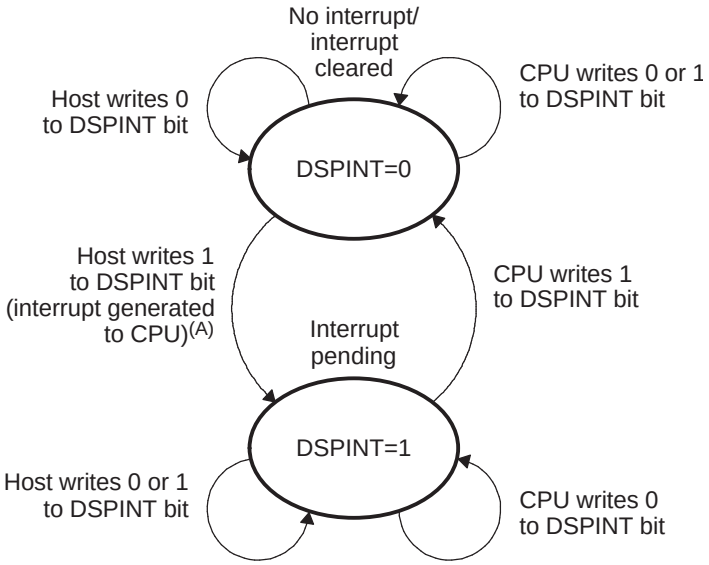
23.2.9 Interrupt Support

The host can interrupt the CPU via the DSPINT bit in HPIC, as described in Section 23.2.9.1. The CPU can send an interrupt to the host by using the HINT bit in HPIC, as described in Section 23.2.9.2.

23.2.9.1 DSPINT Bit: Host-to-CPU Interrupts

The DSPINT bit in HPIC allows the host to send an interrupt request to the CPU. The use of the DSPINT bit is summarized in Figure 23-15.

Figure 23-15. Host-to-CPU Interrupt State Diagram



A When the DSPINT bit transitions from 0 to 1, an interrupt is generated to the CPU. No new interrupt can be generated until the CPU has cleared the bit (DSPINT = 0).

To interrupt the CPU, the host must:

1. Drive both UHPI_HCNTL1 and UHPI_HCNTL0 low to request a write to HPIC.
2. Write 1 to the DSPINT bit in HPIC.

When the host sets the DSPINT bit, the HPI generates an interrupt pulse to the CPU. If this maskable interrupt is properly enabled in the CPU, the CPU executes the corresponding interrupt service routine (ISR).

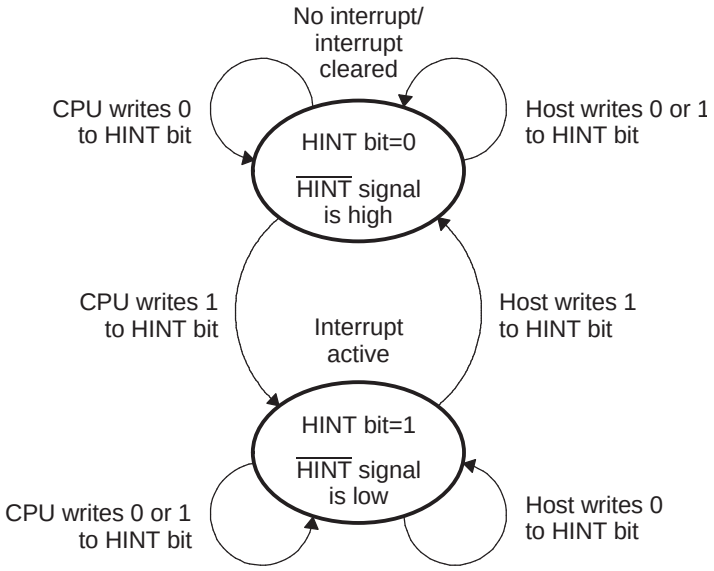
Before the host can use DSPINT to generate a subsequent interrupt to the CPU, the CPU must acknowledge the current interrupt by writing a 1 to the DSPINT bit. When the CPU writes 1, DSPINT is forced to 0. The host should verify that DSPINT = 0 before generating subsequent interrupts. While DSPINT = 1, host writes to the DSPINT bit do not generate an interrupt pulse.

Writes of 0 have no effect. A hardware reset immediately clears DSPINT and thus clears an active host-to-CPU interrupt.

23.2.9.2 HINT Bit: CPU-to-Host Interrupts

The HINT bit in HPIC allows the CPU to send an interrupt request to the host. The use of the HINT bit is summarized in Figure 23-16.

Figure 23-16. CPU-to-Host Interrupt State Diagram



If the CPU writes 1 to the HINT bit of HPIC, the HPI drives the $\overline{\text{UHPI\_HINT}}$ signal low, indicating an interrupt condition to the host. Before the CPU can use the HINT bit generate a subsequent interrupt to host, the host must acknowledge the current interrupt by writing 1 to the HINT bit. When the host does this, the HPI clears the HINT bit (HINT = 0), and this drives the $\overline{\text{UHPI\_HINT}}$ signal high. The CPU should read HPIC and make sure HINT = 0 before generating subsequent interrupts.

Writes of 0 have no effect. A hardware reset immediately clears the HINT bit and thus clears an active CPU-to-host interrupt.

23.2.10 EDMA Event Support

The HPI does not provide synchronization events to the EDMA system. Memory accesses from the HPI are handled automatically, independent of the EDMA controller. The HPI controller has its own dedicated DMA and its operation and configuration are transparent.

23.2.11 Power Management

The HPI peripheral can be placed in reduced-power modes to conserve power during periods of low activity. The power management of the HPI peripheral is controlled by the processor Power and Sleep Controller (PSC). The PSC acts as a master controller for power management for all of the peripherals on the device. For detailed information on power management procedures using the PSC, see the *Power and Sleep Controller (PSC)* chapter.

23.2.12 Emulation Considerations

The FREE and SOFT bits in the power and emulation management register (PWREMU_MGMT) determine the response of the HPI to an emulation suspend condition. If FREE = 1, the HPI is not affected, and the SOFT bit has no effect. If FREE = 0 and SOFT = 0, the HPI is not affected. If FREE = 0 and SOFT = 1:

- The HPI DMA logic halts after the current host and HPI DMA operations are completed.
- The external host interface functions as normal throughout the emulation suspend condition. The host may access the control register (HPIC). The host may also access the HPIA registers and may perform data reads until the read FIFO is empty or data writes until the write FIFO is full. As in normal operation, $\overline{\text{UHPI\_HRDY}}$ is driven low during a host cycle that cannot be completed due to the write FIFO being full or the read FIFO being empty. If this occurs, $\overline{\text{UHPI\_HRDY}}$ continues to be driven low, holding off the host, until the emulation suspend condition is over, and the FIFOs are serviced by the HPI DMA logic, allowing the host cycle to complete.
- When the emulation suspend condition is over, the appropriate requests by the HPI DMA logic are made to process any posted host writes in the write FIFO or to fill the read FIFO as necessary. HPI operation then continues as normal.

23.3 Registers

Table 23-6 lists the memory-mapped registers for the HPI. See your device-specific data manual for the memory addresses of these registers.

Table 23-6. HPI Registers

Offset	Acronym	Register Description	Section
0	REVID	Revision Identification Register	Section 23.3.1
4h	PWREMU_MGMT	Power and Emulation Management Register	Section 23.3.2
Ch	GPIO_EN	GPIO Enable Register	Section 23.3.3
10h	GPIO_DIR1	GPIO Direction 1 Register	Section 23.3.4
14h	GPIO_DAT1	GPIO Data 1 Register	Section 23.3.5
18h	GPIO_DIR2	GPIO Direction 2 Register	Section 23.3.6
1Ch	GPIO_DAT2	GPIO Data 2 Register	Section 23.3.7
30h	HPIC	Host Port Interface Control Register	Section 23.3.8
34h	HPIAW	Host Port Interface Write Address Register	Section 23.3.9
38h	HPIAR	Host Port Interface Read Address Register	Section 23.3.10

23.3.1 Revision Identification Register (REVID)

The revision identification register (REVID) contains identification data for the peripheral. REVID is shown in Figure 23-17 and described in Table 23-7.

Figure 23-17. Revision Identification Register (REVID)

31	0
REV	
R-4421 210Ah	

LEGEND: R = Read only; -*n* = value after reset

Table 23-7. Revision Identification Register (REVID) Field Descriptions

Bit	Field	Value	Description
31-0	REV	0-4421 210Ah	Revision identification

23.3.2 Power and Emulation Management Register (PWREMU_MGMT)

The power and emulation management register (PWREMU_MGMT) determines the emulation mode of the HPI. PWREMU_MGMT is shown in Figure 23-18 and described in Table 23-8.

Figure 23-18. Power and Emulation Management Register (PWREMU_MGMT)

31	16
Reserved	
R-0	

15	2	1	0
Reserved		SOFT	FREE
R-0		R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 23-8. Power and Emulation Management Register (PWREMU_MGMT) Field Descriptions

Bit	Field	Value	Description
31-2	Reserved	0	Reserved
1	SOFT		Determines emulation mode functionality of the HPI. When the FREE bit is cleared to 0, the SOFT bit selects the HPI mode.
		0	Upon emulation suspend, the HPI operation is not affected.
		1	In response to an emulation suspend event, the HPI logic halts after the current HPI transaction is completed.
0	FREE		Free run emulation control. Determines emulation mode functionality of the HPI. When the FREE bit is cleared to 0, the SOFT bit selects the HPI mode.
		0	The SOFT bit selects the HPI mode.
		1	The HPI runs free regardless of the SOFT bit.

23.3.3 GPIO Enable Register (GPIO_EN)

The GPIO enable register (GPIO_EN) enables the pin for general-purpose I/O. GPIO_EN is shown in Figure 23-19 and described in Table 23-9.

Figure 23-19. GPIO Enable Register (GPIO_EN)

31							16
Reserved							
R-0							

15						9	8
Reserved							GPIOEN8
R-0							R/W-0

7	6	5	4	3	2	1	0
GPIOEN7	GPIOEN6	GPIOEN5	GPIOEN4	Reserved	GPIOEN2	GPIOEN1	GPIOEN0
R/W-0	R/W-0	R/W-0	R/W-0	R-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 23-9. GPIO Enable Register (GPIO_EN) Field Descriptions

Bit	Field	Value	Description
31-9	Reserved	0	Reserved
8	GPIOEN8		Enable as GPIO for UHPI_HD[15:8] pins
		0	Disable pins for GPIO. Pins functions as HPI signal.
		1	Enable pins for GPIO.
7	GPIOEN7		Enable as GPIO for UHPI_HD[7:0] pins.
		0	Disable pins for GPIO. Pins functions as HPI signal.
		1	Enable pins for GPIO.
6	GPIOEN6		Enable as GPIO for $\overline{\text{UHPI\_HINT}}$ pin.
		0	Disable pin for GPIO. Pin functions as HPI signal.
		1	Enable pin for GPIO.
5	GPIOEN5		Enable as GPIO for UHPI_HRDY pin.
		0	Disable pin for GPIO. Pin functions as HPI signal.
		1	Enable pin for GPIO.
4	GPIOEN4		Enable as GPIO for UHPI_HHWIL pin.
		0	Disable pin for GPIO. Pin functions as HPI signal.
		1	Enable pin for GPIO.
3	Reserved	0	Reserved
2	GPIOEN2		Enable as GPIO for $\overline{\text{UHPI\_HAS}}$ pin.
		0	Disable pin for GPIO. Pin functions as HPI signal.
		1	Enable pin for GPIO.
1	GPIOEN1		Enable as GPIO for UHPI_HCNTL[1:0] pins.
		0	Disable pins for GPIO. Pins functions as HPI signal.
		1	Enable pins for GPIO.
0	GPIOEN0		Enable as GPIO for $\overline{\text{UHPI\_HCS}}$, $\overline{\text{UHPI\_HDS1}}$, $\overline{\text{UHPI\_HDS2}}$, UHPI_HR/$\overline{\text{W}}$ pins.
		0	Disable pins for GPIO. Pins functions as HPI signal.
		1	Enable pins for GPIO.

23.3.4 GPIO Direction 1 Register (GPIO_DIR1)

The GPIO direction 1 register (GPIO_DIR1) determines if the UHPI_HD*n* pin is an input or an output. GPIO_DIR1 is shown in Figure 23-20 and described in Table 23-10.

Figure 23-20. GPIO Direction 1 Register (GPIO_DIR1)

31															16
Reserved															
R-0															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
HD15	HD14	HD13	HD12	HD11	HD10	HD9	HD8	HD7	HD6	HD5	HD4	HD3	HD2	HD1	HD0
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 23-10. GPIO Direction 1 Register (GPIO_DIR1) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	Reserved
15-0	HD*n*		Direction control for UHPI_HD*n* pin.
		0	UHPI_HD*n* pin is an input.
		1	UHPI_HD*n* pin is an output.

23.3.5 GPIO Data 1 Register (GPIO_DAT1)

The GPIO data 1 register (GPIO_DAT1) determines the value driven on the corresponding UHPI_HD*n* pin, if the pin is configured as an output (GPIO_DIR1.HD*n* = 1). Writes do not affect pins not configured as GPIO outputs. The bits in GPIO_DAT1 are set or cleared by writing directly to this register. A read of GPIO_DAT1 returns the value of the register bit (HD*n*) not the value at the UHPI_HD*n* pin (that might be configured as an input). GPIO_DAT1 is shown in Figure 23-21 and described in Table 23-11.

Figure 23-21. GPIO Data 1 Register (GPIO_DAT1)

31															16
Reserved															
R-0															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
HD15	HD14	HD13	HD12	HD11	HD10	HD9	HD8	HD7	HD6	HD5	HD4	HD3	HD2	HD1	HD0
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 23-11. GPIO Data 1 Register (GPIO_DAT1) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	Reserved
15-0	HD*n*	0-1	Data read from/written to UHPI_HD*n* pin.

23.3.6 GPIO Direction 2 Register (GPIO_DIR2)

The GPIO direction 2 register (GPIO_DIR2) determines if the HPI pin is an input or an output. GPIO_DIR2 is shown in Figure 23-22 and described in Table 23-12.

Figure 23-22. GPIO Direction 2 Register (GPIO_DIR2)

31							16
Reserved							
R-0							

15						10	9	8
Reserved							HRDY	HINTZ
R-0							R/W-0	R/W-0

7	6	5	4	3	2	1	0
HCNTL0	HCNTL1	HHWIL	HRW	HDS2Z	HDS1Z	HCSZ	HASZ
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; *-n* = value after reset

Table 23-12. GPIO Direction 2 Register (GPIO_DIR2) Field Descriptions

Bit	Field	Value	Description
31-10	Reserved	0	Reserved
9	HRDY		Direction control for UHPI_HRDY pin.
		0	UHPI_HRDY pin is an input.
		1	UHPI_HRDY pin is an output.
8	HINTZ		Direction control for $\overline{\text{UHPI\_HINT}}$ pin.
		0	$\overline{\text{UHPI\_HINT}}$ pin is an input.
		1	$\overline{\text{UHPI\_HINT}}$ pin is an output.
7	HCNTL0		Direction control for UHPI_HCNTL0 pin.
		0	UHPI_HCNTL0 pin is an input.
		1	UHPI_HCNTL0 pin is an output.
6	HCNTL1		Direction control for UHPI_HCNTL1 pin.
		0	UHPI_HCNTL1 pin is an input.
		1	UHPI_HCNTL1 pin is an output.
5	HHWIL		Direction control for UHPI_HHWIL pin.
		0	UHPI_HHWIL pin is an input.
		1	UHPI_HHWIL pin is an output.
4	HRW		Direction control for UHPI_HR/$\overline{\text{W}}$ pin.
		0	UHPI_HR/$\overline{\text{W}}$ pin is an input.
		1	UHPI_HR/$\overline{\text{W}}$ pin is an output.
3	HDS2Z		Direction control for $\overline{\text{UHPI\_HDS2}}$ pin.
		0	$\overline{\text{UHPI\_HDS2}}$ pin is an input.
		1	$\overline{\text{UHPI\_HDS2}}$ pin is an output.
2	HDS1Z		Direction control for $\overline{\text{UHPI\_HDS1}}$ pin.
		0	$\overline{\text{UHPI\_HDS1}}$ pin is an input.
		1	$\overline{\text{UHPI\_HDS1}}$ pin is an output.
1	HCSZ		Direction control for $\overline{\text{UHPI\_HCS}}$ pin.
		0	$\overline{\text{UHPI\_HCS}}$ pin is an input.
		1	$\overline{\text{UHPI\_HCS}}$ pin is an output.
0	HASZ		Direction control for $\overline{\text{UHPI\_HAS}}$ pin.
		0	$\overline{\text{UHPI\_HAS}}$ pin is an input.
		1	$\overline{\text{UHPI\_HAS}}$ pin is an output.

23.3.7 GPIO Data 2 Register (GPIO_DAT2)

The GPIO data 2 register (GPIO_DAT2) determines the value driven on the corresponding HPI pin, if the pin is configured as an output (GPIO_DIR2 bit = 1). Writes do not affect pins not configured as GPIO outputs. The bits in GPIO_DAT2 are set or cleared by writing directly to this register. A read of GPIO_DAT2 returns the value of the register bit not the value at the HPI pin (that might be configured as an input). GPIO_DAT2 is shown in Figure 23-23 and described in Table 23-13.

Figure 23-23. GPIO Data 2 Register (GPIO_DAT2)

31							16
Reserved							
R-0							
15					10	9	8
Reserved						HRDY	HINTZ
R-0						R/W-0	R/W-0
7	6	5	4	3	2	1	0
HCNTL0	HCNTL1	HHWIL	HRW	HDS2Z	HDS1Z	HCSZ	HASZ
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 23-13. GPIO Data 2 Register (GPIO_DAT2) Field Descriptions

Bit	Field	Value	Description
31-10	Reserved	0	Reserved
9	HRDY	0-1	Data read from/written to UHPI_HRDY pin.
8	HINTZ	0-1	Data read from/written to $\overline{\text{UHPI\_HINT}}$ pin.
7	HCNTL0	0-1	Data read from/written to UHPI_HCNTL0 pin.
6	HCNTL1	0-1	Data read from/written to UHPI_HCNTL1 pin.
5	HHWIL	0-1	Data read from/written to UHPI_HHWIL pin.
4	HRW	0-1	Data read from/written to UHPI_HR/$\overline{\text{W}}$ pin.
3	HDS2Z	0-1	Data read from/written to $\overline{\text{UHPI\_HDS2}}$ pin.
2	HDS1Z	0-1	Data read from/written to $\overline{\text{UHPI\_HDS1}}$ pin.
1	HCSZ	0-1	Data read from/written to $\overline{\text{UHPI\_HCS}}$ pin.
0	HASZ	0-1	Data read from/written to $\overline{\text{UHPI\_HAS}}$ pin.

23.3.8 Host Port Interface Control Register (HPIC)

The host port interface control register (HPIC) stores configuration and control information for the HPI. As shown in Figure 23-24 and Figure 23-25 and described in Table 23-14, the host and CPU do not have the same access permissions. The host has full read/write access; the CPU has primarily read-only access, but with the exception that the CPU can write 1 to the HINT bit to generate an interrupt to the host.

Figure 23-24. Host Port Interface Control Register (HPIC)–Host Access Permissions

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
R-0															

15	14	13	12	11	10	9	8
Reserved				HPIASEL	Reserved	DUALHPIA	HWOBSTAT
R-0				R/W-0	R/W-0	R/W-0	R-0

7	6	5	4	3	2	1	0
HPIRST	Reserved		FETCH	Reserved	HINT	DSPINT	HWOB
R-1	R-2h		R/W-0	R-1	R/W-1 (Host) R/W1C-0 (CPU)	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; W1C = Write 1 to clear (writing 0 has no effect); -*n* = value after reset

Figure 23-25. Host Port Interface Control Register (HPIC)–CPU Access Permissions

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
R-0															

15	14	13	12	11	10	9	8
Reserved				HPIASEL	Reserved	DUALHPIA	HWOBSTAT
R-0				R-0	R-0	R-0	R-0

7	6	5	4	3	2	1	0
HPIRST	Reserved		FETCH	Reserved	HINT	DSPINT	HWOB
R/W-1	R-2h		R-0	R-1	R/W-1 (Host) R/W1C-0 (CPU)	R/W-0	R-0

LEGEND: R/W = Read/Write; R = Read only; W1C = Write 1 to clear (writing 0 has no effect); -*n* = value after reset

Table 23-14. Host Port Interface Control Register (HPIC) Field Descriptions

Bit	Field	Value	Description
31-12	Reserved	0	Reserved
11	HPIASEL		HPI address register select bit. When DUALHPIA = 1, the HPIASEL bit is used to select the HPI address register to be accessed.
		0	Selects the HPI write address register (HPIAW).
		1	Selects the HPI read address register (HPIAR).
10	Reserved	0	Reserved. Always write 0 to this bit.
9	DUALHPIA		Dual HPIA mode configuration bit. The CPU can access both HPI address registers separately, regardless of the DUALHPIA setting. (Regardless of this bit, dual HPIA mode is implied when the CPU has ownership of the HPI address registers).
		0	The two HPI address registers (HPIAW and HPIAR) operate as a single HPI address register in terms of host accesses.
		1	Dual HPIA mode operation is enabled.
8	HWOBSTAT		HWOB status. The value of the HWOB bit is also stored in this bit position. A write to the HWOB bit also updates HWOBSTAT.
		0	HWOB bit is logic 0.
		1	HWOB bit is logic 1.
7	HPIRST		HPI reset. Some HPI logic is held in reset when the HPIRST bit is set. The HPIRST bit must be cleared to 0 before data transactions can take place.
		0	HPI is released from reset.
		1	HPI is held in reset.
6-5	Reserved	2h	Reserved
4	FETCH		Host data fetch request bit. Only the host may write to FETCH. When a host writes a 1 to FETCH, a request is posted in the HPI to prefetch data into the read FIFO. Host and CPU reads of FETCH return a 0.
3	Reserved	1	Reserved
2	HINT		Processor-to-host interrupt. The CPU writes a 1 to HINT to generate a host interrupt. HINT has an inverted logic level to the $\overline{\text{UHPI\_HINT}}$ pin. The host must write a 1 to HINT to clear the $\overline{\text{UHPI\_HINT}}$ pin; writing a 0 to HINT by the host or processor has no effect.
		0	No effect.
		1	A CPU write generates a host interrupt ($\overline{\text{UHPI\_HINT}}$ signal goes low). A host write sets the $\overline{\text{UHPI\_HINT}}$ signal high (clears the interrupt).
1	DSPINT		Host-to-processor interrupt. The host writes a 1 to DSPINT to generate a processor interrupt; writing a 0 to DSPINT by the host or processor has no effect.
		0	No effect.
		1	A host write generates a processor interrupt.
0	HWOB		Halfword ordering bit. HWOB affects both data and address transfers. HWOB must be initialized before the first data or address register access.
		0	First halfword is most significant.
		1	First halfword is least significant.

23.3.9 Host Port Interface Write Address Register (HPIAW)

The HPI contains two 32-bit address registers: one for read operations (HPIAR) and one for write operations (HPIAW). The host port interface write address register (HPIAW) is shown in Figure 23-26 and described in Table 23-15. The HPI can be configured such that HPIAR and HPIAW act as a single 32-bit HPIA (single-HPIA mode) or as two separate 32-bit HPIAs (dual-HPIA mode) from the perspective of the host. For details about these HPIA modes, see Section 23.2.6.1.

Note that the addresses loaded into the HPI address registers can be configured by the HPIBYTEAD bit in the chip configuration 1 register (CFGCHIP1) of the system configuration module. If byte address is selected (HPIBYTEAD = 1), the address must be 32-bit word aligned (with the least-significant two bits equal to zero).

Figure 23-26. Host Port Interface Write Address Register (HPIAW)

31	0
HPIAW	
R-0000 8000h	

LEGEND: R = Read only; -*n* = value after reset

Table 23-15. Host Port Interface Write Address Register (HPIAW) Field Descriptions

Bit	Field	Value	Description
31-0	HPIAW	0-FFFF FFFFh	Host port interface write address.

23.3.10 Host Port Interface Read Address Register (HPIAR)

The HPI contains two 32-bit address registers: one for read operations (HPIAR) and one for write operations (HPIAW). The host port interface read address register (HPIAR) is shown in Figure 23-27 and described in Table 23-16. The HPI can be configured such that HPIAR and HPIAW act as a single 32-bit HPIA (single-HPIA mode) or as two separate 32-bit HPIAs (dual-HPIA mode) from the perspective of the host. For details about these HPIA modes, see Section 23.2.6.1.

Note that the addresses loaded into the HPI address registers can be configured by the HPIBYTEAD bit in the chip configuration 1 register (CFGCHIP1) of the system configuration module. If byte address is selected (HPIBYTEAD = 1), the address must be 32-bit word aligned (with the least-significant two bits equal to zero).

Figure 23-27. Host Port Interface Read Address Register (HPIAR)

31	0
HPIAR	
R-0000 8000h	

LEGEND: R = Read only; -*n* = value after reset

Table 23-16. Host Port Interface Read Address Register (HPIAR) Field Descriptions

Bit	Field	Value	Description
31-0	HPIAR	0-FFFF FFFFh	Host port interface read address.

Inter-Integrated Circuit (I2C) Module

This chapter describes the inter-integrated circuit (I2C) peripheral. The scope of this chapter assumes that you are familiar with the Philips Semiconductors Inter-IC bus (I2C-bus) specification version 2.1.

Topic **Page**

24.1 Introduction

24.1.1 Purpose of the Peripheral

The I2C peripheral provides an interface between the SoC and other devices that are compliant with the I2C-bus specification and connected by way of an I2C-bus. External components that are attached to this two-wire serial bus can transmit and receive data that is up to eight bits wide both to and from the SoC through the I2C peripheral.

24.1.2 Features

The I2C peripheral has the following features:

- Compliance with the Philips Semiconductors I2C-bus specification (version 2.1):
  - Support for byte format transfer
  - 7-bit and 10-bit addressing modes
  - General call
  - START byte mode
  - Support for multiple master-transmitters and slave-receivers mode
  - Support for multiple slave-transmitters and master-receivers mode
  - Combined master transmit/receive and receive/transmit mode
  - I2C data transfer rate of from 10 kbps up to 400 kbps (Philips I2C rate)
- 2-bit to 8-bit format transfer
- Free data format mode
- One read DMA event and one write DMA event that the DMA can use
- Seven interrupts that the CPU can use
- Peripheral enable/disable capability

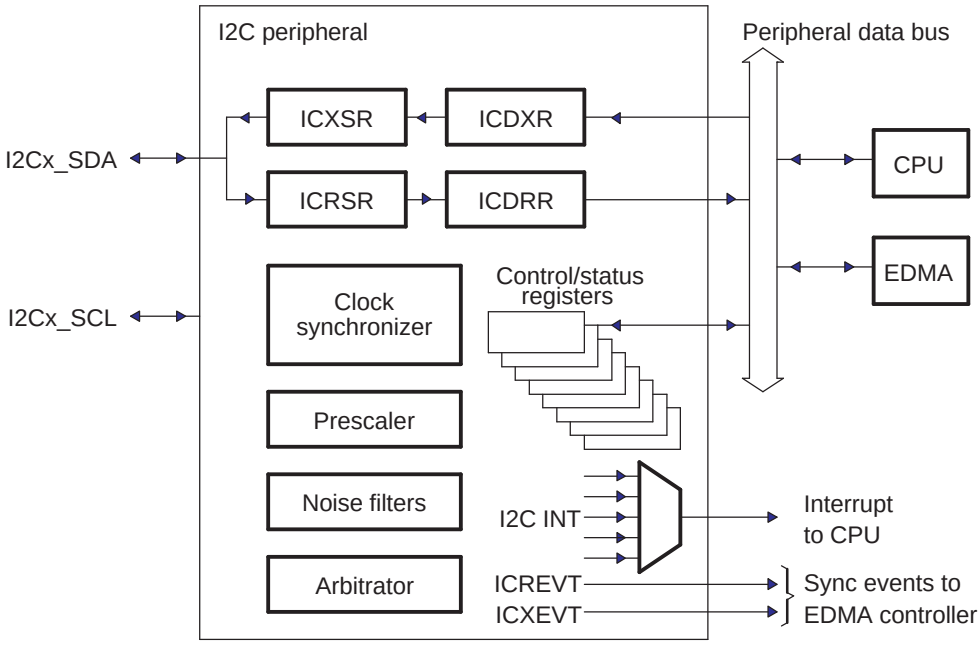
24.1.2.1 Features Not Supported

- High-speed mode
- CBUS-compatibility mode
- The combined format in 10-bit addressing mode (the I2C sends the slave address the second byte every time it sends the slave address the first byte).

24.1.3 Functional Block Diagram

A block diagram of the I2C peripheral is shown in Figure 26-1. Refer to Section 24.2 for detailed information about the architecture of the I2C peripheral.

Figure 24-1. I2C Peripheral Block Diagram



24.1.4 Industry Standard(s) Compliance Statement

The I2C peripheral is compliant with the Philips Semiconductors Inter-IC bus (I2C-bus) specification version 2.1.

24.2 Architecture

The I2C peripheral consists of the following primary blocks:

- A serial interface: one data pin (I2Cx_SDA) and one clock pin (I2Cx_SCL)
- Data registers to temporarily hold receive data and transmit data traveling between the I2Cx_SDA pin and the CPU or the EDMA controller
- Control and status registers
- A peripheral data bus interface to enable the CPU and the EDMA controller to access the I2C peripheral registers
- A clock synchronizer to synchronize the I2C input clock (from the processor clock generator) and the clock on the I2Cx_SCL pin, and to synchronize data transfers with masters of different clock speeds
- A prescaler to divide down the input clock that is driven to the I2C peripheral
- A noise filter on each of the two pins, I2Cx_SDA and I2Cx_SCL
- An arbitrator to handle arbitration between the I2C peripheral (when it is a master) and another master
- Interrupt generation logic, so that an interrupt can be sent to the CPU
- EDMA event generation logic, so that activity in the EDMA controller can be synchronized to data reception and data transmission in the I2C peripheral

Figure 26-1 shows the four registers used for transmission and reception. The CPU or the EDMA controller writes data for transmission to ICDXR and reads received data from ICDRR. When the I2C peripheral is configured as a transmitter, data written to ICDXR is copied to ICXSR and shifted out on the I2Cx_SDA pin one bit a time. When the I2C peripheral is configured as a receiver, received data is shifted into ICRSR and then copied to ICDRR.

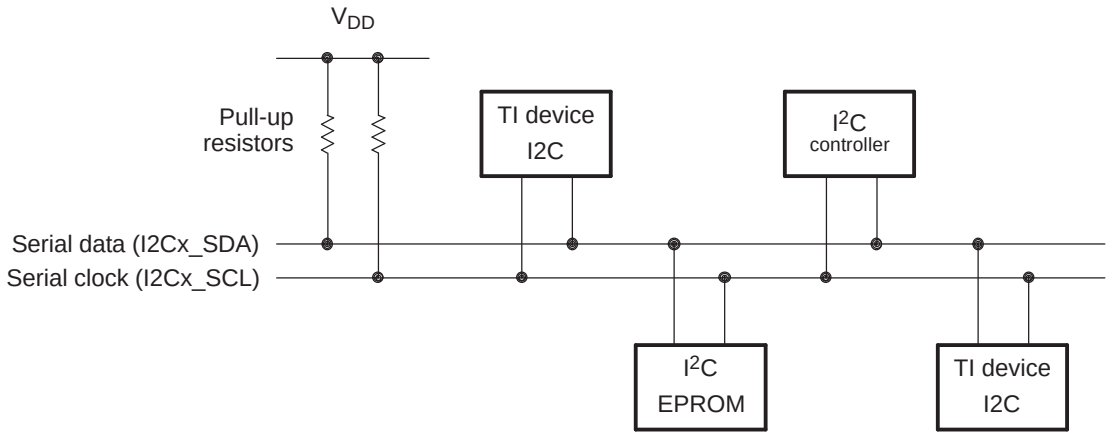
24.2.1 Bus Structure

Figure 26-1 shows how the I2C peripheral is connected to the I2C bus. The I2C bus is a multi-master bus that supports a multi-master mode. This allows more than one device capable of controlling the bus that is connected to it. A unique address recognizes each I2C device. Each I2C device can operate as either transmitter or receiver, depending on the function of the device. Devices that are connected to the I2C bus can be considered a master or slave when performing data transfers, in addition to being a transmitter or receiver.

NOTE: A master device is the device that initiates a data transfer on the bus and generates the clock signals to permit that transfer. Any device that is addressed by this master is considered a slave during this transfer.

An example of multiple I2C modules that are connected for a two-way transfer from one device to other devices is shown in Figure 24-2.

Figure 24-2. Multiple I2C Modules Connected

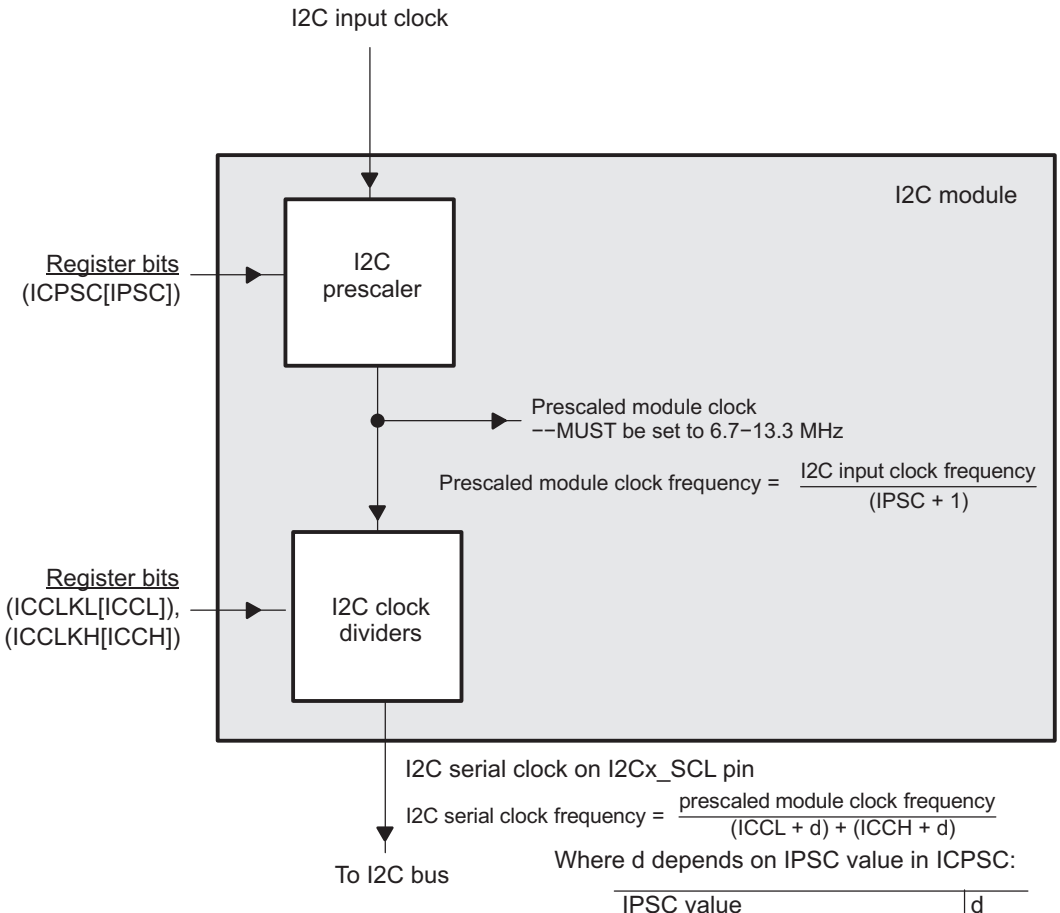


24.2.2 Clock Generation

As shown in Figure 24-3, I2C input clock is fed to the I2C module. A programmable prescaler (IPSC bit in ICPSC) in the I2C module divides down the I2C input clock to produce a prescaled module clock. The prescaled module clock must be operated within the range of 6.7 to 13.3 MHz. The I2C clock dividers divide-down the high (ICCH bit in ICCLKH) and low portions (ICCL bit in ICCLKL) of the prescaled module clock signal to produce the I2C serial clock, which appears on the I2Cx_SCL pin when the I2C module is configured to be a master on the I2C bus.

The prescaler (IPSC bit in ICPSC) must only be initialized while the I2C module is in the reset state (IRS = 0 in ICMDR). The prescaled frequency only takes effect when the IRS bit in ICMDR is changed to 1. Changing the IPSC bit in ICPSC while IRS = 1 in ICMDR has no effect. Likewise, you must configure the I2C clock dividers (ICCH bit in ICCLKH and ICCL bit in ICCLKL) while the I2C module is still in reset (IRS = 0 in ICMDR).

Figure 24-3. Clocking Diagram for the I2C Peripheral



Where d depends on IPSC value in ICPSC:

IPSC value	d
0	7
1	6
2h−FFh	5

CAUTION

Prescaled Module Clock Frequency Range:

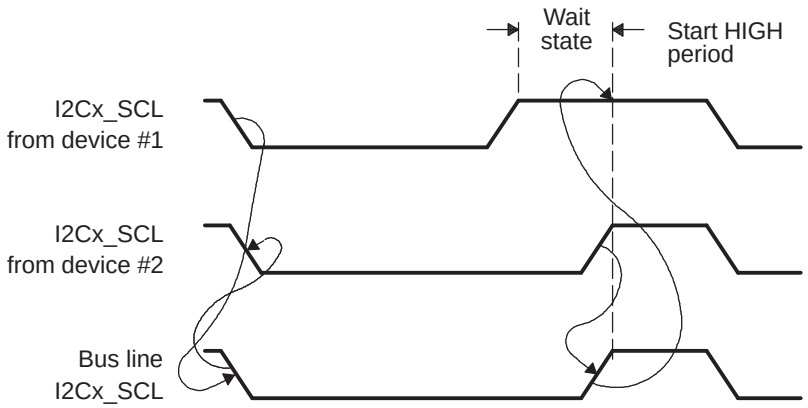
The I2C module must be operated with a prescaled module clock frequency of 6.7 to 13.3 MHz. The I2C prescaler register (ICPSC) must be configured to this frequency range.

24.2.3 Clock Synchronization

Only one master device generates the clock signal (I2Cx_SCL) under normal conditions. However, there are two or more masters during the arbitration procedure; and, you must synchronize the clock so that you can compare the data output. Figure 24-4 illustrates the clock synchronization. The wired-AND property of I2Cx_SCL means that a device that first generates a low period on I2Cx_SCL (device #1) overrules the other devices. At this high-to-low transition, the clock generators of the other devices are forced to start their own low period. The I2Cx_SCL is held low by the device with the longest low period. The other devices that finish their low periods must wait for I2Cx_SCL to be released before starting their high periods. A synchronized signal on I2Cx_SCL is obtained, where the slowest device determines the length of the low period and the fastest device determines the length of the high period.

If a device pulls down the clock line for a longer time, the result is that all clock generators must enter the wait state. This way, a slave slows down a fast master and the slow device creates enough time to store a received data word or to prepare a data word that you are going to transmit.

Figure 24-4. Synchronization of Two I2C Clock Generators During Arbitration



24.2.4 Signal Descriptions

The I2C peripheral has a serial data pin (I2Cx_SDA) and a serial clock pin (I2Cx_SCL) for data communication, as shown in Figure 26-1. These two pins carry information between the device and other devices that are connected to the I2C-bus. The I2Cx_SDA and I2Cx_SCL pins both are bi-directional. They each must be connected to a positive supply voltage using a pull-up resistor. When the bus is free, both pins are high. The driver of these two pins has an open-drain configuration to perform the required wired-AND function.

See your device-specific data manual for additional timing and electrical specifications for these pins.

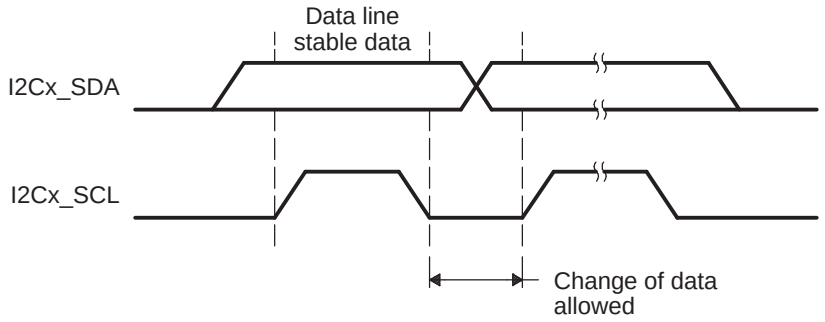
24.2.4.1 Input and Output Voltage Levels

The master device generates one clock pulse for each data bit that is transferred. Due to a variety of different technology devices that can be connected to the I2C-bus, the levels of logic 0 (low) and logic 1 (high) are not fixed and depend on the associated power supply level. See your device-specific data manual for more information.

24.2.4.2 Data Validity

The data on I2Cx_SDA must be stable during the high period of the clock (see Figure 24-5). The high or low state of the data line, I2Cx_SDA, can change only when the clock signal on I2Cx_SCL is low.

Figure 24-5. Bit Transfer on the I2C-Bus



24.2.5 START and STOP Conditions

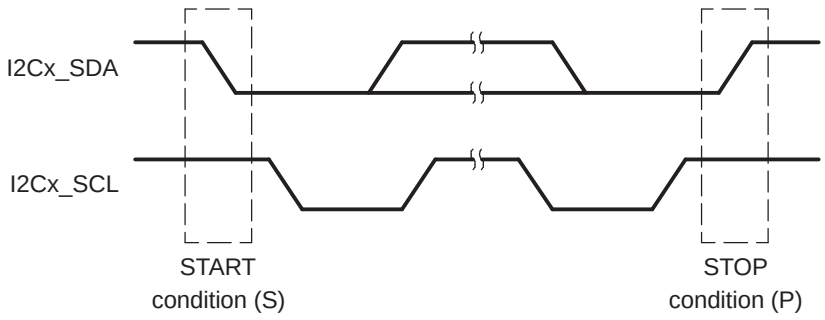
The I2C peripheral can generate START and STOP conditions when the peripheral is configured to be a master on the I2C-bus, as shown in Figure 24-6:

- The START condition is defined as a high-to-low transition on the I2Cx_SDA line while I2Cx_SCL is high. A master drives this condition to indicate the start of a data transfer.
- The STOP condition is defined as a low-to-high transition on the I2Cx_SDA line while I2Cx_SCL is high. A master drives this condition to indicate the end of a data transfer.

The I2C-bus is considered busy after a START condition and before a subsequent STOP condition. The bus busy (BB) bit of ICSTR is 1. The bus is considered free between a STOP condition and the next START condition. The BB is 0.

The master mode (MST) bit and the START condition (STT) bit in ICMDR must both be 1 for the I2C peripheral to start a data transfer with a START condition. The STOP condition (STP) bit must be set to 1 for the I2C peripheral to end a data transfer with a STOP condition. A repeated START condition generates when BB is set to 1 and STT is also set to 1. See Section 24.3.9 for a description of ICMDR (including the MST, STT, and STP bits).

Figure 24-6. I2C Peripheral START and STOP Conditions



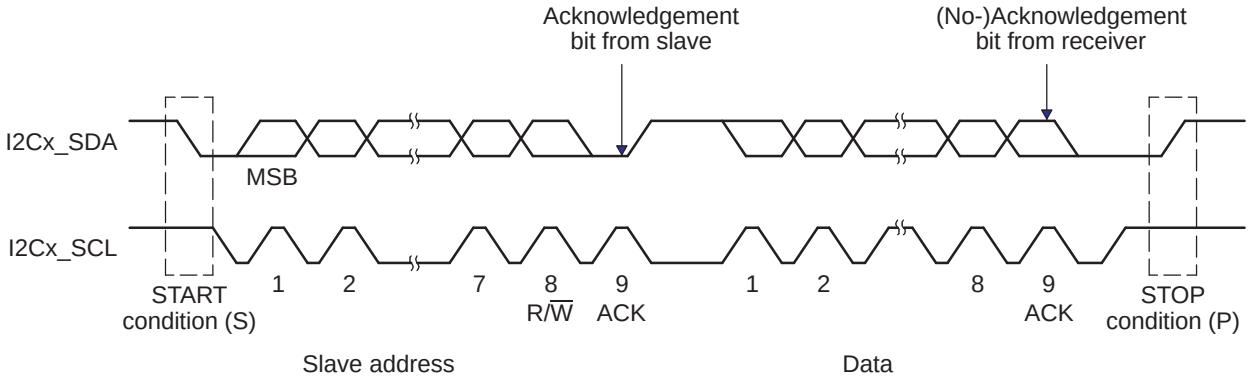
24.2.6 Serial Data Formats

Figure 24-7 shows an example of a data transfer on the I2C-bus. The I2C peripheral supports 1-bit to 8-bit data values. Figure 24-7 is shown in an 8-bit data format (BC = 000 in ICMDR). Each bit put on the I2Cx_SDA line is equivalent to one pulse on the I2Cx_SCL line. The data is always transferred with the most-significant bit (MSB) first. The number of data values that can be transmitted or received is unrestricted; however, the transmitters and receivers must agree on the number of data values being transferred.

The I2C peripheral supports the following data formats:

- 7-bit addressing mode
- 10-bit addressing mode
- Free data format mode

Figure 24-7. I2C Peripheral Data Transfer



24.2.6.1 7-Bit Addressing Format

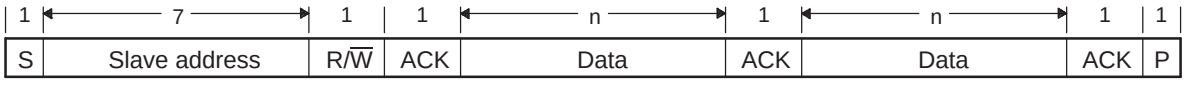
In the 7-bit addressing format (Figure 24-8), the first byte after a START condition (S) consists of a 7-bit slave address followed by a R/$\overline{W}$ bit. The R/$\overline{W}$ bit determines the direction of the data.

- R/$\overline{W}$ = 0: The master writes (transmits) data to the addressed slave.
- R/$\overline{W}$ = 1: The master reads (receives) data from the slave.

An extra clock cycle dedicated for acknowledgment (ACK) is inserted after the R/$\overline{W}$ bit. If the slave inserts the ACK bit, *n* bits of data from the transmitter (master or slave, depending on the R/$\overline{W}$ bit) follow it. *n* is a number from 1 to 8 that the bit count (BC) bits of ICMDR determine. The receiver inserts an ACK bit after the data bits have been transferred.

Write a 0 to the expanded address enable (XA) bit of ICMDR to select the 7-bit addressing format.

Figure 24-8. I2C Peripheral 7-Bit Addressing Format (FDF = 0, XA = 0 in ICMDR)



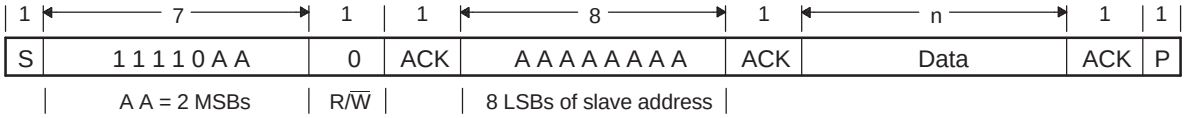
n = The number of data bits (from 1 to 8) specified by the bit count (BC) field of ICM DR.

24.2.6.2 10-Bit Addressing Format

The 10-bit addressing format (Figure 24-9) is like the 7-bit addressing format, but the master sends the slave address in two separate byte transfers. The first byte consists of 11110b, the two MSBs of the 10-bit slave address, and R/$\overline{W}$ = 0 (write). The second byte is the remaining 8 bits of the 10-bit slave address. The slave must send acknowledgment (ACK) after each of the two byte transfers. Once the master has written the second byte to the slave, the master can either write data or use a repeated START condition to change the data direction. (For more information about using 10-bit addressing, see the Philips Semiconductors I2C-bus specification.)

Write 1 to the XA bit of ICMDR to select the 10-bit addressing format.

Figure 24-9. I2C Peripheral 10-Bit Addressing Format With Master-Transmitter Writing to Slave-Receiver (FDF = 0, XA = 1 in ICMDR)



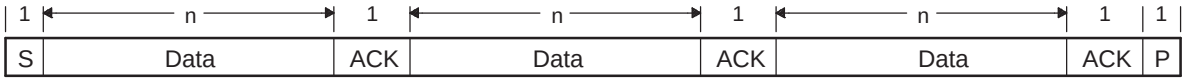
n = The number of data bits (from 1 to 8) specified by the bit count (BC) field of ICMDR.

24.2.6.3 Free Data Format

In the free data format (Figure 24-10), the first bits after a START condition (S) are a data word. An ACK bit is inserted after each data word. The data word can be from 1 to 8 bits, depending on the bit count (BC) bits of ICMDR. No address or data-direction bit is sent. Therefore, the transmitter and the receiver must both support the free data format, and the direction of the data must be constant throughout the transfer.

To select the free data format, write 1 to the free data format (FDF) bit of ICMDR.

Figure 24-10. I2C Peripheral Free Data Format (FDF = 1 in ICMDR)

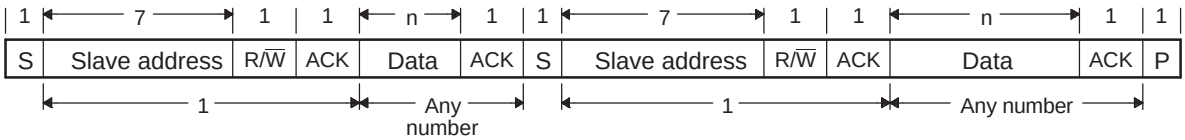


n = The number of data bits (from 1 to 8) specified by the bit count (BC) field of ICMDR.

24.2.6.4 Using a Repeated START Condition

The repeated START condition can be used with the 7-bit addressing, 10-bit addressing, and free data formats. The 7-bit addressing format using a repeated START condition (S) is shown in Figure 24-11. At the end of each data word, the master can drive another START condition. Using this capability, a master can transmit/receive any number of data words before driving a STOP condition. The length of a data word can be from 1 to 8 bits and is selected with the bit count (BC) bits of ICMDR.

Figure 24-11. I2C Peripheral 7-Bit Addressing Format With Repeated START Condition (FDF = 0, XA = 0 in ICMDR)



n = The number of data bits (from 1 to 8) specified by the bit count (BC) field of ICMDR.

24.2.7 Operating Modes

The I2C peripheral has four basic operating modes to support data transfers as a master and as a slave. See Table 24-1 for the names and descriptions of the modes.

If the I2C peripheral is a master, it begins as a master-transmitter and, typically, transmits an address for a particular slave. When giving data to the slave, the I2C peripheral must remain a master-transmitter. In order to receive data from a slave, the I2C peripheral must be changed to the master-receiver mode.

If the I2C peripheral is a slave, it begins as a slave-receiver and, typically, sends acknowledgment when it recognizes its slave address from a master. If the master will be sending data to the I2C peripheral, the peripheral must remain a slave-receiver. If the master has requested data from the I2C peripheral, the peripheral must be changed to the slave-transmitter mode.

Table 24-1. Operating Modes of the I2C Peripheral

Operating Mode	Description
Slave-receiver mode	The I2C peripheral is a slave and receives data from a master. All slave modules begin in this mode. In this mode, serial data bits received on I2Cx_SDA are shifted in with the clock pulses that are generated by the master. As a slave, the I2C peripheral does not generate the clock signal, but it can hold I2Cx_SCL low while the intervention of the processor is required (RSFULL = 1 in ICSTR) after data has been received.
Slave-transmitter mode	The I2C peripheral is a slave and transmits data to a master. This mode can only be entered from the slave-receiver mode; the I2C peripheral must first receive a command from the master. When you are using any of the 7-bit/10-bit addressing formats, the I2C peripheral enters its slave-transmitter mode if the slave address is the same as its own address (in ICOAR) and the master has transmitted R/$\overline{W}$ = 1. As a slave-transmitter, the I2C peripheral then shifts the serial data out on I2Cx_SDA with the clock pulses that are generated by the master. While a slave, the I2C peripheral does not generate the clock signal, but it can hold I2Cx_SCL low while the intervention of the processor is required (XSMT = 0 in ICSTR) after data has been transmitted.
Master-receiver mode	The I2C peripheral is a master and receives data from a slave. This mode can only be entered from the master-transmitter mode; the I2C peripheral must first transmit a command to the slave. When you are using any of the 7-bit/10-bit addressing formats, the I2C peripheral enters its master-receiver mode after transmitting the slave address and R/$\overline{W}$ = 1. Serial data bits on I2Cx_SDA are shifted into the I2C peripheral with the clock pulses generated by the I2C peripheral on I2Cx_SCL. The clock pulses are inhibited and I2Cx_SCL is held low when the intervention of the processor is required (RSFULL = 1 in ICSTR) after data has been received.
Master-transmitter mode	The I2C peripheral is a master and transmits control information and data to a slave. All master modules begin in this mode. In this mode, data assembled in any of the 7-bit/10-bit addressing formats is shifted out on I2Cx_SDA. The bit shifting is synchronized with the clock pulses generated by the I2C peripheral on I2Cx_SCL. The clock pulses are inhibited and I2Cx_SCL is held low when the intervention of the processor is required (XSMT = 0 in ICSTR) after data has been transmitted.

24.2.8 NACK Bit Generation

When the I2C peripheral is a receiver (master or slave), it can acknowledge or ignore bits sent by the transmitter. To ignore any new bits, the I2C peripheral must send a no-acknowledge (NACK) bit during the acknowledge cycle on the bus. Table 24-2 summarizes the various ways the I2C peripheral sends a NACK bit.

Table 24-2. Ways to Generate a NACK Bit

I2C Peripheral Condition	NACK Bit Generation	
	Basic	**Optional**
Slave-receiver mode	• Disable data transfers (STT = 0 in ICSTR). • Allow an overrun condition (RSFULL = 1 in ICSTR). • Reset the peripheral (IRS = 0 in ICMDR) .	Set the NACKMOD bit of ICMDR before the rising edge of the last data bit you intend to receive.
Master-receiver mode AND Repeat mode (RM = 1 in ICMDR)	• Generate a STOP condition (STOP = 1 in ICMDR). • Reset the peripheral (IRS = 0 in ICMDR).	Set the NACKMOD bit of ICMDR before the rising edge of the last data bit you intend to receive.
Master-receiver mode AND Nonrepeat mode (RM = 0 in ICMDR)	• If STP = 1 in ICMDR, allow the internal data counter to count down to 0 and force a STOP condition. • If STP = 0, make STP = 1 to generate a STOP condition. • Reset the peripheral (IRS = 0 in ICMDR).	Set the NACKMOD bit of ICMDR before the rising edge of the last data bit you intend to receive.

24.2.9 Arbitration

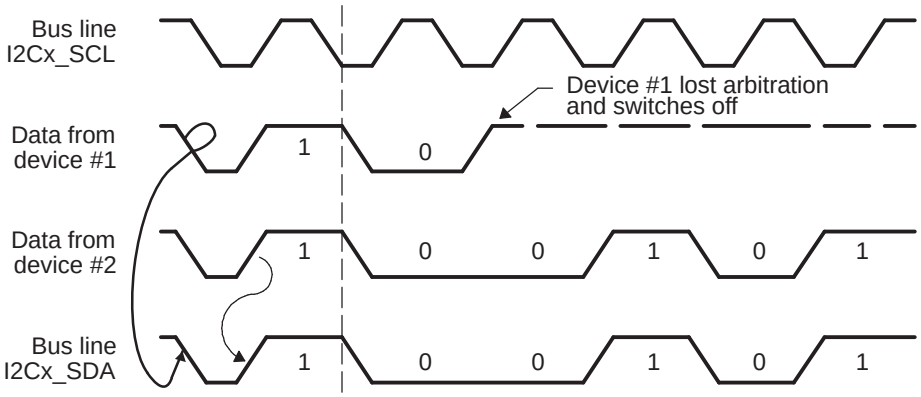
If two or more master-transmitters simultaneously start a transmission on the same bus, an arbitration procedure is invoked. The arbitration procedure uses the data presented on the serial data bus (I2Cx_SDA) by the competing transmitters. Figure 24-12 illustrates the arbitration procedure between two devices. The first master-transmitter, which drives I2Cx_SDA high, is overruled by another master-transmitter that drives I2Cx_SDA low. The arbitration procedure gives priority to the device that transmits the serial data stream with the lowest binary value. Should two or more devices send identical first bytes, arbitration continues on the subsequent bytes.

If the I2C peripheral is the losing master, it switches to the slave-receiver mode, sets the arbitration lost (AL) flag, and generates the arbitration-lost interrupt.

If during a serial transfer the arbitration procedure is still in progress when a repeated START condition or a STOP condition is transmitted to I2Cx_SDA, the master-transmitters involved must send the repeated START condition or the STOP condition at the same position in the format frame. Arbitration is not allowed between:

- A repeated START condition and a data bit
- A STOP condition and a data bit
- A repeated START condition and a STOP condition

Figure 24-12. Arbitration Procedure Between Two Master-Transmitters



24.2.10 Reset Considerations

The I2C peripheral has two reset sources: software reset and hardware reset.

24.2.10.1 Software Reset Considerations

To reset the I2C peripheral, write 0 to the I2C reset (IRS) bit in the I2C mode register (ICMDR). All status bits in the I2C interrupt status register (ICSTR) are forced to their default values, and the I2C peripheral remains disabled until IRS is changed to 1. The I2Cx_SDA and I2Cx_SCL pins are in the high-impedance state.

NOTE: If the IRS bit is cleared to 0 during a transfer, this can cause the I2C bus to hang (I2Cx_SDA and I2Cx_SCL are in the high-impedance state).

24.2.10.2 Hardware Reset Considerations

When a hardware reset occurs, all the registers of the I2C peripheral are set to their default values and the I2C peripheral remains disabled until the I2C reset (IRS) bit in the I2C mode register (ICMDR) is changed to 1.

NOTE: The IRS bit must be cleared to 0 while you configure/reconfigure the I2C peripheral. Forcing IRS to 0 can be used to save power and to clear error conditions.

24.2.11 Initialization

Proper I2C initialization is required prior to starting communication with other I2C device(s). Unless a fully fledged driver is in place, you need to determine the required I2C configuration needed (for example, Master Receiver, etc.) and configure the I2C controller with the desired settings. Enabling the I2C clock should be the first task. Then the I2C controller is placed in reset. You now are ready to configure the I2C controller. Once configuration is done, you need to enable the I2C controller by releasing the controller from reset. Prior to starting communication, you need to make sure that all status bits are cleared and no pending interrupts exist. Once the bus is determined to be available (the bus is not busy), the I2C is ready to proceed with the desired communication.

24.2.11.1 Configuring the I2C in Master Receiver Mode and Servicing Receive Data via CPU

The following initialization procedure is for the I2C controller configured in Master Receiver mode. The CPU is used to move data from the I2C receive register to CPU memory (memory accessible by the CPU).

1. Enable I2C clock from the Power and Sleep Controller, if it is driven by the Power and Sleep Controller (see the *Power and Sleep Controller (PSC)* chapter).
2. Place I2C in reset (clear IRS = 0 in ICMDR).
3. Configure ICMDR:
   - Configure I2C as Master (MST = 1).
   - Indicate the I2C configuration to be used; for example, Data Receiver (TRX = 0)
   - Indicate 7-bit addressing is to be used (XA = 0).
   - Disable repeat mode (RM = 0).
   - Disable loopback mode (DLB = 0).
   - Disable free data format (FDF = 0).
   - Optional: Disable start byte mode if addressing a fully fledged I2C device (STB = 0).
   - Set number of bits to transfer to be 8 bits (BC = 0).
4. Configure Slave Address: the I2C device this I2C master would be addressing (ICSAR = 7BIT ADDRESS).
5. Configure the peripheral clock operation frequency (ICPSC). This value should be selected in such a way that the frequency is between 6.7 and 13.3 MHz.
6. Configure I2C master clock frequency:
   - Configure the low-time divider value (ICCLKL).
   - Configure the high-time divider value (ICCLKH).
7. Make sure the interrupt status register (ICSTR) is cleared:
   - Read ICSTR and write it back (write 1 to clear) ICSTR = ICSTR
   - Read ICIVR until it is 0.
8. Take I2C controller out of reset: enable I2C controller (set IRS bit = 1 in ICMDR).
9. Wait until bus busy bit is cleared (BB = 0 in ICSTR).
10. Generate a START event, followed by Slave Address, etc. (set STT = 1 in ICMDR).
11. Wait until data is received (ICRRDY = 1 in ICSTR).
12. Read data:
    - If ICRRDY = 1 in ICSTR, then read ICDRR.
    - Perform the previous two steps until receiving one byte short of the entire byte expecting to receive.
13. Configure the I2C controller not to generate an ACK on the next/final byte reception: set NACKMOD bit for the I2C to generate a NACK on the last byte received (set NACKMOD = 1 in ICMDR).
14. End transfer/release bus when transfer is done. Generate a STOP event (set STP = 1 in ICMDR).

24.2.12 Interrupt Support

The I2C peripheral is capable of interrupting the CPU. The CPU can determine which I2C events caused the interrupt by reading the I2C interrupt vector register (ICIVR). ICIVR contains a binary-coded interrupt vector type to indicate which interrupt has occurred. Reading ICIVR clears the interrupt flag; if other interrupts are pending, a new interrupt is generated. If there is more than one pending interrupt flag, reading ICIVR clears the highest-priority interrupt flag.

24.2.12.1 Interrupt Events and Requests

The I2C peripheral can generate the interrupts described in Table 24-3. Each interrupt has a flag bit in the I2C interrupt status register (ICSTR) and a mask bit in the interrupt mask register (ICIMR). When one of the specified events occurs, its flag bit is set. If the corresponding mask bit is 0, the interrupt request is blocked; if the mask bit is 1, the request is forwarded to the CPU as an I2C interrupt.

Table 24-3. Descriptions of the I2C Interrupt Events

I2C Interrupt	Initiating Event
Arbitration-lost interrupt (AL)	Generated when the I2C arbitration procedure is lost or illegal START/STOP conditions occur
No-acknowledge interrupt (NACK)	Generated when the master I2C does not receive any acknowledge from the receiver
Registers-ready-for-access interrupt (ARDY)	Generated by the I2C when the previously programmed address, data and command have been performed and the status bits have been updated. This interrupt is used to let the controlling processor know that the I2C registers are ready to be accessed.
Receive interrupt/status (ICRINT and ICRRDY)	Generated when the received data in the receive-shift register (ICRSR) has been copied into the ICDRR. The ICRRDY bit can also be polled by the CPU to read the received data in the ICDRR.
Transmit interrupt/status (ICXINT and ICXRDY)	Generated when the transmitted data has been copied from ICDXR to the transmit-shift register (ICXSR) and shifted out on the I2Cx_SDA pin. This bit can also polled by the CPU to write the next transmitted data into the ICDXR.
Stop-Condition-Detection interrupt (SCD)	Generated when a STOP condition has been detected
Address-as-Slave interrupt (AAS)	Generated when the I2C has recognized its own slave address or an address of all (8) zeros.

24.2.13 DMA Events Generated by the I2C Peripheral

For the EDMA controller to handle transmit and receive data, the I2C peripheral generates the following two EDMA events. Activity in EDMA channels can be synchronized to these events.

- Receive event (ICREVT): When receive data has been copied from the receive shift register (ICRSR) to the data receive register (ICDRR), the I2C peripheral sends an REVT signal to the EDMA controller. In response, the EDMA controller can read the data from ICDRR.
- Transmit event (ICXEVT): When transmit data has been copied from the data transmit register (ICDXR) to the transmit shift register (ICXSR), the I2C peripheral sends an XEVT signal to the EDMA controller. In response, the EDMA controller can write the next transmit data value to ICDXR.

24.2.14 Power Management

The I2C peripheral can be placed in reduced-power modes to conserve power during periods of low activity. The power management of the I2C peripheral is controlled by the processor Power and Sleep Controller (PSC). The PSC acts as a master controller for power management for all of the peripherals on the device. For detailed information on power management procedures using the PSC, see the *Power and Sleep Controller (PSC)* chapter.

24.2.15 Emulation Considerations

The response of the I2C events to emulation suspend events (such as halts and breakpoints) is controlled by the FREE bit in the I2C mode register (ICMDR). The I2C peripheral either stops exchanging data (FREE = 0) or continues to run (FREE = 1) when an emulation suspend event occurs. How the I2C peripheral terminates data transactions is affected by whether the I2C peripheral is acting as a master or a slave. For more information, see the description of the FREE bit in ICMDR (see Section 24.3.9).

24.3 Registers

Table 29-8 lists the memory-mapped registers for the inter-integrated circuit (I2C) peripheral. See your device-specific data manual for the memory address of these registers. All other register offset addresses not listed in Table 29-8 should be considered as reserved locations and the register contents should not be modified.

Table 24-4. Inter-Integrated Circuit (I2C) Registers

Offset	Acronym	Register Description	Section
0h	ICOAR	I2C Own Address Register	Section 24.3.1
4h	ICIMR	I2C Interrupt Mask Register	Section 24.3.2
8h	ICSTR	I2C Interrupt Status Register	Section 24.3.3
Ch	ICCLKL	I2C Clock Low-Time Divider Register	Section 24.3.4
10h	ICCLKH	I2C Clock High-Time Divider Register	Section 24.3.4
14h	ICCNT	I2C Data Count Register	Section 24.3.5
18h	ICDRR	I2C Data Receive Register	Section 24.3.6
1Ch	ICSAR	I2C Slave Address Register	Section 24.3.7
20h	ICDXR	I2C Data Transmit Register	Section 24.3.8
24h	ICMDR	I2C Mode Register	Section 24.3.9
28h	ICIVR	I2C Interrupt Vector Register	Section 24.3.10
2Ch	ICEMDR	I2C Extended Mode Register	Section 24.3.11
30h	ICPSC	I2C Prescaler Register	Section 24.3.12
34h	REVID1	I2C Revision Identification Register 1	Section 24.3.13
38h	REVID2	I2C Revision Identification Register 2	Section 24.3.13
3Ch	ICDMAC	I2C DMA Control Register	Section 24.3.15
48h	ICPFUNC	I2C Pin Function Register	Section 24.3.16
4Ch	ICPDIR	I2C Pin Direction Register	Section 24.3.17
50h	ICPDIN	I2C Pin Data In Register	Section 24.3.18
54h	ICPDOUT	I2C Pin Data Out Register	Section 24.3.19
58h	ICPDSET	I2C Pin Data Set Register	Section 24.3.20
5Ch	ICPDCLR	I2C Pin Data Clear Register	Section 24.3.21

24.3.1 I2C Own Address Register (ICOAR)

The I2C own address register (ICOAR) is used to specify its own slave address, which distinguishes it from other slaves connected to the I2C-bus. If the 7-bit addressing mode is selected (XA = 0 in ICMDR), only bits 6-0 are used; bits 9-7 are ignored. ICOAR is shown in Figure 24-13 and described in Table 24-5.

Figure 24-13. I2C Own Address Register (ICOAR)

31	16
Reserved	
R-0	

15	10	9	0
Reserved		OADDR	
R-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 24-5. I2C Own Address Register (ICOAR) Field Descriptions

Bit	Field	Value	Description
31-10	Reserved	0	These reserved bit locations are always read as zeros. A value written to this field has no effect.
9-0	OADDR	0-3FFh	Own slave address. Provides the slave address of the I2C. In 7-bit addressing mode (XA = 0 in ICMDR): bits 6-0 provide the 7-bit slave address of the I2C. Bits 9-7 are ignored. In 10-bit addressing mode (XA = 1 in ICMDR): bits 9-0 provide the 10-bit slave address of the I2C.

24.3.2 I2C Interrupt Mask Register (ICIMR)

The I2C interrupt mask register (ICIMR) is used to individually enable or disable I2C interrupt requests. ICIMR is shown in Figure 24-14 and described Table 24-6.

Figure 24-14. I2C Interrupt Mask Register (ICIMR)

31							8
Reserved							
R-0							
7	6	5	4	3	2	1	0
Reserved	AAS	SCD	ICXRDY	ICRRDY	ARDY	NACK	AL
R-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 24-6. I2C Interrupt Mask Register (ICIMR) Field Descriptions

Bit	Field	Value	Description
31-7	Reserved	0	These reserved bit locations are always read as zeros. A value written to this field has no effect.
6	AAS		Address-as-slave interrupt enable bit.
		0	Interrupt request is disabled.
		1	Interrupt request is enabled.
5	SCD		Stop condition detected interrupt enable bit.
		0	Interrupt request is disabled.
		1	Interrupt request is enabled.
4	ICXRDY		Transmit-data-ready interrupt enable bit.
		0	Interrupt request is disabled.
		1	Interrupt request is enabled.
3	ICRRDY		Receive-data-ready interrupt enable bit.
		0	Interrupt request is disabled.
		1	Interrupt request is enabled.
2	ARDY		Register-access-ready interrupt enable bit.
		0	Interrupt request is disabled.
		1	Interrupt request is enabled.
1	NACK		No-acknowledgment interrupt enable bit.
		0	Interrupt request is disabled.
		1	Interrupt request is enabled.
0	AL		Arbitration-lost interrupt enable bit
		0	Interrupt request is disabled.
		1	Interrupt request is enabled.

24.3.3 I2C Interrupt Status Register (ICSTR)

The I2C interrupt status register (ICSTR) is used to determine which interrupt has occurred and to read status information. ICSTR is shown in Figure 24-15 and described in Table 24-7.

Figure 24-15. I2C Interrupt Status Register (ICSTR)

31							16
Reserved							
R-0							
15	14	13	12	11	10	9	8
Reserved	SDIR	NACKSNT	BB	RSFULL	XSMT	AAS	AD0
R-0	R/W1C-0	R/W1C-0	R/W1C-0	R-0	R-1	R-0	R-0
7	6	5	4	3	2	1	0
Reserved		SCD	ICXRDY	ICRRDY	ARDY	NACK	AL
R-0		R/W1C-0	R/W1C-1	R/W1C-0	R/W1C-0	R/W1C-0	R/W1C-0

LEGEND: R/W = Read/Write; R = Read only; W1C = Write 1 to clear (writing 0 has no effect); -*n* = value after reset

Table 24-7. I2C Interrupt Status Register (ICSTR) Field Descriptions

Bit	Field	Value	Description
31-15	Reserved	0	These reserved bit locations are always read as zeros. A value written to this field has no effect.
14	SDIR		Slave direction bit. In digital-loopback mode (DLB), the SDIR bit is cleared to 0.
		0	I2C is acting as a master-transmitter/receiver or a slave-receiver. SDIR is cleared by one of the following events: • A STOP or a START condition. • SDIR is manually cleared. To clear this bit, write a 1 to it.
		1	I2C is acting as a slave-transmitter.
13	NACKSNT		No-acknowledgment sent bit. NACKSNT bit is used when the I2C is in the receiver mode. One instance in which NACKSNT is affected is when the NACK mode is used (see the description for NACKMOD in Section 24.3.9).
		0	NACK is not sent. NACKSNT is cleared by one of the following events: • It is manually cleared. To clear this bit, write a 1 to it. • The I2C is reset (either when 0 is written to the IRS bit of ICMDR or when the processor is reset).
		1	NACK is sent. A no-acknowledge bit was sent during the acknowledge cycle on the I2C-bus.
12	BB		Bus busy bit. BB bit indicates whether the I2C-bus is busy or is free for another data transfer. In the master mode, BB is controlled by the software.
		0	Bus is free. BB is cleared by one of the following events: • The I2C receives or transmits a STOP bit (bus free). • BB is manually cleared. To clear this bit, write a 1 to it. • The I2C is reset (either when 0 is written to the IRS bit of ICMDR or when the processor is reset).
		1	Bus is busy. When the STT bit in ICMDR is set to 1, a restart condition is generated. BB is set by one of the following events: • The I2C has received or transmitted a START bit on the bus. • I2Cx_SCL is in a low state and the IRS bit in ICMDR is 0.
11	RSFULL		Receive shift register full bit. RSFULL indicates an overrun condition during reception. Overrun occurs when the receive shift register (ICRSR) is full with new data but the previous data has not been read from the data receive register (ICDRR). The new data will not be copied to ICDRR until the previous data is read. As new bits arrive from the I2Cx_SDA pin, they overwrite the bits in ICRSR.
		0	No overrun is detected. RSFULL is cleared by one of the following events: • ICDRR is read. • The I2C is reset (either when 0 is written to the IRS bit of ICMDR or when the processor is reset).
		1	Overrun is detected.

Table 24-7. I2C Interrupt Status Register (ICSTR) Field Descriptions (continued)

Bit	Field	Value	Description
10	XSMT		Transmit shift register empty bit. XSMT indicates that the transmitter has experienced underflow. Underflow occurs when the transmit shift register (ICXSR) is empty but the data transmit register (ICDXR) has not been loaded since the last ICDXR-to-ICXSR transfer. The next ICDXR-to-ICXSR transfer will not occur until new data is in ICDXR. If new data is not transferred in time, the previous data may be re-transmitted on the I2Cx_SDA pin.
		0	Underflow is detected.
		1	No underflow is detected. XSMT is set by one of the following events: • Data is written to ICDXR. • The I2C is reset (either when 0 is written to the IRS bit of ICMDR or when the processor is reset).
9	AAS		Addressed-as-slave bit.
		0	The AAS bit has been cleared by a repeated START condition or by a STOP condition.
		1	AAS is set by one of the following events: • I2C has recognized its own slave address or an address of all zeros (general call). • The first data word has been received in the free data format (FDF = 1 in ICMDR).
8	AD0		Address 0 bit.
		0	AD0 has been cleared by a START or STOP condition.
		1	An address of all zeros (general call) is detected.
7-6	Reserved	0	These reserved bit locations are always read as zeros. A value written to this field has no effect.
5	SCD		Stop condition detected bit. SCD indicates when a STOP condition has been detected on the I2C bus. The STOP condition could be generated by the I2C or by another I2C device connected to the bus.
		0	No STOP condition has been detected. SCD is cleared by one of the following events: • By reading the INTCODE bits in ICIVR as 110b. • SCD is manually cleared. To clear this bit, write a 1 to it.
		1	A STOP condition has been detected.
4	ICXRDY		Transmit-data-ready interrupt flag bit. ICXRDY indicates that the data transmit register (ICDXR) is ready to accept new data because the previous data has been copied from ICDXR to the transmit shift register (ICXSR). The CPU can poll ICXRDY or use the XRDY interrupt request.
		0	ICDXR is not ready. ICXRDY is cleared by one of the following events: • Data is written to ICDXR. • ICXRDY is manually cleared. To clear this bit, write a 1 to it.
		1	ICDXR is ready. Data has been copied from ICDXR to ICXSR. ICXRDY is forced to 1 when the I2C is reset.
3	ICRRDY		Receive-data-ready interrupt flag bit. ICRRDY indicates that the data receive register (ICDRR) is ready to be read because data has been copied from the receive shift register (ICRSR) to ICDRR. The CPU can poll ICRRDY or use the RRDY interrupt request.
		0	ICDRR is not ready. ICRRDY is cleared by one of the following events: • ICDRR is read. • ICRRDY is manually cleared. To clear this bit, write a 1 to it. • The I2C is reset (either when 0 is written to the IRS bit of ICMDR or when the processor is reset).
		1	ICDRR is ready. Data has been copied from ICRSR to ICDRR.
2	ARDY		Register-access-ready interrupt flag bit (only applicable when the I2C is in the master mode). ARDY indicates that the I2C registers are ready to be accessed because the previously programmed address, data, and command values have been used. The CPU can poll ARDY or use the ARDY interrupt request.
		0	The registers are not ready to be accessed. ARDY is cleared by one of the following events: • The I2C starts using the current register contents. • ARDY is manually cleared. To clear this bit, write a 1 to it. • The I2C is reset (either when 0 is written to the IRS bit of ICMDR or when the processor is reset).
		1	The registers are ready to be accessed. This bit is set after the slave address appears on the I2C bus. • In the nonrepeat mode (RM = 0 in ICMDR): If STP = 0 in ICMDR, ARDY is set when the internal data counter counts down to 0. If STP = 1, ARDY is not affected (instead, the I2C generates a STOP condition when the counter reaches 0). • In the repeat mode (RM = 1): ARDY is set at the end of each data word transmitted from ICDXR.

Table 24-7. I2C Interrupt Status Register (ICSTR) Field Descriptions (continued)

Bit	Field	Value	Description
1	NACK		No-acknowledgment interrupt flag bit. NACK applies when the I2C is a transmitter (master or slave). NACK indicates whether the I2C has detected an acknowledge bit (ACK) or a no-acknowledge bit (NACK) from the receiver. The CPU can poll NACK or use the NACK interrupt request.
		0	ACK received/NACK is not received. NACK is cleared by one of the following events: • An acknowledge bit (ACK) has been sent by the receiver. • NACK is manually cleared. To clear this bit, write a 1 to it. • The CPU reads the interrupt vector register (ICIVR) when the register contains the code for a NACK interrupt. • The I2C is reset (either when 0 is written to the IRS bit of ICMDR or when the processor is reset).
		1	NACK bit is received. The hardware detects that a no-acknowledge (NACK) bit has been received. **Note:** While the I2C performs a general call transfer, NACK is 1, even if one or more slaves send acknowledgment.
0	AL		Arbitration-lost interrupt flag bit (only applicable when the I2C is a master-transmitter). AL primarily indicates when the I2C has lost an arbitration contest with another master-transmitter. The CPU can poll AL or use the AL interrupt request.
		0	Arbitration is not lost. AL is cleared by one of the following events: • AL is manually cleared. To clear this bit, write a 1 to it. • The CPU reads the interrupt vector register (ICIVR) when the register contains the code for an AL interrupt. • The I2C is reset (either when 0 is written to the IRS bit of ICMDR or when the processor is reset).
		1	Arbitration is lost. AL is set by one of the following events: • The I2C senses that it has lost an arbitration with two or more competing transmitters that started a transmission almost simultaneously. • The I2C attempts to start a transfer while the BB (bus busy) bit is set to 1. When AL is set to 1, the MST and STP bits of ICMDR are cleared, and the I2C becomes a slave-receiver.

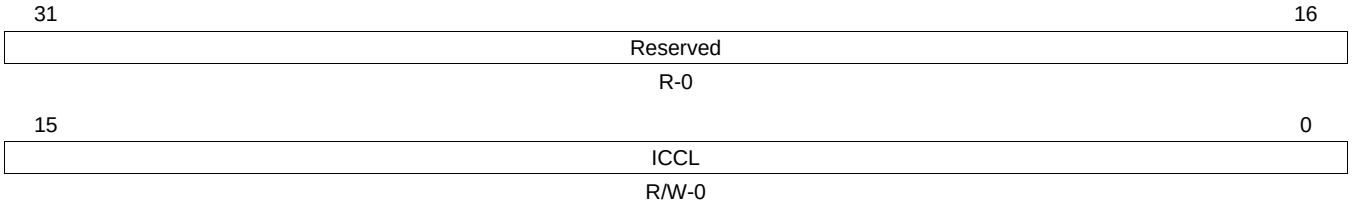
24.3.4 I2C Clock Divider Registers (ICCLKL and ICCLKH)

When the I2C is a master, the prescaled module clock is divided down for use as the I2C serial clock on the I2Cx_SCL pin. The shape of the I2C serial clock depends on two divide-down values, ICCL and ICCH. For detailed information on how these values are programmed, see Section 24.2.2.

24.3.4.1 I2C Clock Low-Time Divider Register (ICCLKL)

For each I2C serial clock cycle, ICCL in the I2C clock low-time divider register (ICCLKL) determines the amount of time the signal is low. ICCLKL must be configured while the I2C is still in reset (IRS = 0 in ICMDR). ICCLKL is shown in Figure 24-16 and described in Table 24-8.

Figure 24-16. I2C Clock Low-Time Divider Register (ICCLKL)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

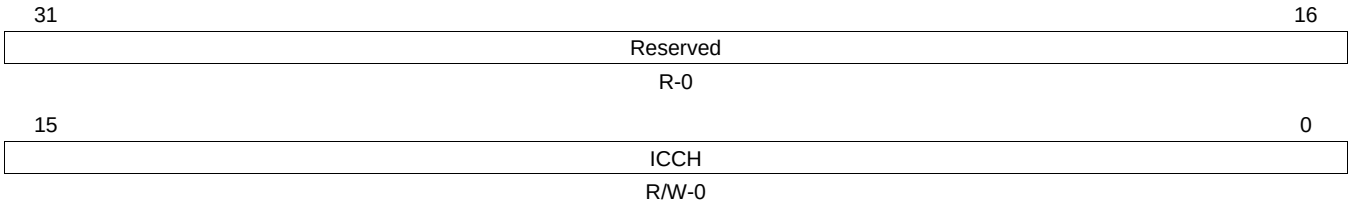
Table 24-8. I2C Clock Low-Time Divider Register (ICCLKL) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	These reserved bit locations are always read as zeros. A value written to this field has no effect.
15-0	ICCL	0-FFFFh	Clock low-time divide-down value of 1-65536. The period of the module clock is multiplied by (ICCL + d) to produce the low-time duration of the I2C serial on the I2Cx_SCL pin.

24.3.4.2 I2C Clock High-Time Divider Register (ICCLKH)

For each I2C serial clock cycle, ICCH in the I2C clock high-time divider register (ICCLKH) determines the amount of time the signal is high. ICCLKH must be configured while the I2C is still in reset (IRS = 0 in ICMDR). ICCLKH is shown in Figure 24-17 and described in Table 24-9.

Figure 24-17. I2C Clock High-Time Divider Register (ICCLKH)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 24-9. I2C Clock High-Time Divider Register (ICCLKH) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	These reserved bit locations are always read as zeros. A value written to this field has no effect.
15-0	ICCH	0-FFFFh	Clock high-time divide-down value of 1-65536. The period of the module clock is multiplied by (ICCH + d) to produce the high-time duration of the I2C serial on the I2Cx_SCL pin.

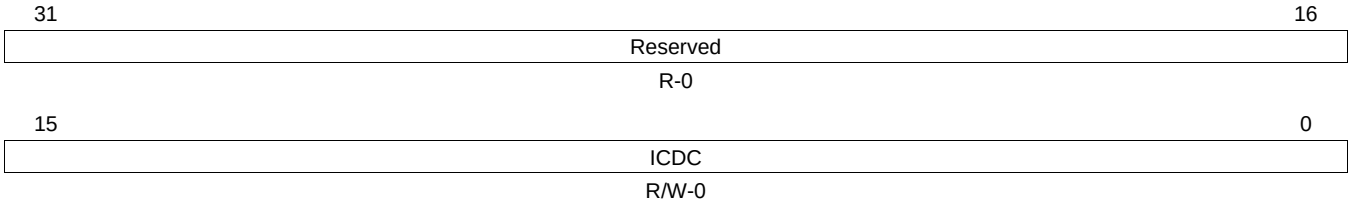
24.3.5 I2C Data Count Register (ICCNT)

The I2C data count register (ICCNT) is used to indicate how many data words to transfer when the I2C is configured as a master-transmitter-receiver (MST = 1 and TRX = 1/0 in ICMDR) and the repeat mode is off (RM = 0 in ICMDR). In the repeat mode (RM = 1), ICCNT is not used.

The value written to ICCNT is copied to an internal data counter. The internal data counter is decremented by 1 for each data word transferred (ICCNT remains unchanged). If a STOP condition is requested (STP = 1 in ICMDR), the I2C terminates the transfer with a STOP condition when the countdown is complete (that is, when the last data word has been transferred).

ICCNT is shown in Figure 24-18 and described in Table 24-10.

Figure 24-18. I2C Data Count Register (ICCNT)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 24-10. I2C Data Count Register (ICCNT) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	These reserved bit locations are always read as zeros. A value written to this field has no effect.
15-0	ICDC	0-FFFFh	Data count value. When RM = 0 in ICMDR, ICDC indicates the number of data words to transfer in the nonrepeat mode. When RM = 1 in ICMDR, the value in ICCNT is a don't care. If STP = 1 in ICMDR, a STOP condition is generated when the internal data counter counts down to 0.
		0	The start value loaded to the internal data counter is 65536.
		1h-FFFFh	The start value loaded to internal data counter is 1-65535.

24.3.6 I2C Data Receive Register (ICDRR)

The I2C data receive register (ICDRR) is used to read the receive data. The ICDRR can receive a data value of up to 8 bits; data values with fewer than 8 bits are right-aligned in the D bits and the remaining D bits are undefined. The number of data bits is selected by the bit count bits (BC) of ICMDR. The I2C receive shift register (ICRSR) shifts in the received data from the I2Cx_SDA pin. Once data is complete, the I2C copies the contents of ICRSR into ICDRR. The CPU and the EDMA controller cannot access ICRSR.

ICDRR is shown in Figure 24-19 and described in Table 24-11.

Figure 24-19. I2C Data Receive Register (ICDRR)

31	16
Reserved	
R-0	

15	8	7	0
Reserved		D	
R-0		R-0	

LEGEND: R = Read only; -*n* = value after reset

Table 24-11. I2C Data Receive Register (ICDRR) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	These reserved bit locations are always read as zeros. A value written to this field has no effect.
7-0	D	0-FFh	Receive data.

24.3.7 I2C Slave Address Register (ICSAR)

The I2C slave address register (ICSAR) contains a 7-bit or 10-bit slave address. When the I2C is not using the free data format (FDF = 0 in ICMDR), it uses this address to initiate data transfers with a slave or slaves. When the address is nonzero, the address is for a particular slave. When the address is 0, the address is a general call to all slaves. If the 7-bit addressing mode is selected (XA = 0 in ICMDR), only bits 6-0 of ICSAR are used; bits 9-7 are ignored.

ICSAR is shown in Figure 24-20 and described in Table 24-12.

Figure 24-20. I2C Slave Address Register (ICSAR)

31	16
Reserved	
R-0	

15	10	9	0
Reserved		SADDR	
R-0		R/W-3FFh	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 24-12. I2C Slave Address Register (ICSAR) Field Descriptions

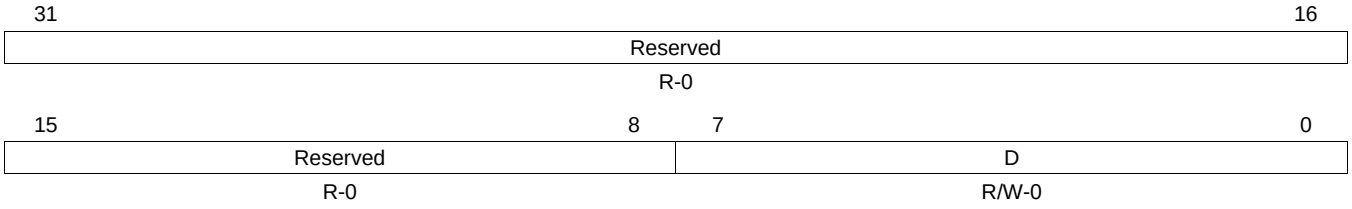
Bit	Field	Value	Description
31-10	Reserved	0	These reserved bit locations are always read as zeros. A value written to this field has no effect.
9-0	SADDR	0-3FFh	Slave address. Provides the slave address of the I2C. In 7-bit addressing mode (XA = 0 in ICMDR): bits 6-0 provide the 7-bit slave address that the I2C transmits when it is in the master-transmitter mode. Bits 9-7 are ignored. In 10-bit addressing mode (XA = 1 in ICMDR): Bits 9-0 provide the 10-bit slave address that the I2C transmits when it is in the master-transmitter mode.

24.3.8 I2C Data Transmit Register (ICDXR)

The CPU or EDMA writes transmit data to the I2C data transmit register (ICDXR). The ICDXR can accept a data value of up to 8 bits. When writing a data value with fewer than 8 bits, the written data must be right-aligned in the D bits. The number of data bits is selected by the bit count bits (BC) of ICMDR. Once data is written to ICDXR, the I2C copies the contents of ICDXR into the I2C transmit shift register (ICXSR). The ICXSR shifts out the transmit data from the I2Cx_SDA pin. The CPU and the EDMA controller cannot access ICXSR.

ICDXR is shown in Figure 24-21 and described in Table 24-13.

Figure 24-21. I2C Data Transmit Register (ICDXR)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 24-13. I2C Data Transmit Register (ICDXR) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	These reserved bit locations are always read as zeros. A value written to this field has no effect.
7-0	D	0-FFh	Transmit data.

24.3.9 I2C Mode Register (ICMDR)

The I2C mode register (ICMDR) contains the control bits of the I2C. ICMDR is shown in shown in Figure 24-22 and described in Table 24-14.

Figure 24-22. I2C Mode Register (ICMDR)

31							16
Reserved							
R-0							
15	14	13	12	11	10	9	8
NACKMOD	FREE	STT	Reserved	STP	MST	TRX	XA
R/W-0	R/W-0	R/W-0	R-0	R/W-0	R/W-0	R/W-0	R/W-0
7	6	5	4	3	2		0
RM	DLB	IRS	STB	FDF	BC		
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0		

LEGEND: R/W = Read/Write; R = Read only; *-n* = value after reset

Table 24-14. I2C Mode Register (ICMDR) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	These reserved bit locations are always read as zeros. A value written to this field has no effect.
15	NACKMOD		No-acknowledge (NACK) mode bit (only applicable when the I2C is a receiver).
		0	In slave-receiver mode: The I2C sends an acknowledge (ACK) bit to the transmitter during the each acknowledge cycle on the bus. The I2C only sends a no-acknowledge (NACK) bit if you set the NACKMOD bit. In master-receiver mode: The I2C sends an ACK bit during each acknowledge cycle until the internal data counter counts down to 0. When the counter reaches 0, the I2C sends a NACK bit to the transmitter. To have a NACK bit sent earlier, you must set the NACKMOD bit.
		1	In either slave-receiver or master-receiver mode: The I2C sends a NACK bit to the transmitter during the next acknowledge cycle on the bus. Once the NACK bit has been sent, NACKMOD is cleared. To send a NACK bit in the next acknowledge cycle, you must set NACKMOD before the rising edge of the last data bit.
14	FREE		This emulation mode bit is used to determine the state of the I2C when a breakpoint is encountered in the high-level language debugger.
		0	When I2C is master: If I2Cx_SCL is low when the breakpoint occurs, the I2C stops immediately and keeps driving I2Cx_SCL low, whether the I2C is the transmitter or the receiver. If I2Cx_SCL is high, the I2C waits until I2Cx_SCL becomes low and then stops. When I2C is slave: A breakpoint forces the I2C to stop when the current transmission/reception is complete.
		1	The I2C runs free; that is, it continues to operate when a breakpoint occurs.
13	STT		START condition bit (only applicable when the I2C is a master). The RM, STT, and STP bits determine when the I2C starts and stops data transmissions (see Table 24-15). Note that the STT and STP bits can be used to terminate the repeat mode.
		0	In master mode, STT is automatically cleared after the START condition has been generated. In slave mode, if STT is 0, the I2C does not monitor the bus for commands from a master. As a result, the I2C performs no data transfers.
		1	In master mode, setting STT to 1 causes the I2C to generate a START condition on the I2C-bus. In slave mode, if STT is 1, the I2C monitors the bus and transmits/receives data in response to commands from a master.
12	Reserved	0	These reserved bit locations are always read as zeros. A value written to this field has no effect.
11	STP		STOP condition bit (only applicable when the I2C is a master). The RM, STT, and STP bits determine when the I2C starts and stops data transmissions (see Table 24-15). Note that the STT and STP bits can be used to terminate the repeat mode.
		0	STP is automatically cleared after the STOP condition has been generated.
		1	STP has been set to generate a STOP condition when the internal data counter of the I2C counts down to 0.

Table 24-14. I2C Mode Register (ICMDR) Field Descriptions (continued)

Bit	Field	Value	Description
10	MST		Master mode bit. MST determines whether the I2C is in the slave mode or the master mode. MST is automatically changed from 1 to 0 when the I2C master generates a STOP condition. See Table 24-16.
		0	Slave mode. The I2C is a slave and receives the serial clock from the master.
		1	Master mode. The I2C is a master and generates the serial clock on the I2Cx_SCL pin.
9	TRX		Transmitter mode bit. When relevant, TRX selects whether the I2C is in the transmitter mode or the receiver mode. Table 24-16 summarizes when TRX is used and when it is a don't care.
		0	Receiver mode. The I2C is a receiver and receives data on the I2Cx_SDA pin.
		1	Transmitter mode. The I2C is a transmitter and transmits data on the I2Cx_SDA pin.
8	XA		Expanded address enable bit.
		0	7-bit addressing mode (normal address mode). The I2C transmits 7-bit slave addresses (from bits 6-0 of ICSAR), and its own slave address has 7 bits (bits 6-0 of ICOAR).
		1	10-bit addressing mode (expanded address mode). The I2C transmits 10-bit slave addresses (from bits 9-0 of ICSAR), and its own slave address has 10 bits (bits 9-0 of ICOAR).
7	RM		Repeat mode bit (only applicable when the I2C is a master). The RM, STT, and STP bits determine when the I2C starts and stops data transmissions (see Table 24-15). If the I2C is configured in slave mode, the RM bit is don't care.
		0	Nonrepeat mode. The value in the data count register (ICCNT) determines how many data words are received/transmitted by the I2C.
		1	Repeat mode. Data words are continuously received/transmitted by the I2C until the STP bit is manually set to 1, regardless of the value in ICCNT.
6	DLB		Digital loopback mode bit (only applicable when the I2C is a master-transmitter). This bit disables or enables the digital loopback mode of the I2C. The effects of this bit are shown in Figure 24-23. Note that DLB mode in the free data format mode (DLB = 1 and FDF = 1) is not supported.
		0	Digital loopback mode is disabled.
		1	Digital loopback mode is enabled. In this mode, the MST bit must be set to 1 and data transmitted out of ICDXR is received in ICDRR after n clock cycles by an internal path, where: n = ((I2C input clock frequency/prescaled module clock frequency) × 8) The transmit clock is also the receive clock. The address transmitted on the I2Cx_SDA pin is the address in ICOAR.
5	IRS		I2C reset bit. Note that if IRS is reset during a transfer, it can cause the I2C bus to hang (I2Cx_SDA and I2Cx_SCL are in a high-impedance state).
		0	The I2C is in reset/disabled. When this bit is cleared to 0, all status bits (in ICSTR) are set to their default values.
		1	The I2C is enabled.
4	STB		START byte mode bit (only applicable when the I2C is a master). As described in version 2.1 of the Philips I2C-bus specification, the START byte can be used to help a slave that needs extra time to detect a START condition. When the I2C is a slave, the I2C ignores a START byte from a master, regardless of the value of the STB bit.
		0	The I2C is not in the START byte mode.
		1	The I2C is in the START byte mode. When you set the START condition bit (STT), the I2C begins the transfer with more than just a START condition. Specifically, it generates: 1. A START condition 2. A START byte (0000 0001b) 3. A dummy acknowledge clock pulse 4. A repeated START condition The I2C sends the slave address that is in ICSAR.
3	FDF		Free data format mode bit. Note that DLB mode in the free data format mode (DLB = 1 and FDF = 1) is not supported. See Table 24-16.
		0	Free data format mode is disabled. Transfers use the 7-/10-bit addressing format selected by the XA bit.
		1	Free data format mode is enabled.

Table 24-14. I2C Mode Register (ICMDR) Field Descriptions (continued)

Bit	Field	Value	Description
2-0	BC	0-7h	Bit count bits. BC defines the number of bits (1 to 8) in the next data word that is to be received or transmitted by the I2C. The number of bits selected with BC must match the data size of the other device. Note that when BC = 0, a data word has 8 bits. If the bit count is less than 8, receive data is right aligned in the D bits of ICDRR and the remaining D bits are undefined. Also, transmit data written to ICDXR must be right aligned.
		0	8 bits per data word
		1h	1 bit per data word
		2h	2 bits per data word
		3h	3 bits per data word
		4h	4 bits per data word
		5h	5 bits per data word
		6h	6 bits per data word
		7h	7 bits per data word

Table 24-15. Master-Transmitter/Receiver Bus Activity Defined by RM, STT, and STP Bits

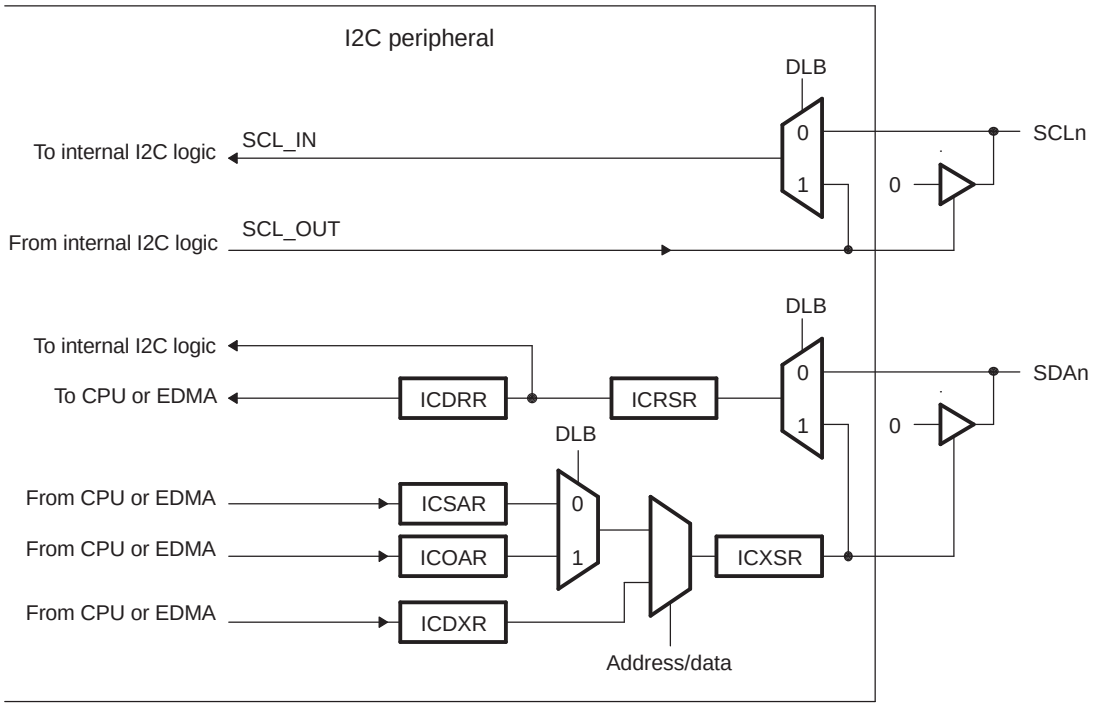
ICMDR Bit				
RM	STT	STP	Bus Activity[(1)]	Description
0	0	0	None	No activity
0	0	1	P	STOP condition
0	1	0	S-A-D..(*n*)..D	START condition, slave address, *n* data words (*n* = value in ICCNT)
0	1	1	S-A-D..(*n*)..D-P	START condition, slave address, *n* data words, STOP condition (*n* = value in ICCNT)
1	0	0	None	No activity
1	0	1	P	STOP condition
1	1	0	S-A-D-D-D..	Repeat mode transfer: START condition, slave address, continuous data transfers until STOP condition or next START condition
1	1	1	None	Reserved bit combination (No activity

(1) A = Address; D = Data word; P = STOP condition; S = START condition

Table 24-16. How the MST and FDF Bits Affect the Role of TRX Bit

ICMDR Bit			
MST	FDF	I2C State	Function of TRX Bit
0	0	In slave mode but not free data format mode	TRX is a don't care. Depending on the command from the master, the I2C responds as a receiver or a transmitter.
0	1	In slave mode and free data format mode	The free data format mode requires that the transmitter and receiver be fixed. TRX identifies the role of the I2C: TRX = 0: The I2C is a receiver. TRX = 1: The I2C is a transmitter.
1	0	In master mode but not free data format mode	TRX identifies the role of the I2C: TRX = 0: The I2C is a receiver. TRX = 1: The I2C is a transmitter.
1	1	In master mode and free data format mode	The free data format mode requires that the transmitter and receiver be fixed. TRX identifies the role of the I2C: TRX = 0: The I2C is a receiver. TRX = 1: The I2C is a transmitter.

Figure 24-23. Block Diagram Showing the Effects of the Digital Loopback Mode (DLB) Bit



24.3.10 I2C Interrupt Vector Register (ICIVR)

The I2C interrupt vector register (ICIVR) is used by the CPU to determine which event generated the I2C interrupt. Reading ICIVR clears the interrupt flag; if other interrupts are pending, a new interrupt is generated. If there are more than one interrupt flag, reading ICIVR clears the highest priority interrupt flag. Note that you must read (clear) ICIVR before doing another start; otherwise, ICIVR could contain an incorrect (old interrupt flags) value.

ICIVR is shown in Figure 24-24 and described in Table 24-17.

Figure 24-24. I2C Interrupt Vector Register (ICIVR)

31	16
Reserved	
R-0	

15	2	0
Reserved	INTCODE	
R-0	R-0	

LEGEND: R= Read only; *-n* = value after reset

Table 24-17. I2C Interrupt Vector Register (ICIVR) Field Descriptions

Bit	Field	Value	Description
31-3	Reserved	0	These reserved bit locations are always read as zeros. A value written to this field has no effect.
2-0	INTCODE	0-7h	Interrupt code bits. The binary code in INTCODE indicates which event generated an I2C interrupt.
		0	None
		1h	Arbitration-lost interrupt (AL). Highest priority if multiple I2C interrupts are pending.
		2h	No-acknowledgment interrupt (NACK)
		3h	Register-access-ready interrupt (ARDY)
		4h	Receive-data-ready interrupt (ICRRDY)
		5h	Transmit-data-ready interrupt (ICXRDY)
		6h	Stop condition detected interrupt (SCD)
		7h	Address-as-slave interrupt (AAS). Lowest priority if multiple I2C interrupts are pending.

24.3.11 I2C Extended Mode Register (ICEMDR)

The I2C extended mode register (ICEMDR) is used to indicate which condition generates a transmit data ready interrupt. ICEMDR is shown in Figure 24-25 and described in Table 24-18.

Figure 24-25. I2C Extended Mode Register (ICEMDR)

31	16
Reserved	
R-0	

15	1	0
Reserved	IGNACK	BCM
R-0	R/W-0	R/W-1

LEGEND: R/W = Read/Write; R= Read only; -*n* = value after reset

Table 24-18. I2C Extended Mode Register (ICEMDR) Field Descriptions

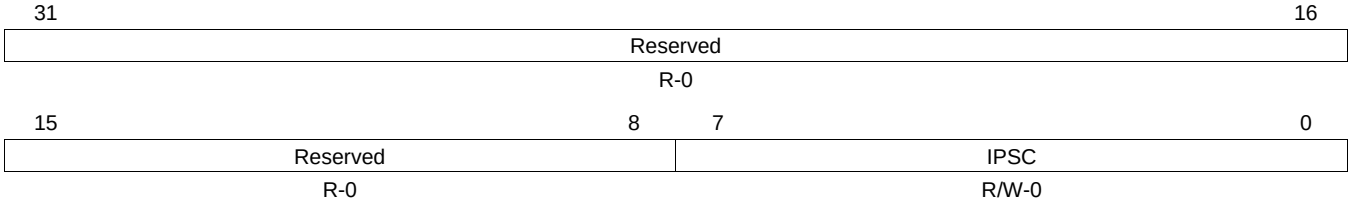
Bit	Field	Value	Description
31-2	Reserved	0	These reserved bit locations are always read as zeros. A value written to this field has no effect.
1	IGNACK		Ignore NACK mode.
		0	Master transmitter operates normally, that is, it discontinues the data transfer and sets the ARDY and NACK bits in ICSTR when receiving a NACK from the slave.
		1	Master transmitter ignores a NACK from the slave.
0	BCM		Backward compatibility mode bit. Determines which condition generates a transmit data ready interrupt.
			The BCM bit only has an effect when the I2C is operating as a slave-transmitter.
		0	The transmit data ready interrupt is generated when the master requests more data by sending an acknowledge signal after the transmission of the last data.
		1	The transmit data ready interrupt is generated when the data in ICDXR is copied to ICXSR.

24.3.12 I2C Prescaler Register (ICPSC)

The I2C prescaler register (ICPSC) is used for dividing down the I2C input clock to obtain the desired prescaled module clock for the operation of the I2C. The IPSC bits must be initialized while the I2C is in reset (IRS = 0 in ICMDR). The prescaled frequency takes effect only when the IRS bit is changed to 1. Changing the IPSC value while IRS = 1 has no effect.

ICPSC is shown in Figure 24-26 and described in Table 24-19.

Figure 24-26. I2C Prescaler Register (ICPSC)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 24-19. I2C Prescaler Register (ICPSC) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	These reserved bit locations are always read as zeros. A value written to this field has no effect.
7-0	IPSC	0-FFh	I2C prescaler divide-down value. IPSC determines how much the I2C input clock is divided to create the I2C prescaled module clock: I2C clock frequency = I2C input clock frequency/(IPSC + 1) **Note:** IPSC must be initialized while the I2C is in reset (IRS = 0 in ICMDR).

24.3.13 I2C Revision Identification Register (REVID1)

The I2C revision identification register (REVID1) contains identification data for the peripheral. REVID1 is shown in Figure 24-27 and described in Table 24-20.

Figure 24-27. I2C Revision Identification Register 1 (REVID1)

31	0
REVID1	
R-4415h	

LEGEND: R = Read only; -*n* = value after reset

Table 24-20. I2C Revision Identification Register 1 (REVID1) Field Descriptions

Bit	Field	Value	Description
31-0	REVID1	4415h	Peripheral Identification Number

24.3.14 I2C Revision Identification Register (REVID2)

The I2C revision identification register (REVID2) contains identification data for the peripheral. REVID2 is shown in Figure 24-28 and described in Table 24-21.

Figure 24-28. I2C Revision Identification Register 2 (REVID2)

31	0
REVID2	
R-6h	

LEGEND: R = Read only; -*n* = value after reset

Table 24-21. I2C Revision Identification Register 2 (REVID2) Field Descriptions

Bit	Field	Value	Description
31-0	REVID2	6h	Peripheral Identification Number

24.3.15 I2C DMA Control Register (ICDMAC)

The I2C DMA control register (ICDMAC) is used to control the transmit DMA event and receive DMA event pin to the system . ICDMAC is shown in Figure 24-29 and described in Table 24-22.

Figure 24-29. I2C DMA Control Register (ICDMAC)

31	16
Reserved	
R-0	

15	1	0
Reserved	TXDMAEN	RXDMAEN
R-0	R/W-1	R/W-1

LEGEND: R/W = Read/Write; R= Read only; -*n* = value after reset

Table 24-22. I2C DMA Control Register (ICDMAC) Field Descriptions

Bit	Field	Value	Description
31-2	Reserved	0	These reserved bit locations are always read as zeros. A value written to this field has no effect.
1	TXDMAEN		Transmit DMA enable. This bit controls the transmit DMA event pin to the system. Always set this bit to 1.
		0	DMA transmit event is disabled.
		1	DMA transmit event is enabled.
0	RXDMAEN		Receive DMA enable . This bit controls the receive DMA event pin to the system. Always set this bit to 1.
		0	DMA receive event is disabled.
		1	DMA receive event is enabled.

24.3.16 I2C Pin Function Register (ICPFUNC)

The I2C pin function register (ICPFUNC) is used to configure the external I2C pins (I2Cx_SDA and I2Cx_SCL) as a I2C peripheral pin or a GPIO pin. ICPFUNC is shown in Figure 24-30 and described in Table 24-23.

Figure 24-30. I2C Pin Function Register (ICPFUNC)

31	16
Reserved	
R-0	

15	1	0
Reserved		PFUNC0
R-0		R/W-0

LEGEND: R/W = Read/Write; R= Read only; -*n* = value after reset

Table 24-23. I2C Pin Function Register (ICPFUNC) Field Descriptions

Bit	Field	Value	Description
31-1	Reserved	0	These reserved bit locations are always read as zeros. A value written to this field has no effect.
0	PFUNC0		Controls the function of the I2Cx_SCL and I2Cx_SDA pins.
		0	Pins function as I2Cx_SCL and I2Cx_SDA.
		1	Pins function as GPIO.
			Note: No hardware protection is required to disable the I2C function when the PFUNC0 bit and the IRS bit in the I2C mode register (ICMDR) are both set to 1. When PFUNC0 = 1 (GPIO mode), the sub-module that controls the I2C function receives the value 1 for I2Cx_SCL and I2Cx_SDA. The IRS bit can be set to 1 regardless of PFUNC0, and the I2C function works whenever the IRS bit is 1. You are expected to hold I2C in reset via the IRS bit when changing to/from GPIO mode via the PFUNC0 bit.

24.3.17 I2C Pin Direction Register (ICPDIR)

The I2C pin direction register (ICPDIR) is used to configure each GPIO pin as either an input or an output. ICPDIR is shown in Figure 24-31 and described in Table 24-24.

Figure 24-31. I2C Pin Direction Register (ICPDIR)

31															16
Reserved															
R-0															
15													2	1	0
Reserved														PDIR1	PDIR0
R-0														R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 24-24. I2C Pin Direction Register (ICPDIR) Field Descriptions

Bit	Field	Value	Description
31-2	Reserved	0	These reserved bit locations are always read as zeros. A value written to this field has no effect.
1	PDIR1		Controls the direction of the I2Cx_SDA pin when configured as GPIO.
		0	I2Cx_SDA pin functions as input.
		1	I2Cx_SDA pin functions as output.
0	PDIR0		Controls the direction of the I2Cx_SCL pin when configured as GPIO.
		0	I2Cx_SCL pin functions as input.
		1	I2Cx_SCL pin functions as output.

24.3.18 I2C Pin Data In Register (ICPDIN)

The I2C pin data in register (ICPDIN) holds the I/O state of each of the I2C pins (I2Cx_SDA and I2Cx_SCL); and should return the value from the pin's input buffer (with appropriate synchronization/DFT considerations). However, this register allows the actual value of the pin to be read regardless of the state of PFUNC or PDIR bits . ICPDIN is shown in Figure 24-32 and described in Table 24-25.

Figure 24-32. I2C Pin Data In Register (ICPDIN)

31	16
Reserved	
R-0	

15	2	1	0
Reserved		PDIN1	PDIN0
R-0		R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 24-25. I2C Pin Data In Register (ICPDIN) Field Descriptions

Bit	Field	Value	Description
31-2	Reserved	0	These reserved bit locations are always read as zeros. A value written to this field has no effect.
1	PDIN1		Indicates the logic level present on the I2Cx_SDA pin.
			During reads:
		0	Logic-low present at I2Cx_SDA pin, regardless of PFUNC bit setting.
		1	Logic-high present at I2Cx_SDA pin, regardless of PFUNC bit setting.
			During writes: Writes have no effect.
0	PDIN0		Indicates the logic level present on the I2Cx_SCL pin.
			During reads:
		0	Logic-low present at I2Cx_SCL pin, regardless of PFUNC bit setting.
		1	Logic-high present at I2Cx_SCL pin, regardless of PFUNC bit setting.
			During writes: Writes have no effect.

24.3.19 I2C Pin Data Out Register (ICPDOUT)

The I2C pin data out register (ICPDOUT) has one bit for each of the GPIO pins. This bit holds a value for data out at all times, and may be read back at all times. The value held by this register is not affected by writing to the PDIR and PFUNC bits. However, the data value in this register is driven out onto the GPIO pin only if the PFUNC0 bit in ICPFUNC is set to 1 (I2Cx_SDA and I2Cx_SCL function as GPIO) and also the corresponding bit in ICPDIR is set to 1 (output).

ICPDOUT is shown in Figure 24-33 and described in Table 24-26.

Figure 24-33. I2C Pin Data Out Register (ICPDOUT)

31	16
Reserved	
R-0	

15	2	1	0
Reserved		PDOUT1	PDOUT0
R-0		R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 24-26. I2C Pin Data Out Register (ICPDOUT) Field Descriptions

Bit	Field	Value	Description
31-2	Reserved	0	These reserved bit locations are always read as zeros. A value written to this field has no effect.
1	PDOUT1		Controls the level driven on the I2Cx_SDA pin when configured as GPIO output. Note: If I2Cx_SDA is connected to an open-drain buffer at the chip level, the I2C cannot drive I2Cx_SDA to high. **During reads:** Reads return register values, not GPIO pin levels.
			During writes:
		0	I2Cx_SDA pin is driven low.
		1	I2Cx_SDA pin is driven high.
0	PDOUT0		Controls the level driven on the I2Cx_SCL pin when configured as GPIO output. Note: If I2Cx_SCL is connected to an open-drain buffer at the chip level, the I2C cannot drive I2Cx_SCL to high. **During reads:** Reads return register values, not GPIO pin levels.
			During writes:
		0	I2Cx_SCL pin is driven low.
		1	I2Cx_SCL pin is driven high.

24.3.20 I2C Pin Data Set Register (ICPDSET)

The I2C pin data set register (ICPDSET) is an alias of the I2C pin data out register (ICPDOUT). Writing a 1 to a bit in ICPDSET sets the corresponding bit in ICPDOUT to a 1, while writing a 0 keeps the bit unchanged. ICPDSET is shown in Figure 24-34 and described in Table 24-27.

Figure 24-34. I2C Pin Data Set Register (ICPDSET)

31			16
Reserved			
R-0			

15	2	1	0
Reserved		PDSET1	PDSET0
R-0		R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; *-n* = value after reset

Table 24-27. I2C Pin Data Set Register (ICPDSET) Field Descriptions

Bit	Field	Value	Description
31-2	Reserved	0	These reserved bit locations are always read as zeros. A value written to this field has no effect.
1	PDSET1		Used to set the PDOUT1 bit in the I2C pin data out register (ICPDOUT) that corresponds to the I2Cx_SDA GPIO pin.
			During reads: Reads return indeterminate values.
			During writes:
		0	No effect
		1	PDOUT1 bit is set to logic high.
0	PDSET0		Used to set the PDOUT0 bit in the I2C pin data out register (ICPDOUT) that corresponds to the I2Cx_SCL GPIO pin.
			During reads: Reads return indeterminate values.
			During writes:
		0	No effect
		1	PDOUT0 bit is set to logic high.

24.3.21 I2C Pin Data Clear Register (ICPDCLR)

The I2C pin data clear register (ICPDCLR) is an alias of the I2C pin data out register (ICPDOUT). Writing a 1 to a bit in ICPDCLR clears the corresponding bit in ICPDOUT to a 0, while writing a 0 keeps the bit unchanged. ICPDCLR is shown in Figure 24-35 and described in Table 24-28.

Figure 24-35. I2C Pin Data Clear Register (ICPDCLR)

31	16
Reserved	
R-0	

15	2	1	0
Reserved		PDCLR1	PDCLR0
R-0		R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 24-28. I2C Pin Data Clear Register (ICPDCLR) Field Descriptions

Bit	Field	Value	Description
31-2	Reserved	0	These reserved bit locations are always read as zeros. A value written to this field has no effect.
1	PDCLR1		Used to clear the PDOUT1 bit in the I2C pin data out register (ICPDOUT) that corresponds to the I2Cx_SDA GPIO pin.
			During reads: Reads return indeterminate values.
			During writes:
		0	No effect
		1	PDOUT1 bit is cleared to logic low.
0	PDCLR0		Used to clear the PDOUT0 bit in the I2C pin data out register (ICPDOUT) that corresponds to the I2Cx_SCL GPIO pin.
			During reads: Reads return indeterminate values.
			During writes:
		0	No effect
		1	PDOUT0 bit is cleared to logic low.

Liquid Crystal Display Controller (LCDC)

The liquid crystal display controller (LCDC) is capable of supporting an asynchronous (memory-mapped) LCD interface and a synchronous (raster-type) LCD interface. This chapter describes the LCDC.

Topic **Page**

25.1 Introduction

25.1.1 Purpose of the Peripheral

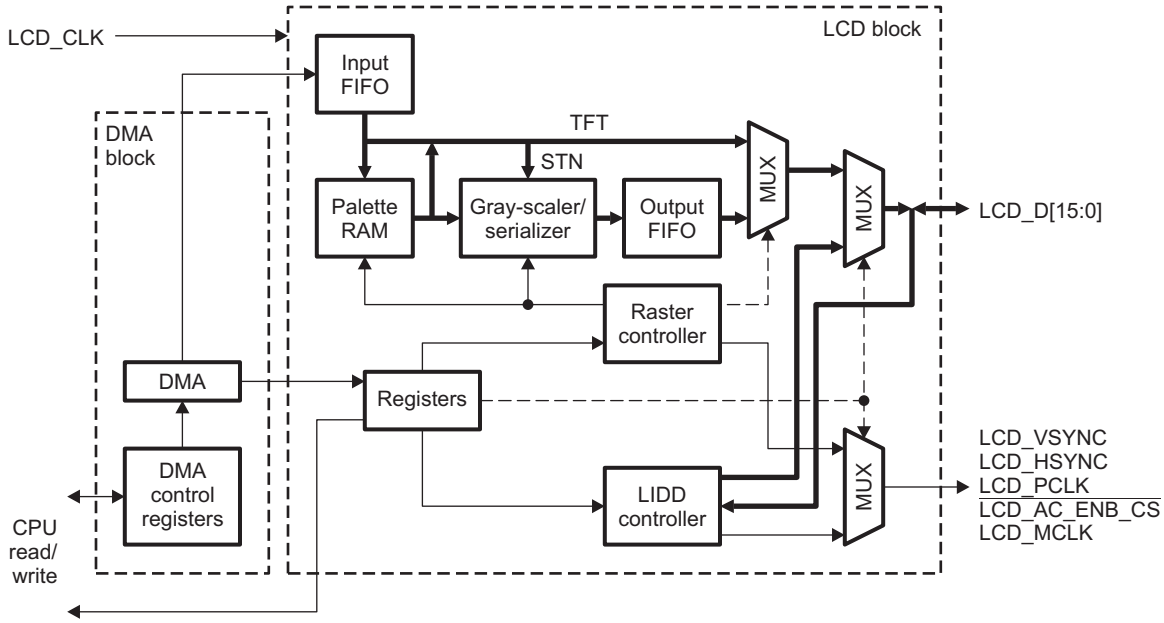
The LCD controller consists of two independent controllers, the Raster Controller and the LCD Interface Display Driver (LIDD) controller. Each controller operates independently from the other and only one of them is active at any given time.

- The Raster Controller handles the synchronous LCD interface. It provides timing and data for constant graphics refresh to a passive display. It supports a wide variety of monochrome and full-color display types and sizes by use of programmable timing controls, a built-in palette, and a gray-scale/serializer. Graphics data is processed and stored in frame buffers. A frame buffer is a contiguous memory block in the system. A built-in DMA engine supplies the graphics data to the Raster engine which, in turn, outputs to the external LCD device.
- The LIDD Controller supports the asynchronous LCD interface. It provides full-timing programmability of control signals and output data.

Figure 25-1 shows the LCD controller details. The raster and LIDD Controllers are responsible for generating the correct external timing. The DMA engine provides a constant flow of data from the frame buffer(s) to the external LCD panel via the Raster and LIDD Controllers. In addition, CPU access is provided to read and write registers.

The solid, thick lines in Figure 25-1 indicate the data path. The Raster Controller's data path is fairly complicated, for a thorough description of the Raster Controller data path, see Section 25.2.5.

Figure 25-1. LCD Controller



25.1.2 Features

See your device-specific data manual to check the features supported by the LCD controller.

25.1.3 Terminology

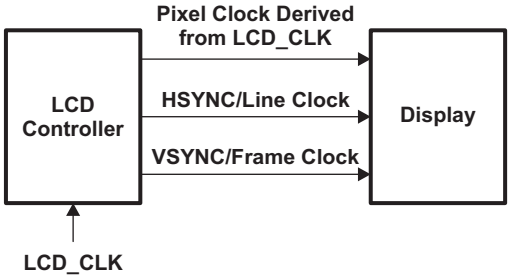
Term	Meaning
Passive (STN) device	Refers to the Super-Twisted Nematic (STN) display device.
Active (TFT) device	Refers to the Thin-Film Transistor (TFT) display device.
BPP	Bits per pixel; that is, the number of bits used for each pixel. In some documentation, this is also referred to as color depth.
RGB	Red, Green, Blue

25.2 Architecture

25.2.1 Clocking

This section details the various clocks and signals. Figure 25-2 shows input and output LCD controller clocks.

Figure 25-2. Input and Output Clocks



25.2.1.1 Pixel Clock

The pixel clock (LCD_PCLK) frequency is derived from LCD_CLK, the reference clock to this LCD module (see Figure 25-2). The pixel clock is used by the LCD display to clock the pixel data into the line shift register.

$$\text{LCD\_PCLK} = \frac{\text{LCD\_CLK}}{\text{CLKDIV}}$$

where CLKDIV is a field in the LCD_CTRL register and should not be 0 or 1.

- **Passive (STN) mode.** LCD_PCLK only transitions when valid data is available for output. It does not transition when the horizontal clock is asserted or during wait state insertion.
- **Active (TFT) mode.** LCD_PCLK continuously toggles as long as the Raster Controller is enabled.

25.2.1.2 Horizontal Clock (LCD_HSYNC)

LCD_HSYNC toggles after all pixels in a horizontal line have been transmitted to the LCD and a programmable number of pixel clock wait states has elapsed both at the beginning and end of each line.

The RASTER_TIMING_0 register fully defines the behavior of this signal.

LCD_HSYNC can be programmed to be synchronized with the rising or falling edge of LCD_PCLK. The configuration field is bits 24 and 25 in the RASTER_TIMING_2 register.

- **Active (TFT) mode.** The horizontal clock or the line clock is also used by TFT displays as the horizontal synchronization signal (LCD_HSYNC).

  The timings of the horizontal clock(line clock) pins are programmable to support:
- Delay insertion both at the beginning and end of each line
- Line clock polarity.
- Line clock pulse width, driven on rising or falling edge of pixel clock.

25.2.1.3 Vertical Clock (LCD_VSYNC)

LCD_VSYNC toggles after all lines in a frame have been transmitted to the LCD and a programmable number of line clock cycles has elapsed both at the beginning and end of each frame.

The RASTER_TIMING_1 register fully defines the behavior of this signal.

LCD_VSYNC can be programmed to be synchronized with the rising or falling edge of LCD_PCLK. The configuration field is bits 24 and 25 in the RASTER_TIMING_2 register.

- **Passive (STN) mode.** The vertical clock; that is, the frame clock, toggles during the first line of the screen.
- **Active (TFT) mode.** The vertical clock, that is, the frame clock, is also used by TFT displays as the vertical synchronization signal (LCD_VSYNC).

  The timings of the vertical clock pins are programmable to support:
- Delay insertion both at the beginning and end of each frame
- Frame clock polarity

25.2.1.4 $\overline{\text{LCD\_AC\_ENB\_CS}}$

- **Passive (STN) mode.** To prevent a dc charge within the screen pixels, the power and ground supplies of the display are periodically switched. The Raster Controller signals the LCD to switch the polarity by toggling this pin ($\overline{\text{LCD\_AC\_ENB\_CS}}$).
- **Active (TFT) mode.** This signal acts as an output enable (OE) signal. It is used to signal the external LCD that the data is valid on the data bus (LCD_D[15:0]).

25.2.2 LCD External I/O Signals

Table 25-1 shows the details of the LCD controller external signals.

Table 25-1. LCD External I/O Signals

Signal	Type	Description
LCD_VSYNC	OUT	Raster controller: Frame clock the LCD uses to signal the start of a new frame of pixels. Also used by TFT displays as the vertical synchronization signal. LIDD character: Register select (RS) LIDD graphics: Register select (RS), address bit 0 (A0), or command/data select (C/D)
LCD_HSYNC	OUT	Raster controller: Line clock the LCD uses to signal the end of a line of pixels that transfers line data from the shift register to the screen and to increment the line pointer(s). Also used by TFT displays as the horizontal synchronization signal. LIDD character: read or write enable LIDD graphics: • 6800 mode = read or write enable • 8080 mode = write strobe
LCD_PCLK	OUT	Raster controller: Pixel clock the LCD uses to clock the pixel data into the line shift register. In passive mode, the pixel clock transitions only when valid data is available on the data lines. In active mode, the pixel clock transitions continuously, and the ac-bias pin is used as an output enable to signal when data is available on the LCD pin. LIDD character: not used. LIDD graphics: • 6800 mode = enable strobe • 8080 mode = read strobe
$\overline{\text{LCD\_AC\_ENB\_CS}}$	OUT	Raster controller: ac-bias used to signal the LCD to switch the polarity of the power supplies to the row and column axis of the screen to counteract DC offset. Used in TFT mode as the output enable to signal when data is latched from the data pins using the pixel clock. LIDD character: Primary enable strobe LIDD graphics: Chip select 0 ($\overline{\text{CS0}}$)
LCD_MCLK	OUT	Raster controller: not used. LIDD character: Secondary enable strobe LIDD graphics: Chip select 1 ($\overline{\text{CS1}}$)
LCD_D[15:0]	Raster: OUT	LCD data bus, providing a 4-, 8-, or 16-bit data path.
	LIDD: OUT/IN	Raster controller: For monochrome displays, each signal represents a pixel; for passive color displays, groupings of three signals represent one pixel (red, green, and blue). LCD_D[3:0] is used for monochrome displays of 2, 4, and 8 BPP; LCD_D[7:0] is used for color STN displays and LCD_D[15:0] is used for active (TFT) mode. LIDD character: Read and write the command and data registers. LIDD graphics: Read and write the command and data registers.

25.2.3 DMA Engine

The DMA engine provides the capability to output graphics data to constantly refresh LCDs, without burdening the CPU, via interrupts or a firmware timer. It operates on one or two frame buffers, which are set up during initialization. Using two frame buffers (ping-pong buffers) enables the simultaneous operation of outputting the current video frame to the external display and updating the next video frame. The ping-pong buffering approach is preferred in most applications.

When the Raster Controller is used, the DMA engine reads data from a frame buffer and writes it to the input FIFO (as shown in Figure 25-1). The Raster Controller requests data from the FIFO for frame refresh; as a result, the DMA's job is to ensure that the FIFO is always kept full.

When the LIDD Controller is used, the DMA engine accesses the LIDD Controller's address and/or data registers.

To program DMA engine, configure the following registers, as shown in Table 25-2.

Table 25-2. Register Configuration for DMA Engine Programming

Register	Configuration
LCDDMA_CTRL	Configure DMA data format
LCDDMA_FB0_BASE LCDDMA_FB0_CEILING	Configure frame buffer 0
LCDDMA_FB1_BASE LCDDMA_FB1_CEILING	Configure frame buffer 1. (If only one frame buffer is used, these two registers will not be used.)

In addition, the LIDD_CTRL register (for LIDD Controller) or the RASTER_CTRL register (for Raster Controller) should also be configured appropriately, along with all the timing registers.

To enable DMA transfers, the LIDD_DMA_EN bit (in the LIDD_CTRL register) or the LCDEN bit (in the RASTER_CTRL register) should be written with 1.

NOTE: If the data left in the frame buffer is smaller than the DMA burst size, the DMA by default transfers 1 word (4 bytes) at a time until the entire frame buffer is transferred. This sometimes causes an input FIFO underflow, which can only be recovered through a Power and Sleep Controller (PSC) reset. Thus, it is recommended that the size of the frame buffer be divisible by the chosen burst size.

25.2.3.1 Interrupts

Interrupts in this LCD module are related to DMA engine operation. Three registers are closely related to this subject:

- The LIDD_CTRL and RASTER_CTRL registers enable or disable each individual interrupt sources.
- The LCD_STAT register collects all the interrupt status information.

25.2.3.1.1 LIDD Mode

When operating in LIDD mode, the DMA engine generates one interrupt signal every time the specified frame buffer has been transferred completely.

- The DONE_INT_EN bit in the LIDD_CTRL register specifies if the interrupt signal is delivered to the system interrupt controller, which in turn may or may not generate an interrupt to CPU.
- The EOF1, EOF0, and DONE bits in the LCD_STAT register reflect the interrupt signal, regardless of being delivered to the system interrupt controller or not.

25.2.3.1.2 Raster Mode

When operating in Raster mode, the DMA engine can generate the interrupts in the following scenarios:

1. **Output FIFO under-run**. This occurs when the DMA engine cannot keep up with the data rate consumed by the LCD (which is determined by the LCD_PCLK.) This is likely due to a system memory throughput issue or an incorrect LCD_PCLK setting. The FUF bit in LCD_STAT is set when this error occurs. This bit is cleared by disabling the Raster Controller (i.e., clearing the LCDEN bit in RASTER_CTRL).
2. **Frame synchronization lost**. This error happens when the DMA engine attempts to read what it believes to be the first word of the video buffer but it cannot be recognized as such. This could be caused by an invalid frame buffer address or an invalid BPP value (for more details, see Section 25.2.5.2). The SYNC bit in the LCD_STAT register is set when such an error is detected. This field is cleared by disabling the Raster Controller (clearing the LCDEN bit in the RASTER_CTRL register).
3. **Palette loaded**. This interrupt can be generated when the palette is loaded into the memory by the DMA engine. At the same time, the PL bit in the LCD_STAT register is set. In data-only (PLM = 2h) and palette-plus-data (PLM = 00) modes, writing 0 to this bit clears the interrupt. In the palette-only (PLM = 1) mode, this bit is cleared by disabling the Raster Controller (clearing the LCDEN bit in the RASTER_CTRL register).
4. **AC bias transition**. If the ACB_I bit in the RASTER_TIMING_2 register is programmed with a non-zero value, an internal counter will be loaded with this value and starts to decrement each time LCD_AC_ENB_CS (AC-bias signal) switches its state. When the counter reaches zero, the ABC bit in the LCD_STAT register is set, which will deliver an interrupt signal to the system interrupt controller (if the interrupt is enabled.) The counter reloads the value in field ACB_I, but does not start to decrement until the ABC bit is cleared by writing 0 to this bit.
5. **Frame transfer completed**. When one frame of data is transferred completely, the DONE bit in the LCD_STAT register is set. This bit is cleared by disabling the Raster Controller (i.e., clearing the LCDEN bit in the RASTER_CTRL register). Note that the EOF0 and EOF1 bits in the LCD_STAT register will be set accordingly.

Note that the interrupt enable bits are in the RASTER_CTRL register. The corresponding enable bit must be set in order to generate an interrupt to the CPU. However, the LCD_STAT register reflects the interrupt signal regardless of the interrupt enable bits settings.

25.2.3.1.3 Interrupt Handling

See your device-specific data manual for information about the LCD interrupt number to the CPU .The interrupt service routine needs to determine the interrupt source by examining the LCD_STAT register and clearing the interrupt properly.

25.2.4 LIDD Controller

The LIDD Controller is designed to support LCD panels with a memory-mapped interface. The types of displays range from low-end character monochrome LCD panels to high-end TFT smart LCD panels.

LIDD mode (and the use of this logic) is enabled by clearing the MODESEL bit in the LCD control register (LCD_CTRL).

LIDD Controller operation is summarized as follows:

- During initialization, the LCD LIDD CS0/CS1 configuration registers (LIDD_CS0_CONF and LIDD_CS1_CONF) are configured to match the requirements of the LCD panel being used.
- During normal operation, the CPU writes display data to the LCD data registers (LIDD_CS0_DATA and LIDD_CS1_DATA). The LIDD interface converts the CPU write into the proper signal transition sequence for the display, as programmed earlier. Note that the first CPU write should send the beginning address of the update to the LCD panel and the subsequent writes update data at display locations starting from the first address and continuing sequentially. Note that DMA may be used instead of CPU.
- The LIDD Controller is also capable of reading back status or data from the LCD panel, if the latter has this capability. This is set up and activated in a similar manner to the write function described above.

NOTE: If an LCD panel is not used, this interface can be used to control any MCU-like peripheral.

See your device-specific data manual to check the LIDD features supported by the LCD controller.

Table 25-3 describes how the signals are used to interface external LCD modules, which are configured by the LIDD_CTRL register.

Table 25-3. LIDD I/O Name Map

Display Type	Interface Type	Data Bits	LIDD_CTRL [2:0]	I/O Name	Display I/O Name	Comment
Character Display	HD44780 Type	4	100	LCD_D[7:4]	DATA[7:4]	Data Bus (length defined by Instruction)
				LCD_HSYNC	R/$\overline{W}$	Read/$\overline{Write}$
				LCD_VSYNC	RS	Register Select (RS = 0, command; RS = 1, data)
				$\overline{LCD\_AC\_ENB\_CS}$	E (or E0)	Enable Strobe (first display)
				LCD_MCLK	E1	Enable Strobe (second display optional)
Character Display	HD44780 Type	8	100	LCD_D[7:0]	DATA[7:0]	Data Bus (length defined by Instruction)
				LCD_HSYNC	R/$\overline{W}$	Read/$\overline{Write}$
				LCD_VSYNC	RS	Register Select (RS = 0, command; RS = 1, data)
				$\overline{LCD\_AC\_ENB\_CS}$	E (or E0)	Enable Strobe (first display)
				LCD_MCLK	E1	Enable Strobe (second display optional)
Micro Interface Graphic Display	6800 Family	Up to 16	001	LCD_D[15:0]	DATA[15:0]	Data Bus (16 bits always available)
				LCD_PCLK	E	Enable Clock
				LCD_HSYNC	R/$\overline{W}$	Read/$\overline{Write}$
				LCD_VSYNC	RS	Register Select (RS = 0, command; RS = 1, data)
				$\overline{LCD\_AC\_ENB\_CS}$	$\overline{CS}$ (or $\overline{CS0}$)	Chip Select (first display)
				LCD_MCLK	$\overline{CS1}$	Chip Select (second display optional)
			000	LCD_MCLK	None	Synchronous Clock (optional)
Micro Interface Graphic Display	8080 Family	Up to 16	011	LCD_D[15:0]	DATA[15:0]	Data Bus (16 bits always available)
				LCD_PCLK	RD	Read Strobe
				LCD_HSYNC	WR	Write Strobe
				LCD_VSYNC	RS	Register Select (RS = 0, command; RS = 1, data)
				$\overline{LCD\_AC\_ENB\_CS}$	$\overline{CS}$ (or $\overline{CS0}$)	Chip Select (first display)
				LCD_MCLK	$\overline{CS1}$	Chip Select (second display optional)
			010	LCD_MCLK	None	Synchronous Clock (optional)

The timing parameters are defined by the LIDD_CS0_CONF and LIDD_CS1_CONF registers, which are described in Section 25.3.5.

The timing configuration is based on an internal reference clock, MCLK. The MCLK is generated out of LCD_CLK, which is determined by the CLKDIV bit in the LCD_CTRL register:

$$\text{MCLK} = \text{LCD\_CLK when CLKDIV} = 0.$$

$$\text{MCLK} = \frac{\text{LCD\_CLK}}{\text{CLKDIV}} \text{ when CLKDIV} \neq 0.$$

See your device-specific data manual for the timing configurations supported by the LCD controller.

25.2.5 Raster Controller

Raster mode (and the use of this logic) is enabled by setting the MODESEL bit in the LCD control register (LCD_CTRL). Table 25-4 shows the active external signals when this mode is active.

Table 25-4. Operation Modes Supported by Raster Controller

Interface	Data Bus Width	Register Bits RASTER_CTRL[9, 7, 1]	Signal Name	Description
Passive (STN) Mono 4-bit	4	001	LCD_D[3:0]	Data bus
			LCD_PCLK	Pixel clock
			LCD_HSYNC	Horizontal clock(Line Clock)
			LCD_VSYNC	Vertical clock (Frame Clock)
			$\overline{\text{LCD\_AC\_ENB\_CS}}$	AC Bias
			LCD_MCLK	Not used
Passive (STN) Mono 8-bit	8	101	LCD_D[7:0]	Data bus
			LCD_PCLK	Pixel clock
			LCD_HSYNC	Horizontal clock(Line Clock)
			LCD_VSYNC	Vertical clock (Frame Clock)
			$\overline{\text{LCD\_AC\_ENB\_CS}}$	AC Bias
			LCD_MCLK	Not used
Passive (STN) Color	8	100	LCD_D[7:0]	Data bus
			LCD_PCLK	Pixel clock
			LCD_HSYNC	Horizontal clock(Line Clock)
			LCD_VSYNC	Vertical clock (Frame Clock)
			$\overline{\text{LCD\_AC\_ENB\_CS}}$	AC Bias
			LCD_MCLK	Not used
Active (TFT) Color	16	x10	LCD_D[15:0]	Data bus
			LCD_PCLK	Pixel clock
			LCD_HSYNC	Horizontal clock(Line Clock)
			LCD_VSYNC	Vertical clock (Frame Clock)
			$\overline{\text{LCD\_AC\_ENB\_CS}}$	Output enable
			LCD_MCLK	Not used

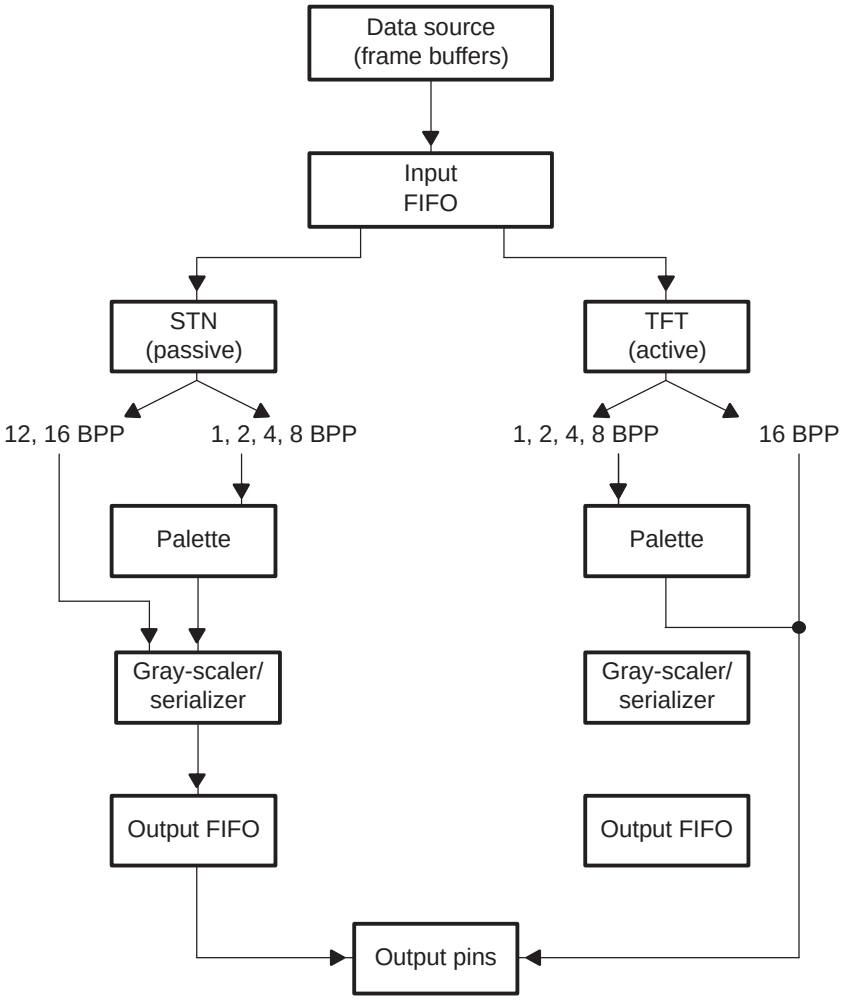
25.2.5.1 Logical Data Path

The block diagram of the Raster Controller is shown in Figure 25-1. Figure 25-3 illustrates its logical data path for various operation modes (passive (STN) versus active (TFT), various BPP size).

Figure 25-3 shows that:

- The gray-scaler/serializer and output FIFO blocks are bypassed in active (TFT) modes.
- The palette is bypassed in both 12- and 16-BPP modes.

Figure 25-3. Logical Data Path for Raster Controller



In summary:

- The display image is stored in frame buffers.
- The built-in DMA engine constantly transfers the data stored in the frame buffers to the Input FIFO.
- The Raster Controller relays data to the external pins according to the specified format.

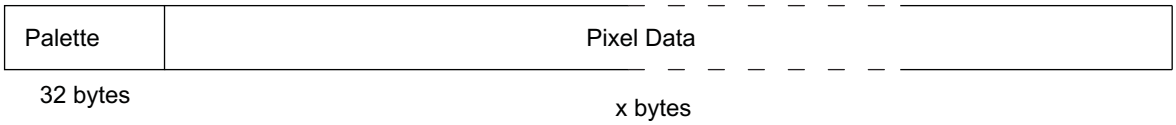
The remainder of this section describes the functioning blocks in Figure 25-3, including frame buffers, palette, and gray-scaler/serializer. Their operation and programming techniques are covered in detail. The output format is also described in Section 25.2.5.5.

25.2.5.2 Frame Buffer

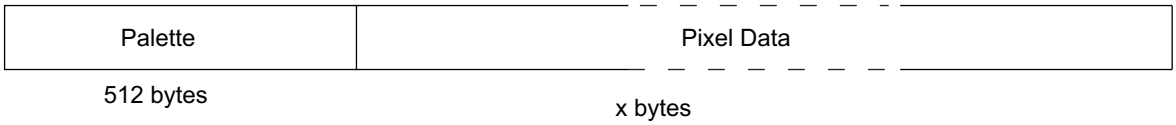
A frame buffer is a contiguous memory block, storing enough data to fill a full LCD screen. For this device, external memory needs to be used for the frame buffer. For specific details on which external memory interface (EMIF) controller can be accessed by the LCD controller, see your device-specific data manual. The data in the frame buffer consists of pixel values as well as a look-up palette. Figure 25-4 shows the frame buffer structure.

Figure 25-4. Frame Buffer Structure

1, 2, 4, 12, 16 BPP Modes



8 BPP Mode



NOTE:

- 8-BPP mode uses the first 512 bytes in the frame buffer as the palette while the other modes use 32 bytes.
- 12- and 16-BPP modes do not need a palette; i.e., the pixel data is the desired RGB value. However, the first 32 bytes are still considered a palette. The first entry should be 4000h (bit 14 is 1) while the remaining entries must be filled with 0. (For details, see Table 25-5.)
- Each entry in a palette occupies 2 bytes. As a result, 8-BPP mode palette has 256 color entries while the other palettes have up to 16 color entries.
- 4-BPP mode uses up the all the 16 entries in a palette.
- 1-BPP mode uses the first 2 entries in a palette while 2-BPP mode uses the first 4 entries. The remaining entries are not used and must be filled with 0.
- In 12- and 16-BPP modes, pixel data is RGB data. For all the other modes, pixel data is actually an index of the palette entry.

Table 25-5. Bits-Per-Pixel Encoding for Palette Entry 0 Buffer

Bit	Name	Value	Description [1] [2]
14-12	BPP		Bits-per-pixel.
		000	1 BPP
		001	2 BPP
		010	4 BPP
		011	8 BPP
		1xx	12 BPP in passive mode (TFT_STN = 0 and STN_565 = 0 in RASTER_CTRL)
			16 BPP in passive mode (TFT_STN = 0 and STN_565 = 1 in RASTER_CTRL)
			16 BPP in active mode (TFT_STN = 1 in RASTER_CTRL)

(1) Eight 1-bit pixels, four 2-bit pixels, and two 4-bit pixels are packed into each byte, and 12-bit pixels are right justified on (16-bit) word boundaries (in the same format as palette entry).

(2) For STN565, see the 16 BPP STN mode bit (Section 25.3.8.8).

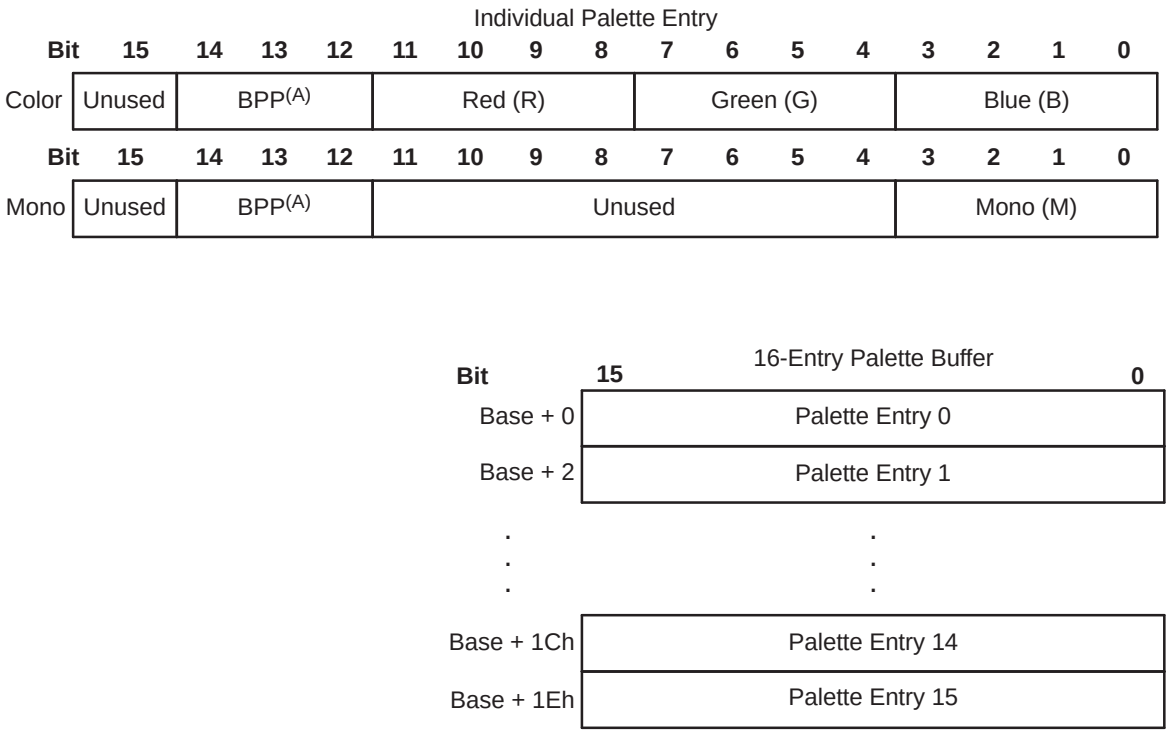
The equations shown in Table 25-6 are used to calculate the total frame buffer size (in bytes) based on varying pixel size encoding and screen sizes.

Figure 25-5 and Figure 25-6 show more detail of the palette entry organization.

Table 25-6. Frame Buffer Size According to BPP

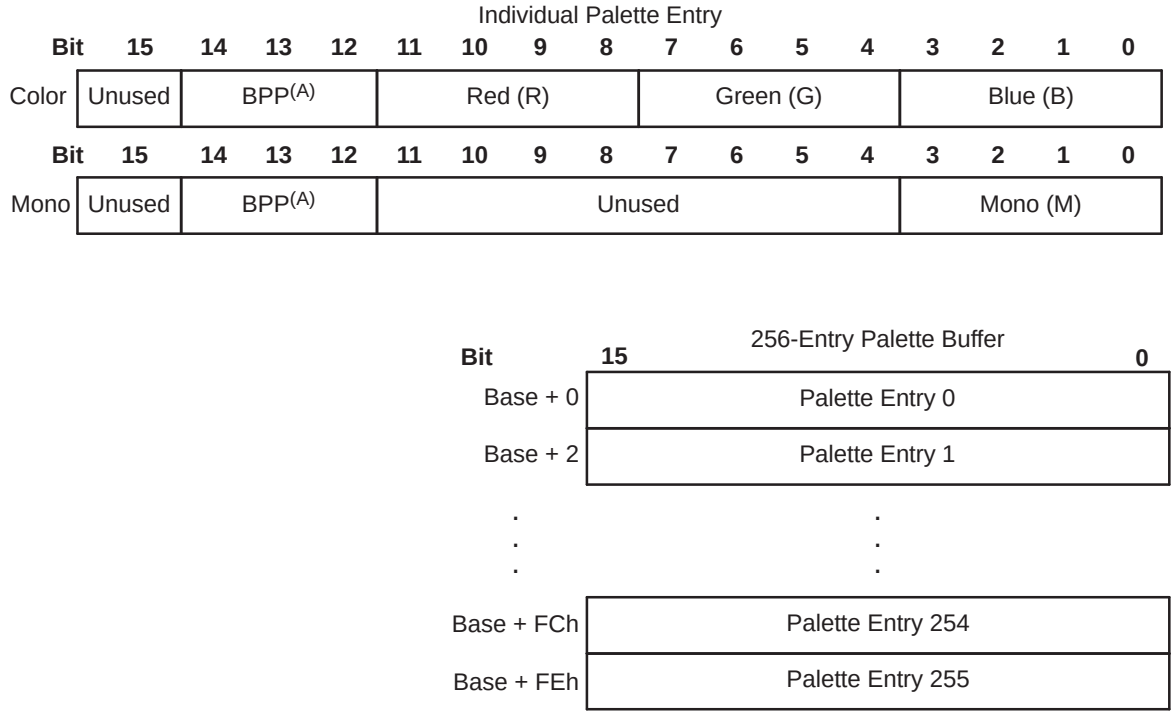
BPP	Frame Buffer Size
1	32 + (Lines × Columns)/8
2	32 + (Lines × Columns)/4
4	32 + (Lines × Columns)/2
8	512 + (Lines × Columns)
12/16	32 + 2 × (Lines × Columns)

Figure 25-5. 16-Entry Palette/Buffer Format (1, 2, 4, 12, 16 BPP)



A. Bits-per-pixels (BPP) is only contained within the first palette entry (palette entry 0).

Figure 25-6. 256-Entry Palette/Buffer Format (8 BPP)



A. Bits-per-pixels (BPP) is only contained within the first palette entry (palette entry 0).

Bits 12, 13, and 14 of the first palette entry select the number of bits-per-pixel to be used in the following frame and thus the number of palette RAM entries. The palette entry is used by the Raster Controller to correctly unpack pixel data.

The following figures show the memory organization within the frame buffer for each pixel encoding size.

Figure 25-7. 16-BPP Data Memory Organization (TFT Mode Only)—Little Endian

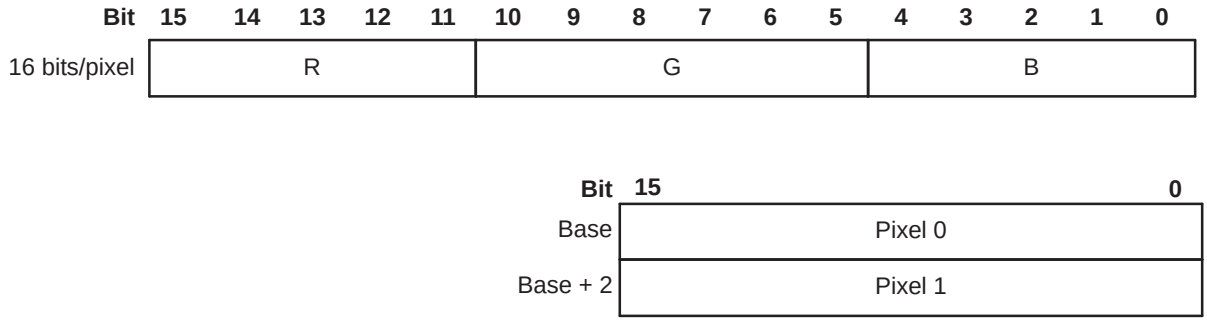
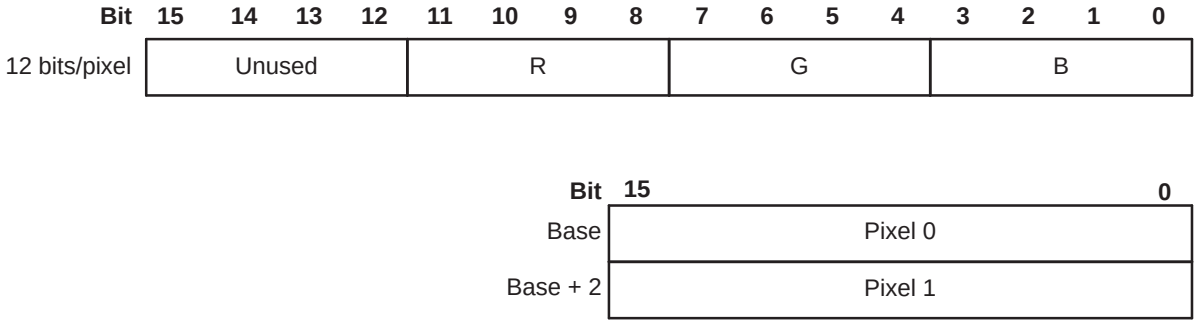


Figure 25-8. 12-BPP Data Memory Organization—Little Endian



Unused [15-12] bits are filled with zeroes in TFT mode.

Figure 25-9. 8-BPP Data Memory Organization

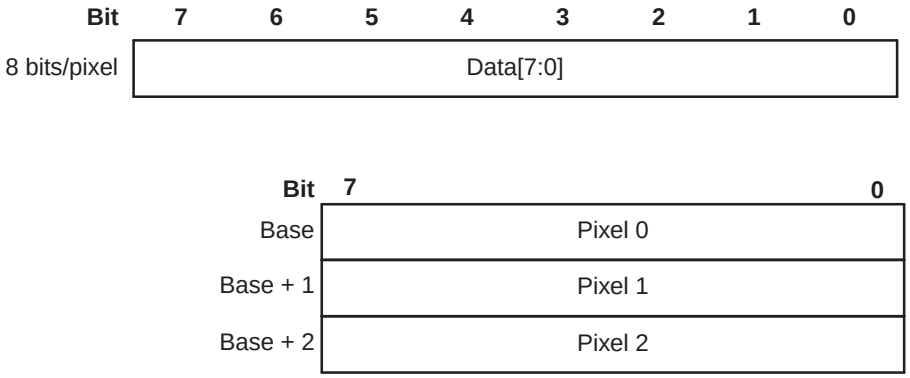


Figure 25-10. 4-BPP Data Memory Organization

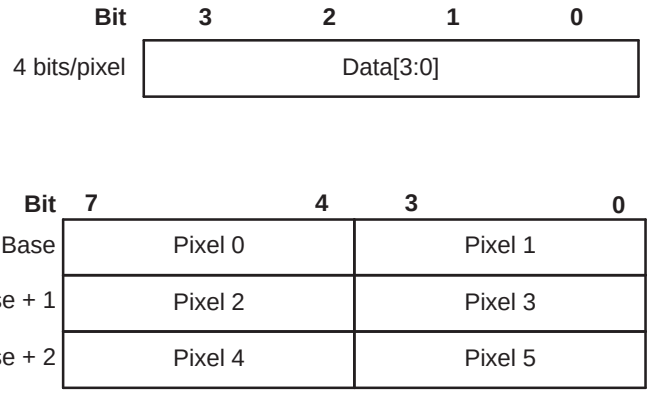


Figure 25-11. 2-BPP Data Memory Organization

Bit	7	6	5	4	3	2	1	0
Base	Pixel 0		Pixel 1		Pixel 2		Pixel 3	
Base + 1	Pixel 4		Pixel 5		Pixel 6		Pixel 7	
Base + 2	Pixel 8		Pixel 9		Pixel 10		Pixel 11	

Figure 25-12. 1-BPP Data Memory Organization

Bit	7	6	5	4	3	2	1	0
Base	P0	P1	P2	P3	P4	P5	P6	P7
Base + 1	P8	P9	P10	P11	P12	P13	P14	P15

25.2.5.3 Palette

As explained in the previous section, the pixel data is an index of palette entry (when palette is used). The number of colors supported is given by $2^{\text{number of BPP}}$. However, due to a limitation of the gray-scaler/serializer block, fewer grayscales or colors may be supported.

The PLM field (in RASTER_CTRL) affects the palette loading:

- If PLM is 00b (palette-plus-data mode) or 01b (palette-only mode), the palette is loaded by the DMA engine at the very beginning, which is followed by the loading of pixel data.
- If PLM is 10b (data-only mode), the palette is not loaded. Instead, the DMA engine loads the pixel data immediately.

25.2.5.4 Gray-Scaler/Serializer

25.2.5.4.1 Passive (STN) Mode

Once a palette entry is selected from the look-up palette by the pixel data, its content is sent to the gray-scaler/serializer. If it is monochrome data, it is encoded as 4 bits. If it is color data, it is encoded as 4 bits (Red), 4 bits (Green), and 4 bits (Blue).

These 4-bit values are used to select one of the 16 intensity levels, as shown in Table 25-7. A patented algorithm is used during this processing to provide an optimized intensity value that matches the eye's visual perception of color/gray gradations.

25.2.5.4.2 Active (TFT) Mode

The gray-scaler/serializer is bypassed.

Table 25-7. Color/Grayscale Intensities and Modulation Rates

Dither Value (4-Bit Value from Palette)	Intensity (0% is White)	Modulation Rate (Ratio of ON to ON+OFF Pixels)
0000	0.0%	0
0001	11.1%	1/9
0010	20.0%	1/5
0011	26.7%	4/15
0100	33.3%	3/9
0101	40.0%	2/5
0110	44.4%	4/9
0111	50.0%	1/2
1000	55.6%	5/9
1001	60.0%	3/5
1010	66.6%	6/9
1011	73.3%	11/15
1100	80.0%	4/5
1101	88.9%	8/9
1110	100.0%	1
1111	100.0%	1

25.2.5.4.3 Summary of Color Depth

Table 25-8. Number of Colors/Shades of Gray Available on Screen

Number of BPP	Passive Mode (TFT_STN = 0)		Active Mode (TFT_STN = 1)
	Monochrome (MONO_COLOR = 1)	Color (MONO_COLOR = 0)	Color Only (MONO_COLOR = 0)
1	2 palette entries to select within 15 grayscales	2 palette entries to select within 3375 possible colors	2 palette entries to select within 4096 possible colors
2	4 palette entries to select within 15 grayscales	4 palette entries to select within 3375 possible colors	4 palette entries to select within 4096 possible colors
4	16 palette entries to select within 15 grayscales	16 palette entries to select within 3375 possible colors	16 palette entries to select within 4096 possible colors
8	Not relevant since it would consist in 256 palette entries to select within 15 grayscales, but exists anyway	256 palette entries to select 3375 possible colors	256 palette entries to select within 4096 possible colors
12	x	3375 possible colors	4096 possible colors
16	x	3375 possible colors (STN_565 = 1)	Up to 65536 possible colors

25.2.5.5 Output Format

25.2.5.5.1 Passive (STN) Mode

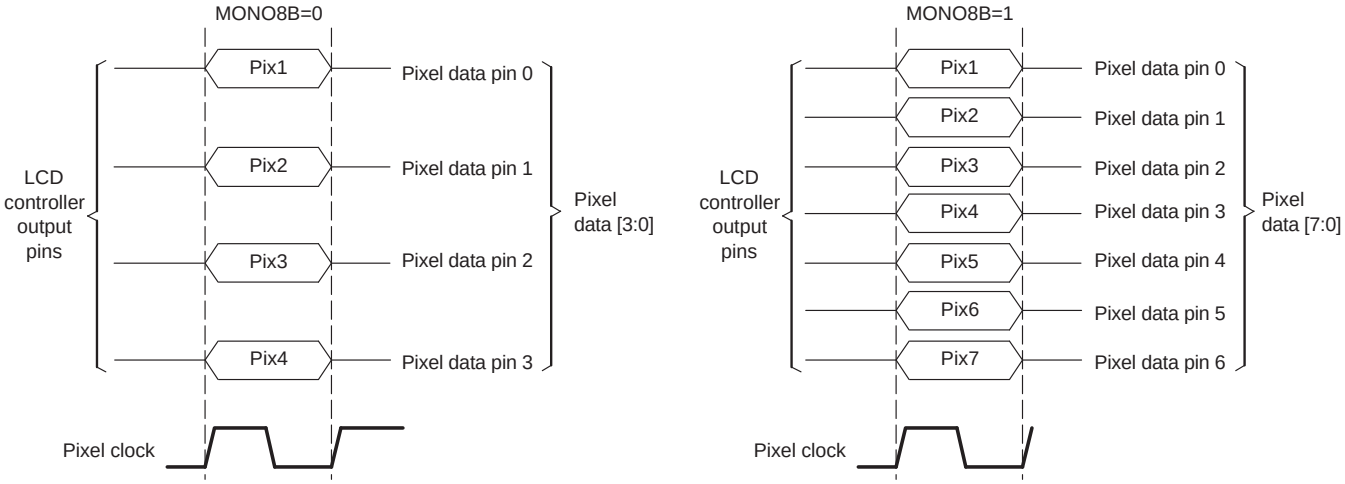
As shown in Figure 25-3, the pixel data stored in frame buffers go through palette (if applicable) and gray-scaler/serializer before reaching the Output FIFO. As a result, it is likely that the data fed to the Output FIFO is numerically different from the data in the frame buffers. (However, they represent the same color or grayscale.)

The output FIFO formats the received data according to display modes (see Table 25-4). Figure 25-13 shows the actual data output on the external pins.

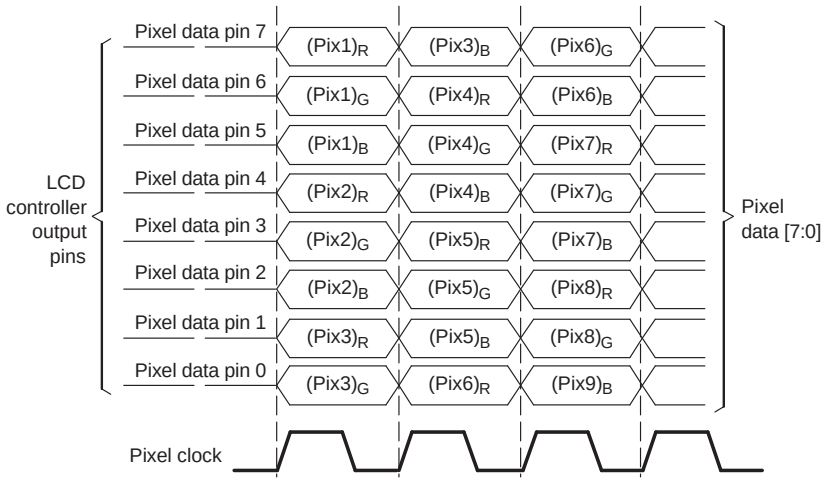
25.2.5.5.2 Active (TFT) Mode

As shown in Figure 25-3, the gray-scaler/serializer and output FIFO are bypassed in active (TFT) mode. Namely, at each pixel clock, one pixel data (16 bits) is output to the external LCD.

Figure 25-13. Monochrome and Color Output



Monochrome



Color

25.2.5.6 Subpanel Feature

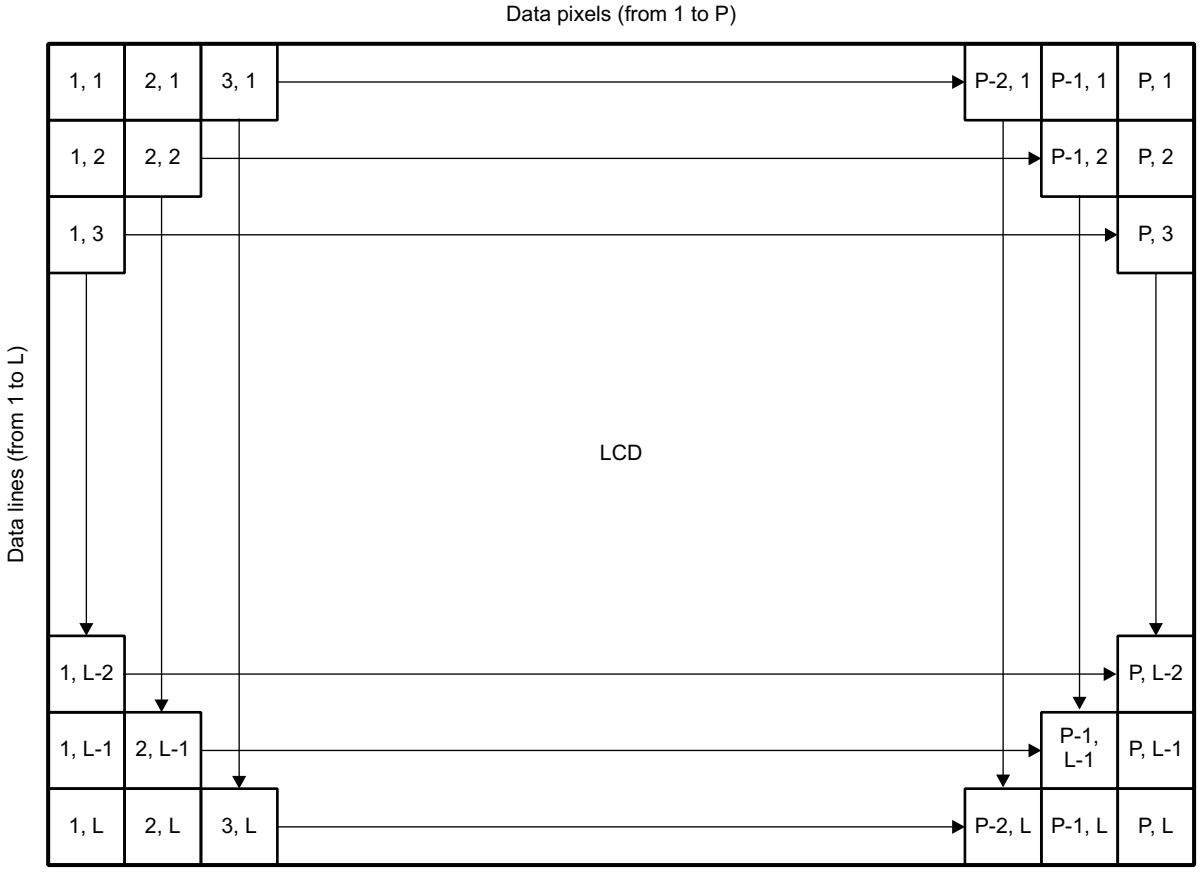
In some applications, it is desired to display only the first or last few lines of the LCD panel (see Figure 25-14). This is mainly used for power saving.

This is supported by the Raster Controller via its subpanel feature. The RASTER_SUBPANEL register fully defines its behavior, that is, the following parameters are defined:

- Whether the first or last few lines will be refreshed.
- A line number, which is the last (or first) line to be refreshed.
- The pixel data to be loaded to the refresh area.

Note that there is only one pixel value for all the pixels in the refresh area. As a result, frame buffers and DMA engine are not used in this case, which leads to power saving.

Figure 25-14. Raster Mode Display Format



25.3 Registers

Table 25-9 lists the memory-mapped registers for the LCD module.

Table 25-9. LCD Controller (LCDC) Registers

Address Offset	Acronym	Register Description	Section
0h	REVID	LCD Revision Identification Register	Section 25.3.1
4h	LCD_CTRL	LCD Control Register	Section 25.3.2
8h	LCD_STAT	LCD Status Register	Section 25.3.3
Ch	LIDD_CTRL	LCD LIDD Control Register	Section 25.3.4
10h	LIDD_CS0_CONF	LCD LIDD CS0 Configuration Register	Section 25.3.5
14h	LIDD_CS0_ADDR	LCD LIDD CS0 Address Read/Write Register	Section 25.3.6
18h	LIDD_CS0_DATA	LCD LIDD CS0 Data Read/Write Register	Section 25.3.7
1Ch	LIDD_CS1_CONF	LCD LIDD CS1 Configuration Register	Section 25.3.5
20h	LIDD_CS1_ADDR	LCD LIDD CS1 Address Read/Write Register	Section 25.3.6
24h	LIDD_CS1_DATA	LCD LIDD CS1 Data Read/Write Register	Section 25.3.7
28h	RASTER_CTRL	LCD Raster Control Register	Section 25.3.8
2Ch	RASTER_TIMING_0	LCD Raster Timing 0 Register	Section 25.3.9
30h	RASTER_TIMING_1	LCD Raster Timing 1 Register	Section 25.3.10
34h	RASTER_TIMING_2	LCD Raster Timing 2 Register	Section 25.3.11
38h	RASTER_SUBPANEL	LCD Raster Subpanel Display Register	Section 25.3.12
40h	LCDDMA_CTRL	LCD DMA Control Register	Section 25.3.13
44h	LCDDMA_FB0_BASE	LCD DMA Frame Buffer 0 Base Address Register	Section 25.3.14
48h	LCDDMA_FB0_CEILING	LCD DMA Frame Buffer 0 Ceiling Address Register	Section 25.3.15
4Ch	LCDDMA_FB1_BASE	LCD DMA Frame Buffer 1 Base Address Register	Section 25.3.14
50h	LCDDMA_FB1_CEILING	LCD DMA Frame Buffer 1 Ceiling Address Register	Section 25.3.15

25.3.1 LCD Revision Identification Register (REVID)

The LCD revision identification register (REVID) is shown in Figure 25-15 and described in Table 25-10.

Figure 25-15. LCD Revision Identification Register (REVID)

31	0
REV	
R-4C10 0100h	

LEGEND: R = Read only; -*n* = value after reset

Table 25-10. LCD Revision Identification Register (REVID) Field Descriptions

Bit	Field	Value	Description
31-0	REV	4C10 0100h	Peripheral Identification Number

25.3.2 LCD Control Register (LCD_CTRL)

The LCD control register (LCD_CTRL) contains the fundamental mode select bit for the LCD controller. The LCD_CTRL is shown in Figure 25-16 and described in Table 25-11.

Figure 25-16. LCD Control Register (LCD_CTRL)

31	16
Reserved	
R-0	

15	8	7	1	0
CLKDIV		Reserved		MODESEL
R/W-0		R-0		R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 25-11. LCD Control Register (LCD_CTRL) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	Reserved
15-8	CLKDIV	0-FFh	Clock Divisor. Value (from 0 to 255) is used to specify the frequency of the pixel clock (in Raster mode) or MCLK (in LIDD mode) based on the LCD_CLK frequency. Pixel clock frequency can range from LCD_CLK/2 to LCD_CLK/255 (CLKDIV = 0 or CLKDIV = 1 are not valid). MCLK can vary from LCD_CLK to LCD_CLK/255 (CLKDIV = 0 or CLKDIV = 1 sets MCLK = LCD_CLK).
7-1	Reserved	0	Reserved
0	MODESEL		LCD Mode Select
		0	LCD Controller in LIDD mode
		1	LCD Controller in Raster mode

The 8-bit clock divider (CLKDIV) field is used to select the frequency of the pixel clock. CLKDIV can generate a range of pixel clock frequencies from LCD_CLK/2 to LCD_CLK/255. The pixel clock frequency must be adjusted to meet the required screen refresh rate.

The refresh rate depends on:

- The number of pixels for the target display.
- Whether monochrome or color mode is selected.
- The number of pixel clock delays programmed at the beginning and end of each line.
- The number of line clocks inserted at the beginning and end of each frame.
- The width of the frame clock (LCD_VSYNC) signal in active mode or VSW line clocks inserted in passive mode.
- The width of the line clock (LCD_HSYNC) signal.

All of these factors alter the time duration from one frame transmission to the next. Different display manufacturers require different frame refresh rates, depending on the physical characteristics of the display. CLKDIV is used to alter the pixel clock frequency in order to meet these requirements. Pixel clock is used to synchronously signal the device to drive data to the LCD data pins, and to signal the output FIFO to latch the data from the pins. The frequency of the pixel clock for a set CLKDIV value or the required CLKDIV value to yield a target pixel clock frequency can be calculated using the following equation:

$$\text{LCD\_PCLK} = \frac{\text{LCD\_CLK}}{\text{CLKDIV}}$$

The pixel clock frequency is programmed taking into account the limitations shown in Table 25-12.

If CLKDIV equals 0 or 1, the effect is undefined. Dividing the pixel clock frequency by an odd number distorts the duty cycle.

Table 25-12. Pixel Clock Frequency Programming Limitations

Type of Screen	Output (In Bits)	Minimum Pixel Clock Divider
TFT 1,2,4,8 BPP	12 (1 pixel)	2
TFT 16 BPP	16 (1 pixel)	2
STN monochrome(4 output lines per panel)	4 (4 pixel)	4
STN monochrome(8 output lines per panel)	8 (8 pixel)	8
STN color	8 (2 2/3 pixel)	3

25.3.3 LCD Status Register (LCD_STAT)

The LCD status register (LCD_STAT) contains bits that signal status and error conditions to the processor. Each of the LCD status bits signals an interrupt request as long as the bit is set AND the interrupt enable for that bit is also set (see the LCD raster control and LCD DMA control registers for these enables). Writing a 1 to each bit clears it; once the bit is cleared, the interrupt is cleared. The LCD_STAT is shown in Figure 25-17 and described in Table 25-13.

Figure 25-17. LCD Status Register (LCD_STAT)

31											16
Reserved											
R-0											
15	10	9	8	7	6	5	4	3	2	1	0
Reserved		EOF1	EOF0	Rsvd	PL	FUF	Rsvd	ABC	SYNC	Rsvd	DONE
R-0		R/W-0	R/W-0	R-0	R/W-0	R/W-0	R-0	R/W-0	R/W-0	R-0	R/W-0

LEGEND: R = Read only; -*n* = value after reset

Table 25-13. LCD Status Register (LCD_STAT) Field Descriptions

Bit	Field	Value	Description
31-10	Reserved	0	Reserved
9	EOF1		End of Frame 1
		0	no end of frame 1 detected
		1	end of frame 1 detected
8	EOF0		End of Frame 0
		0	no end of frame 0 detected
		1	end of frame 0 detected
7	Reserved	0	Reserved
6	PL		Loaded Palette
		0	The palette is not loaded
		1	The palette is loaded
5	FUF		FIFO Underflow Status
		0	FIFO has not underrun
		1	LCD dither logic not supplying data to FIFO at a sufficient rate, FIFO has completely emptied and data pin driver logic has attempted to take added data from FIFO
4	Reserved	0	Reserved
3	ABC		AC Bias Count Status
		0	AC bias transition counter has not decremented to zero
		1	AC bias transition counter has decremented to zero, indicating that the LCD_AC_O line has transitioned the number of times that is specified by the ACB_I control bit field. Counter is reloaded with value in ACB_I but is disabled until the user clears ABC.
2	SYNC		Sync Lost
		0	normal
		1	Frame Synchronization Lost has occurred
1	Reserved	0	Reserved
0	DONE		Raster or LIDD Frame Done (shared; depends on whether Raster or LIDD mode enabled)
		0	Raster or DMA_to_LIDD engine is enabled
		1	Raster or DMA_to_LIDD disabled and the active frame has just completed

25.3.3.1 Frame Done (DONE)

When the LCD is disabled by clearing the LCD Raster Control enable bit (RASTER_EN = 0) in the LCD Raster Control Register, the LCD allows the current frame to complete before it is disabled. After the last set of pixels is clocked out onto the LCD data pins by the pixel clock, the LCD is disabled and DONE is set.

- DONE = 1 when the frame is complete.
- DONE = 0 as long as the frame is not complete.

The frame done (DONE) bit signals the frame is complete. It is cleared when the RASTER_EN bit is set to 1 (turned ON).

25.3.3.2 Frame Synchronization Lost (SYNC)

The frame synchronization lost (SYNC) bit is set if the LCD controller detects a frame synchronization error. A frame synchronization error can occur for one of two reasons:

- when the LCD controller attempts to read what it believes to be the first word of the video buffer but cannot be recognized as such
- if the LCD controller is starved of data, which can happen due to insufficient bandwidth from the source of LCD data through the system interconnect to the LCD controller

To alleviate data bandwidth bottleneck issues to the LCD controller, the following configuration settings can be experimented with:

- Increase EMIFB (if used) Command Re-Ordering (BPRIO) setting from default to a value such as 10h to 20h
- Increase priority for LCD controller DMA
- Increase burst size setting for LCD controller DMA
- Run the EMIFB (if used) at maximum clock speed

This bit is cleared by disabling the LCD controller (RASTER_EN = 0). This also resets the input FIFO in the DMA controller.

- SYNC = 1 when a frame synchronization lost occurred.
- SYNC = 0 as long as no frame synchronization error occurs.

25.3.3.3 AC-Bias Count Status (ABC)

The ac-bias count status (ABC) bit is set each time the ac-bias line transitions a particular number of times as specified by the ac-bias line transitions per interrupt (ACB_I) field in LCD Raster Timing Register 2. If ACB_I is programmed with a non-zero value, a counter is loaded with the value in ACB_I and is decremented each time the ac-bias line reverses state. When the counter reaches zero, the ABC bit is set that signals an interrupt request to the interrupt controller. The counter reloads using the value in ACB_I, but does not start to decrement again until you clear ABC by writing 0 to the LCD status register.

- ABC = 1 when the ac-bias transition counter ACB_I has decremented to 0
- ABC = 0 as long as ACB_I has not decremented to 0

25.3.3.4 FIFO Underflow Status (FUF)

The FIFO underflow status (FUF) bit is set when the input FIFO is completely empty and the LCD data pins driver logic attempts to fetch data from the FIFO. This bit is cleared by disabling the LCD controller (RASTER_EN = 0). To recover from this condition and restart normal function of the LCDC, the peripheral needs to be reset through the Power and Sleep Controller (PSC).

- FUF = 1 when the dithering logic is not supplying data to the FIFO at a sufficient rate.
- FUF = 0 as long as FIFO has not underrun.

25.3.3.5 Loaded Palette (PL)

The loaded palette (PL) bit is a read-only bit that is set after the LCD finished loading the palette into memory.

- PL = 1 when the palette is loaded.
- PL = 0 as long as the palette is not loaded.

In data-only (PL = 10) and palette-plus-data (PL = 00) modes, write 0 to clear the interrupt. However, in the palette only (PL = 01) mode, LCD must be turned off in order to reset/clear the interrupt. But in this particular mode, make sure not to turn off the LCD before getting the loading interrupt.

25.3.4 LCD LIDD Control Register (LIDD_CTRL)

The LCD LIDD control register (LIDD_CTRL) contains the polarity controls for LIDD output signals (to account for variety in the external LCD display/peripheral signal requirements), and the LIDD type select bits. These bits are not valid in Raster mode (when LCD control register bit 0 = 1). The LIDD_CTRL is shown in Figure 25-18 and described in Table 25-14.

NOTE: To activate DMA to drive LIDD interface, all other control bit-fields must be programmed before setting LIDD_DMA_EN = 1 and must also disable LIDD_DMA_EN bit when changing the state of any control bit within the LCD controller.

Figure 25-18. LCD LIDD Control Register (LIDD_CTRL)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
R-0															

15	14	13	12	11	10	9	8
Reserved					DONE_INT_EN	DMA_CS0_CS1	LIDD_DMA_EN
R-0					R/W-0	R/W-0	R/W-0

7	6	5	4	3	2	1	0
CS1_E1_POL	CS0_E0_POL	WS_DIR_POL	RS_EN_POL	RSPOL	LIDD_MODE_SEL		
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0		

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 25-14. LCD LIDD Control Register (LIDD_CTRL) Field Descriptions

Bit	Field	Value	Description
31-11	Reserved	0	Reserved
10	DONE_INT_EN		LIDD Frame Done Interrupt Enable
		0	Disable LIDD Frame Done interrupt
		1	Enable LIDD Frame Done interrupt (seen on LCD Status Reg bit 0)
9	DMA_CS0_CS1		CS0/CS1 Select for LIDD DMA writes
		0	DMA writes to LIDD CS0
		1	DMA writes to LIDD CS1
8	LIDD_DMA_EN		LIDD DMA Enable
		0	Deactivate DMA control of LIDD interface; DMA control is released upon completion of transfer of the current frame of data (LIDD Frame Done) after this bit is cleared. The MPU has direct read/write access to the panel in this mode
		1	Activate DMA to drive LIDD interface to support streaming data to "smart" panels. The MPU cannot access the panel directly in this mode
7	CS1_E1_POL		Chip Select 1/Enable 1 (Secondary) Polarity Control
		0	Do Not Invert Chip Select 1/Enable 1
		1	Invert Chip Select 1/Enable 1 Chip Select 1 is active low by default; Enable 1 is active high by default
6	CS0_E0_POL		Chip Select 0/Enable 0 (Primary) Polarity Control
		0	Do Not Invert Chip Select 0/Enable 0
		1	Invert Chip Select 0/Enable 0 Chip Select 0 is active low by default; Enable 0 is active high by default
5	WS_DIR_POL		Write Strobe/Direction Polarity Control
		0	Do Not Invert Write Strobe/Direction
		1	Invert Write Strobe/Direction Write Strobe/Direction is active low/write low by default
4	RS_EN_POL		Read Strobe/Enable Polarity Control
		0	Do Not Invert Read Strobe/Enable
		1	Invert Read Strobe/Enable Read Strobe is active low by default; Enable is active high by default

Table 25-14. LCD LIDD Control Register (LIDD_CTRL) Field Descriptions (continued)

Bit	Field	Value	Description
3	RSPOL		Register Select (RS) Polarity Control
		0	Do Not Invert RS
		1	Invert RS. RS is active low by default.
2-0	LIDD_MODE_SEL	0-7h	LIDD Mode Select. Selects type of LCD interface for the LIDD to drive. LIDD_MODE_SEL defines the function of LCD external pins as follows:

Pin	001b	011b	100b
LCD_PCLK	E	RD	N/A
LCD_HSYNC	R/$\overline{W}$	WR	R/$\overline{W}$
LCD_VSYNC	RS	RS	RS
$\overline{LCD\_AC\_ENB\_CS}$	$\overline{CS0}$	$\overline{CS0}$	E0
LCD_MCLK	$\overline{CS1}$	$\overline{CS1}$	E1

0	Sync MPU68
1h	Async MPU68
2h	Sync MPU80
3h	Async MPU80
4h	Hitachi (Async)
5h-7h	Reserved

25.3.5 LCD LIDD CS*n* Configuration Registers (LIDD_CS0_CONF and LIDD_CS1_CONF)

The LCD LIDD CS*n* configuration registers (LIDD_CS*n*_CONF) provides the capability to configure Write and Read Strobe timing parameters to meet a variety of interface timing requirements for the Chip Select 0 (Primary) device and Chip Select 1(Secondary) device, respectively. These values are in MCLK cycles; MCLK is divided down from LCD_CLK as defined by the CLKDIV field in the LCD control register. The LIDD_CS*n*_CONF is shown in Figure 25-19 and described in Table 25-15.

Figure 25-19. LCD LIDD CS*n* Configuration Register (LIDD_CS*n*_CONF)

31	27	26	21	20	17	16
W_SU		W_STROBE		W_HOLD		R_SU
R/W-0		R/W-1		R/W-1		R/W-0

15	12	11	6	5	2	1	0
R_SU		R_STROBE		R_HOLD		TA	
R/W-0		R/W-1		R/W-1		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 25-15. LCD LIDD CS*n* Configuration Register (LIDD_CS*n*_CONF) Field Descriptions

Bit	Field	Value	Description
31-27	W_SU	0-1Fh	Write Strobe Set-Up cycles. Field value defines number of MCLK cycles after Data Bus/Pad Output Enable, ALE, Direction bit and Chip Select 0 have been set up before the Write Strobe is asserted when performing a write access.
26-21	W_STROBE	1-3Fh	Write Strobe Duration cycles. Field value defines number of MCLK cycles that the Write Strobe is held active when performing a write access.
20-17	W_HOLD	1-Fh	Write Strobe Hold cycles. Field value defines number of MCLK cycles that the Data Bus/Pad Output Enable, ALE, Direction bit, and Chip Select 0 are held after the Write Strobe is deasserted when performing a write access.
16-12	R_SU	0-1Fh	Read Strobe Set-Up cycles. Field value defines number of MCLK cycles after Data Bus/Pad Output Enable, ALE, Direction bit and Chip Select 0 have been set up before the Read Strobe is asserted when performing a read access.
11-6	R_STROBE	1-3Fh	Read Strobe Duration cycles. Field value defines number of MCLK cycles that the Read Strobe is held active when performing a read access.
5-2	R_HOLD	1-Fh	Read Strobe Hold cycles. Field value defines number of MCLK cycles that the Data Bus/Pad Output Enable, ALE, Direction bit, and Chip Select 0 are held after the Read Strobe is deasserted when performing a read access.
1-0	TA	0-3h	Field value defines number of MCLK cycles between the end of one CS0 device access and the start of another CS0 device access unless the two accesses are both reads, in which case this delay is not incurred. CS_DELAY = ROUNDUP(7/CLKDIV) + TA

25.3.6 LCD LIDD CS*n* Address Read/Write Registers (LIDD_CS0_ADDR and LIDD_CS1_ADDR)

The LCD LIDD CS0 address read/write registers (LIDD_CS*n*_ADDR) are accessed by the processor to perform the address/index read or write operations on the CS0 and CS1 device respectively. Writing to LIDD_CS0_ADDR asserts CS0 and Address Latch Enable, which loads the ADR_INDX field of this register into the address generator of the peripheral device. Likewise, reading from LIDD_CS0_ADDR asserts CS0 and Address Latch Enable, which loads status information from the peripheral device into the ADR_INDX field of this register. Similarly writing to LIDD_CS1_ADDR asserts CS1 and Address Latch Enable, which loads the ADR_INDX field of this register into the address generator of the peripheral device. Likewise, reading from LIDD_CS1_ADDR asserts CS1 and Address Latch Enable, which loads status information from the peripheral device into the ADR_INDX field of this register. The LIDD_CS*n*_ADDR is shown in Figure 25-20 and described in Table 25-16.

Figure 25-20. LCD LIDD CS*n* Address Read/Write Register (LIDD_CS*n*_ADDR)

31	16
Reserved	
R-0	

15	0
ADR_INDX	
R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 25-16. LCD LIDD CS*n* Address Read/Write Register (LIDD_CS*n*_ADDR) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	Reserved
15-0	ADR_INDX	0-FFFFh	Peripheral Device Address/Index value. On writes this field is loaded into the CS0 peripheral device's address generator On reads this field contains the CS0 peripheral device's status.

25.3.7 LCD LIDD CS*n* Data Read/Write Registers (LIDD_CS0_DATA and LIDD_CS1_DATA)

The LCD LIDD CS0 data read/write registers (LIDD_CS*n*_DATA) are accessed by the processor to perform the data read or write operations on the CS0 and CS1 device respectively . Writing to LIDD_CS0_DATA asserts CS0 and deasserts Address Latch Enable, which loads the DATA field of this register into the peripheral device. Likewise, reading from this register asserts CS0 and deasserts Address Latch Enable, which loads data from the peripheral device into the DATA field of this register. Similarly writing to LIDD_CS1_DATA asserts CS1 and deasserts Address Latch Enable, which loads the DATA field of this register into the peripheral device. Likewise, reading from LIDD_CS1_DATA asserts CS1 and deasserts Address Latch Enable, which loads data from the peripheral device into the DATA field of this register. The LIDD_CS*n*_DATA is shown in Figure 25-21 and described in Table 25-17.

Figure 25-21. LCD LIDD CS*n* Data Read/Write Register (LIDD_CS*n*_DATA)

31	16
Reserved	
R-0	

15	0
DATA	
R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 25-17. LCD LIDD CS*n* Data Read/Write Register (LIDD_CS*n*_DATA) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	Reserved
15-0	DATA	0-FFFFh	Peripheral Device Data value. On writes this field is loaded into the CS0 peripheral device On reads this field contains the CS0 peripheral device's data.

25.3.8 LCD Raster Control Register (RASTER_CTRL)

The LCD raster control register (RASTER_CTRL) contains bit-fields that are used to control various functions within the Raster controller sub-module. The RASTER_CTRL is shown in Figure 25-22 and described in Table 25-18.

Figure 25-22. LCD Raster Control Register (RASTER_CTRL)

31							25	24
Reserved								STN_565
R-0								R/W-0
23	22	21	20	19				16
TFT_ALT_MAP	NIB_MODE	PLM		FIFO_DMA_DELAY				
R/W-0	R/W-0	R/W-0		R/W-0				
15			12	11	10	9		8
FIFO_DMA_DELAY				Reserved		MONO8B		RD_ORDER
R/W-0				R-0		R/W-0		R/W-0
7	6	5	4	3	2	1		0
TFT_STN	FUF_EN	SL_EN	PL_EN	DONE_EN	AC_EN	MONO_COLOR		RASTER_EN
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0		R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 25-18. LCD Raster Control Register (RASTER_CTRL) Field Descriptions

Bit	Field	Value	Description
31-25	Reserved	0	Reserved
24	STN_565		12-Bit-Per-Pixel (5-6-5) Mode. This is only available in passive-color (STN) mode when 12 BPP is specified in the palette.
		0	Disabled: The lower 12 bits of pixel data is processed and output; i.e., “X X X X R3 R2 R1 R0 G3 G2 G1 G0 B3 B2 B1 B0” (where X is ignored by the Raster Controller).
		1	Enabled: Pixel data in the frame buffer is 16-bit but only 12 of the bits are processed and output; i.e. “R3 R2 R1 R0 X G3 G2 G1 G0 X X B3 B2 B1 B0 X” (where X is ignored by the Raster Controller).
			The data patterns above refer to frame buffer bits not output bits.
23	TFT_ALT_MAP		TFT Alternative Signal Mapping
		0	Output pixel data for 1, 2, 4, and 8 BPP will be right aligned on LCD_D[11:0]. For example, “R3 R2 R1 R0 G3 G2 G1 G0 B3 B2 B1 B0”.
		1	Output pixel data for 1, 2, 4, and 8 BPP will be converted to 5-6-5 format and transferred via LCD_D[15:0]. For example, “R3 R2 R1 R0 R3 G3 G2 G1 G0 G3 G2 B3 B2 B1 B0 B3”.
			The data patterns above refer to output bits not frame buffer bits.
22	NIB_MODE		Nibble Mode
		0	Nibble Mode disabled.
		1	Nibble Mode enabled.
			For 1, 2, and 4-BPP modes, this bit should be enabled. For 8, 12, and 16-BPP modes, this bit should be disabled.
21-20	PLM	0-3h	Palette Loading Mode
		0	Palette and data.
		1h	Palette only.
		2h	Data only.
		3h	Do not use.
19-12	FIFO_DMA_DELAY	0-FFh	FIFO DMA Request Delay. Encoded value used to specify the number of clocks the input FIFO DMA request should be disabled. The delay clock count starts after 16 words are loaded into the input FIFO. Delay Time = [(LCD Pixel Clock) × FIFO_DMA_DELAY]
11-10	Reserved	0	Reserved

Table 25-18. LCD Raster Control Register (RASTER_CTRL) Field Descriptions (continued)

Bit	Field	Value	Description
9	MONO8B		Mono 8-bit Mode
		0	LCD_D[3:0] is used to output four bits each LCD_PCLK.
		1	LCD_D[7:0] is used to output eight bits each LCD_PCLK.
			This bit is ignored in all other modes.
8	RD_ORDER		Raster Data Order Select
		0	Frame buffer data is ordered from least-to-most significant bit/nibble/byte/word/d-word.
		1	Frame buffer data is ordered from most-to-least significant bit/nibble/byte/word/d-word.
7	TFT_STN		TFT or STN Mode
		0	Passive (STN) display operation enabled.
		1	Active (TFT) display operation enabled.
6	FUF_EN		FIFO Underflow Interrupt Enable
		0	Disable the FIFO Underflow interrupt.
		1	Enable the FIFO Underflow interrupt.
5	SL_EN		Sync Lost Interrupt Enable
		0	Disable the Sync Lost interrupt.
		1	Enable the Sync Lost interrupt.
4	PL_EN		Palette Loaded Interrupt Enable
		0	Disable the Palette Loaded interrupt.
		1	Enable the Palette Loaded interrupt.
3	DONE_EN		Frame Done Interrupt Enable
		0	Disable the Frame Done interrupt.
		1	Enable the Frame Done interrupt.
2	AC_EN		AC Bias Count Interrupt Enable
		0	Disable the AC Bias Count interrupt.
		1	Enable AC Bias Count interrupt.
1	MONO_COLOR		LCD Monochrome or Color
		0	Enable Color display operation.
		1	Enable Monochrome display operation.
0	RASTER_EN		LCD Raster Controller Enable
		0	Disable the LCD Raster controller.
		1	Enable the LCD Raster controller.

25.3.8.1 LCD Raster Controller Enable (RASTER_EN)

NOTE: All other control bit-fields must be programmed before setting RASTER_EN = 1 and must also disable the LCD controller when changing the state of any control bit within the LCD controller.

The LCD Raster Controller enable (RASTER_EN) bit is used to enable and disable all LCD controller operation.

- When RASTER_EN = 0, the LCD controller is disabled.
- When RASTER_EN = 1, the LCD controller is enabled.

You can program the LCD control register (LcdControl) last, and configure all twenty-five bit fields at the same time via a word32 write to the register. If you clear RASTER_EN bit while the LCD controller is enabled, you can complete transmission of the current frame before being disabled. Completion of the current frame is signaled by the LCD controller to the DMA by setting the frame done (Done) bit within the LCD controller status register (see LCD Controller Status Register), which generates an interrupt request. If the LCD controller is disabled, the signals on pixel data [15:0] pins are set to 0 and the pixel clock, frame clock(vertical clock), line clock (horizontal clock), and ac-bias signals are set to their inactive state. This can be 0 or 1, depending on the inversions programmed in the LCD Raster Timing 2 register.

25.3.8.2 LCD Monochrome (MONO_COLOR)

The color/monochrome select (LcdBW) bit is used to determine whether the LCD controller operates in color or monochrome mode.

- When MONO_COLOR = 0:
  - Color mode is selected.
  - Palette entries are 12 bits wide, providing up to 4096 colors in active (TFT) mode and up to 3375 colors in passive (STN) color mode.
  - All three dither blocks are used (in passive mode only: TFT_STN = 0), one for each color component (R, G, B).
- When MONO_COLOR = 1:
  - Monochrome mode is selected.
  - Palette entries are 4 bits wide effective (15 levels of grayscale).
  - 4 or 8 data lines are enabled, according to the mono 8-bit mode (MONO8B).

Table 25-19. LCD Controller Data Pin Utilization for Mono/Color Passive/Active Panels

Color/Mono BPP	Passive/Active Panel	Pins
Mono 1,2,4	Passive	Pixel data[3:0]
Mono 8	Passive	Pixel data[7:0]
Color 1,2,4,8,12,16 (STN_565 = 1)	Passive	Pixel data[7:0]
Color 1,2,4,8,12	Active	Pixel data[11:0] or Pixel data[15:0] according to TFT_ALT_MAP bit in the LCD Raster Control Register (RASTER_CTRL)
Color 16	Active	Pixel data[15:0]

25.3.8.3 TFT_STN (TFT_STN)

The TFT_STN (TFT_STN) bit selects whether the LCD controller operates in passive (STN) or active (TFT) display control mode. When TFT_STN = 0, passive or STN mode is selected. LCD data flows from the frame buffer memory, via the LCD dedicated DMA channel, to the palette (the palette is bypassed for the 12 and 16 BPP modes), to the dithering logic and the output FIFO before being output on the LCD data pins. The clock and data pin behaviors is shown for the monochrome passive mode (Figure 25-23) and for the color passive mode (Figure 25-24).

Figure 25-23. Monochrome Passive Mode Pixel Clock and Data Pin Timing

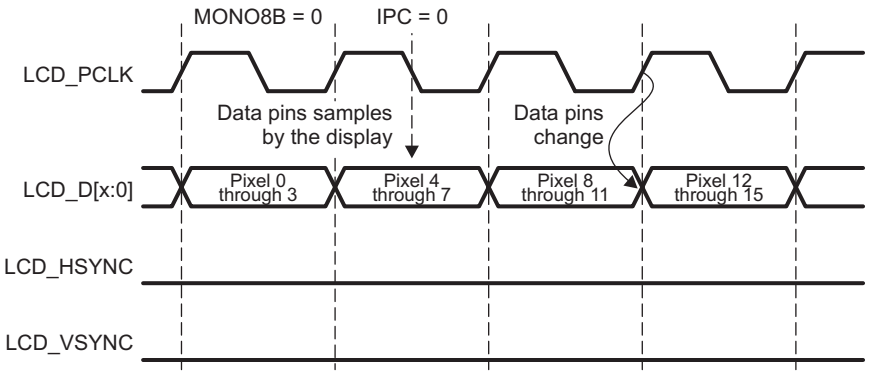
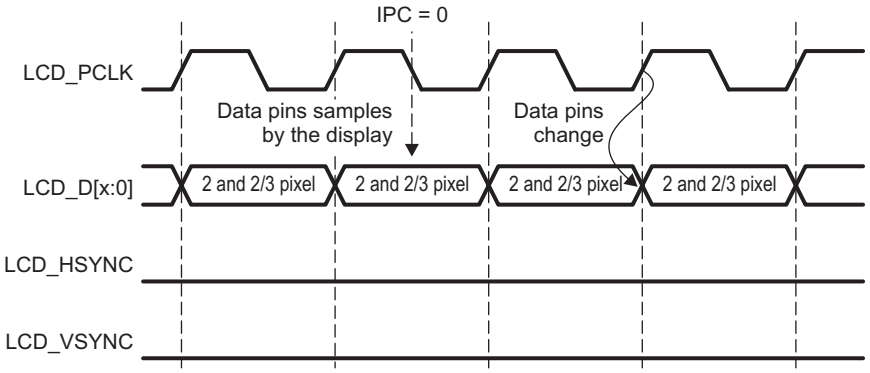
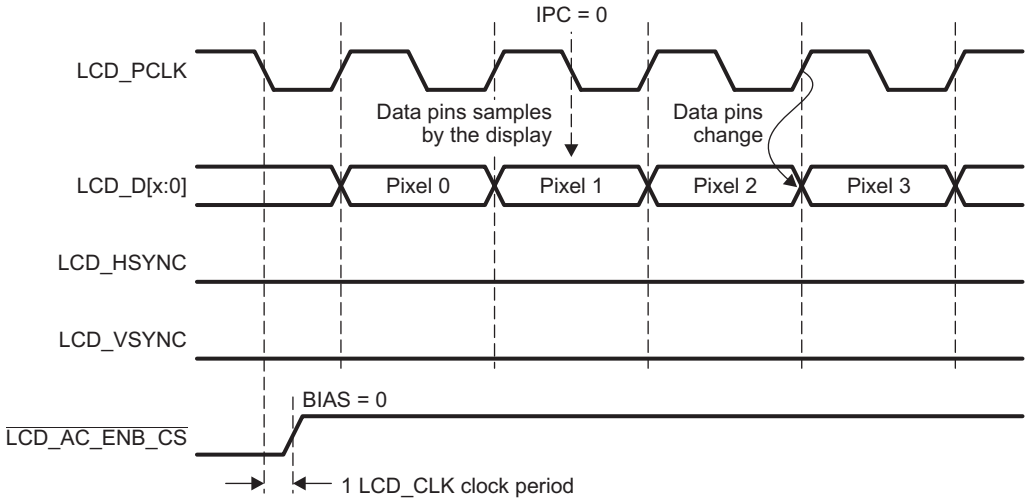


Figure 25-24. Color Passive Mode Pixel Clock and Data Pin Timing



When TFT_STN = 1, active or TFT mode is selected. Video data is transferred via the DMA from memory to the input FIFO, then is unpacked and used to select an entry from the palette (for 1, 2, 4, and 8 bits per pixel modes), just as in passive mode. The value read from the palette; however, bypasses both the LCD dither logic and the output FIFO to be output on the LCD data pins in TFT mode. The pixel size within the frame buffer is increased to 16 bits when 12- or 16-bit pixel encoding mode is enabled (BPP = 1xx). In TFT mode for 12 and 16 bits per pixel, palette entry is not selected. The clock and data pin behaviors is shown in Figure 25-25.

Figure 25-25. Active Mode Pixel Clock and Data Pin Timing



describes the clocks and data pin behaviors in active mode. The size of the pixel encoding is increased in TFT mode because the LCD dither logic is bypassed (the dither logic only supports 4 bits to encode each color component R, G, B that limits the pixel encoding size in passive mode). Increasing the size of the pixel representation allows a total of 64K colors to be addressed using an off-chip palette in conjunction with the LCD controller.

25.3.8.4 Mono 8 Bit Mode (MONO8B)

NOTE: MONO8B does not affect any of the color modes or TFT.

The mono 8-bit mode (MONO8B) bit selects whether four or eight data lines are used to output pixel data to the LCD screen.

- When MONO8B = 0, pixel data [3:0] is used to output four pixel values to the LCD panel at each pixel clock transition.
- When MONO8B = 1, pixel data [7:0] is used to output eight pixel values to the LCD panel at each pixel clock transition

25.3.8.5 FIFO DMA Request Delay (FIFO_DMA_DELAY)

The 8-bit FIFO DMA request delay (FIFO_DMA_DELAY) field is used to select the minimum number of LCD_CLK cycles to wait between the servicing of each DMA request issued by the LCD controller, sending an address to the input FIFO. The goal is to ensure enough bandwidth to other system accesses. A delay of FIFO_DMA_DELAY cycles is inserted every 16 words read from the input FIFO. This function is a concern only in 8 BPP mode, where the palette is 256 words. The FIFO_DMA_DELAY field needs to be set properly to avoid FIFO underflow during palette loading phase. When FDD = 00h, the FIFO DMA request delay function is disabled. This function is only used for palette loading.

25.3.8.6 Palette Loading (PLM)

The 2-bit palette loading field describes how the palette loading behaves when each new frame is loaded from memory.

- When PLM = 0, the data in the frame buffer represents the palette data and the picture data. Both palette and picture data are loaded.
- When PLM = 1 (palette-only mode), the data in the frame buffer just represents a new palette to be loaded. This data is loaded and placed into the palette. But be sure to turn off the LCD after getting the loading interrupt, or the LCD behavior would be unpredictable.
- When PLM = 2h (data loading mode), the data in the frame buffer only represents the picture data (data-only). This data is then used as an index (in the palette) or sent directly out. This mode assumes the palette was previously loaded. There is no need to keep loading the palette if it is not changing. As a matter of fact, in data-only mode, the BPP is fixed and can not change on the fly since the palette is not loaded at every frame.
- PLM = 3h is reserved.

25.3.8.7 TFT Alternate Signal Mapping (TFT_ALT_MAP)

This bit is relevant only if TFT_ALT_MAP = 1.

This bit field controls how the TFT pixel data is output. Via this feature, 12-BPP data can be output to all 16-bit LCD pins (this also applies to 1-, 2-, 4-, and 8- BPP). This feature allows you to switch BPP modes on the fly, duplicating the 12-bit output data across the 16 data lines if they are already hardwired to the 16 data lines.

Figure 25-26 shows how the four red, four green, and four blue bits are mapped to all pixel data [15-0] output pins when TFT_ALT_MAP = 1.

Figure 25-26. TFT Alternate Signal Mapping Output

Pins	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Data	R3	R2	R1	R0	R3	G3	G2	G1	G0	G3	G2	B3	B2	B1	B0	B3

When TFT_ALT_MAP = 0, the four red, four green, and four blue data are right-aligned on pixel data [11-0]. The upper pixel data [15-12] are cleared to 0. There is no duplication.

25.3.8.8 16 BPP STN Mode (STN_565)

The STN_565 bit is relevant only if TFT_STN = 0, but has no effect in 1-, 2-, 4- and 8-BPP modes. If STN_565 = 0, the frame buffer organization is in 12 BPP mode. In this mode, each color component is encoded in 4 bits, as shown in Figure 25-27.

Figure 25-27. 12-Bit STN Data in Frame Buffer

Pins	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Data	Data Ignored				R3	R2	R1	R0	G3	G2	G1	G0	B3	B2	B1	B0

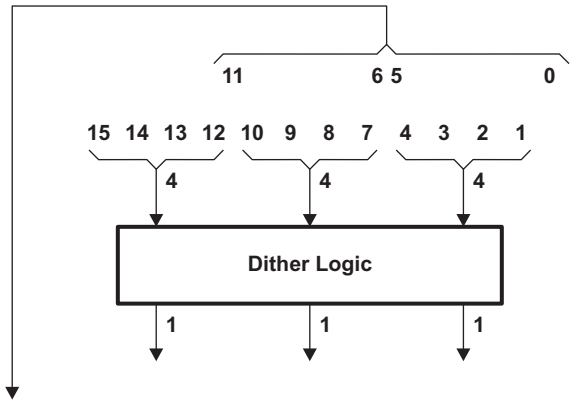
If STN_565 = 1 , the 16-bit STN mode is selected .The only difference from the 12 BPP mode is how the pixel data is organized in the frame buffer and which bits are sent to the dither logic. The 16-bit STN mode appears in frame buffer memory as shown in Figure 25-28.

Figure 25-28. 16-Bit STN Data in Frame Buffer

Pins	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Data	R4	R3	R2	R1	R0	G5	G4	G3	G2	G1	G0	B4	B3	B2	B1	B0

The 16-bit STN mode only sends 12 bits to the dithering logic as well as the 12-BPP STN mode. The LSB bit of the red component (bit 11), the two LSBs of green (bits 6 and 5), and the LSB of blue (bit 0) are not sent to the dithering logic, as shown in Figure 25-29.

Figure 25-29. 16-BPP STN Mode



Note:
Red bit 11, green bits 6, 5 and blue bit 0 are not used as image data and are ignored. The 16-bit STN resolution is equal to the 12-bit STN resolution (3375 colors)

25.3.9 LCD Raster Timing Register 0 (RASTER_TIMING_0)

The LCD raster timing 0 register (RASTER_TIMING_0) contains four bit-fields that are used as modulus values for a collection of down counters, each of which performs a different function to control the timing of several of the LCD's pins. The RASTER_TIMING_0 is shown in Figure 25-30 and described in Table 25-20.

Figure 25-30. LCD Raster Timing Register 0 (RASTER_TIMING_0)

31	24	23	16
HBP		HFP	
R/W-0		R/W-0	

15	10	9	4	3	0
HSW		PPL		Reserved	
R/W-0		R/W-0		R-0	

LEGEND: R = Read only; -*n* = value after reset

Table 25-20. LCD Raster Timing Register 0 (RASTER_TIMING_0) Field Descriptions

Bit	Field	Value	Description
31-24	HBP	0-FFh	Horizontal Back Porch. Encoded value (HBP + 1) is used to specify number of LCD_PCLKs to add to the beginning of a line transmission before the first set of pixels is output to the display (program to value minus one). Note that pixel clock is held in its inactive state during the beginning of line wait period in STN mode while it is active in TFT mode.
23-16	HFP	0-FFh	Horizontal Front Porch. Encoded value (HFP + 1) is used to specify number of LCD_PCLKs to add to the end of a line transmission before line clock is asserted (program to value minus one). Note that pixel clock is held in its inactive state during the end of line wait period in STN mode while it is active in TFT mode.
15-10	HSW	0-3Fh	Horizontal Sync Pulse Width. Encoded value (HSW + 1) is used to specify number of LCD_PCLKs to pulse the line clock at the end of each line (program to value minus one). Note that pixel clock is held in its inactive state during the generation of the line clock in STN mode while it is active in TFT mode.
9-4	PPL	0-3Fh	Pixels per Line. This value specifies the number of pixel transmissions per line . Number of pixels per Line = (PPL + 1) × 16
3-0	Reserved	0	Reserved

25.3.9.1 Pixels-Per-Line (PPL)

NOTE: PPL must be programmed to the value required minus 1 (for example, for a 640-pixel-per-line LCD panel, PPL = (640/16) - 1 = 40 - 1 = 39 = 27h).

The pixels-per-line (PPL) bit-field is used to specify the number of pixels in each line on the screen. The number of pixels per line = (PPL + 1) × 16, represents the screen width. PPL is a 6-bit value. Taking into account that the bottom 4 bits of this register are reserved, it is possible to support displays where the number of pixels-per-line ranges from 16-1024. PPL is used to count the correct number of pixel clocks that must occur before the line clock can be pulsed.

25.3.9.2 Horizontal Synchronization Pulse Width (HSW)

NOTE: The pixel clock does not transition during the line clock pulse in passive display mode, but it transitions in active display mode.

The 6-bit horizontal synchronization pulse width (HSW) field is used to specify the pulse width of the line clock in passive mode, or horizontal synchronization pulse in active mode. The line clock (or LCD_HSYNC) is asserted each time a line or row of pixels is output to the display and a programmable number of pixel clock delays have elapsed. When line clock is asserted, the value in HSW is transferred to a 6-bit down counter that uses the programmed pixel clock frequency to decrement. When the counter reaches zero, the line clock is negated. HSW can be programmed to generate a line clock pulse width ranging from 1–64 pixel clock periods (program to value required minus 1).

25.3.9.3 Horizontal Front Porch (HFP)

NOTE: The pixel clock does not transition during these dummy pixel clock cycles in passive display mode, but it transitions continuously in active display mode.

The 8-bit horizontal front porch (HFP) field is used to specify the number of dummy pixel clocks to insert at the end of each line or row of pixels before pulsing the line clock(or LCD_HSYNC) pin. Once a complete line of pixels is transmitted to the LCD driver, the value in HFP is used to count the number of pixel clocks to wait before pulsing the line clock. HFP generates a wait period ranging from 1–256 pixel clock cycles (program to value required minus 1).

25.3.9.4 Horizontal Back Porch (HBP)

NOTE: The pixel clock does not transition during these dummy pixel clock cycles in passive display mode, but it transitions continuously in active display mode.

The 8-bit horizontal back porch (HBP) field is used to specify the number of dummy pixel clocks to insert at the beginning of each line or row of pixels. After the line clock(or LCD_HSYNC) for the previous line has been negated, the value in HBP is used to count the number of pixel clocks to wait before starting to output the first set of pixels in the next line. HBP generates a wait period ranging from 1–256 pixel clock cycles (program to value required minus 1).

25.3.10 LCD Raster Timing Register 1 (RASTER_TIMING_1)

The LCD raster timing 1 register (RASTER_TIMING_1) contains four bit-fields that are used as modulus values for a collection of down counters, each of which performs a different function to control the timing of several of the LCD's pins. The (RASTER_TIMING_1 is shown in Figure 25-31 and described in Table 25-21.

Figure 25-31. LCD Raster Timing Register 1 (RASTER_TIMING_1)

31	24	23	16
VBP		VFP	
R/W-0		R/W-0	

15	10	9	0
VSW		LPP	
R/W-0		R/W-0	

LEGEND: R = Read only; -*n* = value after reset

Table 25-21. LCD Raster Timing Register 1 (RASTER_TIMING_1) Field Descriptions

Bit	Field	Value	Description
31-24	VBP	0-FFh	Vertical Back Porch. Encoded value (VBP) used to specify number of line clock (LCD_HSYNC) periods to add to the beginning of a frame before the first set of pixels is output to the display. Note that line clock transitions during the insertion of the extra line clock periods.
23-16	VFP	0-FFh	Vertical Front Porch. Encoded value (VFP) used to specify number of line clock (LCD_HSYNC) periods to add to the end of each frame. Note that the line clock transitions during the insertion of the extra line clock periods.
15-10	VSW	0-3Fh	Vertical Synchronization Pulse Width. In TFT mode, encoded value (VSW + 1) defines the number of line clock (LCD_HSYNC) cycles to hold the frame clock (LCD_VSYNC) active. In STN mode, encoded value (VSW + 1) specifies the number of extra line clock (LCD_HSYNC) cycles to be inserted after the vertical front porch (VFP) period has elapsed.
9-0	LPP	0-3FFh	Lines per Panel. Encoded value (LPP + 1) used to specify number of lines per panel. It represents the total number of lines on the LCD.

25.3.10.1 Lines Per Panel (LPP)

NOTE: LPP must be programmed to the value required minus 1 (C7h for 200 lines per panel).

The lines per panel (LPP) bit-field is used to specify the number of lines or rows per LCD panel being controlled. It represents the total number of lines for the entire LCD display (the screen height). LPP is a 10-bit value, which represents between 1–1024 lines per panel. LPP is used to count the correct number of line clocks that must occur before the frame clock can be pulsed.

25.3.10.2 Vertical Synchronization Pulse Width (VSW)

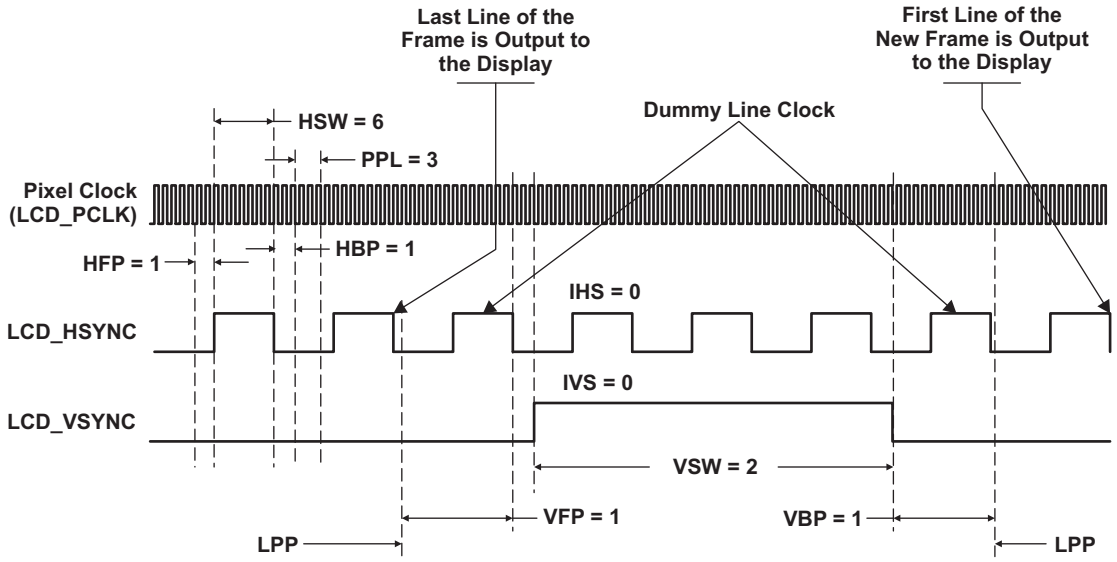
The 6-bit vertical synchronization pulse width (VSW) field is used to specify the pulse width of the vertical synchronization pulse in active mode or is used to add extra dummy line clock cycles between the vertical front porch and vertical back porch in passive mode.

25.3.10.2.1 Active Mode

NOTE: Remember that most of the parameters (HSW, HFP, PPL, HBP) must be programmed to value required minus 1.

In active mode (TFT_STN = 1), VSYNC is asserted each time the last line or row of pixels from the previous frame is output to the display and a programmable number of line clock delays (VFP) has elapsed. When the frame clock (LCD_VSYNC) is asserted, the value in VSW is transferred to a 6-bit down counter that uses the line clock frequency to decrement. When the counter reaches zero, the frame clock (LCD_VSYNC) is negated. VSW can be programmed to generate a vertical synchronization pulse width ranging from 1–64 line clock periods (program to value required minus 1—see Figure 25-32). The following frame starts after LCD_VSYNC is deasserted and a programmable number of line clock delays (VBP) has elapsed.

Figure 25-32. Vertical Synchronization Pulse Width (VSW) - Active Mode



25.3.10.2.2 Passive Mode

NOTE: The pixel clock does not transition during the whole dummy line clock periods that are inserted in passive mode before the frame pulse. The line clock does transition during the insertion of the dummy line clock cycles. VSW must be long enough to load the palette.

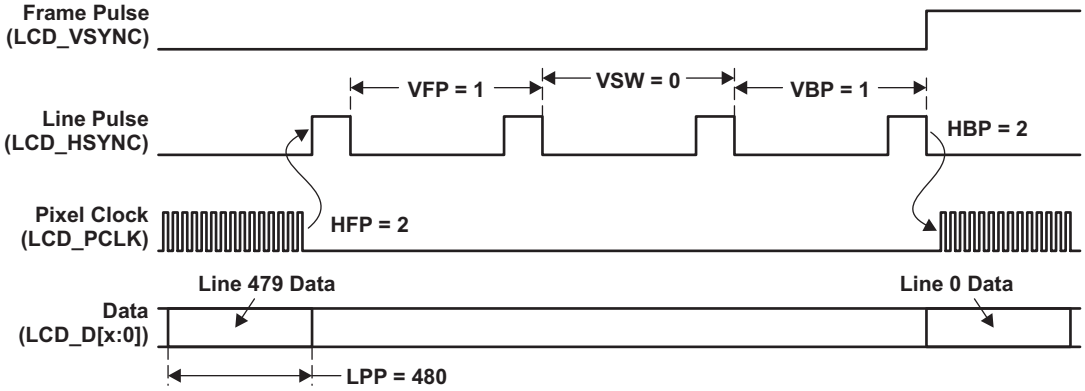
In passive mode (TFT_STN = 0), VSW does not affect the timing of the frame clock, but instead can be used to add extra line clock cycles between the end and beginning of frame line clock cycle counts. The total number of line clock cycles that are inserted between each frame is equal to the sum of the values in VFP, VSW and VBP. A counter is used to insert dummy line clock cycles between frames by first using the value in VFP, then VSW, then VBP. You must ensure that the sum of the values in the three fields is equal to the total number of line clock cycles that are needed between frames. The LCD controller frame clock pin is asserted on the rising-edge of the first pixel clock for each frame. The frame clock remains asserted for the remainder of the first line as pixels are output to the display, also during the assertion of the first line clock for the frame, and then negated on the rising-edge of the first pixel clock of the second line of each frame.

25.3.10.3 Vertical Front Porch (VFP)

NOTE: Remember that VSW must be programmed to value required minus 1.

The 8-bit vertical front porch (VFP) field is used to specify the number of line clocks to insert at the end of each frame. Once a complete frame of pixels is transmitted to the LCD display, the value in VFP is used to count the number of line clock periods to wait. After the count has elapsed the LCD_VSYNC signal is pulsed in active mode or extra line clocks are inserted as specified by the VSW bit-field in passive mode. VFP generates from 0–255 line clock cycles (see Figure 25-33).

Figure 25-33. Vertical Front Porch (VFP)

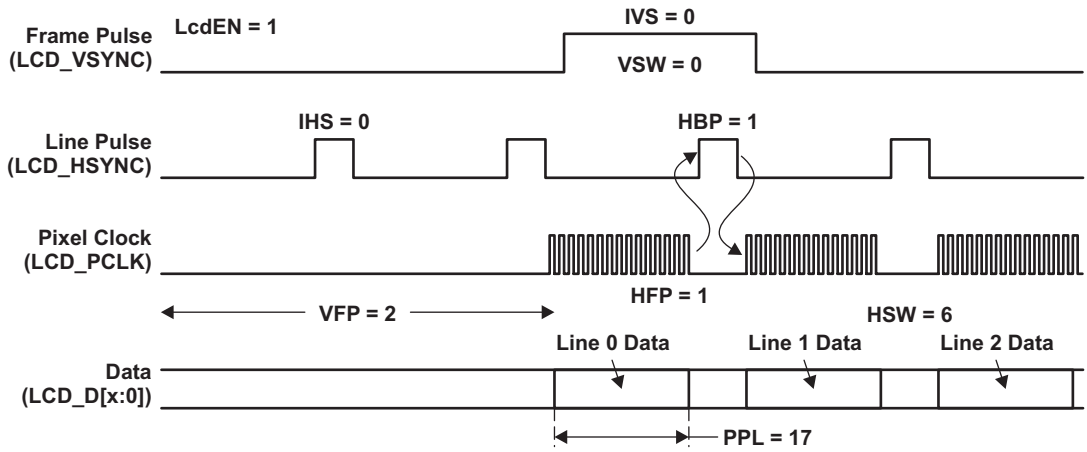


25.3.10.4 Vertical Back Porch (VBP)

NOTE: The line clock transitions during the generation of the VBP line clock wait periods. Note also that you must adjust the value of VBP appropriately such that enough line clock cycles are permitted to elapse; this allows the palette to be completely filled via the DMA, and allows a sufficient number of encoded pixel values to be input from the frame buffer, processed by the dither logic, then placed in the output FIFO, ready to be output to the LCD data lines.

The 8-bit vertical back porch (VBP) field is used to specify the number of line clocks (or LCD_HSYNC) to insert at the beginning of each frame. The VBP count starts just after the LCD_VSYNC signal for the previous frame has been negated for active mode, or the extra line clocks have been inserted as specified by the VSW bit-field in passive mode. After this has occurred, the value in VBP is used to count the number of line clock periods to insert before starting to output pixels in the next frame. VBP generates from 0–255 extra line clock cycles (see Figure 25-34).

Figure 25-34. Vertical Back Porch (VBP)



25.3.11 LCD Raster Timing Register 2 (RASTER_TIMING_2)

LCD raster timing 2 register (RASTER_TIMING_2) contains bit-fields that are used to control various functions associated with the timing of the LCD controller. The RASTER_TIMING_2 is shown in Figure 25-35 and described in Table 25-22.

Figure 25-35. LCD Raster Timing Register 2 (RASTER_TIMING_2)

31	26	25	24
Reserved		SYNC_CTRL	SYNC_EDGE
R-0		R/W-0	R/W-0

23	22	21	20	19	16
BIAS	IPC	IHS	IVS	ACB_I	
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	

15	8	7	0
ACB		Reserved	
R/W-0		R-0	

LEGEND: R/W = Read/Write; R = Read only; *-n* = value after reset

Table 25-22. LCD Raster Timing Register 2 (RASTER_TIMING_2) Field Descriptions

Bit	Field	Value	Description
31-26	Reserved	0	Reserved
25	SYNC_CTRL		Horizontal and Vertical Sync Control
		0	Inactive. SYNC_EDGE is ignored and the activation and deactivation of LCD_HSYNC and LCD_VSYNC will be defined by bit 22 below.
		1	Active. Allow SYNC_EDGE to define the LCD_PCLK edge (rising or falling) used to activate and deactivate LCD_HSYNC and LCD_VSYNC.
24	SYNC_EDGE		Horizontal and Vertical Sync Edge. The activation and deactivation of LCD_HSYNC and LCD_VSYNC will occur on the defined LCD_PCLK edge.
		0	Rising edge.
		1	Falling edge.
			SYNC_CTRL must be active in order to use this bit.
23	BIAS		Invert AC Bias
		0	$\overline{\text{LCD\_AC\_ENB\_CS}}$ is an active-high pulse.
		1	$\overline{\text{LCD\_AC\_ENB\_CS}}$ is an active-low pulse.
			In STN mode, the activation of this bit is ignored.
22	IPC		Invert Pixel Clock
		0	LCD Data (LCD_D[15:0]) is driven on the rising edge of LCD_PCLK, while LCD_VSYNC, LCD_HSYNC, and $\overline{\text{LCD\_AC\_ENB\_CS}}$ are driven on the falling edge.
		1	LCD Data (LCD_D[15:0]) is driven on the falling edge of LCD_PCLK, while LCD_VSYNC, LCD_HSYNC, and $\overline{\text{LCD\_AC\_ENB\_CS}}$ are driven on the rising edge.
			LCD_VSYNC and LCD_HSYNC may be altered as defined by bits 24 and 25 above.
21	IHS		Invert Line Clock
		0	LCD_HSYNC is an active high pulse.
		1	LCD_HSYNC is an active low pulse.
20	IVS		Invert Frame Clock
		0	LCD_VSYNC is an active high pulse.
		1	LCD_VSYNC is an active low pulse.
19-16	ACB_I	0-Fh	This value is used to specify the number of AC Bias ($\overline{\text{LCD\_AC\_ENB\_CS}}$) output transition counts before setting the AC bias interrupt bit in register LCD_STAT. This counter is stopped when the interrupt is set and remains stopped until the AC bias interrupt status is cleared. A value of zero will not produce an interrupt.

Table 25-22. LCD Raster Timing Register 2 (RASTER_TIMING_2) Field Descriptions (continued)

Bit	Field	Value	Description
15-8	ACB	0-FFh	AC Bias Pin Frequency. This value defines the number of Line Clock (LCD_HSYNC) cycles to count before transitioning signal LCD_AC_ENB_CS. This output may be used to periodically invert the polarity of the power supply in order to prevent a display DC charge build-up on the LCD panel. AC Bias Time Period = [2 × ((Line Clock) × (ABC))]
7-0	Reserved	0	Reserved

25.3.11.1 AC-Bias Pin Frequency (ACB)

NOTE: The 8-bit ac-bias frequency (ACB) field has no effect in active mode. This is due to the fact that the pixel clock transitions continuously in active mode ; the ac-bias line is used as an output enable signal. The ac-bias is asserted by the LCD controller in active mode; this occurs whenever pixel data is driven out to the data pins to signal to the display when it can latch pixels using the pixel clock.

The 8-bit ac-bias frequency (ACB) field is used to specify the number of line clock periods to count between each toggle of the ac-bias pin. After the LCD controller is enabled, the value in ACB is loaded to an 8-bit down counter, and the counter begins to decrement using the line clock. When the counter reaches zero it stops, the state of ac-bias pin is reversed, and the whole procedure starts again. The number of line clocks between each ac-bias pin transition ranges from 1–256 (program to value required minus 1). This line is used by the LCD display to periodically reverse the polarity of the power supplied to the screen to eliminate DC offset.

25.3.11.2 AC-Bias Line Transitions Per Interrupt (ACB_I)

The 4-bit ac-bias line transitions per interrupt (ACB_I) field is used to specify the number of line transitions to count before setting the ac-bias count status (ABC) bit in the LCD controller status register that signals an interrupt request. After the LCD controller is enabled, the value in ACB_I is loaded to a 4-bit down counter, and the counter decrements each time the ac-bias line state is inverted. When the counter reaches zero it stops, the ac-bias count (ABC) bit is set in the status register. Once ABC is set, the 4-bit down counter is reloaded with the value in ACB_I and is disabled until ABC is cleared. Once ABC is cleared by the CPU, the down counter is enabled, and again decrements each time the ac-bias line is flipped. The number of ac-bias line transitions between each interrupt request ranges from 0 to 15. Programming ACB_I = 0000 disables the ac-bias line transitions per interrupt function.

25.3.11.3 Invert VSYNC (IVS)

The invert VSYNC(IVS) bit is used to invert the polarity of the frame clock (VSYNC).

- When IVS = 1, the frame clock (VSYNC) is active low.
- When IVS = 0, it is active high.

25.3.11.4 Invert HSYNC (IHS)

The invert HSYNC(IHS) bit is used to invert the polarity of the line clock (HSYNC).

- When IHS = 1, the line clock (HSYNC) is active low.
- When IHS = 0, it is active high.

25.3.11.5 Invert Pixel Clock (IPC)

The invert pixel clock (IPC) bit is used to select the edge of the pixel clock that drives pixel data out onto the LCD data lines.

- When IPC = 1, data is driven onto the LCD data lines on the falling edge of the pixel clock.
- When IPC = 0, data is driven onto the LCD data lines on the rising edge of the pixel clock.

25.3.11.6 Invert Output Enable (BIAS)

NOTE: BIAS does not affect the ac-bias pin in passive display mode.

The invert output enable (BIAS) bit is used to select the active or inactive state of the output enable signal in active display mode. In this mode, the ac-bias pin is used as an enable that signals the device when data is actively being driven out using the pixel clock.

- When BIAS = 1, the ac-bias pin is active low. In active display mode, data is driven onto the LCD data lines on the programmed edge of the pixel clock when ac-bias pin is in its active state.
- When BIAS = 0, the ac-bias pin is active high.

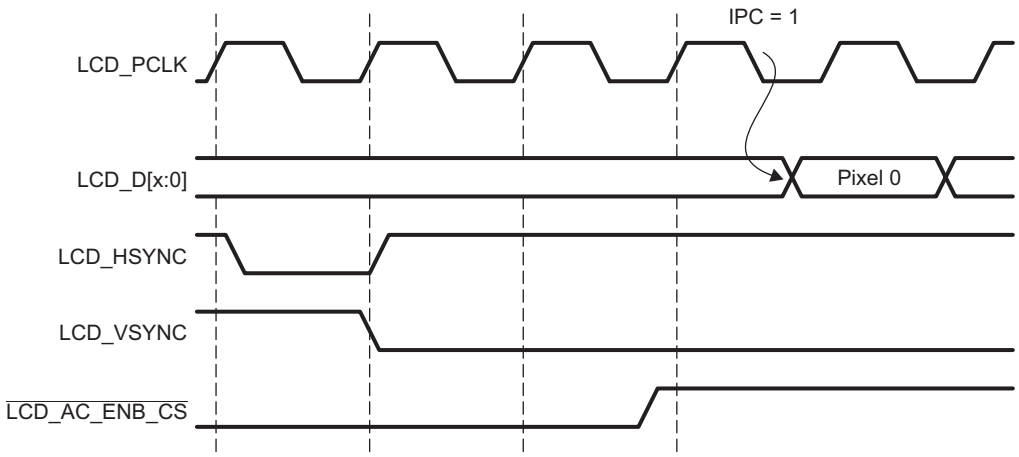
25.3.11.7 Horizontal and Vertical Sync Edge (SYNC_EDGE)

This bit determines whether the HSYNC/VSYNC is driven on the rising or falling edge of the pixel clock (see the SYNC_CTRL bit; SYNC_CTRL must be turned on first). By default, the LCD_HSYNC and LCD_VSYNC signals are driven on the falling edge of the pixel clock, and the pixel data is driven on the rising edge of pixel clock. However, if the invert pixel clock (IPC) bit is set to 1, then the LCD_HSYNC and LCD_VSYNC signals are driven on rising edge of pixel clock and pixel data is driven on falling edge. By setting the SYNC_EDGE bit and enabling it (SYNC_CTRL = 1), you can control on which edge the signals are driven.

In Figure 25-36:

- IPC = 1, pixel data is driven onto the LCD data lines on the falling edge of the pixel clock.
- SYNC_CTRL = 0, LCD_HSYNC and LCD_VSYNC signals are driven on opposite edges of the pixel clock from pixel data (=> rising edge). The rising edge or falling edge is determined by the IPC bit.

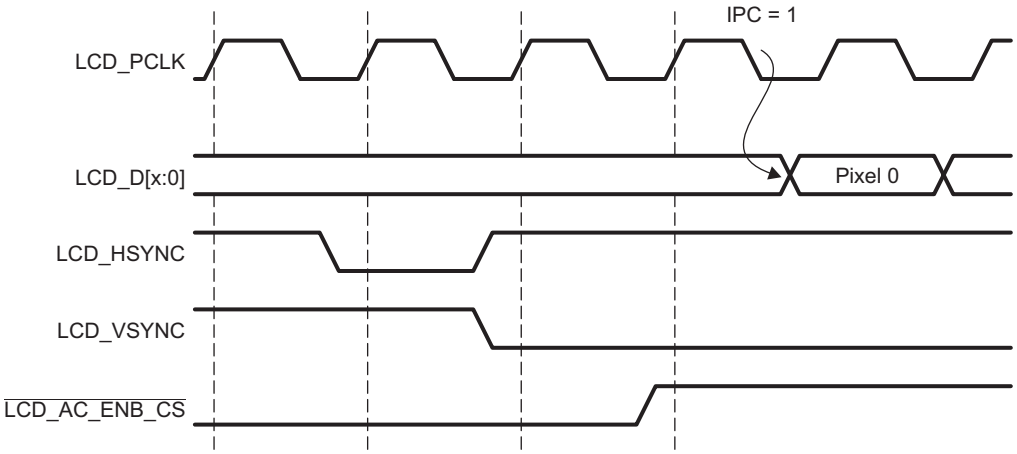
Figure 25-36. SYNC_CTRL = 0, IPC = 1 in TFT Mode



In Figure 25-37:

- IPC = 1, pixel data is driven on the falling edge of the pixel clock.
- SYNC_CTRL = 1, LCD_HSYNC and LCD_VSYNC signals are driven according to the SYNC_EDGE bit.
- SYNC_EDGE = 0, LCD_HSYNC and LCD_VSYNC signals are driven on the falling edge of the pixel clock.

Figure 25-37. SYNC_CTRL = 1, SYNC_EDGE = 0, and IPC = 1



25.3.11.8 Horizontal and Vertical Sync Control (SYNC_CTRL)

This bit enables/disables the possibility to make HSYNC and VSYNC programmable.

- When SYNC_CTRL = 1, HSYNC and VSYNC are driven according to the SYNC_EDGE bit.
- When SYNC_CTRL = 0, HSYNC and VSYNC are driven on opposite edges of the pixel clock from pixel data.

25.3.12 LCD Raster Subpanel Display Register (RASTER_SUBPANEL)

LCD raster subpanel display register (RASTER_SUBPANEL) displays only the first or last *n* lines of the panel and sends a fixed content for the others is supported with the LCD raster subpanel display register. For these others, there is no access to the frame buffer because the value stored in Default Pixel Data will be used. The RASTER_SUBPANEL is shown in Figure 25-38 and described in Table 25-23.

If LPPT is greater than the number of lines per panel then:

- If HOLS = 1: normal panel
- If HOLS = 0: panel with default data

LPPT has a minimum value = 2. DPD, LPPT, HOLS, and SPEN bit fields and bits are not considered if SPEN = 0.

Figure 25-38. LCD Raster Subpanel Display Register (RASTER_SUBPANEL)

31	30	29	28 26	25 16
SPEN	Rsvd	HOLS	Reserved	LPPT
R/W-0	R-0	R/W-0	R-0	R/W-0

15 4	3 0
DPD	Reserved
R/W-0	R-0

LEGEND: R = Read only; -*n* = value after reset

Table 25-23. LCD Raster Subpanel Display Register (RASTER_SUBPANEL) Field Descriptions

Bit	Field	Value	Description
31	SPEN		Subpanel Enable
		0	Disabled
		1	Enabled
30	Reserved	0	Reserved
29	HOLS		High or Low Signal. The field indicates the position of subpanel compared to the LPPT value.
		0	Low, below
		1	High, above
28-26	Reserved	0	Reserved
25-16	LPPT	0-3FFh	Line Per Panel Threshold. This field defines the number of lines to be refreshed (1 to 1024).
15-4	DPD	0-FFFh	Default Pixel Data. DPD defines the default value of the pixel data sent to the panel for the lines until LPPT is reached or after passing the LPPT.
3-0	Reserved	0	Reserved

25.3.12.1 Default Pixel Data (DPD)

The default pixel data (DPD) defines a default value, which is sent to the display in either the top or bottom region of the screen delimited by the LPPT threshold.

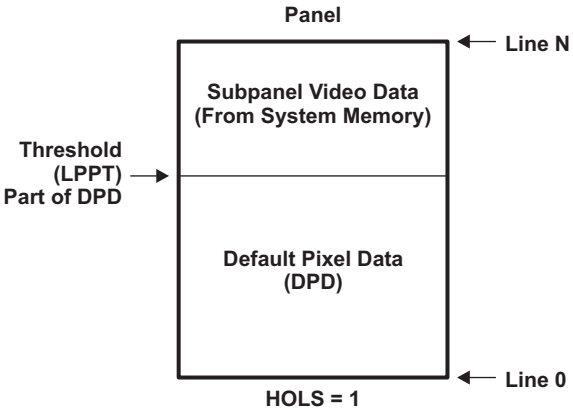
25.3.12.2 Line-per-Panel Threshold (LPPT)

The line-per-panel threshold bit-field delimits the screen portion filled with data fetched from the frame buffer (the subpanel) and the rest of the screen filled with default pixel data (DPD). Note that the LPPT line number points on a line filled with a DPD value when HOLS = 1, but on one filled with video data when HOLS = 0 (see Figure 25-39 and Figure 25-40).

25.3.12.3 High Or Low Signal (HOLS)

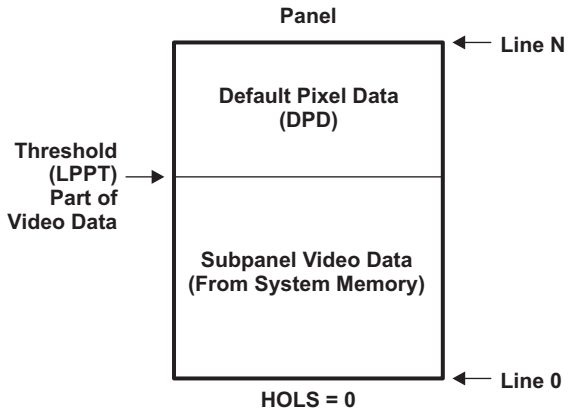
The HOLS bit indicates the position of the subpanel compared to the LPPT value. When HOLS = 1, the image from system memory is displayed above the threshold value. The threshold value is the line number where the DPD value begins to be displayed. The rest of the screen is filled with DPD value.

Figure 25-39. Subpanel Display: SPEN = 1, HOLS = 1



When HOLS = 0, the beginning of the screen is filled with DPD value until the LPPT excluded. From the LPPT line number, the rest of the screen (below LPPT) displays the image from system memory.

Figure 25-40. Subpanel Display: SPEN = 1, HOLS = 0



The bottom of the panel is line 0, and top line of the panel is Line N (where N is the number of lines-per-panel). For example, if you want to display four lines of video data at the bottom of the panel, the correct settings are HOLS = 0 and LPPT = 3. Here, the amount of video data to be transferred from the DMA_LCD channel is only four lines.

If the LPPT is above the number of LPP, then:

- When HOLS = 1: panel with default data (whole panel is filled with DPD value).
- When HOLS = 0: normal panel (whole panel is filled with video data from the frame buffer).

25.3.13 LCD DMA Control Register (LCDDMA_CTRL)

The LCD DMA control register (LCDDMA_CTRL) contains bits that control the LCD channel operation. The LCDDMA_CTRL is shown in Figure 25-41 and described in Table 25-24.

Figure 25-41. LCD DMA Control Register (LCDDMA_CTRL)

31	16
Reserved	
R-0	

15	11	10	8
Reserved		Reserved	
R-0		R-0	

7	6	4	3	2	1	0
Reserved	BURST_SIZE		Reserved	EOF_INTEN	BIGENDIAN	FRAME_MODE
R-0	R/W-0		R-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; *-n* = value after reset

Table 25-24. LCD DMA Control Register (LCDDMA_CTRL) Field Descriptions

Bit	Field	Value	Description
31-11	Reserved	0	Reserved
10-7	Reserved	0	Reserved
6-4	BURST_SIZE	0-7h	Burst Size setting for DMA transfers (all DMA transfers are 32 bits wide)
		0	Burst size of 1
		1h	Burst size of 2
		2h	Burst size of 4
		3h	Burst size of 8
		4h	Burst size of 16
		5h-7h	Reserved
3	Reserved	0	Reserved
2	EOF_INTEN		End-of-Frame Interrupt Enable. Setting this bit allows the end-of-frame 0 or 1 status bits in the LCD status register to trigger an interrupt.
		0	End-of-frame 0/1 interrupt disabled
		1	End-of-frame 0/1 interrupt enabled
1	BIGENDIAN		Big Endian Enable. Use this bit when the processor is operating in Big Endian mode and writes to the frame buffer(s) are less than 32 bits wide; in this scenario only, change the byte alignment for data coming into the FIFO from the frame buffer(s).
		0	Big Endian data reordering disabled
		1	Big Endian data reordering enabled
0	FRAME_MODE		Frame Mode
		0	One frame buffer (FB0 only) used.
		1	Two frame buffers used; DMA ping-pongs between FB0 and FB1 in this mode.

25.3.14 LCD DMA Frame Buffer *n* Base Address Registers (LCDDMA_FB0_BASE and LCDDMA_FB1_BASE)

The LCD DMA frame buffer *n* base address register (LCDDMA_FB*n*_BASE) contains the start address for frame buffer *n*, specified in 32-bit words. The LCDDMA_FB*n*_BASE is shown in Figure 25-42 and described in Table 25-25.

Figure 25-42. LCD DMA Frame Buffer *n* Base Address Register (LCDDMA_FB*n*_BASE)

31	0
FB*n*_BASE	
R/W-0	

LEGEND: R/W = Read/Write; -*n* = value after reset

Table 25-25. LCD DMA Frame Buffer *n* Base Address Register (LCDDMA_FB*n*_BASE) Field Descriptions

Bit	Field	Value	Description
31-0	FB*n*_BASE	0-FFFF FFFFh	Frame Buffer *n* Base Address pointer. Note: The 2 LSBs are hardwired to 00b.

25.3.15 LCD DMA Frame Buffer *n* Ceiling Address Registers (LCDDMA_FB0_CEILING and LCDDMA_FB1_CEILING)

The LCD DMA frame buffer *n* ceiling address register (LCDDMA_FB*n*_CEILING) contains the ending address for frame buffer *n*, specified in 32-bit words. The LCDDMA_FB*n*_CEILING is shown in Figure 25-43 and described in Table 25-26.

Figure 25-43. LCD DMA Frame Buffer *n* Ceiling Address Register (LCDDMA_FB*n*_CEILING)

31	0
FB*n*_CEIL	
R/W-0	

LEGEND: R/W = Read/Write; -*n* = value after reset

Table 25-26. LCD DMA Frame Buffer *n* Ceiling Address Register (LCDDMA_FB*n*_CEILING) Field Descriptions

Bit	Field	Value	Description
31-0	FB*n*_CEIL	0-FFFF FFFFh	Frame Buffer *n* Ceiling Address pointer. Note: The 2 LSBs are hardwired to 00b.

Multichannel Audio Serial Port (McASP)

This chapter describes the multichannel audio serial port (McASP). See your device-specific data manual to determine how many McASPs are available on your device.

Topic **Page**

26.1 Introduction

26.1.1 Purpose of the Peripheral

The multichannel audio serial port (McASP) functions as a general-purpose audio serial port optimized for the needs of multichannel audio applications. The McASP is useful for time-division multiplexed (TDM) stream, Inter-IC Sound (I2S) protocols, and intercomponent digital audio interface transmission (DIT).

The McASP consists of transmit and receive sections that may operate synchronized, or completely independently with separate master clocks, bit clocks, and frame syncs, and using different transmit modes with different bit-stream formats. The McASP module also includes up to 16 serializers that can be individually enabled to either transmit or receive. In addition, all of the McASP pins can be configured as general-purpose input/output (GPIO) pins.

26.1.2 Features

Features of the McASP include:

- Two independent clock generator modules for transmit and receive
  - Clocking flexibility allows the McASP to receive and transmit at different rates. For example, the McASP can receive data at 48 kHz but output up-sampled data at 96 kHz or 192 kHz.
- Independent transmit and receive modules, each includes:
  - Programmable clock and frame sync generator
  - TDM streams from 2 to 32, and 384 time slots
  - Support for time slot sizes of 8, 12, 16, 20, 24, 28, and 32 bits
  - Data formatter for bit manipulation
- Up to 16 individually assignable serial data pins:
  - McASP0 can have up to 16 serial data pins
  - McASP1 can have up to 12 serial data pins
  - McASP2 can have up to 4 serial data pins
- Glueless connection to audio analog-to-digital converters (ADC), digital-to-analog converters (DAC), codec, digital audio interface receiver (DIR), and S/PDIF transmit physical layer components
- Wide variety of Inter-IC Sound (I2S) and similar bit-stream formats
- Integrated digital audio interface transmitter (DIT) supports (McASP2 only):
  - S/PDIF, IEC60958-1, AES-3 formats
  - Up to 4 transmit pins
  - Enhanced channel status/user data RAM
- 384-slot TDM with external digital audio interface receiver (DIR) device
  - For DIR reception, an external DIR receiver integrated circuit should be used with I2S output format and connected to the McASP receive section.
- Extensive error checking and recovery:
  - Transmit underruns and receiver overruns due to the system not meeting real-time requirements
  - Early or late frame sync in TDM mode
  - Out-of-range high-frequency master clock for both transmit and receive
  - External error signal coming into the AMUTEIN input
  - DMA error due to incorrect programming
- McASP Audio FIFO (AFIFO):
  - Provides additional data buffering
  - Provides added tolerance to variations in host/DMA controller response times
  - May be used as a DMA event pacer
  - Independent Read FIFO and Write FIFO

  - 256 bytes of RAM for each FIFO (read and write)
    - 256 bytes = four 32-bit words per serializer in the case of 16 data pins
    - 256 bytes = 64 32-bit words in the case of one data pin
  - Option to bypass Write FIFO and/or Read FIFO independently

26.1.3 Protocols Supported

The McASP supports a wide variety of protocols.

- Transmit section supports
  - Wide variety of I2S and similar bit-stream formats
  - TDM streams from 2 to 32 time slots
  - S/PDIF, IEC60958-1, AES-3 formats
- Receive section supports
  - Wide variety of I2S and similar bit-stream formats
  - TDM streams from 2 to 32 time slots
  - TDM stream of 384 time slots specifically designed for easy interface to external digital interface receiver (DIR) device transmitting DIR frames to McASP using the I2S protocol (one time slot for each DIR subframe)

The transmit and receive sections may each be individually programmed to support the following options on the basic serial protocol:

- Programmable clock and frame sync polarity (rising or falling edge): ACLKR/X, AHCLKR/X, and AFSR/X
- Slot length (number of bits per time slot): 8, 12, 16, 20, 24, 28, 32 bits supported
- Word length (bits per word): 8, 12, 16, 20, 24, 28, 32 bits; always less than or equal to the time slot length
- First-bit data delay: 0, 1, 2 bit clocks
- Left/right alignment of word inside slot
- Bit order: MSB first or LSB first
- Bit mask/pad/rotate function
  - Automatically aligns data for DSP internally in either Q31 or integer formats
  - Automatically masks nonsignificant bits (sets to 0, 1, or extends value of another bit)

In DIT mode (McASP2 only), additional features of the transmitter are:

- Transmit-only mode 384 time slots (subframe) per frame
- Bi-phase encoded 3.3 V output
- Support for consumer and professional applications
- Channel status RAM (384 bits)
- User data RAM (384 bits)
- Separate valid bit (V) for subframe A, B

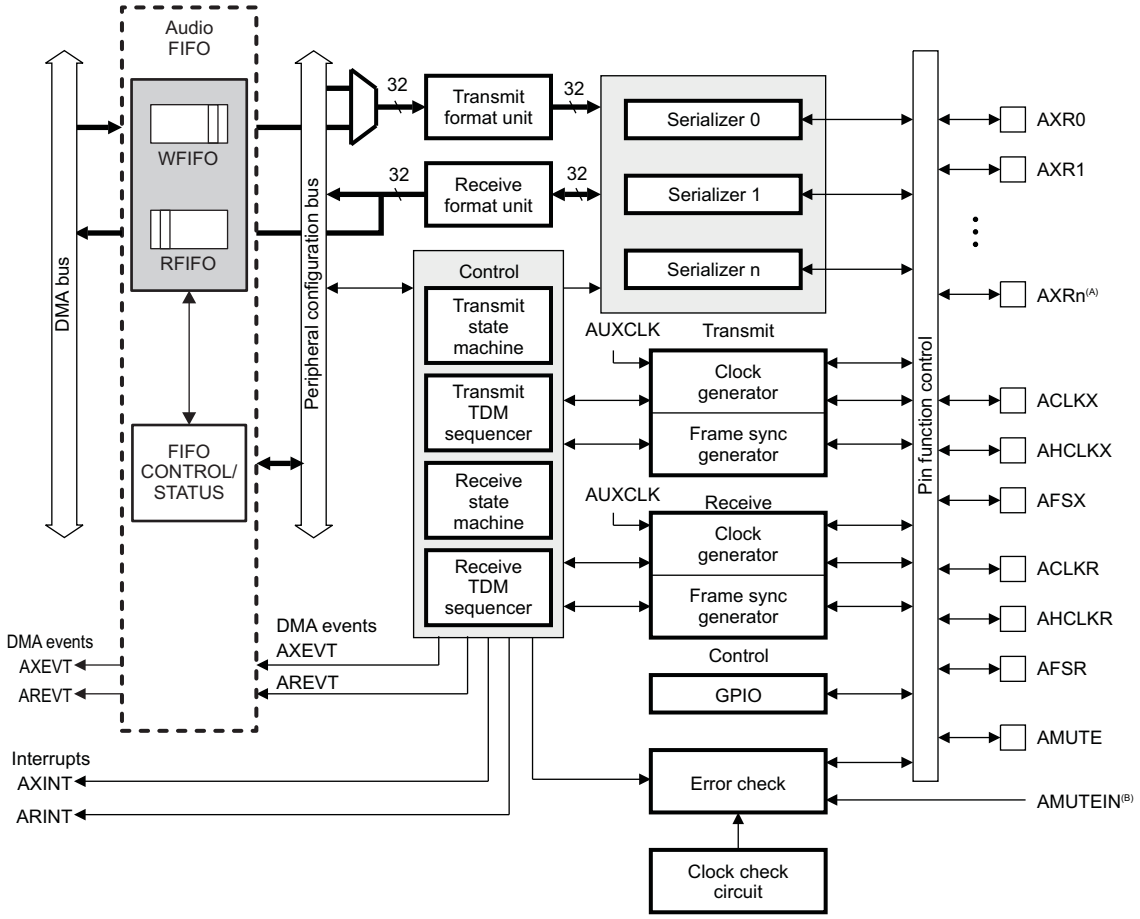
In I2S mode, the transmit and receive sections can support simultaneous transfers on up to all serial data pins operating as 192 kHz stereo channels.

In DIT mode, the transmitter can support a 192 kHz frame rate (stereo) on up to 2 serial data pins simultaneously (note that the internal bit clock for DIT runs two times faster than the equivalent bit clock for I2S mode, due to the need to generate Biphase Mark Encoded Data).

26.1.4 Functional Block Diagram

A block diagram of the McASP is shown in Figure 26-1. The McASP has independent receive/transmit clock generators and frame sync generators.

Figure 26-1. McASP Block Diagram



A McASP0 has up to 16 serial data pins, *n* = 15; McASP1 has up to 12 serial data pins, *n* = 11; McASP2 has up to 4 serial data pins, *n* = 3.

B One of the DSP's external pins, see your device-specific data manual.

26.1.4.1 System Level Connections

Figure 26-2 through Figure 26-5 show examples of McASP usage in digital audio encoder/decoder systems.

Figure 26-2. McASP to Parallel 2-Channel DACs

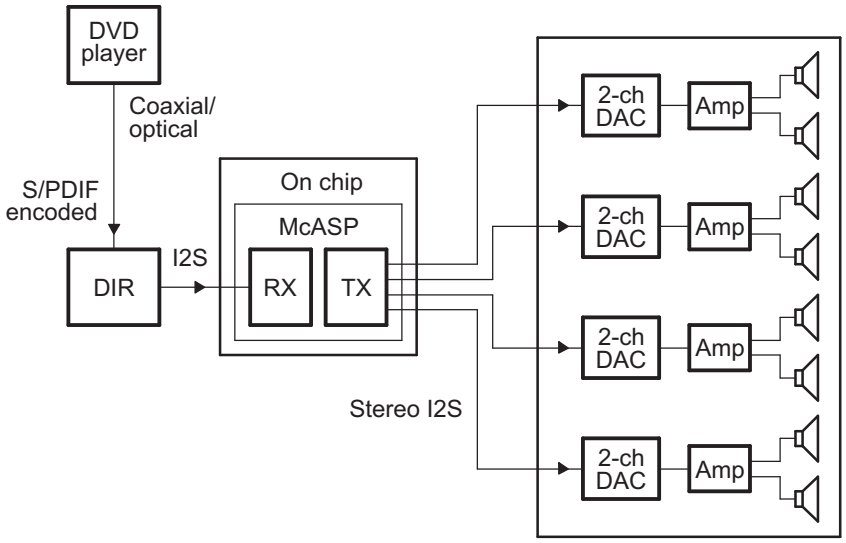


Figure 26-3. McASP to 6-Channel DAC and 2-Channel DAC

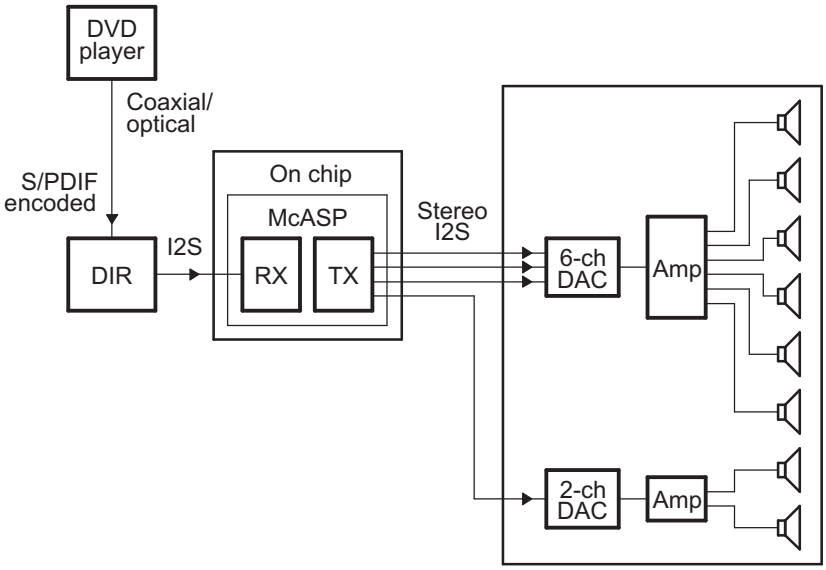


Figure 26-4. McASP to Digital Amplifier

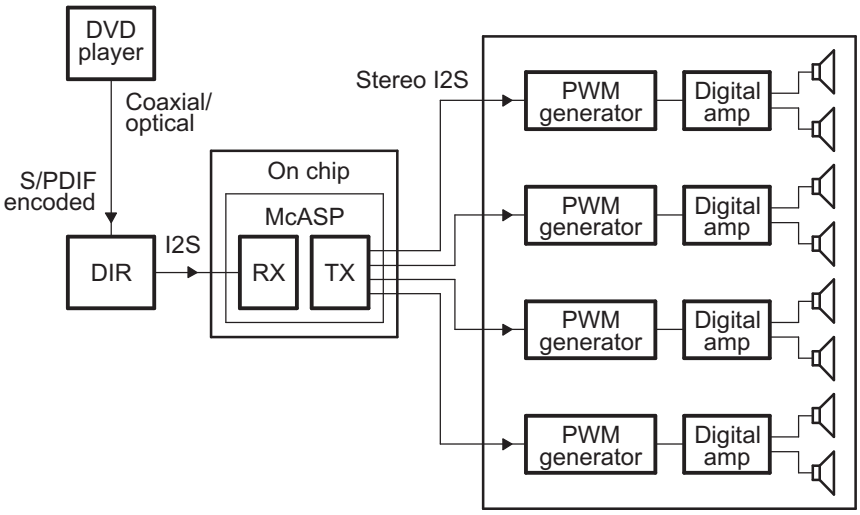
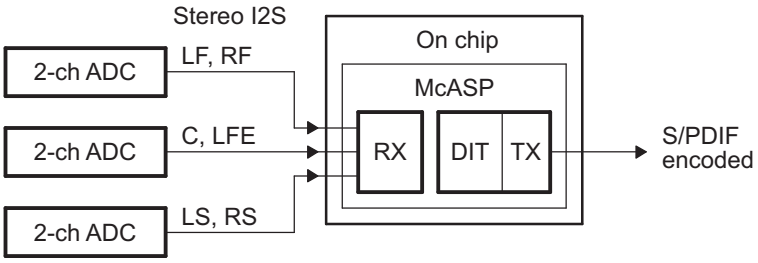


Figure 26-5. McASP as Digital Audio Encoder



26.1.5 Industry Standard Compliance Statement

The McASP supports the following industry standard interfaces.

26.1.5.1 TDM Format

The McASP transmitter and receiver support the multichannel, synchronous time-division-multiplexed (TDM) format via the TDM transfer mode. Within this transfer mode, a wide variety of serial data formats are supported, including formats compatible with devices using the Inter-IC Sound (I2S) protocol. This section briefly discusses the TDM format and the I2S protocol.

26.1.5.1.1 TDM Format

The TDM format is typically used when communicating between integrated circuit devices on the same printed circuit board or on another printed circuit board within the same piece of equipment. For example, the TDM format is used to transfer data between the DSP and one or more analog-to-digital converter (ADC), digital-to-analog converter (DAC), or S/PDIF receiver (DIR) devices.

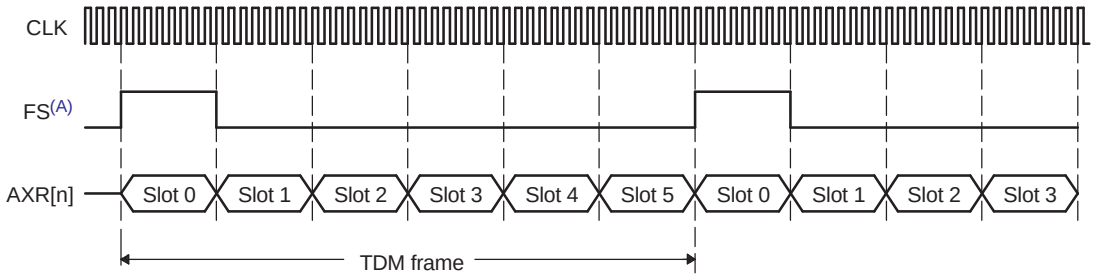
The TDM format consists of three components in a basic synchronous serial transfer: the clock, the data, and the frame sync. In a TDM transfer, all data bits (AXR[n]) are synchronous to the serial clock (ACLKX or ACLKR). The data bits are grouped into words and slots (as defined in Section 26.1.6). The "slots" are also commonly referred to as "time slots" or "channels" in TDM terminology. A frame consists of multiple slots (or channels). Each TDM frame is defined by the frame sync signal (AFSX or AFSR). Data transfer is continuous and periodic, since the TDM format is most commonly used to communicate with data converters that operate at a fixed sample rate.

There are no delays between slots. The last bit of slot N is followed immediately on the next serial clock cycle with the first bit of slot N + 1, and the last bit of the last slot is followed immediately on the next serial clock with the first bit of the first slot. However, the frame sync may be offset from the first bit of the first slot with a 0, 1, or 2-cycle delay.

It is required that the transmitter and receiver in the system agree on the number of bits per slot, since the determination of a slot boundary is not made by the frame sync signal (although the frame sync marks the beginning of slot 0 and the beginning of a new frame).

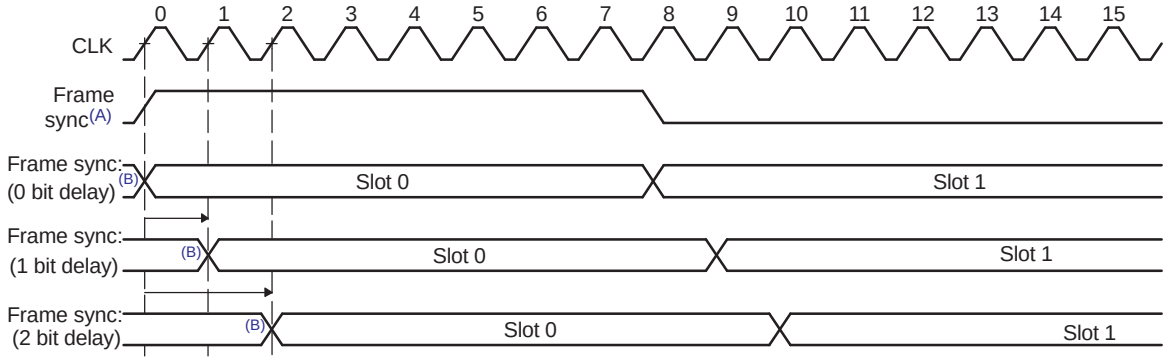
Figure 26-6 shows the TDM format. Figure 26-7 shows the different bit delays from the frame sync.

Figure 26-6. TDM Format–6 Channel TDM Example



A FS duration of slot is shown. FS duration of single bit is also supported.

Figure 26-7. TDM Format Bit Delays from Frame Sync



A FS duration of slot is shown. FS duration of single bit is also supported.

B Last bit of last slot of previous frame. No gap between this bit and the first bit of slot 0 is allowed.

In a typical audio system, one frame of data is transferred during each data converter sample period f_s. To support multiple channels, the choices are to either include more time slots per frame (thus operating with a higher bit clock rate), or to use additional data pins to transfer the same number of channels (thus operating with a slower bit clock rate).

For example, a particular six channel DAC may be designed to transfer over a single serial data pin AXR[n] as shown in Figure 26-6. In this case the serial clock must run fast enough to transfer a total of 6 channels within each frame period. Alternatively, a similar six channel DAC may be designed to use three serial data pins AXR[0,1,2], transferring two channels of data on each pin during each sample period (Figure 26-8). In the latter case, if the sample period remains the same, the serial clock can run three times slower than the former case. The McASP is flexible enough to support either type of DAC.

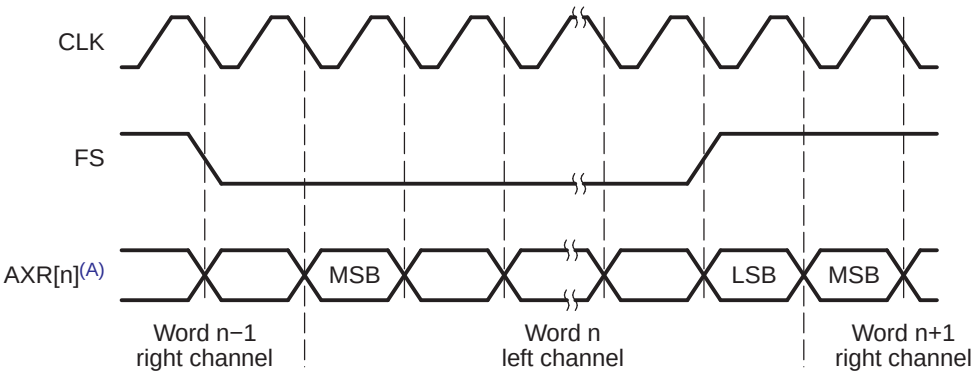
26.1.5.1.2 Inter-IC Sound (I2S) Format

The Inter-IC Sound (I2S) format is used extensively in audio interfaces. The TDM transfer mode of the McASP supports the I2S format when configured to 2 slots per frame.

I2S format is specifically designed to transfer a stereo channel (left and right) over a single data pin AXR[n]. "Slots" are also commonly referred to as "channels". The frame width duration in the I2S format is the same as the slot size. The frame signal is also referred to as "word select" in the I2S format. Figure 26-8 shows the I2S protocol.

The McASP supports transfer of multiple stereo channels over multiple AXR[n] pins.

Figure 26-8. Inter-IC Sound (I2S) Format



A 1 to 16 data pins may be supported.

26.1.5.2 S/PDIF Coding Format

The McASP transmitter supports the S/PDIF format with 3.3V biphase-mark encoded output. The S/PDIF format is supported by the digital audio interface transmit (DIT) transfer mode of the McASP. This section briefly discusses the S/PDIF coding format.

26.1.5.2.1 Biphase-Mark Code (BMC)

In S/PDIF format, the digital signal is coded using the biphase-mark code (BMC). The clock, frame, and data are embedded in only one signal—the data pin AXR[n]. In the BMC system, each data bit is encoded into two logical states (00, 01, 10, or 11) at the pin. These two logical states form a cell. The duration of the cell, which equals to the duration of the data bit, is called a time interval. A logical 1 is represented by two transitions of the signal within a time interval, which corresponds to a cell with logical states 01 or 10. A logical 0 is represented by one transition within a time interval, which corresponds to a cell with logical states 00 or 11. In addition, the logical level at the start of a cell is inverted from the level at the end of the previous cell. Figure 26-9 and Table 26-1 show how data is encoded to the BMC format.

As shown in Figure 26-9, the frequency of the clock is twice the unencoded data bit rate. In addition, the clock is always programmed to 128 × f_s, where f_s is the sample rate (see Section 26.1.5.2.3 for details on how this clock rate is derived based on the S/PDIF format). The device receiving in S/PDIF format can recover the clock and frame information from the BMC signal.

Figure 26-9. Biphase-Mark Code (BMC)

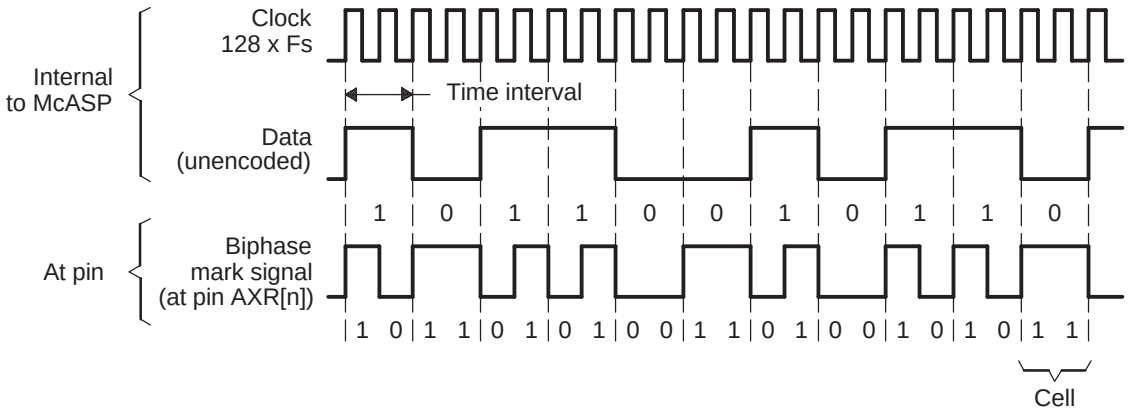


Table 26-1. Biphase-Mark Encoder

Data (Unencoded)	Previous State at Pin AXR[n]	BMC-Encoded Cell Output at AXR[n]
0	0	11
0	1	00
1	0	10
1	1	01

26.1.5.2.2 Subframe Format

Every audio sample transmitted in a subframe consists of 32 S/PDIF time intervals (or cells), numbered from 0 to 31. Figure 26-10 shows a subframe.

- **Time intervals 0-3** carry one of the three permitted preambles to signify the type of audio sample in the current subframe. The preamble is *not* encoded in BMC format, and therefore the preamble code can contain more than two consecutive 0 or 1 logical states in a row. See Table 26-2.
- **Time intervals 4-27** carry the audio sample word in linear 2s-complement representation. The most-significant bit (MSB) is carried by time interval 27. When a 24-bit coding range is used, the least-significant bit (LSB) is in time interval 4. When a 20-bit coding range is used, time intervals 8-27 carry the audio sample word with the LSB in time interval 8. Time intervals 4-7 may be used for other applications and are designated auxiliary sample bits.
- If the source provides fewer bits than the interface allows (either 20 or 24), the unused LSBs are set to logical 0. For a nonlinear PCM audio application or a data application, the main data field may carry any other information.
- **Time interval 28** carries the validity bit (V) associated with the main data field in the subframe.
- **Time interval 29** carries the user data channel (U) associated with the main data field in the subframe.
- **Time interval 30** carries the channel status information (C) associated with the main data field in the subframe. The channel status indicates if the data in the subframe is digital audio or some other type of data.
- **Time interval 31** carries a parity bit (P) such that time intervals 4-31 carry an even number of 1s and an even number of 0s (even parity). As shown in Table 26-2, the preambles (time intervals 0-3) are also defined with even parity.

Figure 26-10. S/PDIF Subframe Format

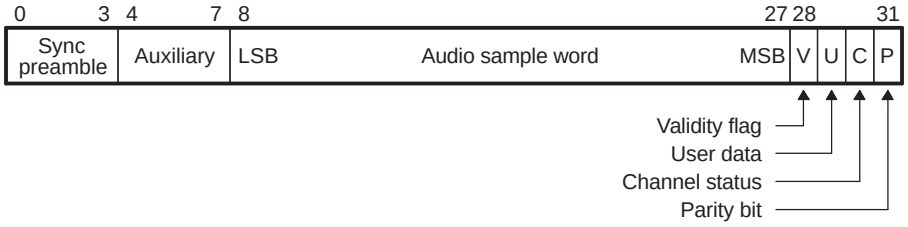


Table 26-2. Preamble Codes

Preamble Code [1]	Previous Logical State	Logical States on pin AXR[n] [2]	Description
B (or Z)	0	1110 1000	Start of a block and subframe 1
M (or X)	0	1110 0010	Subframe 1
W (or Y)	0	1110 0100	Subframe 2

(1) Historically, preamble codes are referred to as B, M, W. For use in professional applications, preambles are referred to as Z, X, Y, respectively.

(2) The preamble is not BMC encoded. Each logical state is synchronized to the serial clock. These 8 logical states make up time slots (cells) 0 to 3 in the S/PDIF stream.

As shown in Table 26-2, the McASP DIT only generates one polarity of preambles and it assumes the previous logical state to be 0. This is because the McASP assures an even-polarity encoding scheme when transmitting in DIT mode. If an underrun condition occurs, the DIT resynchronizes to the correct logic level on the AXR[n] pin before continuing with the next transmission.

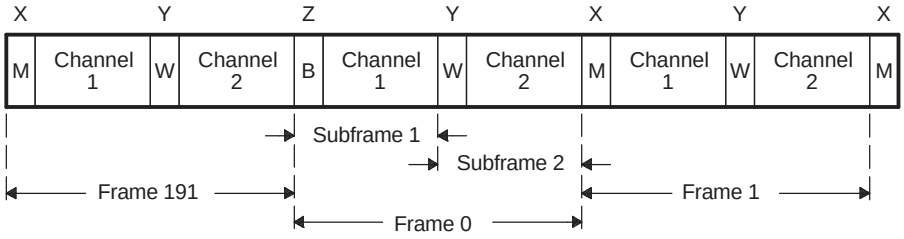
26.1.5.2.3 Frame Format

An S/PDIF frame is composed of two subframes (Figure 26-11). For linear coded audio applications, the rate of frame transmission normally corresponds exactly to the source sampling frequency f_s. The S/PDIF format clock rate is therefore 128 × f_s (128 = 32 cells/subframe × 2 clocks/cell × 2 subframes/sample). For example, for an S/PDIF stream at a 192 kHz sampling frequency, the serial clock is 128 × 192 kHz = 24.58 MHz.

In 2-channel operation mode, the samples taken from both channels are transmitted by time multiplexing in consecutive subframes. Both subframes contain valid data. The first subframe (**left** or **A** channel in stereophonic operation and **primary** channel in monophonic operation) normally starts with preamble M. However, the preamble of the first subframe changes to preamble B once every 192 frames to identify the start of the block structure used to organize the channel status information. The second subframe (**right** or **B** channel in stereophonic operation and **secondary** channel in monophonic operation) always starts with preamble W.

In single-channel operation mode in a professional application, the frame format is the same as in the 2-channel mode. Data is carried in the first subframe and may be duplicated in the second subframe. If the second subframe is not carrying duplicate data, time slot 28 (validity bit) is set to logical 1.

Figure 26-11. S/PDIF Frame Format



26.1.6 Definition of Terms

The serial bit stream transmitted or received by the McASP is a long sequence of 1s and 0s, either output or input on one of the audio transmit/receive pins (AXR[n]). However, the sequence has a hierarchical organization that can be described in terms of frames of data, slots, words, and bits.

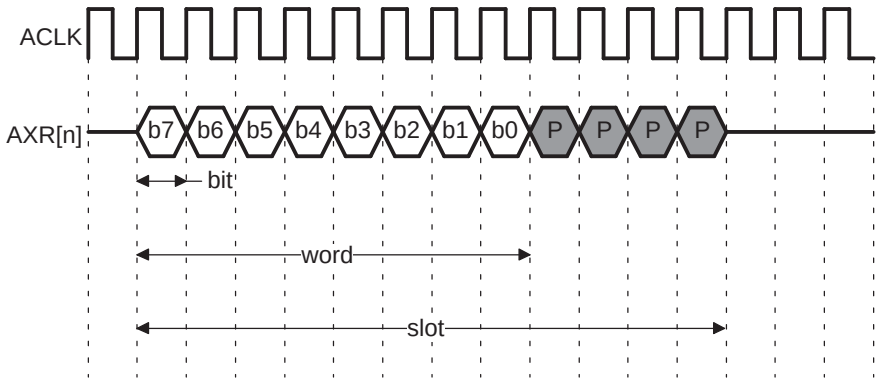
A basic synchronous serial interface consists of three important components: clock, frame sync, and data. Figure 26-12 shows two of the three basic components—the clock (ACLK) and the data (AXR[n]). Figure 26-12 does not specify whether the clock is for transmit (ACLKX) or receive (ACLKR) because the definitions of terms apply to both receive and transmit interfaces. In operation, the transmitter uses ACLKX as the serial clock, and the receiver uses ACLKR as the serial clock. Optionally, the receiver can use ACLKX as the serial clock when the transmitter and receiver of the McASP are configured to operate synchronously.

Bit A bit is the smallest entity in the serial data stream. The beginning and end of each bit is marked by an edge of the serial clock. The duration of a bit is a serial clock period. A 1 is represented by a logic high on the AXR[n] pin for the entire duration of the bit. A 0 is represented by a logic low on the AXR[n] pin for the entire duration of the bit.

Word A word is a group of bits that make up the data being transferred between the DSP and the external device. Figure 26-12 shows an 8-bit word.

Slot A slot consists of the bits that make up the word, and may consist of additional bits used to pad the word to a convenient number of bits for the interface between the DSP and the external device. In Figure 26-12, the audio data consists of only 8 bits of useful data (8-bit word), but it is padded with 4 zeros (12-bit slot) to satisfy the desired protocol in interfacing to an external device. Within a slot, the bits may be shifted in/out of the McASP on the AXR[n] pin either MSB or LSB first. When the word size is smaller than the slot size, the word may be aligned to the left (beginning) of the slot or to the right (end) of the slot. The additional bits in the slot not belonging to the word may be padded with 0, 1, or with one of the bits (the MSB or the LSB typically) from the data word. These options are shown in Figure 26-13.

Figure 26-12. Definition of Bit, Word, and Slot

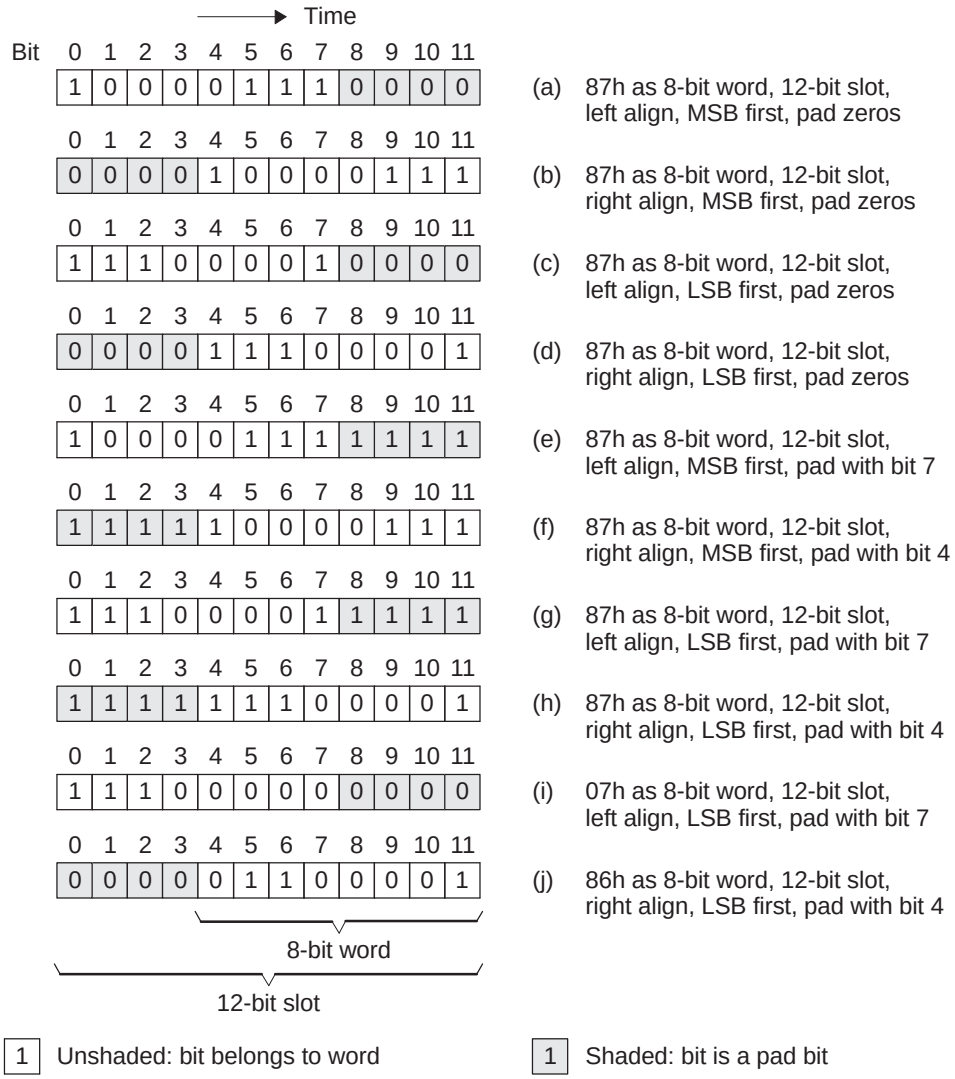


(1) b7:b0 - bits. Bits b7 to b0 form a word.

(2) P - pad bits. Bits b7 to b0, together with the four pad bits, form a slot.

(3) In this example, the data is transmitted MSB first, left aligned.

Figure 26-13. Bit Order and Word Alignment Within a Slot Examples

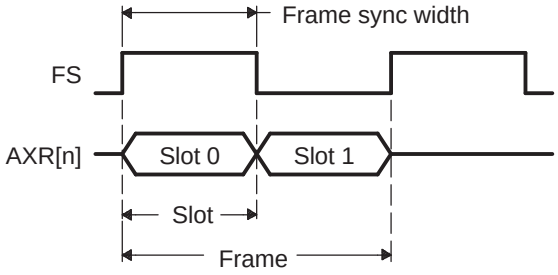


The third basic element of a synchronous serial interface is the frame synchronization signal, also referred to as frame sync in this chapter.

Frame A frame contains one or multiple slots, as determined by the desired protocol. Figure 26-14 shows an example frame of data and the frame definitions. Figure 26-14 does not specify whether the frame sync (FS) is for transmit (AFSX) or receive (AFSR) because the definitions of terms apply to both receive and transmit interfaces. In operation, the transmitter uses AFSX and the receiver uses AFSR. Optionally, the receiver can use AFSX as the frame sync when the transmitter and receiver of the McASP are configured to operate synchronously.

This section only shows the generic definition of the frame sync. See Section 26.1.5.1, Section 26.1.5.2, and Section 26.2.4.2.1 for details on the frame sync formats required for the different transfer modes and protocols (burst mode, TDM mode and I2S format, DIT mode and S/PDIF format).

Figure 26-14. Definition of Frame and Frame Sync Width



(1) In this example, there are two slots in a frame, and FS duration of slot length is shown.

Other terms used throughout this chapter:

TDM	Time-division multiplexed. See Section 26.1.5.1 for details on the TDM protocol.
DIR	Digital audio interface receive. The McASP does not natively support receiving in the S/PDIF format. The McASP supports I2S format output by an external DIR device.
DIT	Digital audio interface transmit. The McASP supports transmitting in S/PDIF format on up to all data pins configured as outputs.
I2S	Inter-IC Sound protocol, commonly used on audio interfaces. The McASP supports the I2S protocol as part of the TDM mode (when configured as a 2-slot frame).
Slot or Time Slot	For TDM format, the term time slot is interchangeable with the term slot defined in this section. For DIT format, a McASP time slot corresponds to a DIT subframe.

26.2 Architecture

26.2.1 Overview

Figure 26-1 shows the major blocks of the McASP. The McASP has independent receive/transmit clock generators and frame sync generators, error-checking logic, and up to 16 serial data pins. See your device-specific data manual for the number of data pins available on your device.

All the McASP pins on the device may be individually programmed as general-purpose I/O (GPIO) if they are not used for serial port functions.

The McASP includes the following pins:

- Serializers
  - Data pins AXR[n]: Up to sixteen per McASP
- Transmit clock generator:
  - AHCLKX: McASP transmit high-frequency master clock
  - ACLKX: McASP transmit bit clock
- Transmit Frame Sync Generator
  - AFSX: McASP transmit frame sync or left/right clock (LRCLK)
- Receive clock generator:
  - AHCLKR: McASP receive high-frequency master clock
  - ACLKR: McASP receive bit clock
- Receive Frame Sync Generator
  - AFSR: McASP receive frame sync or left/right clock (LRCLK)
- Mute in/out:
  - AMUTEIN: McASP mute input (from external device)
  - AMUTE: McASP mute output
  - Data pins AXR[n]

26.2.2 Clock and Frame Sync Generators

The McASP clock generators are able to produce two independent clock zones: transmit and receive clock zones. The serial clock generators may be programmed independently for the transmit section and the receive section, and may be completely asynchronous to each other. The serial clock (clock at the bit rate) may be sourced:

- **Internally** - by passing through two clock dividers off the internal clock source (AUXCLK)
- **Externally** - directly from ACLKR/X pin
- **Mixed** - an external high-frequency clock is input to the McASP on either the AHCLKX or AHCLKR pins, and divided down to produce the bit rate clock

In the internal/mixed cases, the bit rate clock is generated internally and should be driven out on the ACLKX (for transmit) or ACLKR (for receive) pins. In the internal case, an internally-generated high-frequency clock may be driven out onto the AHCLKX or AHCLKR pins to serve as a reference clock for other components in the system.

The McASP requires a minimum of a bit clock and a frame sync to operate, and provides the capability to reference these clocks from an external high-frequency master clock. In DIT mode, it is possible to use only internally-generated clocks and frame syncs.

26.2.2.1 Transmit Clock

The transmit bit clock, ACLKX, (Figure 26-15) may be either externally sourced from the ACLKX pin or internally generated, as selected by the CLKXM bit. If internally generated (CLKXM = 1), the clock is divided down by a programmable bit clock divider (CLKXDIV) from the transmit high-frequency master clock (AHCLKX).

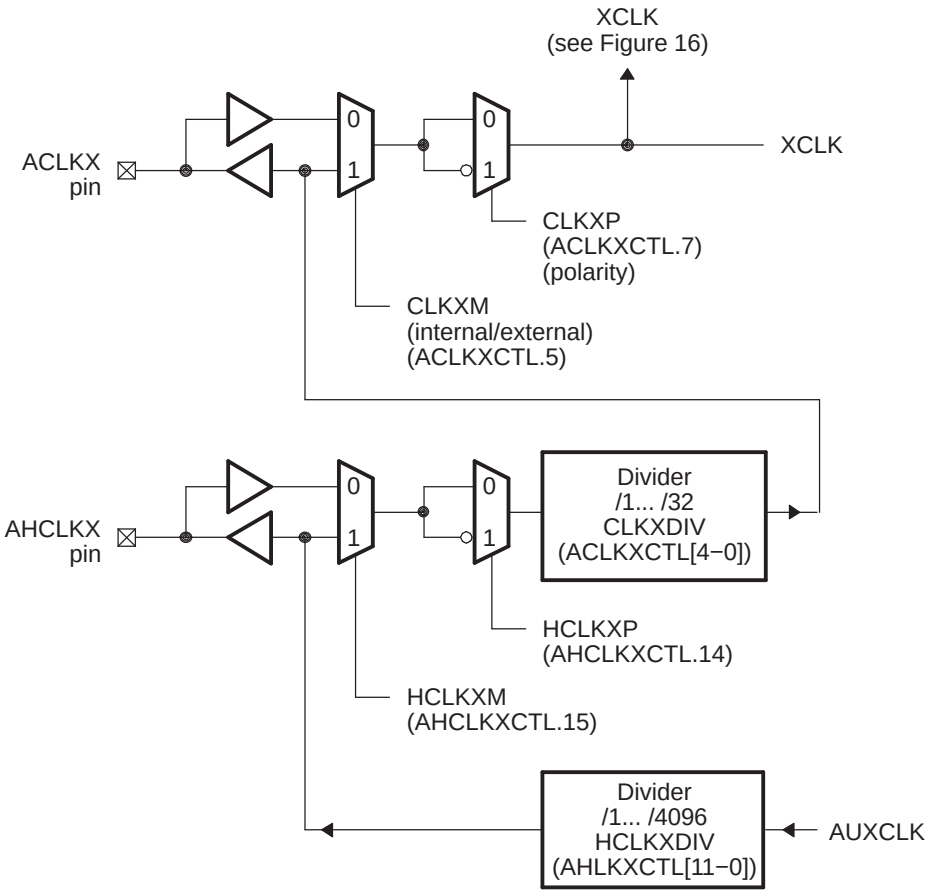
Internally, the McASP always shifts transmit data at the rising edge of the internal transmit clock, XCLK, (Figure 26-15). The CLKXP mux determines if ACLKX needs to be inverted to become XCLK. If CLKXP = 0, the CLKXP mux directly passes ACLKX to XCLK. As a result, the McASP shifts transmit data at the rising edge of ACLKX. If CLKXP = 1, the CLKX mux passes the inverted version of ACLKX to XCLK. As a result, the McASP shifts transmit data at the falling edge of ACLKX.

The transmit high-frequency master clock, AHCLKX, may be either externally sourced from the AHCLKX pin or internally generated, as selected by the HCLKXM bit. If internally generated (HCLKXM = 1), the clock is divided down by a programmable high clock divider (HCLKXDIV) from McASP internal clock source AUXCLK. The transmit high-frequency master clock may be (but is not required to be) output on the AHCLKX pin where it is available to other devices in the system.

The transmit clock configuration is controlled by the following registers:

- ACLKXCTL
- AHCLKXCTL

Figure 26-15. Transmit Clock Generator Block Diagram



26.2.2.2 Receive Clock

The receiver has a clock generation circuit identical to (but independent of) that of the transmitter. The receive bit clock, ACLKR, (Figure 26-16) may be either externally sourced from the ACLKR pin or internally generated, as selected by the CLKRM bit. If internally generated (CLKRM = 1), the clock is divided down by a programmable divider (CLKRDIV) from the receive high-frequency master clock (AHCLKR). Regardless if ACLKR is either internally generated or externally sourced, polarity of the clock may be programmed (CLKRP) to be either rising or falling edge.

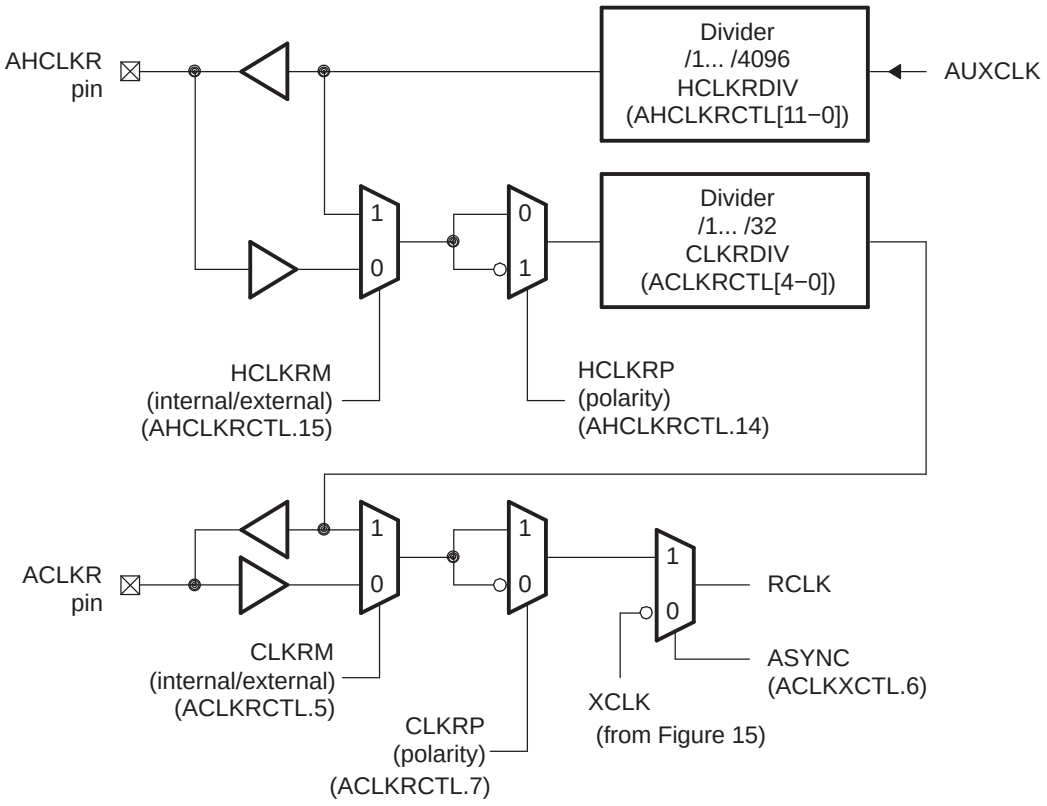
The receive high-frequency master clock, AHCLKR, may be either externally sourced from the AHCLKR pin or internally generated, as selected by the HCLKRM bit. If internally generated (HCLKRM = 1), the clock is divided down by a programmable divider (HCLKRDIV) from AUXCLK. The receive high-frequency master clock may be (but is not required to be) output on the AHCLKR pin where it is available to other devices in the system. Regardless if AHCLKR is either internally generated or externally sourced, polarity of the high-frequency clock may be programmed (HCLKRP) to be either rising or falling edge.

The receiver also has the option to operate synchronously from the ACLKX and AFSX signals. This is achieved when the ASYNC bit in the transmit clock control register (ACLKXCTL) is cleared to 0. See Section 26.2.4.1.5 for details on McASP operation when ACLKXCTL.ASYNC = 0.

The receive clock configuration is controlled by the following registers:

- ACLKRCTL
- AHCLKRCTL

Figure 26-16. Receive Clock Generator Block Diagram



26.2.2.3 Frame Sync Generator

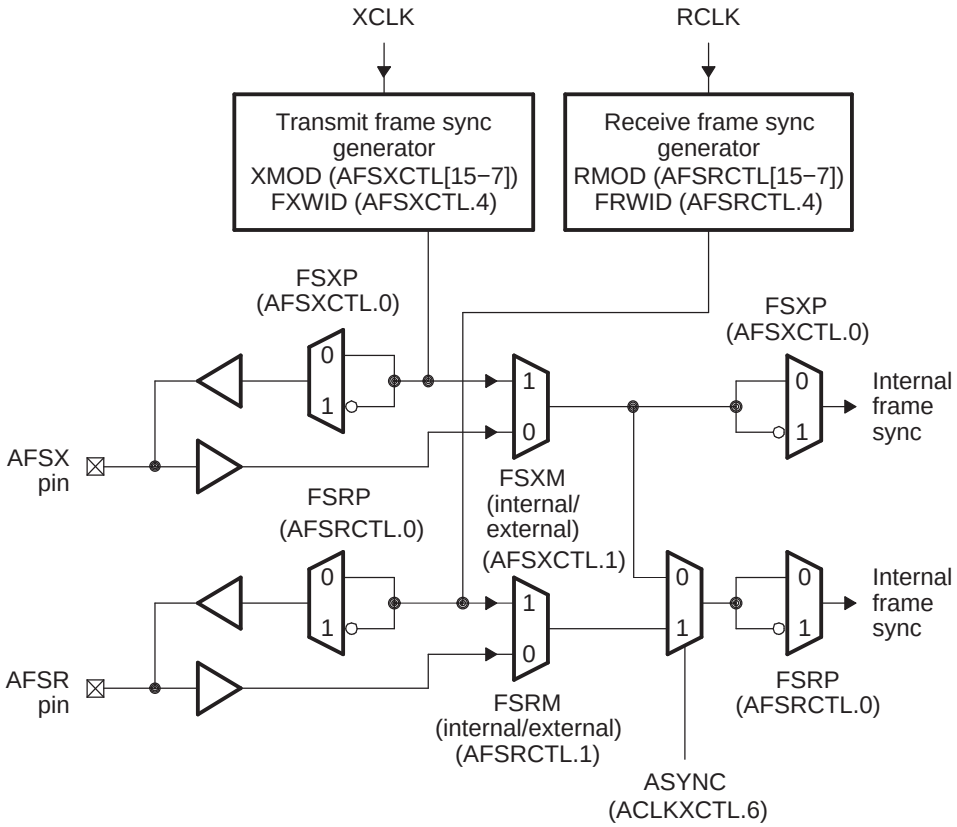
There are two different modes for frame sync: burst and TDM. A block diagram of the frame sync generator is shown in Figure 26-17. The frame sync options are programmed by the receive and transmit frame sync control registers (AFSRCTL and AFSXCTL). The options are:

- Internally-generated or externally-generated
- Frame sync polarity: rising edge or falling edge
- Frame sync width: single bit or single word
- Bit delay: 0, 1, or 2 cycles before the first data bit

The transmit frame sync pin is AFSX and the receive frame sync pin is AFSR. A typical usage for these pins is to carry the left/right clock (LRCLK) signal when transmitting and receiving stereo data.

Regardless if the AFSX/AFSR is internally generated or externally sourced, the polarity of AFSX/AFSR is determined by FSXP/FSRP, respectively, to be either rising or falling edge. If FSXP/FSRP = 0, the frame sync polarity is rising edge. If FSXP/FSRP = 1, the frame sync polarity is falling edge.

Figure 26-17. Frame Sync Generator Block Diagram



26.2.2.4 Clocking Examples

Some examples of processes using the McASP clocking and frame flexibility are:

- Receive data from a DVD at 48 kHz, but output up-sampled or decoded audio at 96 kHz or 192 kHz. This could be accomplished by inputting a high-frequency master clock (for example, 512 × receive FS), receiving with an internally-generated bit clock ratio of divide-by-8, and transmitting with an internally-generated bit clock ratio of divide-by-4 or divide-by-2.
- Transmit/receive data based on one sample rate (for example, 44.1 kHz), and transmit/receive data at a different sample rate (for example, 48 kHz).

26.2.3 General Architecture

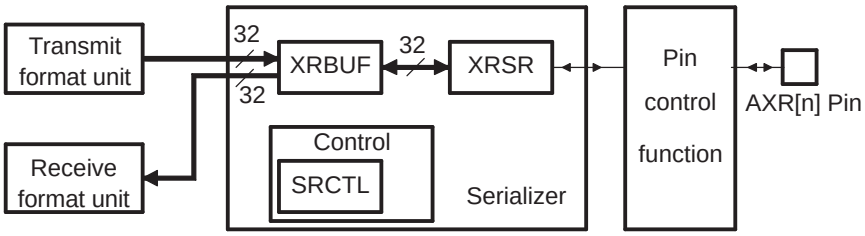
26.2.3.1 Serializers

The serializers take care of shifting serial data in and out of the McASP. Each serializer consists of a shift register (XRSR), a data buffer (XRBUF), a control register (SRCTL), and logic to support the data alignment options of the McASP. For each serializer, there is a dedicated serial data pin (AXR[n]) and a dedicated control register (SRCTL[n]). The control register allows the serializer to be configured as a transmitter, receiver, or as inactive. When configured as a transmitter the serializer shifts out data to the serial data pin AXR[n]. When configured as a receiver, the serializer shifts in data from the AXR[n] pin. The serializer is clocked from the transmit/receive section clock (ACLKX/ACLKR) if configured to transmit/receive respectively.

All serializers that are configured to transmit operate in lock-step. Similarly, all serializers that are configured to receive also operate in lock-step. This means that at most there are two zones per McASP, one for transmit and one for receive.

Figure 26-18 shows the block diagram of the serializer and its interface to other units within the McASP.

Figure 26-18. Individual Serializer and Connections Within McASP



For receive, data is shifted in through the AXR[n] pin to the shift register XRSR. Once the entire slot of data is collected in the XRSR, the data is copied to the data buffer XRBUF. The data is now ready to be read by the DSP through the RBUF register, which is an alias of the XRBUF for receive. When the DSP reads from the RBUF, the McASP passes the data from RBUF through the receive format unit and returns the formatted data to the DSP.

For transmit, the DSP services the McASP by writing data into the XBUF register, which is an alias of the XRBUF for transmit. The data automatically passes through the transmit format unit before actually reaching the XRBUF in the serializer. The data is then copied from XRBUF to XRSR, and shifted out from the AXR[n] synchronously to the serial clock.

In DIT mode, in addition to the data, the serializer shifts out other DIT-specific information accordingly (preamble, user data, etc.).

The serializer configuration is controlled by SRCTL[n].

26.2.3.2 Format Unit

The McASP has two data formatting units, one for transmit and one for receive. These units automatically remap the data bits within the transmitted and received words between a natural format for the DSP (such as a Q31 representation) and the required format for the external serial device (such as "I2S format"). During the remapping process, the format unit also can mask off certain bits or perform sign extension.

Since all transmitters share the same data formatting unit, the McASP only supports one transmit format at a time. For example, the McASP will not transmit in "I2S format" on serializer 0, while transmitting "Left Justified" on serializer 1. Likewise, the receiver section of the McASP only supports one data format at a time, and this format applies to all receiving serializers. However, the McASP can transmit in one format while receiving in a completely different format.

This formatting unit consists of three stages:

- Bit mask and pad (masks off bits, performs sign extension)
- Rotate right (aligns data within word)
- Bit reversal (selects between MSB first or LSB first)

Figure 26-19 shows a block diagram of the receive formatting unit, and Figure 26-20 shows the transmit formatting unit. Note that the order in which data flows through the three stages is different between the transmit and receive formatting units.

Figure 26-19. Receive Format Unit

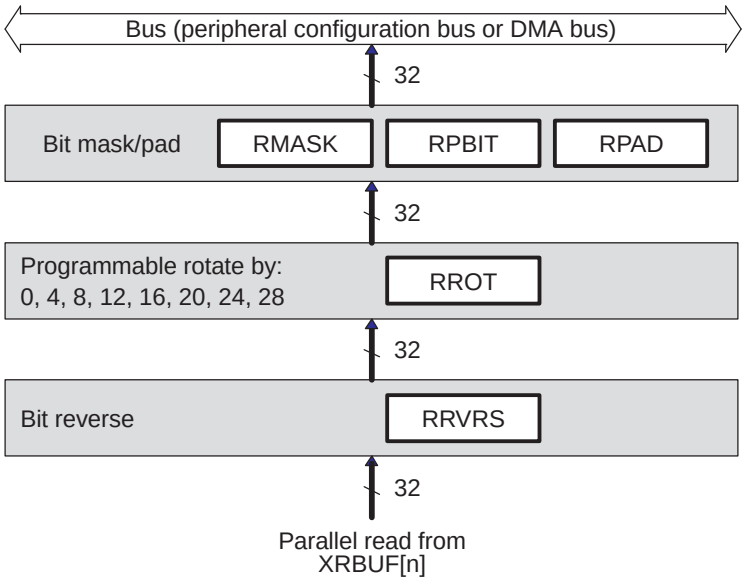
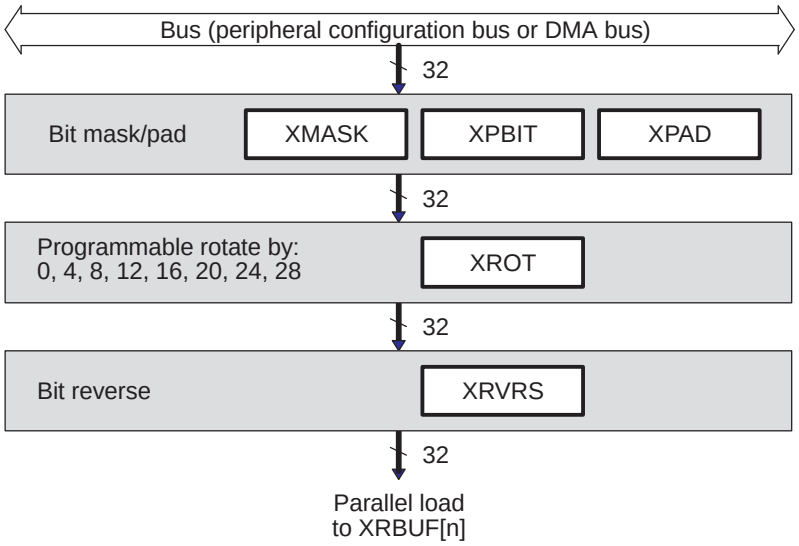


Figure 26-20. Transmit Format Unit



The bit mask and pad stage includes a full 32-bit mask register, allowing selected individual bits to either pass through the stage unchanged, or be masked off. The bit mask and pad then pad the value of the masked off bits by inserting either a 0, a 1, or one of the original 32 bits as the pad value. The last option allows for sign-extension when the sign bit is selected to pad the remaining bits.

The rotate right stage performs bitwise rotation by a multiple of 4 bits (between 0 and 28 bits), programmable by the (R/X)FMT register. Note that this is a rotation process, not a shifting process, so bit 0 gets shifted back into bit 31 during the rotation.

The bit reversal stage either passes all 32 bits directly through, or swaps them. This allows for either MSB or LSB first data formats. If bit reversal is not enabled, then the McASP will naturally transmit and receive in an LSB first order.

Finally, note that the (R/X)DATDLY bits in (R/X)FMT also determine the data format. For example, the difference between I2S format and left-justified is determined by the delay between the frame sync edge and the first data bit of a given time slot. For I2S format, (R/X)DATDLY should be set to a 1-bit delay, whereas for left-justified format, it should be set to a 0-bit delay.

The combination of all the options in (R/X)FMT means that the McASP supports a wide variety of data formats, both on the serial data lines, and in the internal DSP representation.

Section 26.2.4.5 provides more detail and specific examples. The examples use internal representation in integer and Q31 notation, but other fractional notations are also possible.

26.2.3.3 State Machine

The receive and transmit sections have independent state machines. Each state machine controls the interactions between the various units in the respective section. In addition, the state machine keeps track of error conditions and serial port status.

No serial transfers can occur until the respective state machine is released from reset. See initialization sequence for details (Section 26.2.4.1).

The receive state machine is controlled by the RFMT register, and it reports the McASP status and error conditions in the RSTAT register. Similarly, the transmit state machine is controlled by the XFMT register, and it reports the McASP status and error conditions in the XSTAT register.

26.2.3.4 TDM Sequencer

There are separate TDM sequencers for the transmit section and the receive section. Each TDM sequencer keeps track of the slot count. In addition, the TDM sequencer checks the bits of (R/X)TDM and determines if the McASP should receive/transmit in that time slot.

If the McASP should participate (transmit/receive bit is active) in the time slot, the McASP functions normally. If the McASP should not participate (transmit/receive bit is inactive) in the time slot, no transfers between the XRBUF and XRSR registers in the serializer would occur during that time slot. In addition, the serializers programmed as transmitters place their data output pins in a predetermined state (logic low, high, or high impedance) as programmed by each serializer control register (SRCTL). Refer also to Section 26.2.4.2.2 for details on how DMA event or interrupt generations are handled during inactive time slots in TDM mode.

The receive TDM sequencer is controlled by register RTDM and reports current receive slot to RSLOT. The transmit TDM sequencer is controlled by register XTDM and reports current transmit slot to XSLOT.

26.2.3.5 Clock Check Circuit

A common source of error in audio systems is a serial clock failure due to instabilities in the off-chip DIR circuit. To detect a clock error quickly, a clock-check circuit is included in the McASP for both transmit and receive clocks, since both may be sourced from off chip.

The clock check circuit can detect and recover from transmit and receive clock failures. See Section 26.2.4.7.6 for implementation and programming details.

26.2.3.6 Pin Function Control

All McASP pins except AMUTEIN are bidirectional input/output pins. In addition, these bidirectional pins function either as McASP or general-purpose I/O (GPIO) pins. The following registers control the pin functions:

- Pin function register (PFUNC): selects pin to function as McASP or GPIO
- Pin direction register (PDIR): selects pin to be input or output
- Pin data input register (PDIN): shows data input at the pin
- Pin data output register (PDOUT): data to be output at the pin if the pin is configured as GPIO output (PFUNC[n] = 1 and PDIR[n] = 1). Not applicable when the pin is configured as McASP pin (PFUNC[n] = 0).
- Pin data set register (PDSET): alias of PDOUT. Writing a 1 to PDSET[n] sets the respective PDOUT[n] to 1. Writing a 0 has no effect. Applicable only when the pin is configured as GPIO output (PFUNC[n] = 1 and PDIR[n] = 1).
- Pin data clear register (PDCLR): alias of PDOUT. Writing a 1 to PDCLR[n] clears the respective PDOUT[n] to 0. Writing a 0 has no effect. Applicable only when the pin is configured as GPIO output (PFUNC[n] = 1 and PDIR[n] = 1).

See the register descriptions in Section 26.3 for details on the mapping of each McASP pin to the register bits. Figure 26-21 shows the pin control block diagram.

26.2.3.6.1 McASP Pin Control-Transmit and Receive

You must correctly set the McASP GPIO registers PFUNC and PDIR, even when McASP pins are used for their serial port (non-GPIO) function.

Serial port functions include:

- Clock pins (ACLKX, ACLKR, AHCLKX, AHCLKR, AFSX, AFSR) used as clock inputs and outputs
- Serializer data pins (AXR[n]) used to transmit or receive
- AMUTE used as a mute output signal

When using these pins in their serial port function, you must clear PFUNC[n] to 0 for each pin, as opposed to PFUNC[n] = 1, which makes the pin a GPIO.

Also, certain outputs require PDIR[n] = 1, such as clock pins used as clock outputs, serializer data pins used to transmit, and AMUTE used as mute output.

Clock inputs and serializers configured to receive must have PDIR[n] = 0.

PFUNC and PDIR do not control the AMUTEIN device pin, it is usually tied to a device pin (see your device-specific data manual). If used as a mute input, this pin needs to be configured as an input in the appropriate peripheral.

Finally, there is an important advantage to having separate control of pin direction (by PDIR), and the choice of internal versus external clocking (by CLKRM/CLKXM). Depending on the specific device and usage, you might select an external clock (CLKRM = 0), while enabling the internal clock divider, and the clock pin as an output in the PDIR register (PDIR[ACLKR] = 1). In this case, the bit clock is an output (PDIR[ACLKR] = 1) and, therefore, routed to the ACLKR pin. However, because CLKRM = 0, the bit clock is then routed back to the McASP module as an "external" clock source. This may result in less skew between the clock inside the McASP and the clock in the external device, thus producing more balanced setup and hold times for a particular system. As a result, this may allow a higher serial clock rate interface.

26.2.3.6.2 GPIO Pin Control

For GPIO operation, you must set the desired PFUNC[n] to 1 to indicate GPIO function. PDIR[n] must be configured to the desired direction. PDOUT, PDSET, PDCLR control the output value on the pin. PDIN always reflects the state at the pin, regardless of the PDIR and PFUNC setting.

Figure 26-21 and Figure 26-22 display the pin descriptions. The examples that follow (Example 26-1 through Example 26-4) show how the pins can be used as general-purpose input or output pins.

Figure 26-21. McASP I/O Pin Control Block Diagram

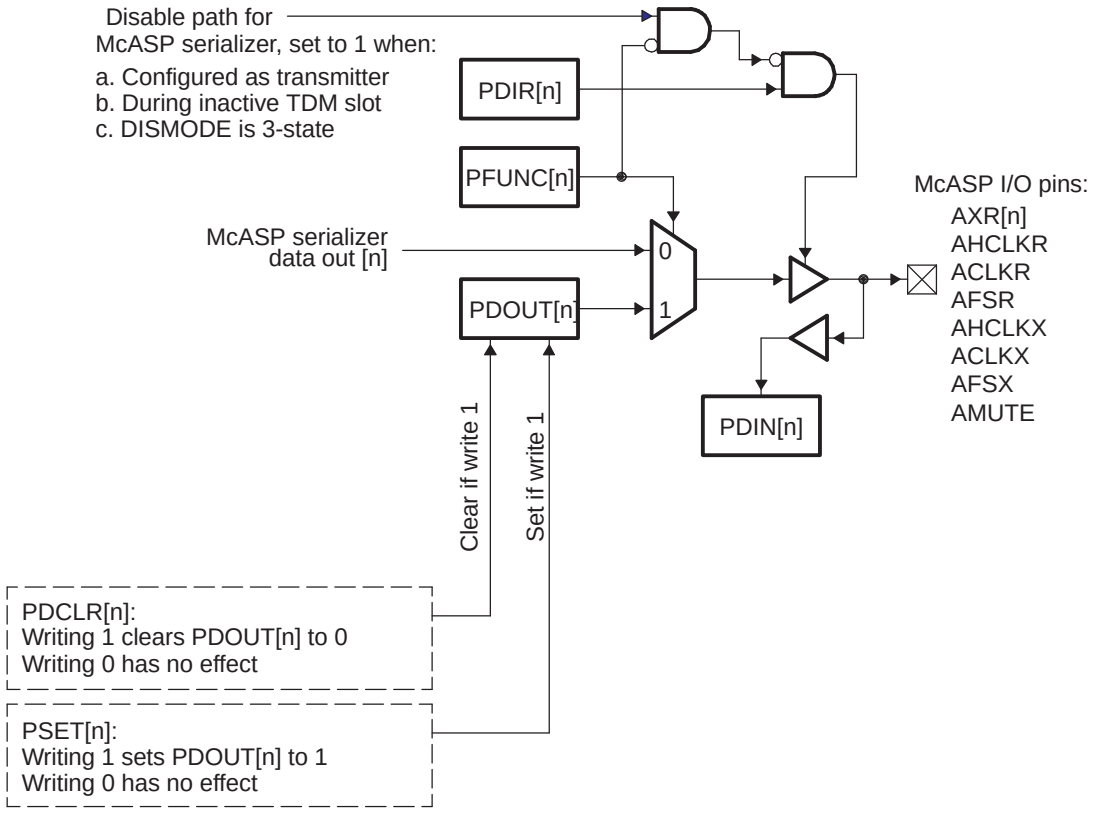


Figure 26-22. McASP I/O Pin to Control Register Mapping

31	30	29	28	27	26	25	24
AFSR	AHCLKR	ACLKR	AFSX	AHCLKX	ACLKX	AMUTE	Reserved
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R-0

23	16
Reserved	
R-0	

15	14	13	12	11	10	9	8
AXR15	AXR14	AXR13	AXR12	AXR11	AXR10	AXR9	AXR8
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

7	6	5	4	3	2	1	0
AXR7	AXR6	AXR5	AXR4	AXR3	AXR2	AXR1	AXR0
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Example 26-1. General-Purpose Input Pin

Because the PDIN register always reflects the state at the pin, you can read the PDIN register to obtain the pin input state. To explicitly set the pin as a general-purpose input pin, you can set the registers as follows:

- PDIR[n] = 0 (input)
- PFUNC[n] = 1 (GPIO function)

Example 26-2. General-Purpose Output Pin—Initialization Using PDOUT

All pins default as inputs. To initialize a pin as output, you should follow this sequence:

1. PDIR[n] = 0 (default as input)
2. PFUNC[n] = 1 (GPIO function)
3. PDOUT[n] = desired output value
4. PDIR[n] = 1 (change to output after desired value is configured in PDOUT[n])

Example 26-3. General-Purpose Output Pin—Change Data from 0 to 1 Using PDSET

If the pin is already configured as a general-purpose output pin driving a 0, and you want to change the output from 0 to 1, the recommended method is to use the PDSET register instead of the PDOUT register. This is because writing to the PDSET register only affects pin(s) in concern. To change a pin from 0 to 1:

- Set PDSET[n]. This sets the respective PDOUT[n].

Example 26-4. General-Purpose Output Pin—Change Data from 1 to 0 Using PDCLR

If the pin is already configured as a general-purpose output pin driving a 1, and you want to change the output from 1 to 0, the recommended method is to use the PDCLR register instead of the PDOUT register. This is because writing to the PDCLR register only affects pin(s) in concern. To change a pin from 1 to 0:

- Set PDCLR[n]. This clears the respective PDOUT[n].

26.2.3.7 McASP Audio FIFO (AFIFO)

The McASP Audio FIFO (AFIFO) provides additional data buffering for the McASP. The time it takes the host CPU or DMA controller to respond to DMA requests from the McASP may vary; the additional buffering provided by the AFIFO allows greater tolerance to such variations.

For convenience, the AFIFO is treated here as a block between McASP and the host/DMA controller (see Figure 26-1). Details on configuration of the AFIFO are provided in Section 26.2.4.4.

26.2.4 Operation

This section discusses the operation of the McASP.

26.2.4.1 Setup and Initialization

This section discusses steps necessary to use the McASP module.

26.2.4.1.1 Considerations When Using a McASP

The following is a list of things to be considered for systems using a McASP:

26.2.4.1.1.1 Clocks

For each receive and transmit section:

- External or internal generated bit clock and high frequency clock?
- If internally generated, what is the bit clock speed and the high frequency clock speed?
- Clock polarity?
- External or internal generated frame sync?
- If internally generated, what is frame sync speed?
- Frame sync polarity?
- Frame sync width?
- Transmit and receive sync or asynchronous?

26.2.4.1.1.2 Data Pins

For each pin of each McASP:

- McASP or GPIO?
- Input or output?

26.2.4.1.1.3 Data Format

For each transmit and receive data:

- Internal numeric representation (integer, Q31 fraction)?
- I2S or DIT (transmit only)?
- Time slot delay (0, 1, or 2 bit)?
- Alignment (left or right)?
- Order (MSB first, LSB first)?
- Pad (if yes, pad with what value)?
- Slot size?
- Rotate?
- Mask?

26.2.4.1.1.4 Data Transfers

- Internal: DMA or CPU?
- External: TDM or burst?
- Bus: peripheral configuration bus or DMA bus?

26.2.4.1.2 Transmit/Receive Section Initialization

You must follow the following steps to properly configure the McASP. If external clocks are used, they should be present prior to the following initialization steps.

1. Reset McASP to default values by setting GBLCTL = 0.
2. Configure McASP Audio FIFO. Recall that the Write FIFO and Read FIFO are enabled/disabled independently.
   (a) Write FIFO:
   - If the Write FIFO will not be enabled, verify that WFIFOCTL.WENA is cleared to 0 (the default value).
   - If the Write FIFO will be enabled, configure WFIFOCTL. Note that WFIFOCTL.WENA should not be set to 1 (enabled) until the other bitfields in this register are configured.

   (b) Read FIFO:
   - If the Read FIFO will not be enabled, verify that RFIFOCTL.RENA is cleared to 0 (the default value).
   - If the Read FIFO will be enabled, configure RFIFOCTL. Note that RFIFOCTL.RENA should not be set to 1 (enabled) until the other bitfields in this register are configured.
3. Configure all McASP registers except GBLCTL in the following order:
   (a) Receive registers: RMASK, RFMT, AFSRCTL, ACLKRCTL, AHCLKRCTL, RTDM, RINTCTL, RCLKCHK. If external clocks AHCLKR and/or ACLKR are used, they must be running already for proper synchronization of the GBLCTL register.
   (b) Transmit registers: XMASK, XFMT, AFSXCTL, ACLKXCTL, AHCLKXCTL, XTDM, XINTCTL, XCLKCHK. If external clocks AHCLKX and/or ACLKX are used, they must be running already for proper synchronization of the GBLCTL register.
   (c) Serializer registers: SRCTL[n].
   (d) Global registers: Registers PFUNC, PDIR, DITCTL, DLBCTL, AMUTE. Note that PDIR should only be programmed after the clocks and frames are set up in the steps above. This is because the moment a clock pin is configured as an output in PDIR, the clock pin starts toggling at the rate defined in the corresponding clock control register. Therefore you must ensure that the clock control register is configured appropriately before you set the pin to be an output. A similar argument applies to the frame sync pins.
   (e) DIT registers: For DIT mode operation, set up registers DITCSRA[n], DITCSRB[n], DITUDRA[n], and DITUDRB[n].
4. Start the respective high-frequency serial clocks AHCLKX and/or AHCLKR. This step is necessary even if external high-frequency serial clocks are used:
   (a) Take the respective internal high-frequency serial clock divider(s) out of reset by setting the RHCLKRST bit for the receiver and/or the XHCLKRST bit for the transmitter in GBLCTL. All other bits in GBLCTL should be held at 0.
   (b) Read back from GBLCTL to ensure the bit(s) to which you wrote are successfully latched in GBLCTL before you proceed.

5. Start the respective serial clocks ACLKX and/or ACLKR. This step can be skipped if external serial clocks are used and they are running:
   (a) Take the respective internal serial clock divider(s) out of reset by setting the RCLKRST bit for the receiver and/or the XCLKRST bit for the transmitter in GBLCTL. All other bits in GBLCTL should be left at the previous state.
   (b) Read back from GBLCTL to ensure the bit(s) to which you wrote are successfully latched in GBLCTL before you proceed.
6. Setup data acquisition as required:
   (a) If DMA is used to service the McASP, set up data acquisition as desired and start the DMA in this step, before the McASP is taken out of reset.
   (b) If CPU interrupt is used to service the McASP, enable the transmit and/ or receive interrupt as required.
   (c) If CPU polling is used to service the McASP, no action is required in this step.
7. Activate serializers.
   (a) Before starting, clear the respective transmitter and receiver status registers by writing XSTAT = FFFFh and RSTAT = FFFFh.
   (b) Take the respective serializers out of reset by setting the RSRCLR bit for the receiver and/or the XSRCLR bit for the transmitter in GBLCTL. All other bits in GBLCTL should be left at the previous state.
   (c) Read back from GBLCTL to ensure the bit(s) to which you wrote are successfully latched in GBLCTL before you proceed.
8. Verify that all transmit buffers are serviced. Skip this step if the transmitter is not used. Also, skip this step if time slot 0 is selected as inactive (special cases, see Figure 26-24, second waveform). As soon as the transmit serializer is taken out of reset, XDATA in the XSTAT register is set, indicating that XBUF is empty and ready to be serviced. The XDATA status causes a DMA event AXEVT to be generated, and can cause an interrupt AXINT to be generated if it is enabled in the XINTCTL register.
   (a) If DMA is used to service the McASP, the DMA automatically services the McASP upon receiving AXEVT. Before proceeding in this step, you should verify that the XDATA bit in the XSTAT is cleared to 0, indicating that all transmit buffers are already serviced by the DMA.
   (b) If CPU interrupt is used to service the McASP, interrupt service routine is entered upon the AXINT interrupt. The interrupt service routine should service the XBUF registers. Before proceeding in this step, you should verify that the XDATA bit in XSTAT is cleared to 0, indicating that all transmit buffers are already serviced by the CPU.
   (c) If CPU polling is used to service the McASP, the XBUF registers should be written to in this step.

CAUTION

The DSP does not support the emulation suspend signal. Therefore, if a data window is open in the Code Composer Studio™ integrated development environment to observe the XRBUF locations, the emulation read from the XRBUF locations causes an undesirable side effect of clearing the RDATA bit in RSTAT. Furthermore, if you write to the XRBUF through the Code Composer Studio™ integrated development environment, the emulation write to the XRBUF locations causes the XDATA bit in XSTAT to be cleared.

9. Release state machines from reset.
   (a) Take the respective state machine(s) out of reset by setting the RSMRST bit for the receiver and/or the XSMRST bit for the transmitter in GBLCTL. All other bits in GBLCTL should be left at the previous state.
   (b) Read back from GBLCTL to ensure the bit(s) to which you wrote are successfully latched in GBLCTL before you proceed.

10. Release frame sync generators from reset. Note that it is necessary to release the internal frame sync generators from reset, even if an external frame sync is being used, because the frame sync error detection logic is built into the frame sync generator.
    (a) Take the respective frame sync generator(s) out of reset by setting the RFRST bit for the receiver, and/or the XFRST bit for the transmitter in GBLCTL. All other bits in GBLCTL should be left at the previous state.
    (b) Read back from GBLCTL to ensure the bit(s) to which you wrote are successfully latched in GBLCTL before you proceed.
11. Upon the first frame sync signal, McASP transfers begin. The McASP synchronizes to an edge on the frame sync pin, not the level on the frame sync pin. This makes it easy to release the state machine and frame sync generators from reset.
    (a) For example, if you configure the McASP for a rising edge transmit frame sync, then you do not need to wait for a low level on the frame sync pin before releasing the McASP transmitter state machine and frame sync generators from reset.

26.2.4.1.3 Separate Transmit and Receive Initialization

In many cases, it is desirable to separately initialize the McASP transmitter and receiver. For example, you may delay the initialization of the transmitter until the type of data coming in on the receiver is recognized. Or a change in the incoming data stream on the receiver may necessitate a reinitialization of the transmitter.

In this case, you may still follow the sequence outlined in Section 26.2.4.1.2, but use it for each section (transmit, receive) individually. The GBLCTL register is aliased to RGBLCTL and XGBLCTL to facilitate separate initialization of transmit and receive sections.

Also, make sure that the initialization or reinitialization sequence follows the guidelines in Table 26-10.

26.2.4.1.4 Importance of Reading Back GBLCTL

In Section 26.2.4.1.2, steps 4b, 5b, 7c, 9b, and 10b state that GBLCTL should be read back until the bits that were written are successfully latched. This is important, because the transmitter and receiver state machines run off of the respective bit clocks, which are typically about tens to hundreds of times slower than the DSP's internal bus clock. Therefore, it takes many cycles between when the DSP writes to GBLCTL (or RGBLCTL and XGBLCTL), and when the McASP actually recognizes the write operation. If you skip this step, then the McASP may never see the reset bits in the global control registers get asserted and deasserted; resulting in an uninitialized McASP.

Therefore, the logic in McASP has been implemented such that once the DSP writes GBLCTL, RGBLCTL, or XGBLCTL, the resulting write is not visible by reading back GBLCTL until the McASP has recognized the change. This typically requires two bit clocks plus two DSP bus clocks to occur.

Also, if the bit clocks can be completely stopped, any software that polls GBLCTL should be implemented with a time-out. If GBLCTL does not have a time-out, and the bit clock stops, the changes written to GBLCTL will not be reflected until the bit clock restarts.

Finally, please note that while RGBLCTL and XGBLCTL allow separate changing of the receive and transmit halves of GBLCTL, they also immediately reflect the updated value (useful for debug purposes). Only GBLCTL can be used for the read back step.

26.2.4.1.5 Synchronous Transmit and Receive Operation (ASYNC = 0)

When ASYNC = 0 in ACLKXCTL, the transmit and receive sections operate synchronously from the transmit section clock and transmit frame sync signals (Figure 26-15). The receive section may have a different (but compatible in terms of slot size) data format. Note that when ASYNC = 0, XCLK is automatically inverted to produce RCLK (note the inversion on the ASYNC multiplexer as shown in Figure 26-16).

When ASYNC = 0, the transmit and receive sections must share some common settings, since they both use the same clock and frame sync signals:

- DITEN = 0 in DITCTL (TDM mode is enabled)
- The total number of bits per frame must be the same (that is, RSSZ × RMOD must equal XSSZ × XMOD)
- Both transmit and receive should either be specified as burst or TDM mode, but not mixed
- The settings in ACLKRCTL are irrelevant
- RCLK is an inverted version of XCLK (note the inversion on the multiplexer labeled “ASYNC” shown in Figure 26-16)
- FSXM must match FSRM
- FXWID must match FRWID

For all other settings, the transmit and receive sections may be programmed independently.

26.2.4.1.6 Asynchronous Transmit and Receive Operation (ASYNC = 1)

When ASYNC = 1 in ACLKXCTL, the transmit and receive sections operate completely independently and have separate clock and frame sync signals (Figure 26-15, Figure 26-16, and Figure 26-17). The events generated by each section come asynchronously.

26.2.4.2 Transfer Modes

26.2.4.2.1 Burst Transfer Mode

The McASP supports a burst transfer mode, which is useful for nonaudio data such as passing control information between two DSPs. Burst transfer mode uses a synchronous serial format similar to the TDM mode. The frame sync generation is not periodic or time-driven as in TDM mode, but data driven, and the frame sync is generated for each data word transferred.

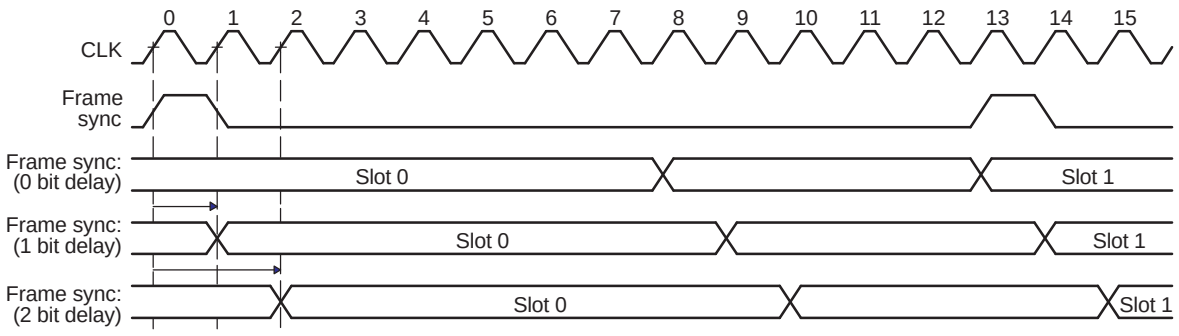
When operating in burst frame sync mode (Figure 26-23), as specified for transmit (XMOD = 0 in AFSXCTL) and receive (RMOD = 0 in AFSRCTL), one slot is shifted for each active edge of the frame sync signal that is recognized. Additional clocks after the slot and before the next frame sync edge are ignored.

In burst frame sync mode, the frame sync delay may be specified as 0, 1, or 2 serial clock cycles. This is the delay between the frame sync active edge and the start of the slot. The frame sync signal lasts for a single bit clock duration (FRWID = 0 in AFSRCTL, FXWID = 0 in AFSXCTL).

For transmit, when generating the transmit frame sync internally, the frame sync begins when the previous transmission has completed and when all the XBUF*n* (for every serializer set to operate as a transmitter) has been updated with new data.

For receive, when generating the receive frame sync internally, frame sync begins when the previous transmission has completed and when all the RBUF*n* (for every serializer set to operate as a receiver) has been read.

Figure 26-23. Burst Frame Sync Mode



The control registers must be configured as follows for the burst transfer mode. The burst mode specific bit fields are in bold face:

- PFUNC: The clock, frame, data pins must be configured for McASP function.
- PDIR: The clock, frame, data pins must be configured to the direction desired.
- PDOUT, PDIN, PDSET, PDCLR: Not applicable. Leave at default.
- GBLCTL: Follow the initialization sequence in Section 26.2.4.1.2 to configure this register.
- AMUTE: Not applicable. Leave at default.
- DLBCTL: If loopback mode is desired, configure this register according to Section 26.2.4.8, otherwise leave this register at default.
- DITCTL: DITEN must be left at default 0 to select non-DIT mode. Leave the register at default.
- RMASK/XMASK: Mask desired bits according to Section 26.2.3.2 and Section 26.2.4.5.
- RFMT/XFMT: Program all fields according to data format desired. See Section 26.2.4.5.
- AFSRCTL/AFSXCTL: Clear **RMOD/XMOD** bits to 0 to indicate burst mode. Clear **FRWID/FXWID** bits to 0 for single bit frame sync duration. Configure other fields as desired.
- ACLKRCTL/ACLKXCTL: Program all fields according to bit clock desired. See Section 26.2.2.
- AHCLKRCTL/AHCLKXCTL: Program all fields according to high-frequency clock desired. See Section 26.2.2.
- RTDM/XTDM: Program RTDMS0/XTDMS0 to 1 to indicate one active slot only. Leave other fields at default.
- RINTCTL/XINTCTL: Program all fields according to interrupts desired.
- RCLKCHK/XCLKCHK: Not applicable. Leave at default.
- SRCTLn: Program SRMOD to inactive/transmitter/receiver as desired. DISMOD is not applicable and should be left at default.
- DITCSRA[n], DITCSRB[n], DITUDRA[n], DITUDRB[n]: Not applicable. Leave at default.

26.2.4.2.2 Time-Division Multiplexed (TDM) Transfer Mode

The McASP time-division multiplexed (TDM) transfer mode supports the TDM format discussed in Section 26.1.5.1.

Transmitting data in the TDM transfer mode requires a minimum set of pins:

- ACLKX - transmit bit clock
- AFSX - transmit frame sync (or commonly called left/right clock)
- One or more serial data pins, AXR[n], whose serializers have been configured to transmit

The transmitter has the option to receive the ACLKX bit clock as an input, or to generate the ACLKX bit clock by dividing down the AHCLKX high-frequency master clock. The transmitter can either generate AHCLKX internally or receive AHCLKX as an input. See Section 26.2.2.1.

Similarly, to receive data in the TDM transfer mode requires a minimum set of pins:

- ACLKR - receive bit clock
- AFSR - receive frame sync (or commonly called left/right clock)
- One or more serial data pins, AXR[n], whose serializers have been configured to receive

The receiver has the option to receive the ACLKR bit clock as an input or to generate the ACLKR bit clock by dividing down the AHCLKR high-frequency master clock. The receiver can either generate AHCLKR internally or receive AHCLKR as an input. See Section 26.2.2.2 and Section 26.2.2.3.

The control registers must be configured as follows for the TDM mode. The TDM mode specific bit fields are in bold face:

- PFUNC: The clock, frame, data pins must be configured for McASP function.
- PDIR: The clock, frame, data pins must be configured to the direction desired.
- PDOUT, PDIN, PDSET, PDCLR: Not applicable. Leave at default.
- GBLCTL: Follow the initialization sequence in Section 26.2.4.1.2 to configure this register.
- AMUTE: Program all fields according to mute control desired.
- DLBCTL: If loopback mode is desired, configure this register according to Section 26.2.4.8, otherwise leave this register at default.
- DITCTL: DITEN must be left at default 0 to select TDM mode. Leave the register at default.
- RMASK/XMASK: Mask desired bits according to Section 26.2.3.2 and Section 26.2.4.5.
- RFMT/XFMT: Program all fields according to data format desired. See Section 26.2.4.5.
- AFSRCTL/AFSXCTL: Set **RMOD/XMOD** bits to 2-32 for TDM mode. Configure other fields as desired.
- ACLKRCTL/ACLKXCTL: Program all fields according to bit clock desired. See Section 26.2.2.
- AHCLKRCTL/AHCLKXCTL: Program all fields according to high-frequency clock desired. See Section 26.2.2.
- RTDM/XTDM: Program all fields according to the time slot characteristics desired.
- RINTCTL/XINTCTL: Program all fields according to interrupts desired.
- RCLKCHK/XCLKCHK: Program all fields according to clock checking desired.
- SRCTLn: Program all fields according to serializer operation desired.
- DITCSRA[n], DITCSRB[n], DITUDRA[n], DITUDRB[n]: Not applicable. Leave at default.

26.2.4.2.2.1 TDM Time Slots

TDM mode on the McASP can extend to support multiprocessor applications, with up to 32 time slots per frame. For each of the time slots, the McASP may be configured to participate or to be inactive by configuring XTDM and/or RTDM (this allows multiple DSPs to communicate on the same TDM serial bus).

The TDM sequencer (separate ones for transmit and receive) functions in this mode. The TDM sequencer counts the slots beginning with the frame sync. For each slot, the TDM sequencer checks the respective bit in either XTDM or RTDM to determine if the McASP should transmit/receive in that time slot.

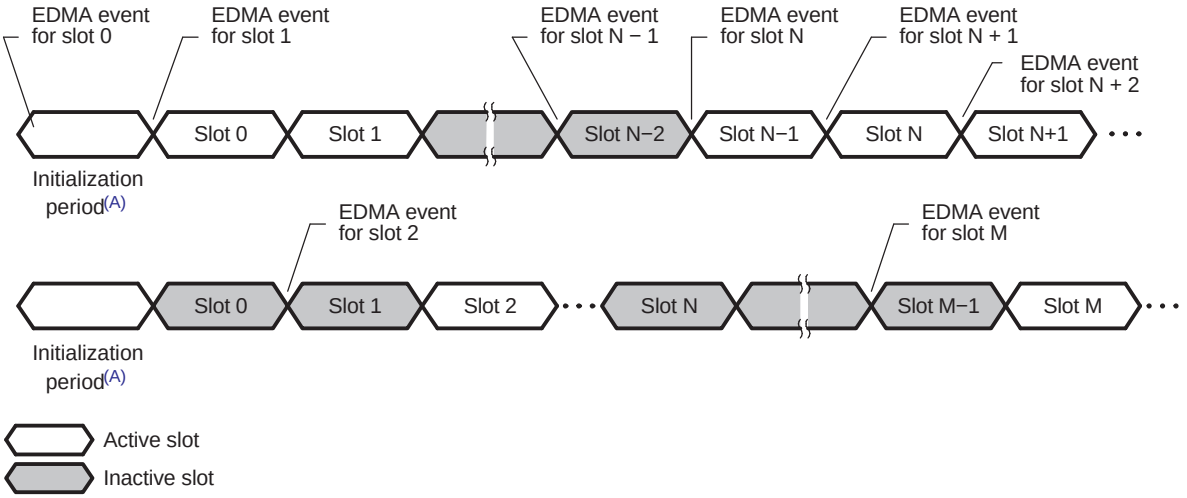
If the transmit/receive bit is active, the McASP functions normally during that time slot; otherwise, the McASP is inactive during that time slot; no update to the buffer occurs, and no event is generated. Transmit pins are automatically set to a high-impedance state, 0, or 1 during that slot, as determined by bit DISMOD in SRCTL[n].

Figure 26-24 shows when the transmit DMA event AXEVT is generated. See Section 26.2.4.3.1 for details on data ready and the initialization period indication. The transmit DMA event for an active time slot (slot N) is generated during the previous time slot (slot N - 1), regardless if the previous time slot (slot N - 1) is active or inactive.

During an active transmit time slot (slot N), if the next time slot (slot N + 1) is configured to be active, the copy from XRBUF[n] to XRSR[n] generates the DMA event for time slot N + 1. If the next time slot (slot N + 1) is configured to be inactive, then the DMA event will be delayed to time slot M - 1. In this case, slot M is the next active time slot. The DMA event for time slot M is generated during the first bit time of slot M - 1.

The receive DMA request generation does not need this capability, since the receive DMA event is generated after data is received in the buffer (looks back in time). If a time slot is disabled, then no data is copied to the buffer for that time slot and no DMA event is generated.

Figure 26-24. Transmit DMA Event (AXEVT) Generation in TDM Time Slots



A See Section 26.2.4.1.2, step 7a.

26.2.4.2.2.2 Special 384 Slot TDM Mode for Connection to External DIR

The McASP receiver also supports a 384 time slot TDM mode (DIR mode), to support S/PDIF, AES-3, IEC-60958 receiver ICs whose natural block (block corresponds to McASP frame) size is 384 samples. The advantage to using the 384 time slot TDM mode is that interrupts may be generated synchronous to the S/PDIF, AES-3, IEC-60958, such as the last slot interrupt.

The receive TDM time slot register (RTDM) should be programmed to all 1s during reception of a DIR block. Other TDM functionalities (for example, inactive slots) are not supported (only the slot counter counts the 384 subframes in a block).

To receive data in the DIR mode, the following pins are typically needed:

- ACLKR - receive bit clock.
- AFSR - receive frame sync (or commonly called left/right clock). In this mode, AFSR should be connected to a DIR which outputs a start of block signal, instead of LRCLK.
- One or more serial data pins, AXR[n], whose serializers have been configured to receive.

For this special DIR mode, the control registers can be configured just as for TDM mode, except set RMOD in AFSRCTL to 384 to receive 384 time slots.

26.2.4.2.3 Digital Audio Interface Transmit (DIT) Transfer Mode

In addition to the TDM and burst transfer modes, which are suitable for transmitting audio data between ICs inside the same system, the digital audio interface transmit (DIT) transfer mode of the McASP also supports transmission of audio data in the S/PDIF, AES-3, or IEC-60958 format. These formats are designed to carry audio data between different systems through an optical or coaxial cable. The DIT mode only applies to serializers configured as transmitters, not receivers. Refer to Section 26.1.5.2 for a description of the S/PDIF format.

26.2.4.2.3.1 Transmit DIT Encoding

The McASP operation in DIT mode is basically identical to the 2 time slot TDM mode, but the data transmitted is output as a biphase mark encoded bit stream, with preamble, channel status, user data, validity, and parity automatically stuffed into the bit stream by the McASP. The McASP includes separate validity bits for even/odd subframes and two 384-bit RAM modules to hold channel status and user data bits.

The transmit TDM time slot register (XTDM) should be programmed to all 1s during DIT mode. TDM functionality is not supported in DIT mode, except that the TDM slot counter counts the DIT subframes.

To transmit data in the DIT mode, the following pins are typically needed:

- AHCLKX - transmit high-frequency master clock
- One or more serial data pins, AXR[n], whose serializers have been configured to transmit

AHCLKX is optional (the internal clock source may be used instead), but if used as a reference, the DSP provides a clock check circuit that continually monitors the AHCLKX input for stability.

If the McASP is configured to transmit in the DIT mode on more than one serial data pin, the bit streams on all pins will be synchronized. In addition, although they will carry unique audio data, they will carry the same channel status, user data, and validity information.

The actual 24-bit audio data must always be in bit positions 23-0 after passing through the first three stages of the transmit format unit.

For left-aligned Q31 data, the following transmit format unit settings process the data into right aligned 24-bit audio data ready for transmission:

- XROT = 010 (rotate right by 8 bits)
- XRVRS = 0 (no bit reversal, LSB first)
- XMASK = FFFF FF00h-FFFF 0000h (depending upon whether 24, 23, 22, 21, 20, 19, 18, 17, or 16 valid audio data bits are present)
- XPAD = 00 (pad extra bits with 0)

For right-aligned data, the following transmit format unit settings process the data into right aligned 24-bit audio data ready for transmission:

- XROT = 000 (rotate right by 0 bits)
- XRVRS = 0 (no bit reversal, LSB first)
- XMASK = 00FF FFFFh to 0000 FFFFh (depending upon whether 24, 23, 22, 21, 20, 19, 18, 17, or 16 valid audio data bits are present)
- XPAD = 00 (pad extra bits with 0)

26.2.4.2.3.2 Transmit DIT Clock and Frame Sync Generation

The DIT transmitter only works in the following configuration:

- In transmit frame control register (AFSXCTL):
  - Internally-generated transmit frame sync, FSXM = 1
  - Rising-edge frame sync, FSXP = 0
  - Bit-width frame sync, FXWID = 0
  - 384-slot TDM, XMOD = 1 1000 0000b
- In transmit clock control register (ACLKXCTL), ASYNC = 1
- In transmit bitstream format register (XFMT), XSSZ = 1111 (32-bit slot size)

All combinations of AHCLKX and ACLKX are supported.

This is a summary of the register configurations required for DIT mode. The DIT mode specific bit fields are in bold face:

- PFUNC: The data pins must be configured for McASP function. If AHCLKX is used, it must also be configured for McASP function. Other pins can be configured to function as GPIO if desired.
- PDIR: The data pins must be configured as outputs. If AHCLKX is used as an input reference, it should be configured as input. If internal clock source AUXCLK is used as the reference clock, it may be output on the AHCLKX pin by configuring AHCLKX as an output.
- PDOUT, PDIN, PDSET, PDCLR: Not applicable for DIT operation. Leave at default.
- GBLCTL: Follow the initialization sequence in Section 26.2.4.1.2 to configure this register.
- AMUTE: Program all fields according to mute control desired.
- DLBCTL: Not applicable. Loopback is not supported for DIT mode. Leave at default.
- DITCTL: **DITEN** bit must be set to 1 to enable DIT mode. Configure other bits as desired.
- RMASK: Not applicable. Leave at default.
- RFMT: Not applicable. Leave at default.
- AFSRCTL: Not applicable. Leave at default.
- ACLKRCTL: Not applicable. Leave at default.
- AHCLKRCTL: Not applicable. Leave at default.
- RTDM: Not applicable. Leave at default.
- RINTCTL: Not applicable. Leave at default.
- RCLKCHK: Not applicable. Leave at default.
- **XMASK**: Mask desired bits according to the discussion in this section, depending upon left-aligned or right-aligned internal data.
- **XFMT: XDATDLY** = 0. **XRVRS** = 0. **XPAD** = 0. **XPBIT** = default (not applicable). **XSSZ** = Fh (32-bit slot). XBUSEL = configured as desired. **XROT** bit is configured according to the discussion in this section, either 0 or 8-bit rotate.
- **AFSXCTL**: Configure the bits according to the discussion in this section.
- **ACLKXCTL**: **ASYNC** = 1. Program CLKXDIV bits to obtain the bit clock rate desired. Configure CLKXP and CLKXM bits as desired, because CLKX is not actually used in the DIT protocol.
- **AHCLKXCTL**: Program all fields according to high-frequency clock desired.
- **XTDM**: Set to FFFF FFFFh for all active slots for DIT transfers.
- XINTCTL: Program all fields according to interrupts desired.
- XCLKCHK: Program all fields according to clock checking desired.
- SRCTLn: Set **SRMOD** = 1 (transmitter) for the DIT pins. DISMOD field is don't care for DIT mode.
- **DITCSRA[n], DITCSRB[n]**: Program the channel status bits as desired.
- **DITUDRA[n], DITUDRB[n]**: Program the user data bits as desired.

26.2.4.2.3.3 DIT Channel Status and User Data Register Files

The channel status registers (DITCSRA*n* and DITCSRB*n*) and user data registers (DITUDRA*n* and DITUDRB*n*) are not double buffered. Typically the programmer uses one of the synchronizing interrupts, such as last slot, to create an event at a safe time so the register may be updated. In addition, the CPU reads the transmit TDM slot counter to determine which word of the register is being used.

It is a requirement that the software avoid writing to the word of user data and channel status that are being used to encode the current time slot; otherwise, it will be indeterminate whether the old or new data is used to encode the bitstream.

The DIT subframe format is defined in Section 26.1.5.2.2. The channel status information (C) and user data (U) are defined in these DIT control registers:

- DITCSRA0 to DITCSRA5: The 192 bits in these six registers contain the channel status information for the LEFT channel within each frame.
- DITCSRB0 to DITCSRB5: The 192 bits in these six registers contain the channel status information for the RIGHT channel within each frame.
- DITUDRA0 to DITUDRA5: The 192 bits in these six registers contain the user data information for the LEFT channel within each frame.
- DITUDRB0 to DITUDRB5: The 192 bits in these six registers contain the user data information for the RIGHT channel within each frame.

The S/PDIF block format is shown in Figure 26-11. There are 192 frames within a block (frame 0 to frame 191). Within each frame there are two subframes (subframe 1 and 2 for left and right channels, respectively). The channel status and user data information sent on each subframe is summarized in Table 26-3.

26.2.4.3 Data Transmission and Reception

The DSP services the McASP by writing data to the XBUF register(s) for transmit operations, and by reading data from the RBUF register(s) for receive operations. The McASP sets status flag and notifies the DSP whenever data is ready to be serviced. Section 26.2.4.3.1 discusses data ready status in detail.

The XBUF and RBUF registers can be accessed through one of the two peripheral ports of the device:

- The DMA port: This port is dedicated for data transfers on the device.
- The peripheral configuration port: This port is used for both data transfers and peripheral configuration control on the device.

Section 26.2.4.3.2 and Section 26.2.4.3.3 discuss how to perform transfers through the DMA bus and the peripheral configuration bus.

Either the CPU or the DMA can be used to service the McASP through any of these two peripheral ports. The CPU and DMA usages are discussed in Section 26.2.4.3.4 and Section 26.2.4.3.5.

Table 26-3. Channel Status and User Data for Each DIT Block

Frame	Subframe	Preamble	Channel Status defined in:	User Data defined in:
Defined by DITCSRA0, DITCSRB0, DITUDRA0, DITUDRB0				
0	1 (L)	B	DITCSRA0[0]	DITUDRA0[0]
0	2 (R)	W	DITCSRB0[0]	DITUDRB0[0]
1	1 (L)	M	DITCSRA0[1]	DITUDRA0[1]
1	2 (R)	W	DITCSRB0[1]	DITUDRB0[1]
2	1 (L)	M	DITCSRA0[2]	DITUDRA0[2]
2	2 (R)	W	DITCSRB0[2]	DITUDRB0[2]
…	…	…	…	…
31	1 (L)	M	DITCSRA0[31]	DITUDRA0[31]
31	2 (R)	W	DITCSRB0[31]	DITUDRB0[31]
Defined by DITCSRA1, DITCSRB1, DITUDRA1, DITUDRB1				
32	1 (L)	M	DITCSRA1[0]	DITUDRA1[0]
32	2 (R)	W	DITCSRB1[0]	DITUDRB1[0]
…	…	…	…	…
63	1 (L)	M	DITCSRA1[31]	DITUDRA1[31]
63	2 (R)	W	DITCSRB1[31]	DITUDRB1[31]
Defined by DITCSRA2, DITCSRB2, DITUDRA2, DITUDRB2				
64	1 (L)	M	DITCSRA2[0]	DITUDRA2[0]
64	2 (R)	W	DITCSRB2[0]	DITUDRB2[0]
…	…	…	…	…
95	1 (L)	M	DITCSRA2[31]	DITUDRA2[31]
95	2 (R)	W	DITCSRB2[31]	DITUDRB2[31]
Defined by DITCSRA3, DITCSRB3, DITUDRA3, DITUDRB3				
96	1 (L)	M	DITCSRA3[0]	DITUDRA3[0]
96	2 (R)	W	DITCSRB3[0]	DITUDRB3[0]
…	…	…	…	…
127	1 (L)	M	DITCSRA3[31]	DITUDRA3[31]
127	2 (R)	W	DITCSRB3[31]	DITUDRB3[31]
Defined by DITCSRA4, DITCSRB4, DITUDRA4, DITUDRB4				
128	1 (L)	M	DITCSRA4[0]	DITUDRA4[0]
128	2 (R)	W	DITCSRB4[0]	DITUDRB4[0]
…	…	…	…	…
159	1 (L)	M	DITCSRA4[31]	DITUDRA4[31]
159	2 (R)	W	DITCSRB4[31]	DITUDRB4[31]
Defined by DITCSRA5, DITCSRB5, DITDRA5, DITUDRB5				
160	1 (L)	M	DITCSRA5[0]	DITUDRA5[0]
160	2 (R)	W	DITCSRB5[0]	DITUDRB5[0]
…	…	…	…	…
191	1 (L)	M	DITCSRA5[31]	DITUDRA5[31]
191	2 (R)	W	DITCSRB5[31]	DITUDRB5[31]

26.2.4.3.1 Data Ready Status and Event/Interrupt Generation

26.2.4.3.1.1 Transmit Data Ready

The transmit data ready flag XDATA bit in the XSTAT register reflects the status of the XBUF register. The XDATA flag is set when data is transferred from the XRBUF[n] buffers to the XRSR[n] shift registers, indicating that the XBUF is empty and ready to accept new data from the DSP. This flag is cleared when the XDATA bit is written with a 1, or when all the serializers configured as transmitters are written by the DSP.

Whenever XDATA is set, an DMA event AXEVT is automatically generated to notify the DMA of the XBUF empty status. An interrupt AXINT is also generated if XDATA interrupt is enabled in the XINTCTL register (See Section 26.2.4.6.1 for details).

For DMA requests, the McASP does not require XSTAT to be read between DMA events. This means that even if XSTAT already has the XDATA flag set to 1 from a previous request, the next transfer triggers another DMA request.

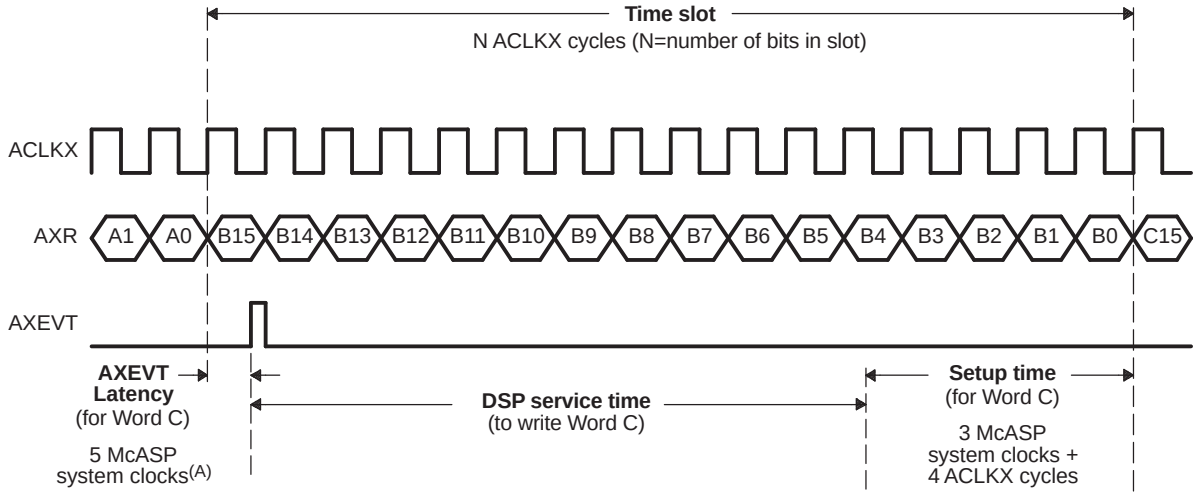
Since all serializers act in lockstep, only one DMA event is generated to indicate that all active transmit serializers are ready to be written to with new data.

Figure 26-25 shows the timing details of when AXEVT is generated at the McASP boundary. In this example, as soon as the last bit (bit A0) of Word A is transmitted, the McASP sets the XDATA flag and generates an AXEVT event. However, it takes up to 5 McASP system clocks (AXEVT Latency) before AXEVT is active at the McASP boundary. Upon AXEVT, the DSP can begin servicing the McASP by writing Word C into the XBUF (DSP Service Time). The DSP must write Word C into the XBUF no later than the setup time required by the McASP (Setup Time).

The maximum DSP Service Time (Figure 26-25) can be calculated as:

DSP Service Time = Time Slot - AXEVT Latency - Setup Time

Figure 26-25. DSP Service Time Upon Transmit DMA Event (AXEVT)



A This is not the same as AUXCLK. The DSP uses SYSCLK2 as the McASP system clock source.

26.2.4.3.1.2 Receive Data Ready

Similarly, the receive data ready flag RDATA bit in the RSTAT reflects the status of the RBUF register. The RDATA flag is set when data is transferred from the XRSR[n] shift registers to the XRBUF[n] buffers, indicating that the RBUF contains received data and is ready to have the DSP read the data. This flag is cleared when the RDATA bit is written with a 1, or when all the serializers configured as receivers are read.

Whenever RDATA is set, an DMA event AREVT is automatically generated to notify the DMA of the RBUF ready status. An interrupt ARINT is also generated if RDATA interrupt is enabled in the RINTCTL register (See Section 26.2.4.6.2 for details).

For DMA requests, the McASP does not require RSTAT to be read between DMA events. This means that even if RSTAT already has the RDATA flag set to 1 from a previous request, the next transfer triggers another DMA request.

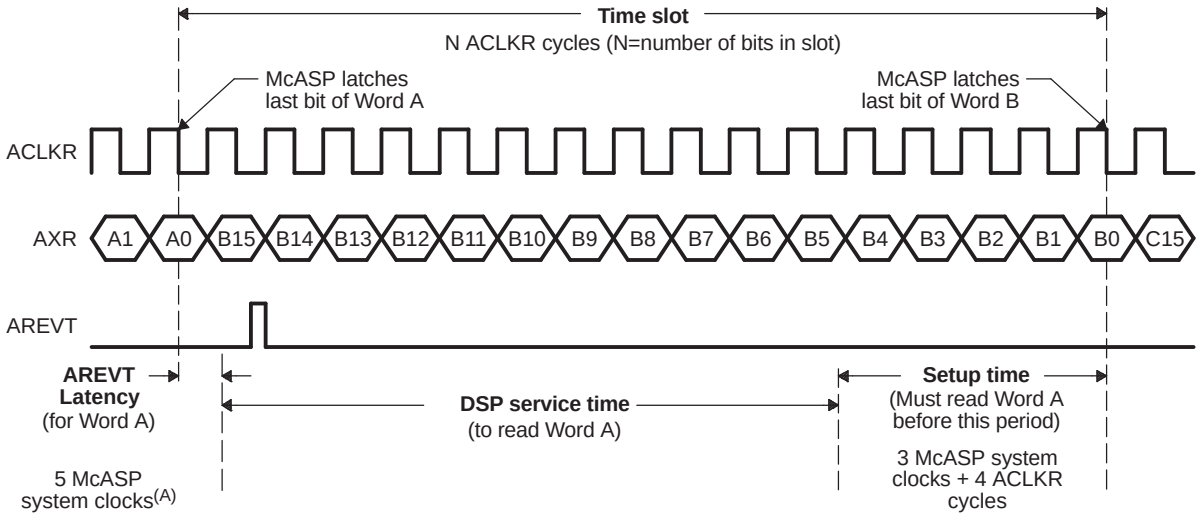
Since all serializers act in lockstep, only one DMA event is generated to indicate that all active receive serializers are ready to receive new data.

Figure 26-26 shows the timing details of when AREVT is generated at the McASP boundary. In this example, as soon as the last bit (bit A0) of Word A is received, the McASP sets the RDATA flag and generates an AREVT event. However, it takes up to 5 McASP system clocks (AREVT Latency) before AREVT is active at the McASP boundary. Upon AREVT, the DSP can begin servicing the McASP by reading Word A from the RBUF (DSP Service Time). The DSP must read Word A from the XBUF no later than the setup time required by the McASP (Setup Time).

The maximum DSP Service Time (Figure 26-26) can be calculated as:

DSP Service Time = Time Slot - AREVT Latency - Setup Time

Figure 26-26. DSP Service Time Upon Receive DMA Event (AREVT)



A This is not the same as AUXCLK. The DSP uses SYSCLK2 as the McASP system clock source.

26.2.4.3.2 Transfers through the DMA Port

CAUTION

To perform internal transfers through the DMA port, clear XBUSEL/RBUSEL bit to 0 in the respective XFMT/RFMT registers. Failure to do so will result in software malfunction.

Typically, you will access the McASP XRBUF registers through the DMA port. To access through the DMA port, simply have the CPU or DMA access the XRBUF through its DMA port location. See your device-specific data manual for the exact memory address. Through the DMA port, the DMA/CPU can service all the serializers through a single address. The McASP automatically cycles through the appropriate serializers.

For transmit operations through the DMA port, the DMA/CPU should write to the same XBUF DMA port address to service all of the active transmit serializers. In addition, the DMA/CPU should write to the XBUF for all active transmit serializers in incremental (although not necessarily consecutive) order. For example, if serializers 0, 4, 5, and 7 are set up as active transmitters, the DMA/CPU should write to the XBUF DMA port address four times with data for serializers 0, 4, 5, and 7 upon each transmit data ready event. This exact servicing order must be followed so that data appears in the appropriate serializers.

Similarly, for receive operations through the DMA port, the DMA/CPU should read from the same RBUF DMA port address to service all of the active receive serializers. In addition, reads from the active receive serializers through the DMA port return data in incremental (although not necessarily consecutive) order. For example, if serializers 1, 2, 3, and 6 are set up as active receivers, the DMA/CPU should read from the RBUF DMA port address four times to obtain data for serializers 1, 2, 3, and 6 in this exact order, upon each receive data ready event.

When transmitting, the DMA/CPU must write data to each serializer configured as "active" and "transmit" within each time slot. Failure to do so results in a buffer underrun condition (Section 26.2.4.7.2). Similarly, when receiving, data must be read from each serializer configured as "active" and "receive" within each time slot. Failure to do results in a buffer overrun condition (Section 26.2.4.7.3).

To perform internal transfers through the DMA port, clear XBUSEL/RBUSEL bit to 0 in the respective XFMT/RFMT registers.

26.2.4.3.3 Transfers Through the Peripheral Configuration Bus

CAUTION

The DSP does not support the emulation suspend signal. Therefore, if a data window is open in the Code Composer Studio™ integrated development environment to observe the XRBUF locations, the emulation read from the XRBUF locations causes an undesirable side effect of clearing the RDATA bit in RSTAT. Furthermore, if you write to the XRBUF through the Code Composer Studio™ integrated development environment, the emulation write to the XRBUF locations causes the XDATA bit in XSTAT to be cleared.

To perform internal transfers through the peripheral configuration bus, set XBUSEL/RBUSEL bit to 1 in the respective XFMT/RFMT registers. Failure to do so will result in software malfunction.

In this method, the DMA/CPU accesses the XRBUF through the peripheral configuration bus address. The exact XRBUF address for any particular serializer is determined by adding the offset for that particular serializer to the base address for the particular McASP (found in the device-specific data manual). XRBUF for the serializers configured as transmitters is given the name XBUF*n*. For example, the XRBUF associated with transmit serializer 2 is named XBUF2. Similarly, XRBUF for the serializers configured as receivers is given the name RBUF*n*.

Accessing the XRBUF through the DMA port is different because the CPU/DMA only needs to access one single address. When accessing through the peripheral configuration bus, the CPU/DMA must provide the exact XBUF*n* or RBUF*n* address for each access.

When transmitting, DMA/CPU must write data to each serializer configured as "active" and "transmit" within each time slot. Failure to do so results in a buffer underrun condition (Section 26.2.4.7.2). Similarly when receiving, data must be read from each serializer configured as "active" and "receive" within each time slot. Failure to do results in a buffer overrun condition (Section 26.2.4.7.3).

26.2.4.3.4 Using the CPU for McASP Servicing

The CPU can be used to service the McASP through interrupt (upon AXINT/ARINT interrupts) or through polling the XDATA bit in the XSTAT register. As discussed in Section 26.2.4.3.2 and Section 26.2.4.3.3, the CPU can access either through the DMA port or through the peripheral configuration port.

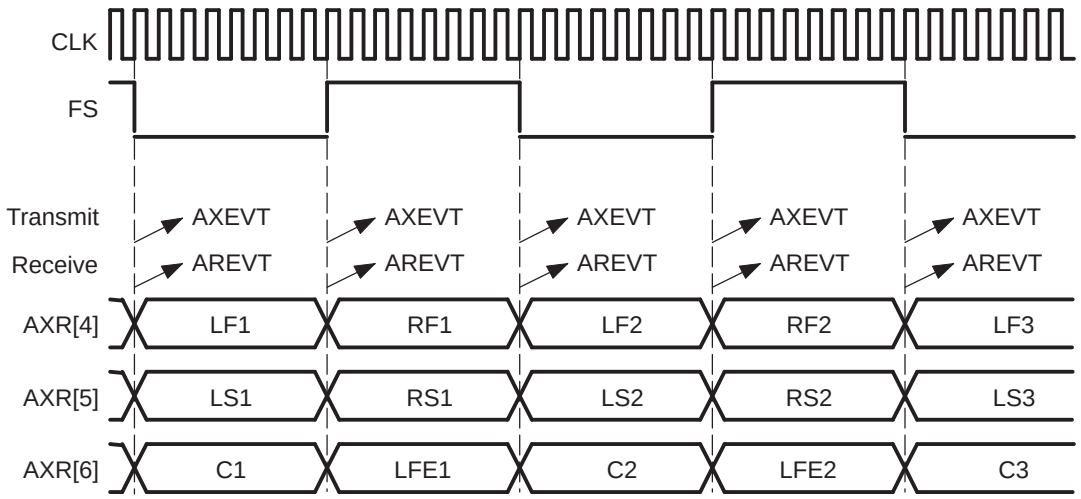
To use the CPU to service the McASP through interrupts, the XSTAT/RSTAT bit must be enabled in the respective XINTCTL/RINTCTL registers, to generate interrupts AXINT/ARINT to the CPU upon data ready.

26.2.4.3.5 Using the DMA for McASP Servicing

The most typical scenario is to use the DMA to service the McASP through the DMA port, although the DMA can also service the McASP through the peripheral configuration port. Use AXEVT/AREVT that is triggered upon each XDATA/RDATA transition from 0 to 1.

Figure 26-27 shows an example audio system with six audio channels (LF, RF, LS, RS, C, and LFE) transmitted from three AXR[n] pins on the McASP and shows when events AXEVT and AREVT are triggered.

Figure 26-27. DMA Events in an Audio Example–Two Events



In Figure 26-27, a DMA event AXEVT/AREVT is triggered on each time slot. In the example, AXEVT is triggered for each of the transmit audio channel time slot (time slot for channels LF, LS, and C; and time slot for channels RF, RS, LFE). Similarly, AREVT is triggered for each of the receive audio channel time slot. This allows for the use of a single DMA to transmit all audio channels, and a single DMA to receive all audio channels.

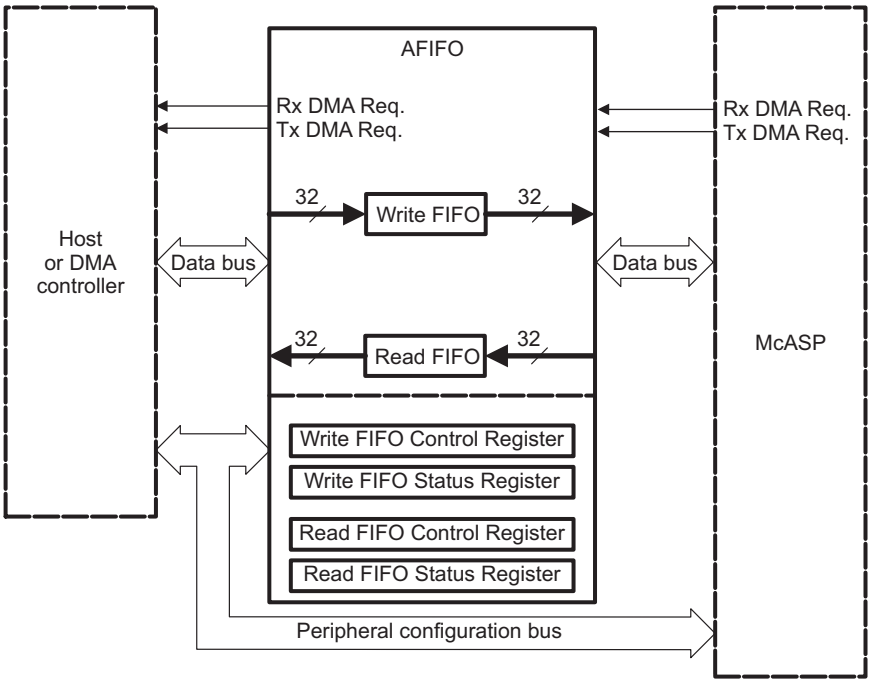
Note the difference between DMA event generation and the CPU interrupt generation. DMA events are generated automatically upon data ready; whereas CPU interrupt generation needs to be enabled in the XINTCTL/RINTCTL register.

26.2.4.4 McASP Audio FIFO (AFIFO)

The AFIFO contains two FIFOs: one Read FIFO (RFIFO), and one Write FIFO (WFIFO). To ensure backward compatibility with existing software, both the Read and Write FIFOs are disabled by default. See Figure 26-28 for a high-level block diagram of the AFIFO.

The AFIFO may be enabled/disabled and configured via the WFIFOCTL and RFIFOCTL registers. Note that if the Read or Write FIFO is to be enabled, it must be enabled prior to initializing the receive/transmit section of the McASP (see Section 26.2.4.1.2 for details).

Figure 26-28. McASP Audio FIFO (AFIFO) Block Diagram



26.2.4.4.1 AFIFO Data Transmission

When the Write FIFO is disabled, transmit DMA requests pass through directly from the McASP to the host/DMA controller. Whether the WFIFO is enabled or disabled, the McASP generates transmit DMA requests as needed; the AFIFO is “invisible” to the McASP.

When the Write FIFO is enabled, transmit DMA requests from the McASP are sent to the AFIFO, which in turn generates transmit DMA requests to the host/DMA controller.

If the Write FIFO is enabled, upon a transmit DMA request from the McASP, the WFIFO writes *WNUMDMA* 32-bit words to the McASP if and when there are at least *WNUMDMA* words in the Write FIFO. If there are not, the WFIFO waits until this condition has been satisfied. At that point, it writes *WNUMDMA* words to the McASP. (See description for WFIFOCTL.WNUMDMA in Section 26.3.45.)

If the host CPU writes to the Write FIFO, independent of a transmit DMA request, the WFIFO will accept host writes until full. After this point, excess data will be discarded.

Note that when the WFIFO is first enabled, it will immediately issue a transmit DMA request to the host. This is because it begins in an empty state, and is therefore ready to accept data.

26.2.4.4.1.1 Transmit DMA Event Pacer

The AFIFO may be configured to delay making a transmit DMA request to the host until the Write FIFO has enough space for a specified number of words. In this situation, the number of transmit DMA requests to the host or DMA controller is reduced.

If the Write FIFO has space to accept *WNUMEVT* 32-bit words, it generates a transmit DMA request to the host and then waits for a response. Once *WNUMEVT* words have been written to the FIFO, it checks again to see if there is space for *WNUMEVT* 32-bit words. If there is space, it generates another transmit DMA request to the host, and so on. In this fashion, the Write FIFO will attempt to stay filled.

Note that if transmit DMA event pacing is desired, WFIFOCTL.WNUMEVT should be set to a non-zero integer multiple of the value in WFIFOCTL.WNUMDMA. If transmit DMA event pacing is not desired, then the value in WFIFOCTL.WNUMEVT should be set equal to the value in WFIFOCTL.WNUMDMA.

26.2.4.4.2 AFIFO Data Reception

When the Read FIFO is disabled, receive DMA requests pass through directly from McASP to the host/DMA controller. Whether the RFIFO is enabled or disabled, the McASP generates receive DMA requests as needed; the AFIFO is “invisible” to the McASP.

When the Read FIFO is enabled, receive DMA requests from the McASP are sent to the AFIFO, which in turn generates receive DMA requests to the host/DMA controller.

If the Read FIFO is enabled and the McASP makes a receive DMA request, the RFIFO reads *RNUMDMA* 32-bit words from the McASP, if and when the RFIFO has space for *RNUMDMA* words. If it does not, the RFIFO waits until this condition has been satisfied; at that point, it reads *RNUMDMA* words from the McASP. (See description for RFIFOCTL.RNUMDMA in Section 26.3.47.)

If the host CPU reads the Read FIFO, independent of a receive DMA request, and the RFIFO at that time contains less than *RNUMEVT* words, those words will be read correctly, emptying the FIFO.

26.2.4.4.2.1 Receive DMA Event Pacer

The AFIFO may be configured to delay making a receive DMA request to the host until the Read FIFO contains a specified number of words. In this situation, the number of receive DMA requests to the host or DMA controller is reduced.

If the Read FIFO contains at least *RNUMEVT* 32-bit words, it generates a receive DMA request to the host and then waits for a response. Once *RNUMEVT* 32-bit words have been read from the RFIFO, the RFIFO checks again to see if it contains at least another *RNUMEVT* words. If it does, it generates another receive DMA request to the host, and so on. In this fashion, the Read FIFO will attempt to stay empty.

Note that if receive DMA event pacing is desired, RFIFOCTL.RNUMEVT should be set to a non-zero integer multiple of the value in RFIFOCTL.RNUMDMA. If receive DMA event pacing is not desired, then the value in RFIFOCTL.RNUMEVT should be set equal to the value in RFIFOCTL.RNUMDMA.

26.2.4.4.3 Arbitration Between Transmit and Receive DMA Requests

If both the WFIFO and the RFIFO are enabled and a transmit DMA request and receive DMA request occur simultaneously, priority is given to the transmit DMA request. Once a transfer is in progress, it is allowed to complete.

If only the WFIFO is enabled and a transmit DMA request and receive DMA request occur simultaneously, priority is given to the transmit DMA request. Once a transfer is in progress, it is allowed to complete.

If only the RFIFO is enabled and a transmit DMA request and receive DMA request occur simultaneously, priority is given to the receive DMA request. Once a transfer is in progress, it is allowed to complete.

26.2.4.5 Formatter

26.2.4.5.1 Transmit Bit Stream Data Alignment

The McASP transmitter supports serial formats of:

- Slot (or Time slot) size = 8, 12, 16, 20, 24, 28, 32 bits
- Word size ≤ Slot size
- Alignment: when more bits/slot than bits/words, then:
  - Left aligned = word shifted first, remaining bits are pad
  - Right aligned = pad bits are shifted first, word occupies the last bits in slot
- Order: order of bits shifted out:
  - MSB: most-significant bit of word is shifted out first, last bit is LSB
  - LSB: least-significant bit of word is shifted out last, last bit is MSB

Hardware support for these serial formats comes from the programmable options in the transmit bitstream format register (XFMT):

- XRVRS: bit reverse (1) or no bit reverse (0)
- XROT: rotate right by 0, 4, 8, 12, 16, 20, 24, or 28 bits
- XSSZ: transmit slot size of 8, 12, 16, 20, 24, 28, or 32 bits

XSSZ should always be programmed to match the slot size of the serial stream. The word size is not directly programmed into the McASP, but rather is used to determine the rotation needed in the XROT field.

Table 26-4 and Figure 26-29 show the XRVRS and XROT fields for each serial format and for both integer and Q31 fractional internal representations.

This discussion assumes that all slot size (SLOT in Table 26-4) and word size (WORD in Table 26-4) options are multiples of 4, since the transmit rotate right unit only supports rotation by multiples of 4. However, the bit mask/pad unit does allow for any number of significant digits. For example, a Q31 number may have 19 significant digits (word) and be transmitted in a 24-bit slot; this would be formatted as a word size of 20 bits and a slot size of 24 bits. However, it is possible to set the bit mask unit to only pass the 19 most-significant digits (program the mask value to FFFF E000h). The digits that are not significant can be set to a selected pad value, which can be any one of the significant digits, a fixed value of 0, or a fixed value of 1.

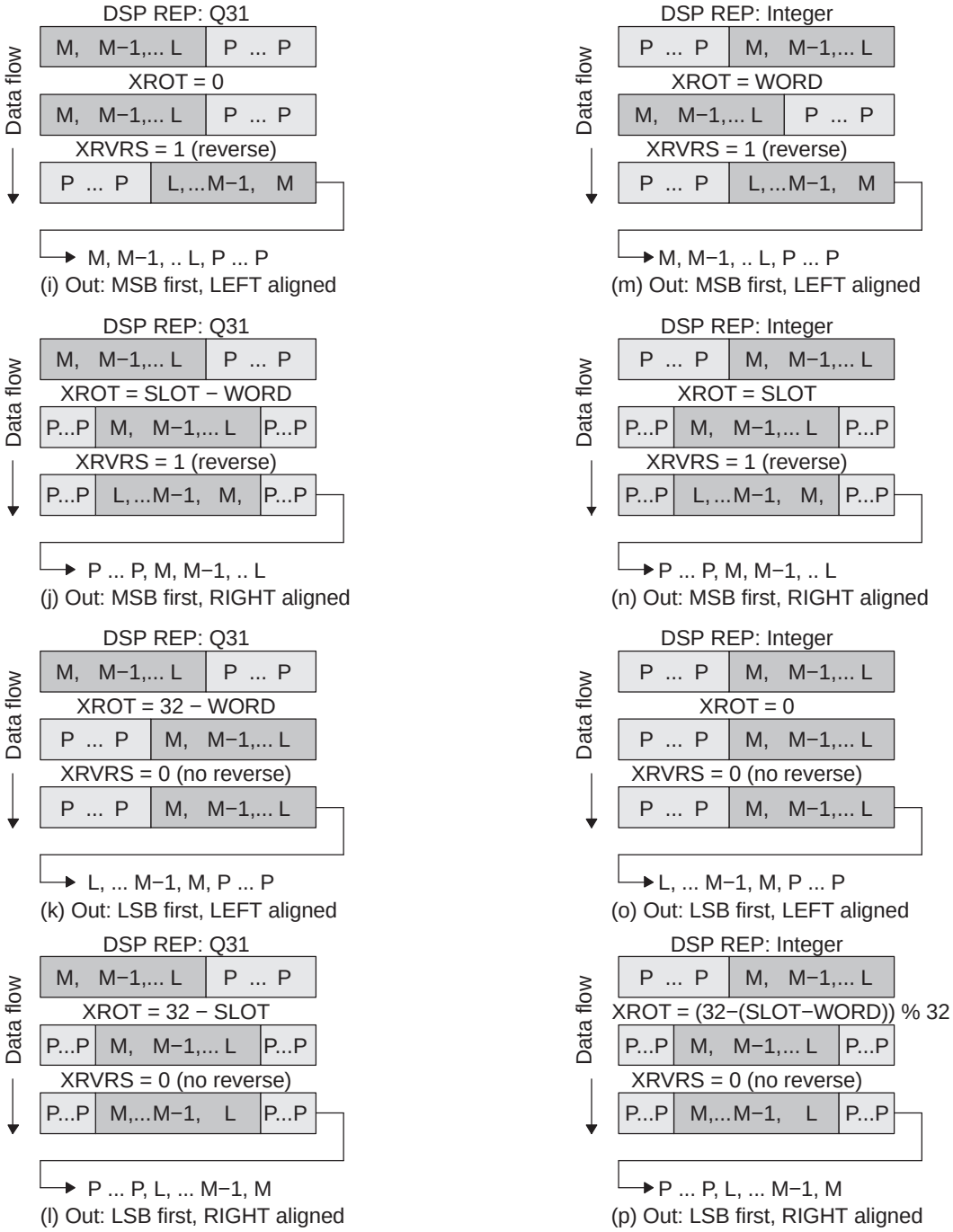
The transmit bit mask/pad unit operates on data as an initial step of the transmit format unit (see Figure 26-20), and the data is aligned in the same representation as it is written to the transmitter by the DSP (typically Q31 or integer).

Table 26-4. Transmit Bitstream Data Alignment

Figure 26-29	Bit Stream Order	Bit Stream Alignment	Internal Numeric Representation	XFMT Bit	
				XROT [1]	XRVRS
(a)[2]	MSB first	Left aligned	Q31 fraction	0	1
(b)	MSB first	Right aligned	Q31 fraction	SLOT - WORD	1
(c)	LSB first	Left aligned	Q31 fraction	32 - WORD	0
(d)	LSB first	Right aligned	Q31 fraction	32 - SLOT	0
(e)[2]	MSB first	Left aligned	Integer	WORD	1
(f)	MSB first	Right aligned	Integer	SLOT	1
(g)	LSB first	Left aligned	Integer	0	0
(h)	LSB first	Right aligned	Integer	(32 - (SLOT - WORD)) % 32	0

(1) WORD = Word size rounded up to the nearest multiple of 4; SLOT = slot size; % = modulo operator
(2) To transmit in I2S format, use MSB first, left aligned, and also select XDATDLY = 01 (1 bit delay)

Figure 26-29. Data Flow Through Transmit Format Unit



26.2.4.5.2 Receive Bit Stream Data Alignment

The McASP receiver supports serial formats of:

- Slot or time slot size = 8, 12, 16, 20, 24, 28, 32 bits
- Word size ≤ Slot size
- Alignment when more bits/slot than bits/words, then:
  - Left aligned = word shifted first, remaining bits are pad
  - Right aligned = pad bits are shifted first, word occupies the last bits in slot
- Order of bits shifted out:
  - MSB: most-significant bit of word is shifted out first, last bit is LSB
  - LSB: least-significant bit of word is shifted out last, last bit is MSB

Hardware support for these serial formats comes from the programmable options in the receive bitstream format register (RFMT):

- RRVRS: bit reverse (1) or no bit reverse (0)
- RROT: rotate right by 0, 4, 8, 12, 16, 20, 24, or 28 bits
- RSSZ: receive slot size of 8, 12, 16, 20, 24, 28, or 32 bits

RSSZ should always be programmed to match the slot size of the serial stream. The word size is not directly programmed into the McASP, but rather is used to determine the rotation needed in the RROT field.

Table 26-5 and Figure 26-30 show the RRVRS and RROT fields for each serial format and for both integer and Q31 fractional internal representations.

This discussion assumes that all slot size and word size options are multiples of 4; since the receive rotate right unit only supports rotation by multiples of 4. However, the bit mask/pad unit does allow for any number of significant digits. For example, a Q31 number may have 19 significant digits (word) and be transmitted in a 24-bit slot; this would be formatted as a word size of 20 bits and a slot size of 24 bits. However, it is possible to set the bit mask unit to only pass the 19 most-significant digits (program the mask value to FFFF E000h). The digits that are not significant can be set to a selected pad value, which can be any one of the significant digits, a fixed value of 0, or a fixed value of 1.

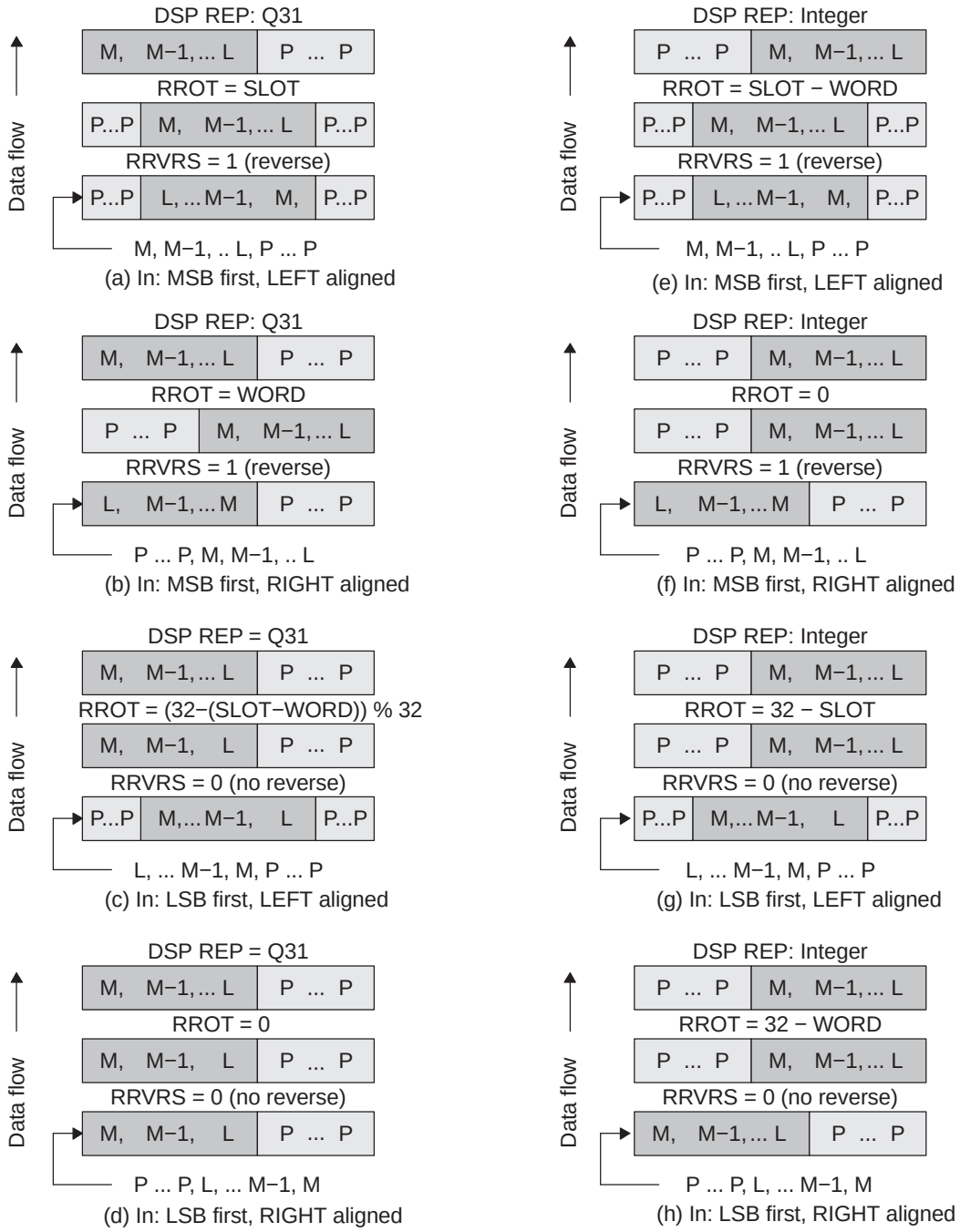
The receive bit mask/pad unit operates on data as the final step of the receive format unit (see Figure 26-19), and the data is aligned in the same representation as it is read from the receiver by the DSP (typically Q31 or integer).

Table 26-5. Receive Bitstream Data Alignment

Figure 26-30	Bit Stream Order	Bit Stream Alignment	Internal Numeric Representation	RFMT Bit	
				RROT [1]	RRVRS
(a)[2]	MSB first	Left aligned	Q31 fraction	SLOT	1
(b)	MSB first	Right aligned	Q31 fraction	WORD	1
(c)	LSB first	Left aligned	Q31 fraction	(32 - (SLOT - WORD)) % 32	0
(d)	LSB first	Right aligned	Q31 fraction	0	0
(e)[2]	MSB first	Left aligned	Integer	SLOT - WORD	1
(f)	MSB first	Right aligned	Integer	0	1
(g)	LSB first	Left aligned	Integer	32 - SLOT	0
(h)	LSB first	Right aligned	Integer	32 - WORD	0

(1) WORD = Word size rounded up to the nearest multiple of 4; SLOT = slot size; % = modulo operator
(2) To transmit in I2S format, select MSB first, left aligned, and also select RDATDLY = 01 (1 bit delay)

Figure 26-30. Data Flow Through Receive Format Unit



26.2.4.6 Interrupts

26.2.4.6.1 Transmit Data Ready Interrupt

The transmit data ready interrupt (XDATA) is generated if XDATA is 1 in the XSTAT register and XDATA is also enabled in XINTCTL. Section 26.2.4.3.1 provides details on when XDATA is set in the XSTAT register.

A transmit start of frame interrupt (XSTAFRM) is triggered by the recognition of transmit frame sync. A transmit last slot interrupt (XLAST) is a qualified version of the data ready interrupt (XDATA). It has the same behavior as the data ready interrupt, but is further qualified by having the data requested belonging to the last slot (the slot that just ended was next-to-last TDM slot, current slot is last slot).

26.2.4.6.2 Receive Data Ready Interrupt

The receive data ready interrupt (RDATA) is generated if RDATA is 1 in the RSTAT register and RDATA is also enabled in RINTCTL. Section 26.2.4.3.2 provides details on when RDATA is set in the RSTAT register.

A receiver start of frame interrupt (RSTAFRM) is triggered by the recognition of a receiver frame sync. A receiver last slot interrupt (RLAST) is a qualified version of the data ready interrupt (RDATA). It has the same behavior as the data ready interrupt, but is further qualified by having the data in the buffer come from the last TDM time slot (the slot that just ended was last TDM slot).

26.2.4.6.3 Error Interrupts

Upon detection, the following error conditions generate interrupt flags:

- In the receive status register (RSTAT):
  - Receiver overrun (ROVRN)
  - Unexpected receive frame sync (RSYNCERR)
  - Receive clock failure (RCKFAIL)
  - Receive DMA error (RDMAERR)
- In the transmit status register (XSTAT):
  - Transmit underrun (XUNDRN)
  - Unexpected transmit frame sync (XSYNCERR)
  - Transmit clock failure (XCKFAIL)
  - Transmit DMA error (XDMAERR)

Each interrupt source also has a corresponding enable bit in the receive interrupt control register (RINTCTL) and transmit interrupt control register (XINTCTL). If the enable bit is set in RINTCTL or XINTCTL, an interrupt is requested when the interrupt flag is set in RSTAT or XSTAT. If the enable bit is not set, no interrupt request is generated. However, the interrupt flag may be polled.

26.2.4.6.4 Audio Mute (AMUTE) Function

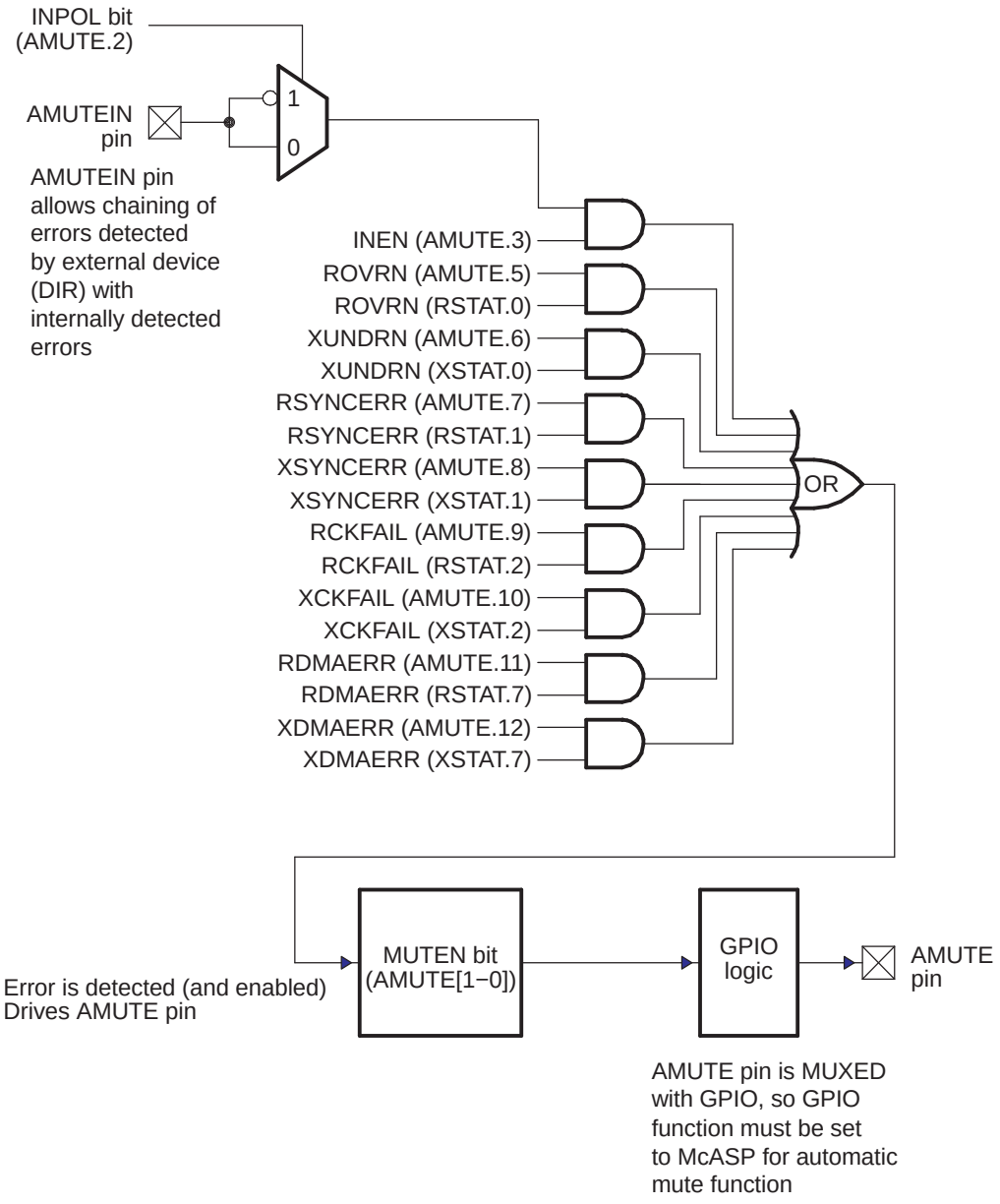
The McASP includes an automatic audio mute function (Figure 26-31) that asserts in hardware the AMUTE device pin to a preprogrammed output state, as selected by the MUTEN bit in the audio mute control register (AMUTE). The AMUTE device pin is asserted when one of the interrupt flags is set or an external device issues an error signal on the AMUTEIN input. Typically, the AMUTEIN input is shared with a device pin.

The AMUTEIN input allows the on-chip logic to consider a mute input from other devices in the system, so that all errors may be considered. The AMUTEIN input has a programmable polarity to allow it to adapt to different devices, as selected by the INPOL bit in AMUTE, and it must be enabled explicitly.

In addition to the external AMUTEIN input, the AMUTE device pin output may be asserted when one of the error interrupt flags is set and its mute function is enabled in AMUTE.

When one or more of the errors is detected and enabled, the AMUTE device pin is driven to an active state that is selected by MUTEN in AMUTE. The active polarity of the AMUTE device pin is programmable by MUTEN (and the inactive polarity is the opposite of the active polarity). The AMUTE device pin remains driven active until software clears all the error interrupt flags that are enabled to mute, and until the AMUTEIN is inactive.

Figure 26-31. Audio Mute (AMUTE) Block Diagram



26.2.4.6.5 Multiple Interrupts

This only applies to interrupts and not to DMA requests. The following terms are defined:

- **Active Interrupt Request:** a flag in RSTAT or XSTAT is set and the interrupt is enabled in RINTCTL or XINTCTL.
- **Outstanding Interrupt Request:** An interrupt request has been issued on one of the McASP transmit/receive interrupt ports, but that request has not yet been serviced.
- **Serviced:** The CPU writes to RSTAT or XSTAT to clear one or more of the active interrupt request flags.

The first interrupt request to become active for the transmitter with the interrupt flag set in XSTAT and the interrupt enabled in XINTCTL generates a request on the McASP transmit interrupt port AXINT.

If more than one interrupt request becomes active in the same cycle, a single interrupt request is generated on the McASP transmit interrupt port. Subsequent interrupt requests that become active while the first interrupt request is outstanding do not immediately generate a new request pulse on the McASP transmit interrupt port.

The transmit interrupt is serviced with the CPU writing to XSTAT. If any interrupt requests are active after the write, a new request is generated on the McASP transmit interrupt port.

The receiver operates in a similar way, but using RSTAT, RINTCTL, and the McASP receive interrupt port ARINT.

One outstanding interrupt request is allowed on each port, so a transmit and a receive interrupt request may both be outstanding at the same time.

26.2.4.7 Error Handling and Management

To support the design of a robust audio system, the McASP includes error-checking capability for the serial protocol, data underrun, and data overrun. In addition, the McASP includes a timer that continually measures the high-frequency master clock every 32 AHCLKX/AHCLKR clock cycles. The timer value can be read to get a measurement of the clock frequency and has a minimum and maximum range setting that can set an error flag if the master clock goes out of a specified range.

Upon the detection of any one or more errors (software selectable), or the assertion of the AMUTEIN input pin, the AMUTE output pin may be asserted to a high or low level to immediately mute the audio output. In addition, an interrupt may be generated if desired, based on any one or more of the error sources.

26.2.4.7.1 Unexpected Frame Sync Error

An unexpected frame sync occurs when:

- In burst mode, when the next active edge of the frame sync occurs early such that the current slot will not be completed by the time the next slot is scheduled to begin.
- In TDM mode, a further constraint is that the frame sync must occur exactly during the correct bit clock (not a cycle earlier or later) and only before slot 0. An unexpected frame sync occurs if this condition is not met.

When an unexpected frame sync occurs, there are two possible actions depending upon when the unexpected frame sync occurs:

1. Early: An early unexpected frame sync occurs when the McASP is in the process of completing the current frame and a new frame sync is detected (not including overlap that occurs due to a 1 or 2 bit frame sync delay). When an early unexpected frame sync occurs:
   - Error interrupt flag is set (XSYNCERR, if an unexpected transmit frame sync occurs; RSYNCERR, if an unexpected receive frame sync occurs).
   - Current frame is not resynchronized. The number of bits in the current frame is completed. The next frame sync, which occurs after the current frame is completed, will be resynchronized.

2. Late: A late unexpected frame sync occurs when there is a gap or delay between the last bit of the previous frame and the first bit of the next frame. When a late unexpected frame sync occurs (as soon as the gap is detected):
   - Error interrupt flag is set (XSYNCERR, if an unexpected transmit frame sync occurs; RSYNCERR, if an unexpected receive frame sync occurs).
   - Resynchronization occurs upon the arrival of the next frame sync.

Late frame sync is detected the same way in both burst mode and TDM mode; however, in burst mode, late frame sync is not meaningful and its interrupt enable should not be set.

26.2.4.7.2 Buffer Underrun Error - Transmitter

A buffer underrun can only occur for serializers programmed to be transmitters. A buffer underrun occurs when the serializer is instructed by the transmit state machine to transfer data from XRBUF[n] to XRSR[n], but XRBUF[n] has not yet been written with new data since the last time the transfer occurred. When this occurs, the transmit state machine sets the XUNDRN flag.

An underrun is checked only once per time slot. The XUNDRN flag is set when an underrun condition occurs. Once set, the XUNDRN flag remains set until the DSP explicitly writes a 1 to the XUNDRN bit to clear the XUNDRN bit.

In DIT mode, a pair of BMC zeros is shifted out when an underrun occurs (four bit times at 128 × f_s). By shifting out a pair of zeros, a clock may be recovered on the receiver. To recover, reset the McASP and start again with the proper initialization.

In TDM mode, during an underrun case, a long stream of zeros are shifted out causing the DACs to mute. To recover, reset the McASP and start again with the proper initialization.

26.2.4.7.3 Buffer Overrun Error - Receiver

A buffer overrun can only occur for serializers programmed to be receivers. A buffer overrun occurs when the serializer is instructed to transfer data from XRSR[n] to XRBUF[n], but XRBUF[n] has not yet been read by either the DMA or the DSP. When this occurs, the receiver state machine sets the ROVRN flag. However, the individual serializer writes over the data in the XRBUF[n] register (destroying the previous sample) and continues shifting.

An overrun is checked only once per time slot. The ROVRN flag is set when an overrun condition occurs. It is possible that an overrun occurs on one time slot but then the DSP catches up and does not cause an overrun on the following time slots. However, once the ROVRN flag is set, it remains set until the DSP explicitly writes a 1 to the ROVRN bit to clear the ROVRN bit.

26.2.4.7.4 DMA Error - Transmitter

A transmit DMA error, as indicated by the XDMAERR flag in the XSTAT register, occurs when the DMA (or CPU) writes more words to the DMA port of the McASP than it should. For each DMA event, the DMA should write exactly as many words as there are serializers enabled as transmitters.

XDMAERR indicates that the DMA (or CPU) wrote too many words to the McASP for a given transmit DMA event. Writing too few words results in a transmit underrun error setting XUNDRN in XSTAT.

While XDMAERR occurs infrequently, an occurrence indicates a serious loss of synchronization between the McASP and the DMA or CPU. You should reinitialize both the McASP transmitter and the DMA to resynchronize them.

26.2.4.7.5 DMA Error - Receiver

A receive DMA error, as indicated by the RDMAERR flag in the RSTAT register, occurs when the DMA (or CPU) reads more words from the DMA port of the McASP than it should. For each DMA event, the DMA should read exactly as many words as there are serializers enabled as receivers.

RDMAERR indicates that the DMA (or CPU) read too many words from the McASP for a given receive DMA event. Reading too few words results in a receiver overrun error setting ROVRN in RSTAT.

While RDMAERR occurs infrequently, an occurrence indicates a serious loss of synchronization between the McASP and the DMA or CPU. You should reinitialize both the McASP receiver and the DMA to resynchronize them.

26.2.4.7.6 Clock Failure Detection

26.2.4.7.6.1 Clock-Failure Check Startup

It is expected, initially, that the clock-failure circuits will generate an error until at least one measurement has been taken. Therefore, the clock failure interrupts, clock switch, and mute functions should not immediately be enabled, but be enabled only after a specific startup procedure. The startup procedure is:

1. For the transmit clock failure check:
   (a) Configure transmit clock failure detect logic (XMIN, XMAX, XPS) in the transmit clock check control register (XCLKCHK).
   (b) Clear transmit clock failure flag (XCKFAIL) in the transmit status register (XSTAT).
   (c) Wait until first measurement is taken (> 32 AHCLKX clock periods).
   (d) Verify no clock failure is detected.
   (e) Repeat steps b–d until clock is running and is no longer issuing clock failure errors.
   (f) After the transmit clock is measured and falls within the acceptable range, the following may be enabled:
      (i) transmit clock failure interrupt enable bit (XCKFAIL) in the transmitter interrupt control register (XINTCTL)
      (ii) transmit clock failure detect autoswitch enable bit (XCKFAILSW) in the transmit clock check control register (XCLKCHK)
      (iii) mute option (XCKFAIL) in the mute control register (AMUTE)
2. For the receive clock failure check:
   (a) Configure receive clock failure detect logic (RMIN, RMAX, RPS) in the receive clock check control register (RCLKCHK).
   (b) Clear receive clock failure flag (RCKFAIL) in the receive status register (RSTAT).
   (c) Wait until first measurement is taken (> 32 AHCLKR clock periods).
   (d) Verify no clock failure is detected.
   (e) Repeat steps b–d until clock is running and is no longer issuing clock failure errors.
   (f) After the receive clock is measured and falls within the acceptable range, the following may be enabled:
      (i) receive clock failure interrupt enable bit (RCKFAIL) in the receiver interrupt control register (RINTCTL)
      (ii) mute option (RCKFAIL) in the mute control register (AMUTE)

26.2.4.7.6.2 Transmit Clock Failure Check and Recovery

The transmit clock failure check circuit (Figure 26-32) works off both the internal McASP system clock and the external high-frequency serial clock (AHCLKX). It continually counts the number of system clocks for every 32 high rate serial clock (AHCLKX) periods, and stores the count in XCNT of the transmit clock check control register (XCLKCHK) every 32 high rate serial clock cycles.

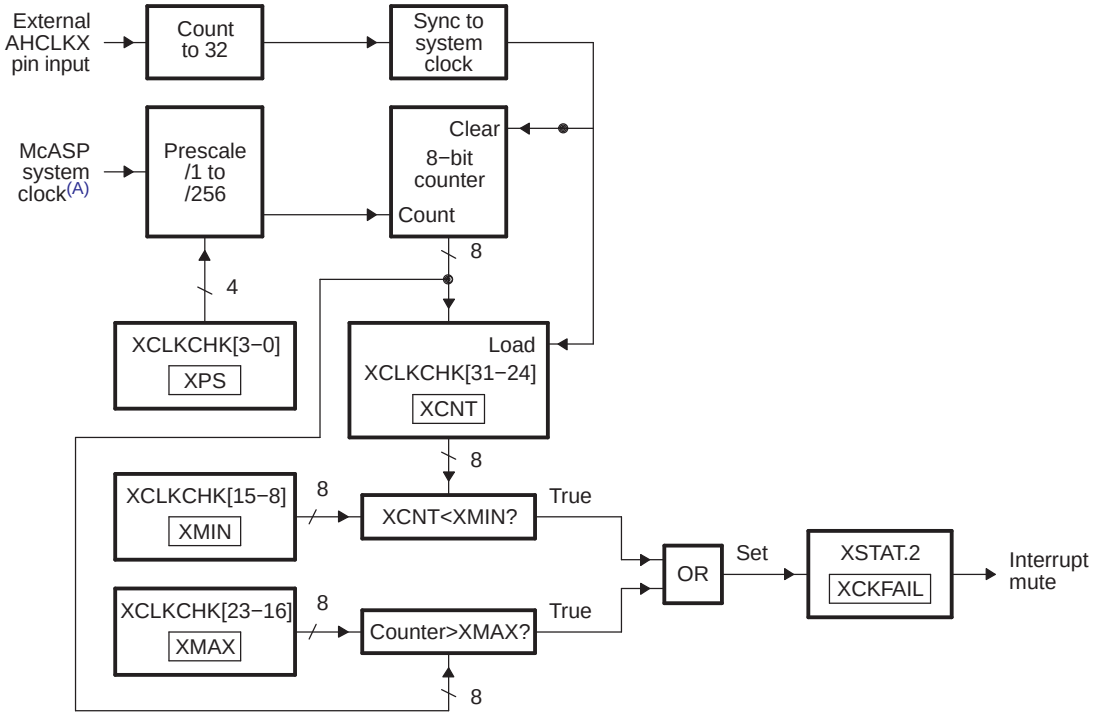
The logic compares the count against a user-defined minimum allowable boundary (XMIN), and automatically flags an interrupt (XCKFAIL in XSTST) when an out-of-range condition occurs. An out-of-range minimum condition occurs when the count is smaller than XMIN. The logic continually compares the current count (from the running system clock counter) against the maximum allowable boundary (XMAX). This is in case the external clock completely stops, so that the counter value is not copied to XCNT. An out-of-range maximum condition occurs when the count is greater than XMAX. Note that the XMIN and XMAX fields are 8-bit unsigned values, and the comparison is performed using unsigned arithmetic.

An out-of-range count may indicate either that an unstable clock was detected, or that the audio source has changed and a new sample rate is being used.

In order for the transmit clock failure check circuit to operate correctly, the high-frequency serial clock divider must be taken out of reset regardless if AHCLKX is internally generated or externally sourced.

If a clock failure is detected, the transmit clock failure flag (XCKFAIL) in XSTAT is set. This causes an interrupt, if the transmit clock failure interrupt enable bit (XCKFAIL) in XINTCTL is set.

Figure 26-32. Transmit Clock Failure Detection Circuit Block Diagram



A This is not the same as AUXCLK. The DSP uses SYSCLK2 as the McASP system clock.

26.2.4.7.6.3 Receive Clock Failure Check and Recovery

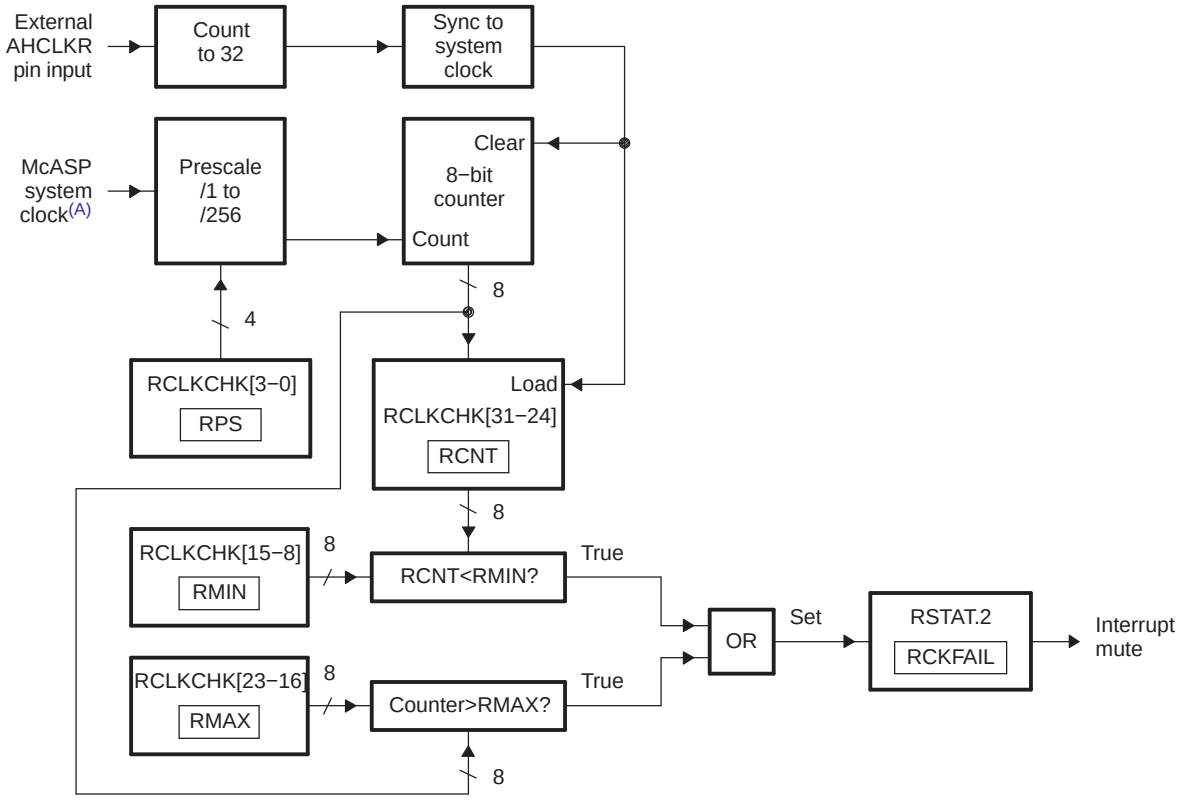
The receive clock failure check circuit (Figure 26-33) works off both the internal McASP system clock and the external high-frequency serial clock (AHCLKR). It continually counts the number of system clocks for every 32 high rate serial clock (AHCLKR) periods, and stores the count in RCNT of the receive clock check control register (RCLKCHK) every 32 high rate serial clock cycles.

The logic compares the count against a user-defined minimum allowable boundary (RMIN) and automatically flags an interrupt (RCKFAIL in RSTAT) when an out-of-range condition occurs. An out-of-range minimum condition occurs when the count is smaller than RMIN. The logic continually compares the current count (from the running system clock counter) against the maximum allowable boundary (RMAX). This is in case the external clock completely stops, so that the counter value is not copied to RCNT. An out-of-range maximum condition occurs when the count is greater than RMAX. Note that the RMIN and RMAX fields are 8-bit unsigned values, and the comparison is performed using unsigned arithmetic.

An out-of-range count may indicate either that an unstable clock was detected or that the audio source has changed and a new sample rate is being used.

In order for the receive clock failure check circuit to operate correctly, the high-frequency serial clock divider must be taken out of reset regardless if AHCLKR is internally generated or externally sourced.

Figure 26-33. Receive Clock Failure Detection Circuit Block Diagram



A This is not the same as AUXCLK. The DSP uses SYSCLK2 as the McASP system clock source.

26.2.4.8 Loopback Modes

The McASP features a digital loopback mode (DLB) that allows testing of the McASP code in TDM mode with a single DSP device. In loopback mode, output of the transmit serializers is connected internally to the input of the receive serializers. Therefore, you can check the receive data against the transmit data to ensure that the McASP settings are correct. Digital loopback mode applies to TDM mode only (2 to 32 slots in a frame). It does not apply to DIT mode (XMOD = 180h) or burst mode (XMOD = 0).

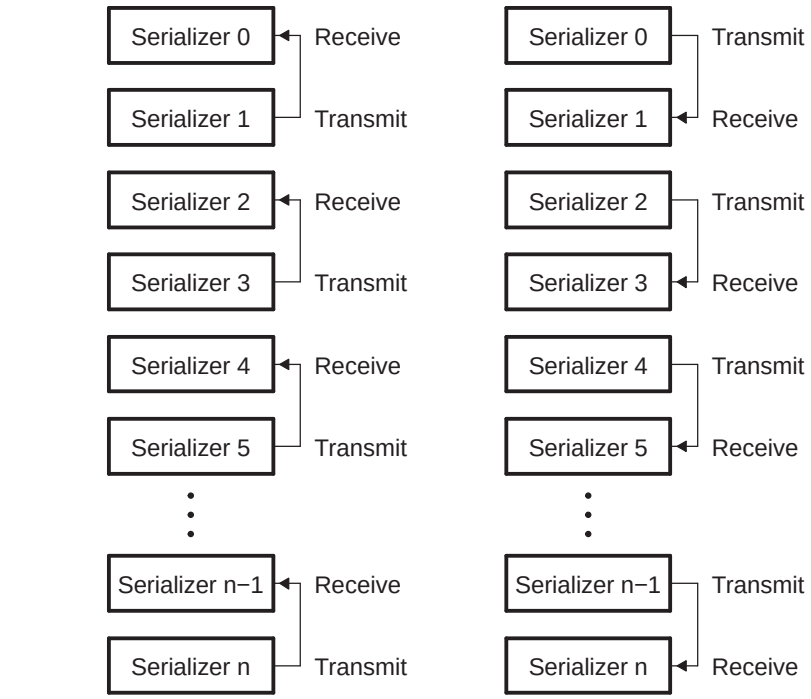
Figure 26-34 shows the basic logical connection of the serializers in loopback mode. Two types of loopback connections are possible, selected by the ORD bit in the digital loopback control register (DLBCTL) as follows:

- ORD = 0: Outputs of odd serializers are connected to inputs of even serializers. If this mode is selected, you should configure odd serializers to be transmitters and even serializers to be receivers.
- ORD = 1: Outputs of even serializers are connected to inputs of odd serializers. If this mode is selected, you should configure even serializers to be transmitters and odd serializers to be receivers.

Data can be externally visible at the I/O pin of the transmit serializer if the pin is configured as a McASP output pin by setting the corresponding PFUNC bit to 0 and PDIR bit to 1.

In loopback mode, the transmit clock and frame sync are used by both the transmit and receive sections of the McASP. The transmit and receive sections operate synchronously. This is achieved by setting the MODE bit of the DLBCTL register to 01b and the ASYNC bit of the ACLKXCTL register to 0.

Figure 26-34. Serializers in Loopback Mode



(a) DLBEN = 1 (loopback enabled) and ORD = 0 (even receive, odd transmit)

(b) DLBEN = 1 (loopback enabled) and ORD = 1 (odd receive, even transmit)

26.2.4.8.1 Loopback Mode Configurations

This is a summary of the settings required for digital loopback mode for TDM format:

- The DLBEN bit in DLBCTL must be set to 1 to enable loopback mode.
- The MODE bits in DLBCTL must be set to 01b for both the transmit and receive sections to use the transmit clock and frame sync generator.
- The ORD bit in DLBCTL must be programmed appropriately to select odd or even serializers to be transmitters or receivers. The corresponding serializers must be configured accordingly.
- The ASYNC bit in ACLKXCTL must be cleared to 0 to ensure synchronous transmit and receive operations.
- RMOD field in AFSRCTL and XMOD field in AFSXCTL must be set to 2h to 20h to indicate TDM mode. Loopback mode does not apply to DIT or burst mode.

26.2.5 Reset Considerations

The McASP has two reset sources: software reset and hardware reset.

26.2.5.1 Software Reset Considerations

The transmitter and receiver portions of the McASP may be put in reset through the global control register (GBLCTL). Note that a valid serial clock must be supplied to the desired portion of the McASP (transmit and/or receive) in order to assert the software reset bits in GBLCTL. See Section 26.2.4.1.2 for details on how to ensure reset has occurred.

The entire McASP module may also be reset through the Power and Sleep Controller (PSC). Note that from the McASP perspective, this reset appears as a hardware reset to the entire module.

26.2.5.2 Hardware Reset Considerations

When the McASP is reset due to device reset, the entire serial port (including the transmitter and receiver state machines, and other registers) is reset.

26.2.6 EDMA Event Support

The McASP-related EDMA events are shown in Table 26-6.

Table 26-6. EDMA Events - McASP

Channel	Event Name	Event Description
0	AREVT0	McASP0 Receive Event
1	AXEVT0	McASP0 Transmit Event
2	AREVT1	McASP1 Receive Event
3	AXEVT1	McASP1 Transmit Event
4	AREVT2	McASP2 Receive Event
5	AXEVT2	McASP2 Transmit Event

26.2.7 Power Management

The McASP can be placed in reduced power modes to conserve power during periods of low activity. The power management of the peripheral is controlled by the processor Power and Sleep Controller (PSC). The PSC acts as a master controller for power management for all of the peripherals on the device. For information on power management procedures using the PSC, see the *Power and Sleep Controller (PSC)* chapter.

26.3 Registers

Control registers for the McASP are summarized in Table 26-7. The control registers are accessed through the peripheral configuration port. The receive buffer registers (RBUF) and transmit buffer registers (XBUF) can also be accessed through the DMA port, as listed in Table 26-8. See your device-specific data manual for the memory address of these registers.

Control registers for the McASP Audio FIFO (AFIFO) are summarized in Table 26-9. Note that the AFIFO Write FIFO (WFIFO) and Read FIFO (RFIFO) have independent control and status registers. The AFIFO control registers are accessed through the peripheral configuration port. See your device-specific data manual for the memory address of these registers.

Table 26-7. McASP Registers Accessed by CPU/EDMA Through Peripheral Configuration Port

Offset	Acronym	Register Description	Section
0h	REV	Revision identification register	Section 26.3.2
10h	PFUNC	Pin function register	Section 26.3.3
14h	PDIR	Pin direction register	Section 26.3.4
18h	PDOUT	Pin data output register	Section 26.3.5
1Ch	PDIN	Read returns: Pin data input register	Section 26.3.6
1Ch	PDSET	Writes affect: Pin data set register (alternate write address: PDOUT)	Section 26.3.7
20h	PDCLR	Pin data clear register (alternate write address: PDOUT)	Section 26.3.8
44h	GBLCTL	Global control register	Section 26.3.9
48h	AMUTE	Audio mute control register	Section 26.3.10
4Ch	DLBCTL	Digital loopback control register	Section 26.3.11
50h	DITCTL	DIT mode control register	Section 26.3.12
60h	RGBLCTL	Receiver global control register: Alias of GBLCTL, only receive bits are affected - allows receiver to be reset independently from transmitter	Section 26.3.13
64h	RMASK	Receive format unit bit mask register	Section 26.3.14
68h	RFMT	Receive bit stream format register	Section 26.3.15
6Ch	AFSRCTL	Receive frame sync control register	Section 26.3.16
70h	ACLKRCTL	Receive clock control register	Section 26.3.17
74h	AHCLKRCTL	Receive high-frequency clock control register	Section 26.3.18
78h	RTDM	Receive TDM time slot 0-31 register	Section 26.3.19
7Ch	RINTCTL	Receiver interrupt control register	Section 26.3.20
80h	RSTAT	Receiver status register	Section 26.3.21
84h	RSLOT	Current receive TDM time slot register	Section 26.3.22
88h	RCLKCHK	Receive clock check control register	Section 26.3.23
8Ch	REVTCTL	Receiver DMA event control register	Section 26.3.24
A0h	XGBLCTL	Transmitter global control register. Alias of GBLCTL, only transmit bits are affected - allows transmitter to be reset independently from receiver	Section 26.3.25
A4h	XMASK	Transmit format unit bit mask register	Section 26.3.26
A8h	XFMT	Transmit bit stream format register	Section 26.3.27
ACh	AFSXCTL	Transmit frame sync control register	Section 26.3.28
B0h	ACLKXCTL	Transmit clock control register	Section 26.3.29
B4h	AHCLKXCTL	Transmit high-frequency clock control register	Section 26.3.30
B8h	XTDM	Transmit TDM time slot 0-31 register	Section 26.3.31
BCh	XINTCTL	Transmitter interrupt control register	Section 26.3.32
C0h	XSTAT	Transmitter status register	Section 26.3.33
C4h	XSLOT	Current transmit TDM time slot register	Section 26.3.34
C8h	XCLKCHK	Transmit clock check control register	Section 26.3.35
CCh	XEVTCTL	Transmitter DMA event control register	Section 26.3.36

Table 26-7. McASP Registers Accessed by CPU/EDMA Through Peripheral Configuration Port (continued)

Offset	Acronym	Register Description	Section
100h	DITCSRA0	Left (even TDM time slot) channel status register (DIT mode) 0	Section 26.3.38
104h	DITCSRA1	Left (even TDM time slot) channel status register (DIT mode) 1	Section 26.3.38
108h	DITCSRA2	Left (even TDM time slot) channel status register (DIT mode) 2	Section 26.3.38
10Ch	DITCSRA3	Left (even TDM time slot) channel status register (DIT mode) 3	Section 26.3.38
110h	DITCSRA4	Left (even TDM time slot) channel status register (DIT mode) 4	Section 26.3.38
114h	DITCSRA5	Left (even TDM time slot) channel status register (DIT mode) 5	Section 26.3.38
118h	DITCSRB0	Right (odd TDM time slot) channel status register (DIT mode) 0	Section 26.3.39
11Ch	DITCSRB1	Right (odd TDM time slot) channel status register (DIT mode) 1	Section 26.3.39
120h	DITCSRB2	Right (odd TDM time slot) channel status register (DIT mode) 2	Section 26.3.39
124h	DITCSRB3	Right (odd TDM time slot) channel status register (DIT mode) 3	Section 26.3.39
128h	DITCSRB4	Right (odd TDM time slot) channel status register (DIT mode) 4	Section 26.3.39
12Ch	DITCSRB5	Right (odd TDM time slot) channel status register (DIT mode) 5	Section 26.3.39
130h	DITUDRA0	Left (even TDM time slot) channel user data register (DIT mode) 0	Section 26.3.40
134h	DITUDRA1	Left (even TDM time slot) channel user data register (DIT mode) 1	Section 26.3.40
138h	DITUDRA2	Left (even TDM time slot) channel user data register (DIT mode) 2	Section 26.3.40
13Ch	DITUDRA3	Left (even TDM time slot) channel user data register (DIT mode) 3	Section 26.3.40
140h	DITUDRA4	Left (even TDM time slot) channel user data register (DIT mode) 4	Section 26.3.40
144h	DITUDRA5	Left (even TDM time slot) channel user data register (DIT mode) 5	Section 26.3.40
148h	DITUDRB0	Right (odd TDM time slot) channel user data register (DIT mode) 0	Section 26.3.41
14Ch	DITUDRB1	Right (odd TDM time slot) channel user data register (DIT mode) 1	Section 26.3.41
150h	DITUDRB2	Right (odd TDM time slot) channel user data register (DIT mode) 2	Section 26.3.41
154h	DITUDRB3	Right (odd TDM time slot) channel user data register (DIT mode) 3	Section 26.3.41
158h	DITUDRB4	Right (odd TDM time slot) channel user data register (DIT mode) 4	Section 26.3.41
15Ch	DITUDRB5	Right (odd TDM time slot) channel user data register (DIT mode) 5	Section 26.3.41
180h	SRCTL0	Serializer control register 0	Section 26.3.37
184h	SRCTL1	Serializer control register 1	Section 26.3.37
188h	SRCTL2	Serializer control register 2	Section 26.3.37
18Ch	SRCTL3	Serializer control register 3	Section 26.3.37
190h	SRCTL4	Serializer control register 4	Section 26.3.37
194h	SRCTL5	Serializer control register 5	Section 26.3.37
198h	SRCTL6	Serializer control register 6	Section 26.3.37
19Ch	SRCTL7	Serializer control register 7	Section 26.3.37
1A0h	SRCTL8	Serializer control register 8	Section 26.3.37
1A4h	SRCTL9	Serializer control register 9	Section 26.3.37
1A8h	SRCTL10	Serializer control register 10	Section 26.3.37
1ACh	SRCTL11	Serializer control register 11	Section 26.3.37
1B0h	SRCTL12	Serializer control register 12	Section 26.3.37
1B4h	SRCTL13	Serializer control register 13	Section 26.3.37
1B8h	SRCTL14	Serializer control register 14	Section 26.3.37
1BCh	SRCTL15	Serializer control register 15	Section 26.3.37

Table 26-7. McASP Registers Accessed by CPU/EDMA Through Peripheral Configuration Port (continued)

Offset	Acronym	Register Description	Section
200h	XBUF0[1]	Transmit buffer register for serializer 0	Section 26.3.42
204h	XBUF1[1]	Transmit buffer register for serializer 1	Section 26.3.42
208h	XBUF2[1]	Transmit buffer register for serializer 2	Section 26.3.42
20Ch	XBUF3[1]	Transmit buffer register for serializer 3	Section 26.3.42
210h	XBUF4[1]	Transmit buffer register for serializer 4	Section 26.3.42
214h	XBUF5[1]	Transmit buffer register for serializer 5	Section 26.3.42
218h	XBUF6[1]	Transmit buffer register for serializer 6	Section 26.3.42
21Ch	XBUF7[1]	Transmit buffer register for serializer 7	Section 26.3.42
220h	XBUF8[1]	Transmit buffer register for serializer 8	Section 26.3.42
224h	XBUF9[1]	Transmit buffer register for serializer 9	Section 26.3.42
228h	XBUF10[1]	Transmit buffer register for serializer 10	Section 26.3.42
22Ch	XBUF11[1]	Transmit buffer register for serializer 11	Section 26.3.42
230h	XBUF12[1]	Transmit buffer register for serializer 12	Section 26.3.42
234h	XBUF13[1]	Transmit buffer register for serializer 13	Section 26.3.42
238h	XBUF14[1]	Transmit buffer register for serializer 14	Section 26.3.42
23Ch	XBUF15[1]	Transmit buffer register for serializer 15	Section 26.3.42
280h	RBUF0[2]	Receive buffer register for serializer 0	Section 26.3.43
284h	RBUF1[2]	Receive buffer register for serializer 1	Section 26.3.43
288h	RBUF2[2]	Receive buffer register for serializer 2	Section 26.3.43
28Ch	RBUF3[2]	Receive buffer register for serializer 3	Section 26.3.43
290h	RBUF4[2]	Receive buffer register for serializer 4	Section 26.3.43
294h	RBUF5[2]	Receive buffer register for serializer 5	Section 26.3.43
298h	RBUF6[2]	Receive buffer register for serializer 6	Section 26.3.43
29Ch	RBUF7[2]	Receive buffer register for serializer 7	Section 26.3.43
2A0h	RBUF8[2]	Receive buffer register for serializer 8	Section 26.3.43
2A4h	RBUF9[2]	Receive buffer register for serializer 9	Section 26.3.43
2A8h	RBUF10[2]	Receive buffer register for serializer 10	Section 26.3.43
2ACh	RBUF11[2]	Receive buffer register for serializer 11	Section 26.3.43
2B0h	RBUF12[2]	Receive buffer register for serializer 12	Section 26.3.43
2B4h	RBUF13[2]	Receive buffer register for serializer 13	Section 26.3.43
2B8h	RBUF14[2]	Receive buffer register for serializer 14	Section 26.3.43
2BCh	RBUF15[2]	Receive buffer register for serializer 15	Section 26.3.43

(1) Writes to XRBUF[n] by way of XBUF*n* by the CPU/EDMA can only occur through the peripheral configuration port when XBUSEL = 1 in XFMT.

(2) Reads from XRBUF[n] by way of RBUF*n* by the CPU/EDMA can only occur through the peripheral configuration port when RBUSEL = 1 in RFMT.

Table 26-8. McASP Registers Accessed by CPU/EDMA Through DMA Port

Offset [1]	Access	Acronym	Register Description
2000h	Read Accesses	RBUF	Receive buffer DMA port address. Cycles through receive serializers, skipping over transmit serializers and inactive serializers. Starts at the lowest serializer at the beginning of each time slot. Reads from XRBUF[n] by way of RBUF by the CPU/EDMA can only occur through the DMA port when RBUSEL = 0 in RFMT.
2000h	Write Accesses	XBUF	Transmit buffer DMA port address. Cycles through transmit serializers, skipping over receive and inactive serializers. Starts at the lowest serializer at the beginning of each time slot. Writes to XRBUF[n] by way of XBUF by the CPU/EDMA can only occur through the DMA port when XBUSEL = 0 in XFMT.

(1) RBUF and XBUF are at the same address location. Reads access RBUF and writes access XBUF.

Table 26-9. McASP AFIFO Registers Accessed Through Peripheral Configuration Port[1]

Offset	Acronym	Register Description	Section
1000h	AFIFOREV	AFIFO revision identification register	Section 26.3.44
1010h	WFIFOCTL	Write FIFO control register	Section 26.3.45
1014h	WFIFOSTS	Write FIFO status register	Section 26.3.46
1018h	RFIFOCTL	Read FIFO control register	Section 26.3.47
101Ch	RFIFOSTS	Read FIFO status register	Section 26.3.48

(1) The AFIFO cannot be used with the peripheral configuration port. Only the DMA port has access to the AFIFO.

26.3.1 Register Bit Restrictions

Some bit fields (see Table 26-10) have restrictions on when they may be changed. These restrictions take the form of certain registers that must be asserted in GBLCTL. Once these registers have been asserted, the user may then, and only then, change the desired bit field.

Table 26-10. Bits With Restrictions on When They May be Changed

To Change Register:	To Change Bit Field:	... these registers must be asserted in GBLCTL									
		HCLKRRST	RGRST	RSRCLR	RSMRST	RFRST	HCLKXRST	XGRST	XSRCLR	XSMRST	XFRST
DITCTL	DITEN									x	x
XFMT	XSSZ									x	
XFMT	XDATDLY				x					x	
RFMT	RSSZ				x						
RFMT	RDATDLY				x						
AFSXCTL	FSXP									x	x
AFSXCTL	FSXM									x	x
AFSXCTL	FXWID									x	x
AFSXCTL	XMOD									x	x
AFSRCTL	FSRP				x	x					
AFSRCTL	FSRM				x	x					
AFSRCTL	FRWID				x	x					
AFSRCTL	RMOD				x	x					
ACLKXCTL	CLKXDIV							x	x	x	x
ACLKXCTL	CLKXM								x	x	x
ACLKXCTL	ASYNC				x	x					
ACLKXCTL	CLKXP								x	x	x
ACLKRCTL	CLKRDIV		x	x	x	x					
ACLKRCTL	CLKRM			x	x	x					
ACLKRCTL	CLKRP			x	x	x					

Table 26-10. Bits With Restrictions on When They May be Changed (continued)

To Change Register:	To Change Bit Field:	... these registers must be asserted in GBLCTL									
		HCLKRRST	RGRST	RSRCLR	RSMRST	RFRST	HCLKXRST	XGRST	XSRCLR	XSMRST	XFRST
AHCLKXCTL	HCLKXDIV						x	x	x	x	x
AHCLKXCTL	HCLKXP						x	x	x	x	x
AHCLKXCTL	HCLKXM						x	x	x	x	x
AHCLKRCTL	HCLKRDIV	x	x	x	x	x					
AHCLKRCTL	HCLKRP	x	x	x	x	x					
AHCLKRCTL	HCLKRM	x	x	x	x	x					
DLBCTL	DLBEN			x	x	x			x	x	x
DLBCTL	ORD			x	x	x			x	x	x
DLBCTL	MODE			x	x	x			x	x	x

26.3.2 Revision Identification Register (REV)

The revision identification register (REV) contains revision data for the peripheral. The REV is shown in Figure 26-35 and described in Table 26-11.

Figure 26-35. Revision Identification Register (REV)

31	0
REV	
R-4430 0A02h	

LEGEND: R = Read only; -*n* = value after reset

Table 26-11. Revision Identification Register (REV) Field Descriptions

Bit	Field	Value	Description
31-0	REV	4430 0A02h	Identifies revision of peripheral.

26.3.3 Pin Function Register (PFUNC)

The pin function register (PFUNC) specifies the function of AXR[n], ACLKX, AHCLKX, AFSX, ACLKR, AHCLKR, and AFSR pins as either a McASP pin or a general-purpose input/output (GPIO) pin. The PFUNC is shown in Figure 26-36 and described in Table 26-12.

CAUTION

Writing to Reserved Bits

Writing a value other than 0 to reserved bits in this register may cause improper device operation. This includes bits that are not implemented on a particular DSP.

Figure 26-36. Pin Function Register (PFUNC)

31	30	29	28	27	26	25	24
AFSR	AHCLKR	ACLKR	AFSX	AHCLKX	ACLKX	AMUTE	Reserved (A)
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R-0

23	16
Reserved (A)	
R-0	

15	14	13	12	11	10	9	8
AXR15	AXR14	AXR13	AXR12	AXR11	AXR10	AXR9	AXR8
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

7	6	5	4	3	2	1	0
AXR7	AXR6	AXR5	AXR4	AXR3	AXR2	AXR1	AXR0
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

A If writing to this field, always write the default value for future device compatibility.

Table 26-12. Pin Function Register (PFUNC) Field Descriptions

Bit	Field	Value	Description
31	AFSR		Determines if AFSR pin functions as McASP or GPIO.
		0	Pin functions as McASP pin.
		1	Pin functions as GPIO pin.
30	AHCLKR		Determines if AHCLKR pin functions as McASP or GPIO.
		0	Pin functions as McASP pin.
		1	Pin functions as GPIO pin.
29	ACLKR		Determines if ACLKR pin functions as McASP or GPIO.
		0	Pin functions as McASP pin.
		1	Pin functions as GPIO pin.
28	AFSX		Determines if AFSX pin functions as McASP or GPIO.
		0	Pin functions as McASP pin.
		1	Pin functions as GPIO pin.
27	AHCLKX		Determines if AHCLKX pin functions as McASP or GPIO.
		0	Pin functions as McASP pin.
		1	Pin functions as GPIO pin.
26	ACLKX		Determines if ACLKX pin functions as McASP or GPIO.
		0	Pin functions as McASP pin.
		1	Pin functions as GPIO pin.
25	AMUTE		Determines if AMUTE pin functions as McASP or GPIO.
		0	Pin functions as McASP pin.
		1	Pin functions as GPIO pin.
24-16	Reserved	0	Reserved. The reserved bit location always returns the default value. A value written to this field has no effect. If writing to this field, always write the default value for future device compatibility.
15-0	AXR[15-0]		Determines if AXR[n] pin functions as McASP or GPIO.
		0	Pin functions as McASP pin.
		1	Pin functions as GPIO pin.

26.3.4 Pin Direction Register (PDIR)

The pin direction register (PDIR) specifies the direction of AXR[n], ACLKX, AHCLKX, AFSX, ACLKR, AHCLKR, and AFSR pins as either an input or an output pin. The PDIR is shown in Figure 26-37 and described in Table 26-13.

Regardless of the pin function register (PFUNC) setting, each PDIR bit must be set to 1 for the specified pin to be enabled as an output and each PDIR bit must be cleared to 0 for the specified pin to be an input.

For example, if the McASP is configured to use an internally-generated bit clock and the clock is to be driven out to the system, the PFUNC bit must be cleared to 0 (McASP function) and the PDIR bit must be set to 1 (an output).

When AXR[n] is configured to transmit, the PFUNC bit must be cleared to 0 (McASP function) and the PDIR bit must be set to 1 (an output). Similarly, when AXR[n] is configured to receive, the PFUNC bit must be cleared to 0 (McASP function) and the PDIR bit must be cleared to 0 (an input).

CAUTION

Writing to Reserved Bits

Writing a value other than 0 to reserved bits in this register may cause improper device operation. This includes bits that are not implemented on a particular DSP.

Figure 26-37. Pin Direction Register (PDIR)

31	30	29	28	27	26	25	24
AFSR	AHCLKR	ACLKR	AFSX	AHCLKX	ACLKX	AMUTE	Reserved (A)
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R-0

23	16
Reserved (A)	
R-0	

15	14	13	12	11	10	9	8
AXR15	AXR14	AXR13	AXR12	AXR11	AXR10	AXR9	AXR8
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

7	6	5	4	3	2	1	0
AXR7	AXR6	AXR5	AXR4	AXR3	AXR2	AXR1	AXR0
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

A If writing to this field, always write the default value for future device compatibility.

Table 26-13. Pin Direction Register (PDIR) Field Descriptions

Bit	Field	Value	Description
31	AFSR		Determines if AFSR pin functions as an input or output.
		0	Pin functions as input.
		1	Pin functions as output.
30	AHCLKR		Determines if AHCLKR pin functions as an input or output.
		0	Pin functions as input.
		1	Pin functions as output.
29	ACLKR		Determines if ACLKR pin functions as an input or output.
		0	Pin functions as input.
		1	Pin functions as output.
28	AFSX		Determines if AFSX pin functions as an input or output.
		0	Pin functions as input.
		1	Pin functions as output.
27	AHCLKX		Determines if AHCLKX pin functions as an input or output.
		0	Pin functions as input.
		1	Pin functions as output.
26	ACLKX		Determines if ACLKX pin functions as an input or output.
		0	Pin functions as input.
		1	Pin functions as output.
25	AMUTE		Determines if AMUTE pin functions as an input or output.
		0	Pin functions as input.
		1	Pin functions as output.
24-16	Reserved	0	Reserved. The reserved bit location always returns the default value. A value written to this field has no effect. If writing to this field, always write the default value for future device compatibility.
15-0	AXR[15-0]		Determines if AXR[n] pin functions as an input or output.
		0	Pin functions as input.
		1	Pin functions as output.

26.3.5 Pin Data Output Register (PDOUT)

The pin data output register (PDOUT) holds a value for data out at all times, and may be read back at all times. The value held by PDOUT is not affected by writing to PDIR and PFUNC. However, the data value in PDOUT is driven out onto the McASP pin only if the corresponding bit in PFUNC is set to 1 (GPIO function) and the corresponding bit in PDIR is set to 1 (output). When reading data, returns the corresponding bit value in PDOUT[n], does not return input from I/O pin; when writing data, writes to the corresponding PDOUT[n] bit. The PDOUT is shown in Figure 26-38 and described in Table 26-14.

PDOUT has these aliases or alternate addresses:

- PDSET - when written to at this address, writing a 1 to a bit in PDSET sets the corresponding bit in PDOUT to 1; writing a 0 has no effect and keeps the bits in PDOUT unchanged.
- PDCLR - when written to at this address, writing a 1 to a bit in PDCLR clears the corresponding bit in PDOUT to 0; writing a 0 has no effect and keeps the bits in PDOUT unchanged.

There is only one set of data out bits, PDOUT[31-0]. The other registers, PDSET and PDCLR, are just different addresses for the same control bits, with different behaviors during writes.

CAUTION

Writing to Reserved Bits

Writing a value other than 0 to reserved bits in this register may cause improper device operation. This includes bits that are not implemented on a particular DSP.

Figure 26-38. Pin Data Output Register (PDOUT)

31	30	29	28	27	26	25	24
AFSR	AHCLKR	ACLKR	AFSX	AHCLKX	ACLKX	AMUTE	Reserved (A)
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R-0

23	16
Reserved (A)	
R-0	

15	14	13	12	11	10	9	8
AXR15	AXR14	AXR13	AXR12	AXR11	AXR10	AXR9	AXR8
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

7	6	5	4	3	2	1	0
AXR7	AXR6	AXR5	AXR4	AXR3	AXR2	AXR1	AXR0
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

A If writing to this field, always write the default value for future device compatibility.

Table 26-14. Pin Data Output Register (PDOUT) Field Descriptions

Bit	Field	Value	Description
31	AFSR		Determines drive on AFSR output pin when the corresponding PFUNC[31] and PDIR[31] bits are set to 1.
		0	Pin drives low.
		1	Pin drives high.
30	AHCLKR		Determines drive on AHCLKR output pin when the corresponding PFUNC[30] and PDIR[30] bits are set to 1.
		0	Pin drives low.
		1	Pin drives high.
29	ACLKR		Determines drive on ACLKR output pin when the corresponding PFUNC[29] and PDIR[29] bits are set to 1.
		0	Pin drives low.
		1	Pin drives high.
28	AFSX		Determines drive on AFSX output pin when the corresponding PFUNC[28] and PDIR[28] bits are set to 1.
		0	Pin drives low.
		1	Pin drives high.
27	AHCLKX		Determines drive on AHCLKX output pin when the corresponding PFUNC[27] and PDIR[27] bits are set to 1.
		0	Pin drives low.
		1	Pin drives high.
26	ACLKX		Determines drive on ACLKX output pin when the corresponding PFUNC[26] and PDIR[26] bits are set to 1.
		0	Pin drives low.
		1	Pin drives high.
25	AMUTE		Determines drive on AMUTE output pin when the corresponding PFUNC[25] and PDIR[25] bits are set to 1.
		0	Pin drives low.
		1	Pin drives high.
24-16	Reserved	0	Reserved. The reserved bit location always returns the default value. A value written to this field has no effect. If writing to this field, always write the default value for future device compatibility.
15-0	AXR[15-0]		Determines drive on AXR[n] output pin when the corresponding PFUNC[n] and PDIR[n] bits are set to 1.
		0	Pin drives low.
		1	Pin drives high.

26.3.6 Pin Data Input Register (PDIN)

The pin data input register (PDIN) holds the I/O pin state of each of the McASP pins. PDIN allows the actual value of the pin to be read, regardless of the state of PFUNC and PDIR. The value after reset for registers 1 through 15 and 24 through 31 depends on how the pins are being driven. The PDIN is shown in Figure 26-39 and described in Table 26-15.

CAUTION

Writing to Reserved Bits

Writing a value other than 0 to reserved bits in this register may cause improper device operation. This includes bits that are not implemented on a particular DSP.

Figure 26-39. Pin Data Input Register (PDIN)

31	30	29	28	27	26	25	24
AFSR	AHCLKR	ACLKR	AFSX	AHCLKX	ACLKX	AMUTE	Reserved (A)
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R-0

23	16
Reserved (A)	
R-0	

15	14	13	12	11	10	9	8
AXR15	AXR14	AXR13	AXR12	AXR11	AXR10	AXR9	AXR8
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

7	6	5	4	3	2	1	0
AXR7	AXR6	AXR5	AXR4	AXR3	AXR2	AXR1	AXR0
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

A If writing to this field, always write the default value for future device compatibility.

Table 26-15. Pin Data Input Register (PDIN) Field Descriptions

Bit	Field	Value	Description
31	AFSR		Logic level on AFSR pin.
		0	Pin is logic low.
		1	Pin is logic high.
30	AHCLKR		Logic level on AHCLKR pin.
		0	Pin is logic low.
		1	Pin is logic high.
29	ACLKR		Logic level on ACLKR pin.
		0	Pin is logic low.
		1	Pin is logic high.
28	AFSX		Logic level on AFSX pin.
		0	Pin is logic low.
		1	Pin is logic high.
27	AHCLKX		Logic level on AHCLKX pin.
		0	Pin is logic low.
		1	Pin is logic high.
26	ACLKX		Logic level on ACLKX pin.
		0	Pin is logic low.
		1	Pin is logic high.
25	AMUTE		Logic level on AMUTE pin.
		0	Pin is logic low.
		1	Pin is logic high.
24-16	Reserved	0	Reserved. The reserved bit location always returns the default value. A value written to this field has no effect. If writing to this field, always write the default value for future device compatibility.
15-0	AXR[15-0]		Logic level on AXR[n] pin.
		0	Pin is logic low.
		1	Pin is logic high.

26.3.7 Pin Data Set Register (PDSET)

The pin data set register (PDSET) is an alias of the pin data output register (PDOUT) for writes only. Writing a 1 to the PDSET bit sets the corresponding bit in PDOUT and, if PFUNC = 1 (GPIO function) and PDIR = 1 (output), drives a logic high on the pin. PDSET is useful for a multitasking system because it allows you to set to a logic high only the desired pin(s) within a system without affecting other I/O pins controlled by the same McASP. The PDSET is shown in Figure 26-40 and described in Table 26-16.

CAUTION

Writing to Reserved Bits

Writing a value other than 0 to reserved bits in this register may cause improper device operation. This includes bits that are not implemented on a particular DSP.

Figure 26-40. Pin Data Set Register (PDSET)

31	30	29	28	27	26	25	24
AFSR	AHCLKR	ACLKR	AFSX	AHCLKX	ACLKX	AMUTE	Reserved (A)
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R-0

23	16
Reserved (A)	
R-0	

15	14	13	12	11	10	9	8
AXR15	AXR14	AXR13	AXR12	AXR11	AXR10	AXR9	AXR8
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

7	6	5	4	3	2	1	0
AXR7	AXR6	AXR5	AXR4	AXR3	AXR2	AXR1	AXR0
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

A If writing to this field, always write the default value for future device compatibility.

Table 26-16. Pin Data Set Register (PDSET) Field Descriptions

Bit	Field	Value	Description
31	AFSR		Allows the corresponding AFSR bit in PDOUT to be set to a logic high without affecting other I/O pins controlled by the same port.
		0	No effect.
		1	PDOUT[31] bit is set to 1.
30	AHCLKR		Allows the corresponding AHCLKR bit in PDOUT to be set to a logic high without affecting other I/O pins controlled by the same port.
		0	No effect.
		1	PDOUT[30] bit is set to 1.
29	ACLKR		Allows the corresponding ACLKR bit in PDOUT to be set to a logic high without affecting other I/O pins controlled by the same port.
		0	No effect.
		1	PDOUT[29] bit is set to 1.
28	AFSX		Allows the corresponding AFSX bit in PDOUT to be set to a logic high without affecting other I/O pins controlled by the same port.
		0	No effect.
		1	PDOUT[28] bit is set to 1.
27	AHCLKX		Allows the corresponding AHCLKX bit in PDOUT to be set to a logic high without affecting other I/O pins controlled by the same port.
		0	No effect.
		1	PDOUT[27] bit is set to 1.
26	ACLKX		Allows the corresponding ACLKX bit in PDOUT to be set to a logic high without affecting other I/O pins controlled by the same port.
		0	No effect.
		1	PDOUT[26] bit is set to 1.
25	AMUTE		Allows the corresponding AMUTE bit in PDOUT to be set to a logic high without affecting other I/O pins controlled by the same port.
		0	No effect.
		1	PDOUT[25] bit is set to 1.
24-16	Reserved	0	Reserved. The reserved bit location always returns the default value. A value written to this field has no effect. If writing to this field, always write the default value for future device compatibility.
15-0	AXR[15-0]		Allows the corresponding AXR[n] bit in PDOUT to be set to a logic high without affecting other I/O pins controlled by the same port.
		0	No effect.
		1	PDOUT[n] bit is set to 1.

26.3.8 Pin Data Clear Register (PDCLR)

The pin data clear register (PDCLR) is an alias of the pin data output register (PDOUT) for writes only. Writing a 1 to the PDCLR bit clears the corresponding bit in PDOUT and, if PFUNC = 1 (GPIO function) and PDIR = 1 (output), drives a logic low on the pin. PDCLR is useful for a multitasking system because it allows you to clear to a logic low only the desired pin(s) within a system without affecting other I/O pins controlled by the same McASP. The PDCLR is shown in Figure 26-41 and described in Table 26-17.

CAUTION

Writing to Reserved Bits

Writing a value other than 0 to reserved bits in this register may cause improper device operation. This includes bits that are not implemented on a particular DSP.

Figure 26-41. Pin Data Clear Register (PDCLR)

31	30	29	28	27	26	25	24
AFSR	AHCLKR	ACLKR	AFSX	AHCLKX	ACLKX	AMUTE	Reserved (A)
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R-0

23	16
Reserved (A)	
R-0	

15	14	13	12	11	10	9	8
AXR15	AXR14	AXR13	AXR12	AXR11	AXR10	AXR9	AXR8
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

7	6	5	4	3	2	1	0
AXR7	AXR6	AXR5	AXR4	AXR3	AXR2	AXR1	AXR0
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

A If writing to this field, always write the default value for future device compatibility.

Table 26-17. Pin Data Clear Register (PDCLR) Field Descriptions

Bit	Field	Value	Description
31	AFSR		Allows the corresponding AFSR bit in PDOUT to be cleared to a logic low without affecting other I/O pins controlled by the same port.
		0	No effect.
		1	PDOUT[31] bit is cleared to 0.
30	AHCLKR		Allows the corresponding AHCLKR bit in PDOUT to be cleared to a logic low without affecting other I/O pins controlled by the same port.
		0	No effect.
		1	PDOUT[30] bit is cleared to 0.
29	ACLKR		Allows the corresponding ACLKR bit in PDOUT to be cleared to a logic low without affecting other I/O pins controlled by the same port.
		0	No effect.
		1	PDOUT[29] bit is cleared to 0.
28	AFSX		Allows the corresponding AFSX bit in PDOUT to be cleared to a logic low without affecting other I/O pins controlled by the same port.
		0	No effect.
		1	PDOUT[28] bit is cleared to 0.
27	AHCLKX		Allows the corresponding AHCLKX bit in PDOUT to be cleared to a logic low without affecting other I/O pins controlled by the same port.
		0	No effect.
		1	PDOUT[27] bit is cleared to 0.
26	ACLKX		Allows the corresponding ACLKX bit in PDOUT to be cleared to a logic low without affecting other I/O pins controlled by the same port.
		0	No effect.
		1	PDOUT[26] bit is cleared to 0.
25	AMUTE		Allows the corresponding AMUTE bit in PDOUT to be cleared to a logic low without affecting other I/O pins controlled by the same port.
		0	No effect.
		1	PDOUT[25] bit is cleared to 0.
24-16	Reserved	0	Reserved. The reserved bit location always returns the default value. A value written to this field has no effect. If writing to this field, always write the default value for future device compatibility.
15-0	AXR[15-0]		Allows the corresponding AXR[n] bit in PDOUT to be cleared to a logic low without affecting other I/O pins controlled by the same port.
		0	No effect.
		1	PDOUT[n] bit is cleared to 0.

26.3.9 Global Control Register (GBLCTL)

The global control register (GBLCTL) provides initialization of the transmit and receive sections. The GBLCTL is shown in Figure 26-42 and described in Table 26-18.

The bit fields in GBLCTL are synchronized and latched by the corresponding clocks (ACLKX for bits 12-8 and ACLKR for bits 4-0). Before GBLCTL is programmed, you must ensure that serial clocks are running. If the corresponding external serial clocks, ACLKX and ACLKR, are not yet running, you should select the internal serial clock source in AHCLKXCTL, AHCLKRCTL, ACLKXCTL, and ACLKRCTL before GBLCTL is programmed. Also, after programming any bits in GBLCTL you should not proceed until you have read back from GBLCTL and verified that the bits are latched in GBLCTL.

Figure 26-42. Global Control Register (GBLCTL)

31	16
Reserved (A)	
R-0	

15	13	12	11	10	9	8
Reserved (A)		XFRST	XSMRST	XSRCLR	XHCLKRST	XCLKRST
R-0		R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

7	5	4	3	2	1	0
Reserved (A)		RFRST	RSMRST	RSRCLR	RHCLKRST	RCLKRST
R-0		R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

A If writing to this field, always write the default value for future device compatibility.

Table 26-18. Global Control Register (GBLCTL) Field Descriptions

Bit	Field	Value	Description
31-13	Reserved	0	Reserved. The reserved bit location always returns the default value. A value written to this field has no effect. If writing to this field, always write the default value for future device compatibility.
12	XFRST		Transmit frame sync generator reset enable bit.
		0	Transmit frame sync generator is reset.
		1	Transmit frame sync generator is active. When released from reset, the transmit frame sync generator begins counting serial clocks and generating frame sync as programmed.
11	XSMRST		Transmit state machine reset enable bit.
		0	Transmit state machine is held in reset. AXR[n] pin state: If PFUNC[n] = 0 and PDIR[n] = 1; then the serializer drives the AXR[n] pin to the state specified for inactive time slot (as determined by DISMOD bits in SRCTL).
		1	Transmit state machine is released from reset. When released from reset, the transmit state machine immediately transfers data from XRBUF[n] to XRSR[n]. The transmit state machine sets the underrun flag (XUNDRN) in XSTAT, if XRBUF[n] have not been preloaded with data before reset is released. The transmit state machine also immediately begins detecting frame sync and is ready to transmit. Transmit TDM time slot begins at slot 0 after reset is released.
10	XSRCLR		Transmit serializer clear enable bit. By clearing then setting this bit, the transmit buffer is flushed to an empty state (XDATA = 1). If XSMRST = 1, XSRCLR = 1, XDATA = 1, and XBUF is not loaded with new data before the start of the next active time slot, an underrun will occur.
		0	Transmit serializers are cleared.
		1	Transmit serializers are active. When the transmit serializers are first taken out of reset (XSRCLR changes from 0 to 1), the transmit data ready bit (XDATA) in XSTAT is set to indicate XBUF is ready to be written.
9	XHCLKRST		Transmit high-frequency clock divider reset enable bit.
		0	Transmit high-frequency clock divider is held in reset.
		1	Transmit high-frequency clock divider is running.

Table 26-18. Global Control Register (GBLCTL) Field Descriptions (continued)

Bit	Field	Value	Description
8	XCLKRST		Transmit clock divider reset enable bit.
		0	Transmit clock divider is held in reset. When the clock divider is in reset, it passes through a divide-by-1 of its input.
		1	Transmit clock divider is running.
7-5	Reserved	0	Reserved. The reserved bit location always returns the default value. A value written to this field has no effect. If writing to this field, always write the default value for future device compatibility.
4	RFRST		Receive frame sync generator reset enable bit.
		0	Receive frame sync generator is reset.
		1	Receive frame sync generator is active. When released from reset, the receive frame sync generator begins counting serial clocks and generating frame sync as programmed.
3	RSMRST		Receive state machine reset enable bit.
		0	Receive state machine is held in reset.
		1	Receive state machine is released from reset. When released from reset, the receive state machine immediately begins detecting frame sync and is ready to receive. Receive TDM time slot begins at slot 0 after reset is released.
2	RSRCLR		Receive serializer clear enable bit. By clearing then setting this bit, the receive buffer is flushed.
		0	Receive serializers are cleared.
		1	Receive serializers are active.
1	RHCLKRST		Receive high-frequency clock divider reset enable bit.
		0	Receive high-frequency clock divider is held in reset.
		1	Receive high-frequency clock divider is running.
0	RCLKRST		Receive clock divider reset enable bit.
		0	Receive clock divider is held in reset. When the clock divider is in reset, it passes through a divide-by-1 of its input.
		1	Receive clock divider is running.

26.3.10 Audio Mute Control Register (AMUTE)

The audio mute control register (AMUTE) controls the McASP audio mute (AMUTE) output pin. The value after reset for register 4 depends on how the pins are being driven. The AMUTE is shown in Figure 26-43 and described in Table 26-19.

Figure 26-43. Audio Mute Control Register (AMUTE)

31							16
Reserved [A]							
R-0							
15		13	12	11	10	9	8
Reserved [A]			XDMAERR	RDMAERR	XCKFAIL	RCKFAIL	XSYNCERR
R-0			R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
7	6	5	4	3	2	1	0
RSYNCERR	XUNDRN	ROVRN	INSTAT	INEN	INPOL	MUTEN	
R/W-0	R/W-0	R/W-0	R-0	R/W-0	R/W-0	R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

A If writing to this field, always write the default value for future device compatibility.

Table 26-19. Audio Mute Control Register (AMUTE) Field Descriptions

Bit	Field	Value	Description
31-13	Reserved	0	Reserved. The reserved bit location always returns the default value. A value written to this field has no effect. If writing to this field, always write the default value for future device compatibility.
12	XDMAERR		If transmit DMA error (XDMAERR), drive AMUTE active enable bit.
		0	Drive is disabled. Detection of transmit DMA error is ignored by AMUTE.
		1	Drive is enabled (active). Upon detection of transmit DMA error, AMUTE is active and is driven according to MUTEN bit.
11	RDMAERR		If receive DMA error (RDMAERR), drive AMUTE active enable bit.
		0	Drive is disabled. Detection of receive DMA error is ignored by AMUTE.
		1	Drive is enabled (active). Upon detection of receive DMA error, AMUTE is active and is driven according to MUTEN bit.
10	XCKFAIL		If transmit clock failure (XCKFAIL), drive AMUTE active enable bit.
		0	Drive is disabled. Detection of transmit clock failure is ignored by AMUTE.
		1	Drive is enabled (active). Upon detection of transmit clock failure, AMUTE is active and is driven according to MUTEN bit
9	RCKFAIL		If receive clock failure (RCKFAIL), drive AMUTE active enable bit.
		0	Drive is disabled. Detection of receive clock failure is ignored by AMUTE.
		1	Drive is enabled (active). Upon detection of receive clock failure, AMUTE is active and is driven according to MUTEN bit.
8	XSYNCERR		If unexpected transmit frame sync error (XSYNCERR), drive AMUTE active enable bit.
		0	Drive is disabled. Detection of unexpected transmit frame sync error is ignored by AMUTE.
		1	Drive is enabled (active). Upon detection of unexpected transmit frame sync error, AMUTE is active and is driven according to MUTEN bit.
7	RSYNCERR		If unexpected receive frame sync error (RSYNCERR), drive AMUTE active enable bit.
		0	Drive is disabled. Detection of unexpected receive frame sync error is ignored by AMUTE.
		1	Drive is enabled (active). Upon detection of unexpected receive frame sync error, AMUTE is active and is driven according to MUTEN bit.
6	XUNDRN		If transmit underrun error (XUNDRN), drive AMUTE active enable bit.
		0	Drive is disabled. Detection of transmit underrun error is ignored by AMUTE.
		1	Drive is enabled (active). Upon detection of transmit underrun error, AMUTE is active and is driven according to MUTEN bit.

Table 26-19. Audio Mute Control Register (AMUTE) Field Descriptions (continued)

Bit	Field	Value	Description
5	ROVRN		If receiver overrun error (ROVRN), drive AMUTE active enable bit.
		0	Drive is disabled. Detection of receiver overrun error is ignored by AMUTE.
		1	Drive is enabled (active). Upon detection of receiver overrun error, AMUTE is active and is driven according to MUTEN bit.
4	INSTAT		Determines drive on AXR[n] pin when PFUNC[n] and PDIR[n] bits are set to 1.
		0	AMUTEIN pin is inactive.
		1	AMUTEIN pin is active. Audio mute in error is detected.
3	INEN		Drive AMUTE active when AMUTEIN error is active (INSTAT = 1).
		0	Drive is disabled. AMUTEIN is ignored by AMUTE.
		1	Drive is enabled (active). INSTAT = 1 drives AMUTE active.
2	INPOL		Audio mute in (AMUTEIN) polarity select bit.
		0	Polarity is active high. A high on AMUTEIN sets INSTAT to 1.
		1	Polarity is active low. A low on AMUTEIN sets INSTAT to 1.
1-0	MUTEN	0-3h	AMUTE pin enable bit (unless overridden by GPIO registers).
		0	AMUTE pin is disabled, pin goes to tri-state condition.
		1h	AMUTE pin is driven high if error is detected.
		2h	AMUTE pin is driven low if error is detected.
		3h	Reserved

26.3.11 Digital Loopback Control Register (DLBCTL)

The digital loopback control register (DLBCTL) controls the internal loopback settings of the McASP in TDM mode. The DLBCTL is shown in Figure 26-44 and described in Table 26-20.

Figure 26-44. Digital Loopback Control Register (DLBCTL)

31	16
Reserved (A)	
R-0	

15	4	3	2	1	0
Reserved (A)		MODE		ORD	DLBEN
R-0		R/W-0		R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

A If writing to this field, always write the default value for future device compatibility.

Table 26-20. Digital Loopback Control Register (DLBCTL) Field Descriptions

Bit	Field	Value	Description
31-4	Reserved	0	Reserved. The reserved bit location always returns the default value. A value written to this field has no effect. If writing to this field, always write the default value for future device compatibility.
3-2	MODE	0-3h	Loopback generator mode bits. Applies only when loopback mode is enabled (DLBEN = 1).
		0	Default and reserved on loopback mode (DLBEN = 1). When in non-loopback mode (DLBEN = 0), MODE should be left at default (00). When in loopback mode (DLBEN = 1), MODE = 00 is reserved and not applicable.
		1h	Transmit clock and frame sync generators used by both transmit and receive sections. When in loopback mode (DLBEN = 1), MODE must be 01.
		2h-3h	Reserved.
1	ORD		Loopback order bit when loopback mode is enabled (DLBEN = 1).
		0	Odd serializers N + 1 transmit to even serializers N that receive. The corresponding serializers must be programmed properly.
		1	Even serializers N transmit to odd serializers N+1 that receive. The corresponding serializers must be programmed properly.
0	DLBEN		Loopback mode enable bit.
		0	Loopback mode is disabled.
		1	Loopback mode is enabled.

26.3.12 Digital Mode Control Register (DITCTL)

The DIT mode control register (DITCTL) controls DIT operations of the McASP. The DITCTL is shown in Figure 26-45 and described in Table 26-21.

Figure 26-45. Digital Mode Control Register (DITCTL)

31	16
Reserved [A]	
R-0	

15	4	3	2	1	0
Reserved [A]		VB	VA	Rsvd [A]	DITEN
R-0		R/W-0	R/W-0	R-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

A If writing to this field, always write the default value for future device compatibility.

Table 26-21. Digital Mode Control Register (DITCTL) Field Descriptions

Bit	Field	Value	Description
31-4	Reserved	0	Reserved. The reserved bit location always returns the default value. A value written to this field has no effect. If writing to this field, always write the default value for future device compatibility.
3	VB		Valid bit for odd time slots (DIT right subframe).
		0	V bit is 0 during odd DIT subframes.
		1	V bit is 1 during odd DIT subframes.
2	VA		Valid bit for even time slots (DIT left subframe).
		0	V bit is 0 during even DIT subframes.
		1	V bit is 1 during even DIT subframes.
1	Reserved	0	Reserved. The reserved bit location always returns the default value. A value written to this field has no effect. If writing to this field, always write the default value for future device compatibility.
0	DITEN		DIT mode enable bit. DITEN should only be changed while the XSMRST bit in GBLCTL is in reset (and for startup, XSRCLR also in reset). However, it is not necessary to reset the XCLKRST or XHCLKRST bits in GBLCTL to change DITEN.
		0	DIT mode is disabled. Transmitter operates in TDM or burst mode.
		1	DIT mode is enabled. Transmitter operates in DIT encoded mode.

26.3.13 Receiver Global Control Register (RGBLCTL)

Alias of the global control register (GBLCTL). Writing to the receiver global control register (RGBLCTL) affects only the receive bits of GBLCTL (bits 4-0). Reads from RGBLCTL return the value of GBLCTL. RGBLCTL allows the receiver to be reset independently from the transmitter. The RGBLCTL is shown in Figure 26-46 and described in Table 26-22. See Section 26.3.9 for a detailed description of GBLCTL.

Figure 26-46. Receiver Global Control Register (RGBLCTL)

31	16
Reserved (A)	
R-0	

15	13	12	11	10	9	8
Reserved (A)		XFRST	XSMRST	XSRCLR	XHCLKRST	XCLKRST
R-0		R-0	R-0	R-0	R-0	R-0

7	5	4	3	2	1	0
Reserved (A)		RFRST	RSMRST	RSRCLR	RHCLKRST	RCLKRST
R-0		R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

A If writing to this field, always write the default value for future device compatibility.

Table 26-22. Receiver Global Control Register (RGBLCTL) Field Descriptions

Bit	Field	Value	Description
31-13	Reserved	0	Reserved. The reserved bit location always returns the default value. A value written to this field has no effect. If writing to this field, always write the default value for future device compatibility.
12	XFRST	x	Transmit frame sync generator reset enable bit. A read of this bit returns the XFRST bit value of GBLCTL. Writes have no effect.
11	XSMRST	x	Transmit state machine reset enable bit. A read of this bit returns the XSMRST bit value of GBLCTL. Writes have no effect.
10	XSRCLR	x	Transmit serializer clear enable bit. A read of this bit returns the XSRCLR bit value of GBLCTL. Writes have no effect.
9	XHCLKRST	x	Transmit high-frequency clock divider reset enable bit. A read of this bit returns the XHCLKRST bit value of GBLCTL. Writes have no effect.
8	XCLKRST	x	Transmit clock divider reset enable bit. a read of this bit returns the XCLKRST bit value of GBLCTL. Writes have no effect.
7-5	Reserved	0	Reserved. The reserved bit location always returns the default value. A value written to this field has no effect. If writing to this field, always write the default value for future device compatibility.
4	RFRST		Receive frame sync generator reset enable bit. A write to this bit affects the RFRST bit of GBLCTL.
		0	Receive frame sync generator is reset.
		1	Receive frame sync generator is active.
3	RSMRST		Receive state machine reset enable bit. A write to this bit affects the RSMRST bit of GBLCTL.
		0	Receive state machine is held in reset.
		1	Receive state machine is released from reset.
2	RSRCLR		Receive serializer clear enable bit. A write to this bit affects the RSRCLR bit of GBLCTL.
		0	Receive serializers are cleared.
		1	Receive serializers are active.
1	RHCLKRST		Receive high-frequency clock divider reset enable bit. A write to this bit affects the RHCLKRST bit of GBLCTL.
		0	Receive high-frequency clock divider is held in reset.
		1	Receive high-frequency clock divider is running.
0	RCLKRST		Receive clock divider reset enable bit. A write to this bit affects the RCLKRST bit of GBLCTL.
		0	Receive clock divider is held in reset.
		1	Receive clock divider is running.

26.3.14 Receive Format Unit Bit Mask Register (RMASK)

The receive format unit bit mask register (RMASK) determines which bits of the received data are masked off and padded with a known value before being read by the CPU or DMA. The RMASK is shown in Figure 26-47 and described in Table 26-23.

Figure 26-47. Receive Format Unit Bit Mask Register (RMASK)

31	30	29	28	27	26	25	24
RMASK31	RMASK30	RMASK29	RMASK28	RMASK27	RMASK26	RMASK25	RMASK24
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
23	22	21	20	19	18	17	16
RMASK23	RMASK22	RMASK21	RMASK20	RMASK19	RMASK18	RMASK17	RMASK16
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
15	14	13	12	11	10	9	8
RMASK15	RMASK14	RMASK13	RMASK12	RMASK11	RMASK10	RMASK9	RMASK8
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
7	6	5	4	3	2	1	0
RMASK7	RMASK6	RMASK5	RMASK4	RMASK3	RMASK2	RMASK1	RMASK0
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; -*n* = value after reset

Table 26-23. Receive Format Unit Bit Mask Register (RMASK) Field Descriptions

Bit	Field	Value	Description
31-0	RMASK[31-0]		Receive data mask enable bit.
		0	Corresponding bit of receive data (after passing through reverse and rotate units) is masked out and then padded with the selected bit pad value (RPAD and RPBIT bits in RFMT).
		1	Corresponding bit of receive data (after passing through reverse and rotate units) is returned to CPU or DMA.

26.3.15 Receive Bit Stream Format Register (RFMT)

The receive bit stream format register (RFMT) configures the receive data format. The RFMT is shown in Figure 26-48 and described in Table 26-24.

Figure 26-48. Receive Bit Stream Format Register (RFMT)

31																18	17	16
Reserved [A]																	RDATDLY	
R-0																	R/W-0	

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RRVRS	RPAD		RPBIT					RSSZ				RBUSEL	RROT		
R/W-0	R/W-0		R/W-0					R/W-0				R/W-0	R/W-0		

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

A If writing to this field, always write the default value for future device compatibility.

Table 26-24. Receive Bit Stream Format Register (RFMT) Field Descriptions

Bit	Field	Value	Description
31-18	Reserved	0	Reserved. The reserved bit location always returns the default value. A value written to this field has no effect. If writing to this field, always write the default value for future device compatibility.
17-16	RDATDLY	0-3h	Receive bit delay.
		0	0-bit delay. The first receive data bit, AXR[n], occurs in same ACLKR cycle as the receive frame sync (AFSR).
		1h	1-bit delay. The first receive data bit, AXR[n], occurs one ACLKR cycle after the receive frame sync (AFSR).
		2h	2-bit delay. The first receive data bit, AXR[n], occurs two ACLKR cycles after the receive frame sync (AFSR).
		3h	Reserved.
15	RRVRS		Receive serial bitstream order.
		0	Bitstream is LSB first. No bit reversal is performed in receive format bit reverse unit.
		1	Bitstream is MSB first. Bit reversal is performed in receive format bit reverse unit.
14-13	RPAD	0-3h	Pad value for extra bits in slot not belonging to the word. This field only applies to bits when RMASK[n] = 0.
		0	Pad extra bits with 0.
		1h	Pad extra bits with 1.
		2h	Pad extra bits with one of the bits from the word as specified by RPBIT bits.
		3h	Reserved.
12-8	RPBIT	0-1Fh	RPBIT value determines which bit (as read by the CPU or DMA from RBUF[n]) is used to pad the extra bits. This field only applies when RPAD = 2h.
		0	Pad with bit 0 value.
		1h-1Fh	Pad with bit 1 to bit 31 value.

Table 26-24. Receive Bit Stream Format Register (RFMT) Field Descriptions (continued)

Bit	Field	Value	Description
7-4	RSSZ	0-Fh	Receive slot size.
		0-2h	Reserved
		3h	Slot size is 8 bits.
		4h	Reserved
		5h	Slot size is 12 bits.
		6h	Reserved
		7h	Slot size is 16 bits.
		8h	Reserved
		9h	Slot size is 20 bits.
		Ah	Reserved
		Bh	Slot size is 24 bits
		Ch	Reserved
		Dh	Slot size is 28 bits.
		Eh	Reserved
		Fh	Slot size is 32 bits.
3	RBUSEL		Selects whether reads from serializer buffer XRBUF[n] by way of RBUF*n* by the CPU/EDMA occur through the peripheral configuration port or the DMA port.
		0	Reads from XRBUF[n] originate on the DMA port. Reads from XRBUF[n] on the peripheral configuration port are ignored.
		1	Reads from XRBUF[n] originate on the peripheral configuration port. Reads from XRBUF[n] on the DMA port are ignored.
2-0	RROT	0-7h	Right-rotation value for receive rotate right format unit.
		0	Rotate right by 0 (no rotation).
		1h	Rotate right by 4 bit positions.
		2h	Rotate right by 8 bit positions.
		3h	Rotate right by 12 bit positions.
		4h	Rotate right by 16 bit positions.
		5h	Rotate right by 20 bit positions.
		6h	Rotate right by 24 bit positions.
		7h	Rotate right by 28 bit positions.

26.3.16 Receive Frame Sync Control Register (AFSRCTL)

The receive frame sync control register (AFSRCTL) configures the receive frame sync (AFSR). The AFSRCTL is shown in Figure 26-49 and described in Table 26-25.

Figure 26-49. Receive Frame Sync Control Register (AFSRCTL)

31	16
Reserved [A]	
R-0	

15	7	6	5	4	3	2	1	0
RMOD		Reserved [A]		FRWID	Reserved [A]		FSRM	FSRP
R/W-0		R-0		R/W-0	R-0		R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

A If writing to this field, always write the default value for future device compatibility.

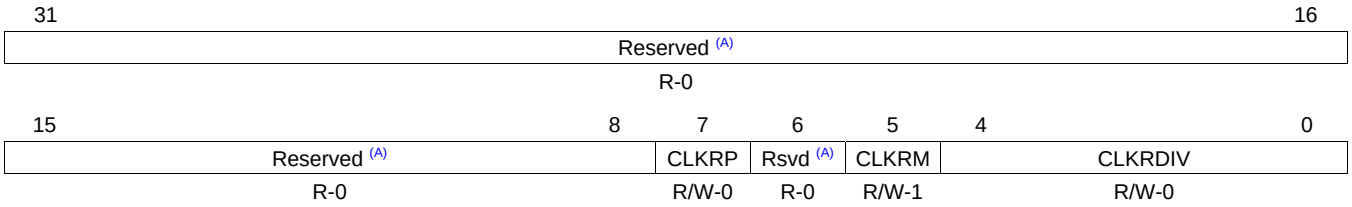
Table 26-25. Receive Frame Sync Control Register (AFSRCTL) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	Reserved. The reserved bit location always returns the default value. A value written to this field has no effect. If writing to this field, always write the default value for future device compatibility.
15-7	RMOD	0-1FFh	Receive frame sync mode select bits.
		0	Burst mode
		1h	Reserved
		2h-20h	2-slot TDM (I2S mode) to 32-slot TDM
		21h-17Fh	Reserved
		180h	384-slot TDM (external DIR IC inputting 384-slot DIR frames to McASP over I2S interface)
		181h-1FFh	Reserved
6-5	Reserved	0	Reserved. The reserved bit location always returns the default value. A value written to this field has no effect. If writing to this field, always write the default value for future device compatibility.
4	FRWID		Receive frame sync width select bit indicates the width of the receive frame sync (AFSR) during its active period.
		0	Single bit
		1	Single word
3-2	Reserved	0	Reserved. The reserved bit location always returns the default value. A value written to this field has no effect. If writing to this field, always write the default value for future device compatibility.
1	FSRM		Receive frame sync generation select bit.
		0	Externally-generated receive frame sync
		1	Internally-generated receive frame sync
0	FSRP		Receive frame sync polarity select bit.
		0	A rising edge on receive frame sync (AFSR) indicates the beginning of a frame.
		1	A falling edge on receive frame sync (AFSR) indicates the beginning of a frame.

26.3.17 Receive Clock Control Register (ACLKRCTL)

The receive clock control register (ACLKRCTL) configures the receive bit clock (ACLKR) and the receive clock generator. The ACLKRCTL is shown in Figure 26-50 and described in Table 26-26.

Figure 26-50. Receive Clock Control Register (ACLKRCTL)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

A If writing to this field, always write the default value for future device compatibility.

Table 26-26. Receive Clock Control Register (ACLKRCTL) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved. The reserved bit location always returns the default value. A value written to this field has no effect. If writing to this field, always write the default value for future device compatibility.
7	CLKRP		Receive bitstream clock polarity select bit. Note that this bitfield does not have any effect, if ACLKXCTL.ASYNC = 0 (see Section 26.3.29 for a description for the ASYNC bit).
		0	Falling edge. Receiver samples data on the falling edge of the serial clock, so the external transmitter driving this receiver must shift data out on the rising edge of the serial clock.
		1	Rising edge. Receiver samples data on the rising edge of the serial clock, so the external transmitter driving this receiver must shift data out on the falling edge of the serial clock.
6	Reserved	0	Reserved. The reserved bit location always returns the default value. A value written to this field has no effect. If writing to this field, always write the default value for future device compatibility.
5	CLKRM		Receive bit clock source bit. Note that this bitfield does not have any effect, if ACLKXCTL.ASYNC = 0 (see Section 26.3.29 for a description for the ASYNC bit).
		0	External receive clock source from ACLKR pin.
		1	Internal receive clock source from output of programmable bit clock divider.
4-0	CLKRDIV	0-1Fh	Receive bit clock divide ratio bits determine the divide-down ratio from AHCLKR to ACLKR. Note that this bitfield does not have any effect, if ACLKXCTL.ASYNC = 0 (see Section 26.3.29 for a description for the ASYNC bit).
		0	Divide-by-1
		1h	Divide-by-2
		2h-1Fh	Divide-by-3 to divide-by-32

26.3.18 Receive High-Frequency Clock Control Register (AHCLKRCTL)

The receive high-frequency clock control register (AHCLKRCTL) configures the receive high-frequency master clock (AHCLKR) and the receive clock generator. The AHCLKRCTL is shown in Figure 26-51 and described in Table 26-27.

Figure 26-51. Receive High-Frequency Clock Control Register (AHCLKRCTL)

31					16
Reserved [A]					
R-0					

15	14	13	12	11	0
HCLKRM	HCLKRP	Reserved [A]		HCLKRDIV	
R/W-1	R/W-0	R/W-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

A If writing to this field, always write the default value for future device compatibility.

Table 26-27. Receive High-Frequency Clock Control Register (AHCLKRCTL) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	Reserved. The reserved bit location always returns the default value. A value written to this field has no effect. If writing to this field, always write the default value for future device compatibility.
15	HCLKRM		Receive high-frequency clock source bit.
		0	External receive high-frequency clock source from AHCLKR pin.
		1	Internal receive high-frequency clock source from output of programmable high clock divider.
14	HCLKRP		Receive bitstream high-frequency clock polarity select bit.
		0	Not inverted. AHCLKR is not inverted before programmable bit clock divider. In the special case where the receive bit clock (ACLKR) is internally generated and the programmable bit clock divider is set to divide-by-1 (CLKRDIV = 0 in ACLKRCTL), AHCLKR is directly passed through to the ACLKR pin.
		1	Inverted. AHCLKR is inverted before programmable bit clock divider. In the special case where the receive bit clock (ACLKR) is internally generated and the programmable bit clock divider is set to divide-by-1 (CLKRDIV = 0 in ACLKRCTL), AHCLKR is directly passed through to the ACLKR pin.
13-12	Reserved	0	Reserved. The reserved bit location always returns the default value. A value written to this field has no effect. If writing to this field, always write the default value for future device compatibility.
11-0	HCLKRDIV	0-FFFh	Receive high-frequency clock divide ratio bits determine the divide-down ratio from AUXCLK to AHCLKR.
		0	Divide-by-1
		1h	Divide-by-2
		2h-FFFh	Divide-by-3 to divide-by-4096

26.3.19 Receive TDM Time Slot Register (RTDM)

The receive TDM time slot register (RTDM) specifies which TDM time slot the receiver is active. The RTDM is shown in Figure 26-52 and described in Table 26-28.

Figure 26-52. Receive TDM Time Slot Register (RTDM)

31	30	29	28	27	26	25	24
RTDMS31	RTDMS30	RTDMS29	RTDMS28	RTDMS27	RTDMS26	RTDMS25	RTDMS24
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
23	22	21	20	19	18	17	16
RTDMS23	RTDMS22	RTDMS21	RTDMS20	RTDMS19	RTDMS18	RTDMS17	RTDMS16
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
15	14	13	12	11	10	9	8
RTDMS15	RTDMS14	RTDMS13	RTDMS12	RTDMS11	RTDMS10	RTDMS9	RTDMS8
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
7	6	5	4	3	2	1	0
RTDMS7	RTDMS6	RTDMS5	RTDMS4	RTDMS3	RTDMS2	RTDMS1	RTDMS0
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; -*n* = value after reset

Table 26-28. Receive TDM Time Slot Register (RTDM) Field Descriptions

Bit	Field	Value	Description
31-0	RTDMS[31-0]		Receiver mode during TDM time slot *n*.
		0	Receive TDM time slot *n* is inactive. The receive serializer does not shift in data during this slot.
		1	Receive TDM time slot *n* is active. The receive serializer shifts in data during this slot.

26.3.20 Receiver Interrupt Control Register (RINTCTL)

The receiver interrupt control register (RINTCTL) controls generation of the McASP receive interrupt (RINT). When the register bit(s) is set to 1, the occurrence of the enabled McASP condition(s) generates RINT. The RINTCTL is shown in Figure 26-53 and described in Table 26-29. See Section 26.3.21 for a description of the interrupt conditions.

Figure 26-53. Receiver Interrupt Control Register (RINTCTL)

31							8
Reserved (A)							
R-0							
7	6	5	4	3	2	1	0
RSTAFRM	Reserved (A)	RDATA	RLAST	RDMAERR	RCKFAIL	RSYNCERR	ROVRN
R/W-0	R-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

A If writing to this field, always write the default value for future device compatibility.

Table 26-29. Receiver Interrupt Control Register (RINTCTL) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved. The reserved bit location always returns the default value. A value written to this field has no effect. If writing to this field, always write the default value for future device compatibility.
7	RSTAFRM		Receive start of frame interrupt enable bit.
		0	Interrupt is disabled. A receive start of frame interrupt does not generate a McASP receive interrupt (RINT).
		1	Interrupt is enabled. A receive start of frame interrupt generates a McASP receive interrupt (RINT).
6	Reserved	0	Reserved. The reserved bit location always returns the default value. A value written to this field has no effect. If writing to this field, always write the default value for future device compatibility.
5	RDATA		Receive data ready interrupt enable bit.
		0	Interrupt is disabled. A receive data ready interrupt does not generate a McASP receive interrupt (RINT).
		1	Interrupt is enabled. A receive data ready interrupt generates a McASP receive interrupt (RINT).
4	RLAST		Receive last slot interrupt enable bit.
		0	Interrupt is disabled. A receive last slot interrupt does not generate a McASP receive interrupt (RINT).
		1	Interrupt is enabled. A receive last slot interrupt generates a McASP receive interrupt (RINT).
3	RDMAERR		Receive DMA error interrupt enable bit.
		0	Interrupt is disabled. A receive DMA error interrupt does not generate a McASP receive interrupt (RINT).
		1	Interrupt is enabled. A receive DMA error interrupt generates a McASP receive interrupt (RINT).
2	RCKFAIL		Receive clock failure interrupt enable bit.
		0	Interrupt is disabled. A receive clock failure interrupt does not generate a McASP receive interrupt (RINT).
		1	Interrupt is enabled. A receive clock failure interrupt generates a McASP receive interrupt (RINT).
1	RSYNCERR		Unexpected receive frame sync interrupt enable bit.
		0	Interrupt is disabled. An unexpected receive frame sync interrupt does not generate a McASP receive interrupt (RINT).
		1	Interrupt is enabled. An unexpected receive frame sync interrupt generates a McASP receive interrupt (RINT).
0	ROVRN		Receiver overrun interrupt enable bit.
		0	Interrupt is disabled. A receiver overrun interrupt does not generate a McASP receive interrupt (RINT).
		1	Interrupt is enabled. A receiver overrun interrupt generates a McASP receive interrupt (RINT).

26.3.21 Receiver Status Register (RSTAT)

The receiver status register (RSTAT) provides the receiver status and receive TDM time slot number. If the McASP logic attempts to set an interrupt flag in the same cycle that the CPU writes to the flag to clear it, the McASP logic has priority and the flag remains set. This also causes a new interrupt request to be generated. The RSTAT is shown in Figure 26-54 and described in Table 26-30.

Figure 26-54. Receiver Status Register (RSTAT)

31							9	8
Reserved (A)								RERR
R-0								R/W-0
7	6	5	4	3	2	1		0
RDMAERR	RSTAFRM	RDATA	RLAST	RTDMSLOT	RCKFAIL	RSYNCERR		ROVRN
R/W-0	R/W-0	R/W-0	R/W-0	R-0	R/W-0	R/W-0		R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

A If writing to this field, always write the default value for future device compatibility.

Table 26-30. Receiver Status Register (RSTAT) Field Descriptions

Bit	Field	Value	Description
31-9	Reserved	0	Reserved. The reserved bit location always returns the default value. A value written to this field has no effect. If writing to this field, always write the default value for future device compatibility.
8	RERR		RERR bit always returns a logic-OR of: ROVRN | RSYNCERR | RCKFAIL | RDMAERR Allows a single bit to be checked to determine if a receiver error interrupt has occurred.
		0	No errors have occurred.
		1	An error has occurred.
7	RDMAERR		Receive DMA error flag. RDMAERR is set when the CPU or DMA reads more serializers through the DMA port in a given time slot than were programmed as receivers. Causes a receive interrupt (RINT), if this bit is set and RDMAERR in RINTCTL is set. This bit is cleared by writing a 1 to this bit. Writing a 0 to this bit has no effect.
		0	Receive DMA error did not occur.
		1	Receive DMA error did occur.
6	RSTAFRM		Receive start of frame flag. Causes a receive interrupt (RINT), if this bit is set and RSTAFRM in RINTCTL is set. This bit is cleared by writing a 1 to this bit. Writing a 0 to this bit has no effect.
		0	No new receive frame sync (AFSR) is detected.
		1	A new receive frame sync (AFSR) is detected.
5	RDATA		Receive data ready flag. Causes a receive interrupt (RINT), if this bit is set and RDATA in RINTCTL is set. This bit is cleared by writing a 1 to this bit. Writing a 0 to this bit has no effect.
		0	No new data in RBUF.
		1	Data is transferred from XRSR to RBUF and ready to be serviced by the CPU or DMA. When RDATA is set, it always causes a DMA event (AREVT).
4	RLAST		Receive last slot flag. RLAST is set along with RDATA, if the current slot is the last slot in a frame. Causes a receive interrupt (RINT), if this bit is set and RLAST in RINTCTL is set. This bit is cleared by writing a 1 to this bit. Writing a 0 to this bit has no effect.
		0	Current slot is not the last slot in a frame.
		1	Current slot is the last slot in a frame. RDATA is also set.
3	RTDMSLOT		Returns the LSB of RSLOT. Allows a single read of RSTAT to determine whether the current TDM time slot is even or odd.
		0	Current TDM time slot is odd.
		1	Current TDM time slot is even.
2	RCKFAIL		Receive clock failure flag. RCKFAIL is set when the receive clock failure detection circuit reports an error (see Section 26.2.4.7.6). Causes a receive interrupt (RINT), if this bit is set and RCKFAIL in RINTCTL is set. This bit is cleared by writing a 1 to this bit. Writing a 0 to this bit has no effect.
		0	Receive clock failure did not occur.
		1	Receive clock failure did occur.

Table 26-30. Receiver Status Register (RSTAT) Field Descriptions (continued)

Bit	Field	Value	Description
1	RSYNCERR		Unexpected receive frame sync flag. RSYNCERR is set when a new receive frame sync (AFSR) occurs before it is expected. Causes a receive interrupt (RINT), if this bit is set and RSYNCERR in RINTCTL is set. This bit is cleared by writing a 1 to this bit. Writing a 0 to this bit has no effect.
		0	Unexpected receive frame sync did not occur.
		1	Unexpected receive frame sync did occur.
0	ROVRN		Receiver overrun flag. ROVRN is set when the receive serializer is instructed to transfer data from XRSR to RBUF, but the former data in RBUF has not yet been read by the CPU or DMA. Causes a receive interrupt (RINT), if this bit is set and ROVRN in RINTCTL is set. This bit is cleared by writing a 1 to this bit. Writing a 0 to this bit has no effect.
		0	Receiver overrun did not occur.
		1	Receiver overrun did occur.

26.3.22 Current Receive TDM Time Slot Registers (RSLOT)

The current receive TDM time slot register (RSLOT) indicates the current time slot for the receive data frame. The RSLOT is shown in Figure 26-55 and described in Table 26-31.

Figure 26-55. Current Receive TDM Time Slot Registers (RSLOT)

31	16
Reserved (A)	
R-0	

15	9	8	0
Reserved (A)		RSLOTCNT	
R-0		R-0	

LEGEND: R = Read only; -*n* = value after reset

A If writing to this field, always write the default value for future device compatibility.

Table 26-31. Current Receive TDM Time Slot Registers (RSLOT) Field Descriptions

Bit	Field	Value	Description
31-9	Reserved	0	Reserved. The reserved bit location always returns the default value. A value written to this field has no effect. If writing to this field, always write the default value for future device compatibility.
8-0	RSLOTCNT	0-17Fh	Current receive time slot count. Legal values: 0 to 383 (17Fh). TDM function is not supported for > 32 time slots. However, TDM time slot counter may count to 383 when used to receive a DIR block (transferred over TDM format).

26.3.23 Receive Clock Check Control Register (RCLKCHK)

The receive clock check control register (RCLKCHK) configures the receive clock failure detection circuit. The RCLKCHK is shown in Figure 26-56 and described in Table 26-32.

Figure 26-56. Receive Clock Check Control Register (RCLKCHK)

31	24	23	16
RCNT		RMAX	
R-0		R/W-0	

15	8	7	4	3	0
RMIN		Reserved (A)		RPS	
R/W-0		R-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

A If writing to this field, always write the default value for future device compatibility.

Table 26-32. Receive Clock Check Control Register (RCLKCHK) Field Descriptions

Bit	Field	Value	Description
31-24	RCNT	0-FFh	Receive clock count value (from previous measurement). The clock circuit continually counts the number of DSP system clocks for every 32 receive high-frequency master clock (AHCLKR) signals, and stores the count in RCNT until the next measurement is taken.
23-16	RMAX	0-FFh	Receive clock maximum boundary. This 8-bit unsigned value sets the maximum allowed boundary for the clock check counter after 32 receive high-frequency master clock (AHCLKR) signals have been received. If the current counter value is greater than RMAX after counting 32 AHCLKR signals, RCKFAIL in RSTAT is set. The comparison is performed using unsigned arithmetic.
15-8	RMIN	0-FFh	Receive clock minimum boundary. This 8-bit unsigned value sets the minimum allowed boundary for the clock check counter after 32 receive high-frequency master clock (AHCLKR) signals have been received. If RCNT is less than RMIN after counting 32 AHCLKR signals, RCKFAIL in RSTAT is set. The comparison is performed using unsigned arithmetic.
7-4	Reserved	0	Reserved. The reserved bit location always returns the default value. A value written to this field has no effect. If writing to this field, always write the default value for future device compatibility.
3-0	RPS	0-Fh	Receive clock check prescaler value.
		0	McASP system clock divided by 1
		1h	McASP system clock divided by 2
		2h	McASP system clock divided by 4
		3h	McASP system clock divided by 8
		4h	McASP system clock divided by 16
		5h	McASP system clock divided by 32
		6h	McASP system clock divided by 64
		7h	McASP system clock divided by 128
		8h	McASP system clock divided by 256
		9h-Fh	Reserved

26.3.24 Receiver DMA Event Control Register (REVTCTL)

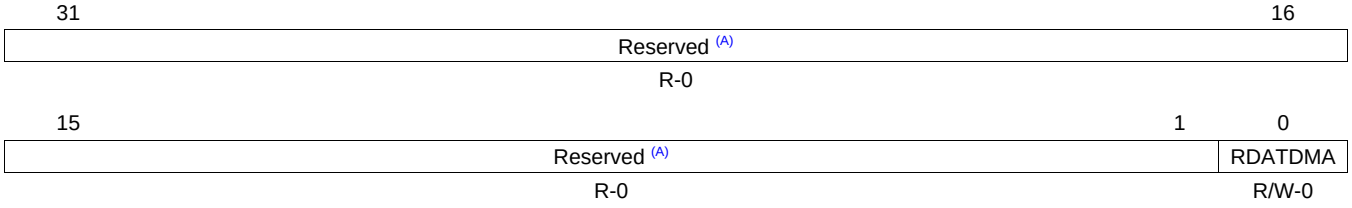
The receiver DMA event control register (REVTCTL) is shown in Figure 26-57 and described in Table 26-33.

CAUTION

DSP specific registers

Accessing REVTCTL not implemented on a specific DSP may cause improper device operation.

Figure 26-57. Receiver DMA Event Control Register (REVTCTL)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

A If writing to this field, always write the default value for future device compatibility.

Table 26-33. Receiver DMA Event Control Register (REVTCTL) Field Descriptions

Bit	Field	Value	Description
31-1	Reserved	0	Reserved. The reserved bit location always returns the default value. A value written to this field has no effect. If writing to this field, always write the default value for future device compatibility.
0	RDATDMA		Receive data DMA request enable bit. If writing to this field, always write the default value of 0.
		0	Receive data DMA request is enabled.
		1	Reserved.

26.3.25 Transmitter Global Control Register (XGBLCTL)

Alias of the global control register (GBLCTL). Writing to the transmitter global control register (XGBLCTL) affects only the transmit bits of GBLCTL (bits 12-8). Reads from XGBLCTL return the value of GBLCTL. XGBLCTL allows the transmitter to be reset independently from the receiver. The XGBLCTL is shown in Figure 26-58 and described in Table 26-34. See Section 26.3.9 for a detailed description of GBLCTL.

Figure 26-58. Transmitter Global Control Register (XGBLCTL)

31	16
Reserved [A]	
R-0	

15	13	12	11	10	9	8
Reserved [A]		XFRST	XSMRST	XSRCLR	XHCLKRST	XCLKRST
R-0		R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

7	5	4	3	2	1	0
Reserved [A]		RFRST	RSMRST	RSRCLR	RHCLKRST	RCLKRST
R-0		R-0	R-0	R-0	R-0	R-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

A If writing to this field, always write the default value for future device compatibility.

Table 26-34. Transmitter Global Control Register (XGBLCTL) Field Descriptions

Bit	Field	Value	Description
31-13	Reserved	0-FFh	Reserved. The reserved bit location always returns the default value. A value written to this field has no effect. If writing to this field, always write the default value for future device compatibility.
12	XFRST		Transmit frame sync generator reset enable bit. A write to this bit affects the XFRST bit of GBLCTL.
		0	Transmit frame sync generator is reset.
		1	Transmit frame sync generator is active.
11	XSMRST		Transmit state machine reset enable bit. A write to this bit affects the XSMRST bit of GBLCTL.
		0	Transmit state machine is held in reset.
		1	Transmit state machine is released from reset.
10	XSRCLR		Transmit serializer clear enable bit. A write to this bit affects the XSRCLR bit of GBLCTL.
		0	Transmit serializers are cleared.
		1	Transmit serializers are active.
9	XHCLKRST		Transmit high-frequency clock divider reset enable bit. A write to this bit affects the XHCLKRST bit of GBLCTL.
		0	Transmit high-frequency clock divider is held in reset.
		1	Transmit high-frequency clock divider is running.
8	XCLKRST		Transmit clock divider reset enable bit. A write to this bit affects the XCLKRST bit of GBLCTL.
		0	Transmit clock divider is held in reset.
		1	Transmit clock divider is running.
7-5	Reserved	0	Reserved. The reserved bit location always returns the default value. A value written to this field has no effect. If writing to this field, always write the default value for future device compatibility.
4	RFRST	x	Receive frame sync generator reset enable bit. A read of this bit returns the RFRST bit value of GBLCTL. Writes have no effect.
3	RSMRST	x	Receive state machine reset enable bit. A read of this bit returns the RSMRST bit value of GBLCTL. Writes have no effect.
2	RSRCLR	x	Receive serializer clear enable bit. A read of this bit returns the RSRSCLR bit value of GBLCTL. Writes have no effect.
1	RHCLKRST	x	Receive high-frequency clock divider reset enable bit. A read of this bit returns the RHCLKRST bit value of GBLCTL. Writes have no effect.
0	RCLKRST	x	Receive clock divider reset enable bit. A read of this bit returns the RCLKRST bit value of GBLCTL. Writes have no effect.

26.3.26 Transmit Format Unit Bit Mask Register (XMASK)

The transmit format unit bit mask register (XMASK) determines which bits of the transmitted data are masked off and padded with a known value before being shifted out the McASP. The XMASK is shown in Figure 26-59 and described in Table 26-35.

Figure 26-59. Transmit Format Unit Bit Mask Register (XMASK)

31	30	29	28	27	26	25	24
XMASK31	XMASK30	XMASK29	XMASK28	XMASK27	XMASK26	XMASK25	XMASK24
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
23	22	21	20	19	18	17	16
XMASK23	XMASK22	XMASK21	XMASK20	XMASK19	XMASK18	XMASK17	XMASK16
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
15	14	13	12	11	10	9	8
XMASK15	XMASK14	XMASK13	XMASK12	XMASK11	XMASK10	XMASK9	XMASK8
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
7	6	5	4	3	2	1	0
XMASK7	XMASK6	XMASK5	XMASK4	XMASK3	XMASK2	XMASK1	XMASK0
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; *-n* = value after reset

Table 26-35. Transmit Format Unit Bit Mask Register (XMASK) Field Descriptions

Bit	Field	Value	Description
31-0	XMASK[31-0]		Transmit data mask enable bit.
		0	Corresponding bit of transmit data (before passing through reverse and rotate units) is masked out and then padded with the selected bit pad value (XPAD and XPBIT bits in XFMT), which is transmitted out the McASP in place of the original bit.
		1	Corresponding bit of transmit data (before passing through reverse and rotate units) is transmitted out the McASP.

26.3.27 Transmit Bit Stream Format Register (XFMT)

The transmit bit stream format register (XFMT) configures the transmit data format. The XFMT is shown in Figure 26-60 and described in Table 26-36.

Figure 26-60. Transmit Bit Stream Format Register (XFMT)

31																		18	17	16
Reserved [A]																			XDATDLY	
R-0																			R/W-0	

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
XRVRS	XPAD		XPBIT					XSSZ				XBUSEL	XROT		
R/W-0	R/W-0		R/W-0					R/W-0				R/W-0	R/W-0		

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

A If writing to this field, always write the default value for future device compatibility.

Table 26-36. Transmit Bit Stream Format Register (XFMT) Field Descriptions

Bit	Field	Value	Description
31-18	Reserved	0	Reserved. The reserved bit location always returns the default value. A value written to this field has no effect. If writing to this field, always write the default value for future device compatibility.
17-16	XDATDLY	0-3h	Transmit sync bit delay.
		0	0-bit delay. The first transmit data bit, AXR[n], occurs in same ACLKX cycle as the transmit frame sync (AFSX).
		1h	1-bit delay. The first transmit data bit, AXR[n], occurs one ACLKX cycle after the transmit frame sync (AFSX).
		2h	2-bit delay. The first transmit data bit, AXR[n], occurs two ACLKX cycles after the transmit frame sync (AFSX).
		3h	Reserved.
15	XRVRS		Transmit serial bitstream order.
		0	Bitstream is LSB first. No bit reversal is performed in transmit format bit reverse unit.
		1	Bitstream is MSB first. Bit reversal is performed in transmit format bit reverse unit.
14-13	XPAD	0-3h	Pad value for extra bits in slot not belonging to word defined by XMASK. This field only applies to bits when XMASK[n] = 0.
		0	Pad extra bits with 0.
		1h	Pad extra bits with 1.
		2h	Pad extra bits with one of the bits from the word as specified by XPBIT bits.
		3h	Reserved
12-8	XPBIT	0-1Fh	XPBIT value determines which bit (as written by the CPU or DMA to XBUF[n]) is used to pad the extra bits before shifting. This field only applies when XPAD = 2h.
		0	Pad with bit 0 value.
		1-1Fh	Pad with bit 1 to bit 31 value.

Table 26-36. Transmit Bit Stream Format Register (XFMT) Field Descriptions (continued)

Bit	Field	Value	Description
7-4	XSSZ	0-Fh	Transmit slot size.
		0-2h	Reserved
		3h	Slot size is 8 bits.
		4h	Reserved
		5h	Slot size is 12 bits.
		6h	Reserved.
		7h	Slot size is 16 bits.
		8h	Reserved.
		9h	Slot size is 20 bits.
		Ah	Reserved.
		Bh	Slot size is 24 bits.
		Ch	Reserved.
		Dh	Slot size is 28 bits.
		Eh	Reserved.
		Fh	Slot size is 32 bits.
3	XBUSEL		Selects whether writes to serializer buffer XRBUF[n] by way of XBUF*n* by the CPU/EDMA occur through the peripheral configuration port or the DMA port.
		0	Writes to XRBUF[n] originate from the DMA port. Writes to XRBUF[n] from the peripheral configuration port are ignored with no effect to the McASP.
		1	Writes to XRBUF[n] originate from the peripheral configuration port. Writes to XRBUF[n] from the DMA port are ignored with no effect to the McASP.
2-0	XROT	0-7h	Right-rotation value for transmit rotate right format unit.
		0	Rotate right by 0 (no rotation).
		1h	Rotate right by 4 bit positions.
		2h	Rotate right by 8 bit positions.
		3h	Rotate right by 12 bit positions.
		4h	Rotate right by 16 bit positions.
		5h	Rotate right by 20 bit positions.
		6h	Rotate right by 24 bit positions.
		7h	Rotate right by 28 bit positions.

26.3.28 Transmit Frame Sync Control Register (AFSXCTL)

The transmit frame sync control register (AFSXCTL) configures the transmit frame sync (AFSX). The AFSXCTL is shown in Figure 26-61 and described in Table 26-37.

Figure 26-61. Transmit Frame Sync Control Register (AFSXCTL)

31							16
Reserved [A]							
R-0							
15	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
XMOD		Reserved [A]		FXWID	Reserved [A]		FSXM	FSXP
R/W-0		R-0		R/W-0	R-0		R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

A If writing to this field, always write the default value for future device compatibility.

Table 26-37. Transmit Frame Sync Control Register (AFSXCTL) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	Reserved. The reserved bit location always returns the default value. A value written to this field has no effect. If writing to this field, always write the default value for future device compatibility.
15-7	XMOD	0-1FFh	Transmit frame sync mode select bits.
		0	Burst mode
		1h	Reserved
		2h-20h	2-slot TDM (I2S mode) to 32-slot TDM
		21h-17Fh	Reserved
		180h	384-slot DIT mode
		181h-1FFh	Reserved
6-5	Reserved	0	Reserved. The reserved bit location always returns the default value. A value written to this field has no effect. If writing to this field, always write the default value for future device compatibility.
4	FXWID		Transmit frame sync width select bit indicates the width of the transmit frame sync (AFSX) during its active period.
		0	Single bit
		1	Single word
3-2	Reserved	0	Reserved. The reserved bit location always returns the default value. A value written to this field has no effect. If writing to this field, always write the default value for future device compatibility.
1	FSXM		Transmit frame sync generation select bit.
		0	Externally-generated transmit frame sync
		1	Internally-generated transmit frame sync
0	FSXP		Transmit frame sync polarity select bit.
		0	A rising edge on transmit frame sync (AFSX) indicates the beginning of a frame.
		1	A falling edge on transmit frame sync (AFSX) indicates the beginning of a frame.

26.3.29 Transmit Clock Control Register (ACLKXCTL)

The transmit clock control register (ACLKXCTL) configures the transmit bit clock (ACLKX) and the transmit clock generator. The ACLKXCTL is shown in Figure 26-62 and described in Table 26-38.

Figure 26-62. Transmit Clock Control Register (ACLKXCTL)

31						16
Reserved [A]						
R-0						
15	**8**	**7**	**6**	**5**	**4**	**0**
Reserved [A]		CLKXP	ASYNC	CLKXM	CLKXDIV	
R-0		R/W-0	R/W-1	R/W-1	R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

A If writing to this field, always write the default value for future device compatibility.

Table 26-38. Transmit Clock Control Register (ACLKXCTL) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved. The reserved bit location always returns the default value. A value written to this field has no effect. If writing to this field, always write the default value for future device compatibility.
7	CLKXP		Transmit bitstream clock polarity select bit.
		0	Rising edge. External receiver samples data on the falling edge of the serial clock, so the transmitter must shift data out on the rising edge of the serial clock.
		1	Falling edge. External receiver samples data on the rising edge of the serial clock, so the transmitter must shift data out on the falling edge of the serial clock.
6	ASYNC		Transmit/receive operation asynchronous enable bit.
		0	Synchronous. Transmit clock and frame sync provides the source for both the transmit and receive sections. Note that in this mode, the receive bit clock is an inverted version of the transmit bit clock. See Section 26.2.4.1.5 for more details.
		1	Asynchronous. Separate clock and frame sync used by transmit and receive sections.
5	CLKXM		Transmit bit clock source bit.
		0	External transmit clock source from ACLKX pin.
		1	Internal transmit clock source from output of programmable bit clock divider.
4-0	CLKXDIV	0-1Fh	Transmit bit clock divide ratio bits determine the divide-down ratio from AHCLKX to ACLKX.
		0	Divide-by-1
		1h	Divide-by-2
		2h-1Fh	Divide-by-3 to divide-by-32

26.3.30 Transmit High-Frequency Clock Control Register (AHCLKXCTL)

The transmit high-frequency clock control register (AHCLKXCTL) configures the transmit high-frequency master clock (AHCLKX) and the transmit clock generator. The AHCLKXCTL is shown in Figure 26-63 and described in Table 26-39.

Figure 26-63. Transmit High-Frequency Clock Control Register (AHCLKXCTL)

31					16
Reserved [A]					
R-0					

15	14	13	12	11	0
HCLKXM	HCLKXP	Reserved [A]		HCLKXDIV	
R/W-1	R/W-0	R/W-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

A If writing to this field, always write the default value for future device compatibility.

Table 26-39. Transmit High-Frequency Clock Control Register (AHCLKXCTL) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	Reserved. The reserved bit location always returns the default value. A value written to this field has no effect. If writing to this field, always write the default value for future device compatibility.
15	HCLKXM		Transmit high-frequency clock source bit.
		0	External transmit high-frequency clock source from AHCLKX pin.
		1	Internal transmit high-frequency clock source from output of programmable high clock divider.
14	HCLKXP		Transmit bitstream high-frequency clock polarity select bit.
		0	Not inverted. AHCLKX is not inverted before programmable bit clock divider. In the special case where the transmit bit clock (ACLKX) is internally generated and the programmable bit clock divider is set to divide-by-1 (CLKXDIV = 0 in ACLKXCTL), AHCLKX is directly passed through to the ACLKX pin.
		1	Inverted. AHCLKX is inverted before programmable bit clock divider. In the special case where the transmit bit clock (ACLKX) is internally generated and the programmable bit clock divider is set to divide-by-1 (CLKXDIV = 0 in ACLKXCTL), AHCLKX is directly passed through to the ACLKX pin.
13-12	Reserved	0	Reserved. The reserved bit location always returns the default value. A value written to this field has no effect. If writing to this field, always write the default value for future device compatibility.
11-0	HCLKXDIV	0-FFFh	Transmit high-frequency clock divide ratio bits determine the divide-down ratio from AUXCLK to AHCLKX.
		0	Divide-by-1
		1h	Divide-by-2
		2h-FFFh	Divide-by-3 to divide-by-4096

26.3.31 Transmit TDM Time Slot Register (XTDM)

The transmit TDM time slot register (XTDM) specifies in which TDM time slot the transmitter is active. TDM time slot counter range is extended to 384 slots (to support SPDIF blocks of 384 subframes). XTDM operates modulo 32, that is, XTDMS specifies the TDM activity for time slots 0, 32, 64, 96, 128, etc. The XTDM is shown in Figure 26-64 and described in Table 26-40.

Figure 26-64. Transmit TDM Time Slot Register (XTDM)

31	30	29	28	27	26	25	24
XTDMS31	XTDMS30	XTDMS29	XTDMS28	XTDMS27	XTDMS26	XTDMS25	XTDMS24
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
23	22	21	20	19	18	17	16
XTDMS23	XTDMS22	XTDMS21	XTDMS20	XTDMS19	XTDMS18	XTDMS17	XTDMS16
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
15	14	13	12	11	10	9	8
XTDMS15	XTDMS14	XTDMS13	XTDMS12	XTDMS11	XTDMS10	XTDMS9	XTDMS8
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
7	6	5	4	3	2	1	0
XTDMS7	XTDMS6	XTDMS5	XTDMS4	XTDMS3	XTDMS2	XTDMS1	XTDMS0
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; *-n* = value after reset

Table 26-40. Transmit TDM Time Slot Register (XTDM) Field Descriptions

Bit	Field	Value	Description
31-0	XTDMS[31-0]		Transmitter mode during TDM time slot *n*.
		0	Transmit TDM time slot *n* is inactive. The transmit serializer does not shift out data during this slot.
		1	Transmit TDM time slot *n* is active. The transmit serializer shifts out data during this slot according to the serializer control register (SRCTL).

26.3.32 Transmitter Interrupt Control Register (XINTCTL)

The transmitter interrupt control register (XINTCTL) controls generation of the McASP transmit interrupt (XINT). When the register bit(s) is set to 1, the occurrence of the enabled McASP condition(s) generates XINT. The XINTCTL is shown in Figure 26-65 and described in Table 26-41. See Section 26.3.33 for a description of the interrupt conditions.

Figure 26-65. Transmitter Interrupt Control Register (XINTCTL)

31							8
Reserved (A)							
R-0							
7	6	5	4	3	2	1	0
XSTAFRM	Reserved (A)	XDATA	XLAST	XDMAERR	XCKFAIL	XSYNCERR	XUNDRN
R/W-0	R-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

A If writing to this field, always write the default value for future device compatibility.

Table 26-41. Transmitter Interrupt Control Register (XINTCTL) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved. The reserved bit location always returns the default value. A value written to this field has no effect. If writing to this field, always write the default value for future device compatibility.
7	XSTAFRM		Transmit start of frame interrupt enable bit.
		0	Interrupt is disabled. A transmit start of frame interrupt does not generate a McASP transmit interrupt (XINT).
		1	Interrupt is enabled. A transmit start of frame interrupt generates a McASP transmit interrupt (XINT).
6	Reserved	0	Reserved. The reserved bit location always returns the default value. A value written to this field has no effect. If writing to this field, always write the default value for future device compatibility.
5	XDATA		Transmit data ready interrupt enable bit.
		0	Interrupt is disabled. A transmit data ready interrupt does not generate a McASP transmit interrupt (XINT).
		1	Interrupt is enabled. A transmit data ready interrupt generates a McASP transmit interrupt (XINT).
4	XLAST		Transmit last slot interrupt enable bit.
		0	Interrupt is disabled. A transmit last slot interrupt does not generate a McASP transmit interrupt (XINT).
		1	Interrupt is enabled. A transmit last slot interrupt generates a McASP transmit interrupt (XINT).
3	XDMAERR		Transmit DMA error interrupt enable bit.
		0	Interrupt is disabled. A transmit DMA error interrupt does not generate a McASP transmit interrupt (XINT).
		1	Interrupt is enabled. A transmit DMA error interrupt generates a McASP transmit interrupt (XINT).
2	XCKFAIL		Transmit clock failure interrupt enable bit.
		0	Interrupt is disabled. A transmit clock failure interrupt does not generate a McASP transmit interrupt (XINT).
		1	Interrupt is enabled. A transmit clock failure interrupt generates a McASP transmit interrupt (XINT).
1	XSYNCERR		Unexpected transmit frame sync interrupt enable bit.
		0	Interrupt is disabled. An unexpected transmit frame sync interrupt does not generate a McASP transmit interrupt (XINT).
		1	Interrupt is enabled. An unexpected transmit frame sync interrupt generates a McASP transmit interrupt (XINT).
0	XUNDRN		Transmitter underrun interrupt enable bit.
		0	Interrupt is disabled. A transmitter underrun interrupt does not generate a McASP transmit interrupt (XINT).
		1	Interrupt is enabled. A transmitter underrun interrupt generates a McASP transmit interrupt (XINT).

26.3.33 Transmitter Status Register (XSTAT)

The transmitter status register (XSTAT) provides the transmitter status and transmit TDM time slot number. If the McASP logic attempts to set an interrupt flag in the same cycle that the CPU writes to the flag to clear it, the McASP logic has priority and the flag remains set. This also causes a new interrupt request to be generated. The XSTAT is shown in Figure 26-66 and described in Table 26-42.

Figure 26-66. Transmitter Status Register (XSTAT)

31							9	8
Reserved (A)								XERR
R-0								R/W-0
7	6	5	4	3	2	1	0	
XDMAERR	XSTAFRM	XDATA	XLAST	XTDMSLOT	XCKFAIL	XSYNCERR	XUNDRN	
R/W-0	R/W-0	R/W-0	R/W-0	R-0	R/W-0	R/W-0	R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

A If writing to this field, always write the default value for future device compatibility.

Table 26-42. Transmitter Status Register (XSTAT) Field Descriptions

Bit	Field	Value	Description
31-9	Reserved	0	Reserved. The reserved bit location always returns the default value. A value written to this field has no effect. If writing to this field, always write the default value for future device compatibility.
8	XERR		XERR bit always returns a logic-OR of: XUNDRN | XSYNCERR | XCKFAIL | XDMAERR Allows a single bit to be checked to determine if a transmitter error interrupt has occurred.
		0	No errors have occurred.
		1	An error has occurred.
7	XDMAERR		Transmit DMA error flag. XDMAERR is set when the CPU or DMA writes more serializers through the DMA port in a given time slot than were programmed as transmitters. Causes a transmit interrupt (XINT), if this bit is set and XDMAERR in XINTCTL is set. This bit is cleared by writing a 1 to this bit. Writing a 0 has no effect.
		0	Transmit DMA error did not occur.
		1	Transmit DMA error did occur.
6	XSTAFRM		Transmit start of frame flag. Causes a transmit interrupt (XINT), if this bit is set and XSTAFRM in XINTCTL is set. This bit is cleared by writing a 1 to this bit. Writing a 0 has no effect.
		0	No new transmit frame sync (AFSX) is detected.
		1	A new transmit frame sync (AFSX) is detected.
5	XDATA		Transmit data ready flag. Causes a transmit interrupt (XINT), if this bit is set and XDATA in XINTCTL is set. This bit is cleared by writing a 1 to this bit. Writing a 0 has no effect.
		0	XBUF is written and is full.
		1	Data is copied from XBUF to XRSR. XBUF is empty and ready to be written. XDATA is also set when the transmit serializers are taken out of reset. When XDATA is set, it always causes a DMA event (AXEVT).
4	XLAST		Transmit last slot flag. XLAST is set along with XDATA, if the current slot is the last slot in a frame. Causes a transmit interrupt (XINT), if this bit is set and XLAST in XINTCTL is set. This bit is cleared by writing a 1 to this bit. Writing a 0 has no effect.
		0	Current slot is not the last slot in a frame.
		1	Current slot is the last slot in a frame. XDATA is also set.
3	XTDMSLOT		Returns the LSB of XSLOT. Allows a single read of XSTAT to determine whether the current TDM time slot is even or odd.
		0	Current TDM time slot is odd.
		1	Current TDM time slot is even.
2	XCKFAIL		Transmit clock failure flag. XCKFAIL is set when the transmit clock failure detection circuit reports an error (see Section 26.2.4.7.6). Causes a transmit interrupt (XINT), if this bit is set and XCKFAIL in XINTCTL is set. This bit is cleared by writing a 1 to this bit. Writing a 0 has no effect.
		0	Transmit clock failure did not occur.
		1	Transmit clock failure did occur.

Table 26-42. Transmitter Status Register (XSTAT) Field Descriptions (continued)

Bit	Field	Value	Description
1	XSYNCERR		Unexpected transmit frame sync flag. XSYNCERR is set when a new transmit frame sync (AFSX) occurs before it is expected. Causes a transmit interrupt (XINT), if this bit is set and XSYNCERR in XINTCTL is set. This bit is cleared by writing a 1 to this bit. Writing a 0 has no effect.
		0	Unexpected transmit frame sync did not occur.
		1	Unexpected transmit frame sync did occur.
0	XUNDRN		Transmitter underrun flag. XUNDRN is set when the transmit serializer is instructed to transfer data from XBUF to XRSR, but XBUF has not yet been serviced with new data since the last transfer. Causes a transmit interrupt (XINT), if this bit is set and XUNDRN in XINTCTL is set. This bit is cleared by writing a 1 to this bit. Writing a 0 has no effect.
		0	Transmitter underrun did not occur.
		1	Transmitter underrun did occur. See Section 26.2.4.7.2 for details on McASP action upon underrun conditions.

26.3.34 Current Transmit TDM Time Slot Register (XSLOT)

The current transmit TDM time slot register (XSLOT) indicates the current time slot for the transmit data frame. The XSLOT is shown in Figure 26-67 and described in Table 26-43.

Figure 26-67. Current Transmit TDM Time Slot Register (XSLOT)

31	16
Reserved (A)	
R-0	

15	9	8	0
Reserved (A)		XSLOTCNT	
R-0		R-17Fh	

LEGEND: R = Read only; -*n* = value after reset

A If writing to this field, always write the default value for future device compatibility.

Table 26-43. Current Transmit TDM Time Slot Register (XSLOT) Field Descriptions

Bit	Field	Value	Description
31-9	Reserved	0	Reserved. The reserved bit location always returns the default value. A value written to this field has no effect. If writing to this field, always write the default value for future device compatibility.
8-0	XSLOTCNT	0-17Fh	Current transmit time slot count. Legal values: 0 to 383 (17Fh). During reset, this counter value is 383 so the next count value, which is used to encode the first DIT group of data, will be 0 and encodes the B preamble. TDM function is not supported for > 32 time slots. However, TDM time slot counter may count to 383 when used to transmit a DIT block.

26.3.35 Transmit Clock Check Control Register (XCLKCHK)

The transmit clock check control register (XCLKCHK) configures the transmit clock failure detection circuit. The XCLKCHK is shown in Figure 26-68 and described in Table 26-44.

Figure 26-68. Transmit Clock Check Control Register (XCLKCHK)

31	24	23	16
XCNT		XMAX	
R-0		R/W-0	

15	8	7	4	3	0
XMIN		Reserved (A)		XPS	
R/W-0		R-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

A If writing to this field, always write the default value for future device compatibility.

Table 26-44. Transmit Clock Check Control Register (XCLKCHK) Field Descriptions

Bit	Field	Value	Description
31-24	XCNT	0	Transmit clock count value (from previous measurement). The clock circuit continually counts the number of DSP system clocks for every 32 transmit high-frequency master clock (AHCLKX) signals, and stores the count in XCNT until the next measurement is taken.
23-16	XMAX	0-FFh	Transmit clock maximum boundary. This 8-bit unsigned value sets the maximum allowed boundary for the clock check counter after 32 transmit high-frequency master clock (AHCLKX) signals have been received. If the current counter value is greater than XMAX after counting 32 AHCLKX signals, XCKFAIL in XSTAT is set. The comparison is performed using unsigned arithmetic.
15-8	XMIN	0-FFh	Transmit clock minimum boundary. This 8-bit unsigned value sets the minimum allowed boundary for the clock check counter after 32 transmit high-frequency master clock (AHCLKX) signals have been received. If XCNT is less than XMIN after counting 32 AHCLKX signals, XCKFAIL in XSTAT is set. The comparison is performed using unsigned arithmetic.
7-4	Reserved	0	Reserved. The reserved bit location always returns the default value. A value written to this field has no effect. If writing to this field, always write the default value for future device compatibility.
3-0	XPS	0-Fh	Transmit clock check prescaler value.
		0	McASP system clock divided by 1
		1h	McASP system clock divided by 2
		2h	McASP system clock divided by 4
		3h	McASP system clock divided by 8
		4h	McASP system clock divided by 16
		5h	McASP system clock divided by 32
		6h	McASP system clock divided by 64
		7h	McASP system clock divided by 128
		8h	McASP system clock divided by 256
		9h-Fh	Reserved

26.3.36 Transmitter DMA Event Control Register (XEVTCTL)

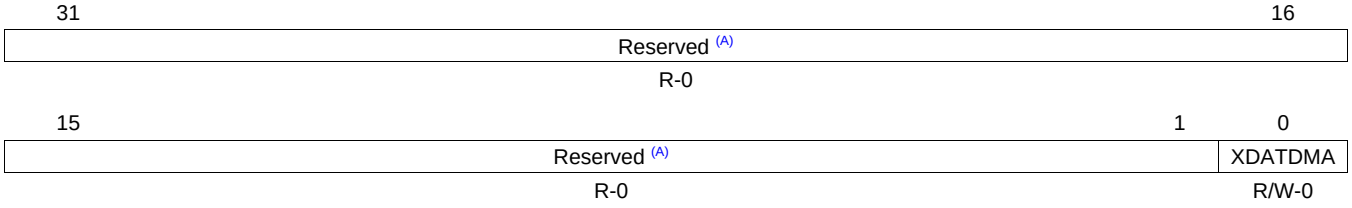
The transmitter DMA event control register (XEVTCTL) is shown in Figure 26-69 and described in Table 26-45.

CAUTION

DSP specific registers

Accessing XEVTCTL not implemented on a specific DSP may cause improper device operation.

Figure 26-69. Transmitter DMA Event Control Register (XEVTCTL)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

A If writing to this field, always write the default value for future device compatibility.

Table 26-45. Transmitter DMA Event Control Register (XEVTCTL) Field Descriptions

Bit	Field	Value	Description
31-1	Reserved	0	Reserved. The reserved bit location always returns the default value. A value written to this field has no effect. If writing to this field, always write the default value for future device compatibility.
0	XDATDMA		Transmit data DMA request enable bit. If writing to this field, always write the default value of 0.
		0	Transmit data DMA request is enabled.
		1	Reserved.

26.3.37 Serializer Control Registers (SRCTL*n*)

Each serializer on the McASP has a serializer control register (SRCTL). There are up to 16 serializers per McASP. The SRCTL is shown in Figure 26-70 and described in Table 26-46.

CAUTION

DSP specific registers

Accessing SRCTL*n* not implemented on a specific DSP may cause improper device operation.

Figure 26-70. Serializer Control Registers (SRCTL*n*)

31							16
Reserved [A]							
R-0							
15	**6**	**5**	**4**	**3**	**2**	**1**	**0**
Reserved [A]		RRDY	XRDY	DISMOD		SRMOD	
R-0		R-0	R-0	R/W-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

A If writing to this field, always write the default value for future device compatibility.

Table 26-46. Serializer Control Registers (SRCTL*n*) Field Descriptions

Bit	Field	Value	Description
31-6	Reserved	0	Reserved. The reserved bit location always returns the default value. A value written to this field has no effect. If writing to this field, always write the default value for future device compatibility.
5	RRDY		Receive buffer ready bit. RRDY indicates the current receive buffer state. Always reads 0 when programmed as a transmitter or as inactive. If SRMOD bit is set to receive (2h), RRDY switches from 0 to 1 whenever data is transferred from XRSR to RBUF.
		0	Receive buffer (RBUF) is empty.
		1	Receive buffer (RBUF) contains data and needs to be read before the start of the next time slot or a receiver overrun occurs.
4	XRDY		Transmit buffer ready bit. XRDY indicates the current transmit buffer state. Always reads 0 when programmed as a receiver or as inactive. If SRMOD bit is set to transmit (1h), XRDY switches from 0 to 1 when XSRCLR in GBLCTL is switched from 0 to 1 to indicate an empty transmitter. XRDY remains set until XSRCLR is forced to 0, data is written to the corresponding transmit buffer, or SRMOD bit is changed to receive (2h) or inactive (0).
		0	Transmit buffer (XBUF) contains data.
		1	Transmit buffer (XBUF) is empty and needs to be written before the start of the next time slot or a transmit underrun occurs.
3-2	DISMOD	0-3h	Serializer pin drive mode bit. Drive on pin when in inactive TDM slot of transmit mode or when serializer is inactive. This field only applies if the pin is configured as a McASP pin (PFUNC = 0).
		0	Drive on pin is 3-state.
		1h	Reserved
		2h	Drive on pin is logic low.
		3h	Drive on pin is logic high.
1-0	SRMOD	0-3h	Serializer mode bit.
		0	Serializer is inactive.
		1h	Serializer is transmitter.
		2h	Serializer is receiver.
		3h	Reserved

26.3.38 DIT Left Channel Status Registers (DITCSRA0-DITCSRA5)

The DIT left channel status registers (DITCSRA) provide the status of each left channel (even TDM time slot). Each of the six 32-bit registers (Figure 26-71) can store 192 bits of channel status data for a complete block of transmission. The DIT reuses the same data for the next block. It is your responsibility to update the register file in time, if a different set of data need to be sent.

Figure 26-71. DIT Left Channel Status Registers (DITCSRA0-DITCSRA5)

31	0
DITCSRA*n*	
R/W-0	

LEGEND: R/W = Read/Write; -*n* = value after reset

26.3.39 DIT Right Channel Status Registers (DITCSRB0-DITCSRB5)

The DIT right channel status registers (DITCSRB) provide the status of each right channel (odd TDM time slot). Each of the six 32-bit registers (Figure 26-72) can store 192 bits of channel status data for a complete block of transmission. The DIT reuses the same data for the next block. It is your responsibility to update the register file in time, if a different set of data need to be sent.

Figure 26-72. DIT Right Channel Status Registers (DITCSRB0-DITCSRB5)

31	0
DITCSRB*n*	
R/W-0	

LEGEND: R/W = Read/Write; -*n* = value after reset

26.3.40 DIT Left Channel User Data Registers (DITUDRA0-DITUDRA5)

The DIT left channel user data registers (DITUDRA) provides the user data of each left channel (even TDM time slot). Each of the six 32-bit registers (Figure 26-73) can store 192 bits of user data for a complete block of transmission. The DIT reuses the same data for the next block. It is your responsibility to update the register in time, if a different set of data need to be sent.

Figure 26-73. DIT Left Channel User Data Registers (DITUDRA0-DITUDRA5)

31	0
DITUDRA*n*	
R/W-0	

LEGEND: R/W = Read/Write; -*n* = value after reset

26.3.41 DIT Right Channel User Data Registers (DITUDRB0-DITUDRB5)

The DIT right channel user data registers (DITUDRB) provides the user data of each right channel (odd TDM time slot). Each of the six 32-bit registers (Figure 26-74) can store 192 bits of user data for a complete block of transmission. The DIT reuses the same data for the next block. It is your responsibility to update the register in time, if a different set of data need to be sent.

Figure 26-74. DIT Right Channel User Data Registers (DITUDRB0-DITUDRB5)

31	0
DITUDRB*n*	
R/W-0	

LEGEND: R/W = Read/Write; -*n* = value after reset

26.3.42 Transmit Buffer Registers (XBUF*n*)

The transmit buffers for the serializers (XBUF) hold data from the transmit format unit. For transmit operations, the XBUF (Figure 26-75) is an alias of the XRBUF in the serializer. The XBUF can be accessed through the peripheral configuration port (Table 26-7) or through the DMA port (Table 26-8).

CAUTION

DSP specific registers

Accessing XBUF registers not implemented on a specific DSP may cause improper device operation.

Figure 26-75. Transmit Buffer Registers (XBUF*n*)

31	0
XBUF*n*	
R/W-0	

LEGEND: R/W = Read/Write; -*n* = value after reset

26.3.43 Receive Buffer Registers (RBUF*n*)

The receive buffers for the serializers (RBUF) hold data from the serializer before the data goes to the receive format unit. For receive operations, the RBUF (Figure 26-76) is an alias of the XRBUF in the serializer. The RBUF can be accessed through the peripheral configuration port (Table 26-7) or through the DMA port (Table 26-8).

CAUTION

DSP specific registers

Accessing RBUF registers not implemented on a specific DSP may cause improper device operation.

Figure 26-76. Receive Buffer Registers (RBUF*n*)

31	0
RBUF*n*	
R/W-0	

LEGEND: R/W = Read/Write; -*n* = value after reset

26.3.44 AFIFO Revision Identification Register (AFIFOREV)

The Audio FIFO (AFIFO) revision identification register (AFIFOREV) contains revision data for the Audio FIFO (AFIFO). The AFIFOREV is shown in Figure 26-77 and described in Table 26-47.

Figure 26-77. AFIFO Revision Identification Register (AFIFOREV)

31	0
REV	
R-4431 1100h	

LEGEND: R = Read only; -*n* = value after reset

Table 26-47. AFIFO Revision Identification Register (AFIFOREV) Field Descriptions

Bit	Field	Value	Description
31-0	REV	4431 1100h	Identifies revision of Audio FIFO.

26.3.45 Write FIFO Control Register (WFIFOCTL)

The Write FIFO control register (WFIFOCTL) is shown in Figure 26-78 and described in Table 26-48.

NOTE: The WNUMEVT and WNUMDMA values must be set prior to enabling the Write FIFO.

If the Write FIFO is to be enabled, it must be enabled prior to taking the McASP out of reset.

Figure 26-78. Write FIFO Control Register (WFIFOCTL)

31	17	16
Reserved		WENA
R-0		R/W-0

15	8	7	0
WNUMEVT		WNUMDMA	
R/W-10h		R/W-4h	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 26-48. Write FIFO Control Register (WFIFOCTL) Field Descriptions

Bit	Field	Value	Description
31-17	Reserved	0	Reserved
16	WENA		Write FIFO enable bit.
		0	Write FIFO is disabled. The WLVL field in the Write FIFO status register (WFIFOSTS) is reset to 0 and pointers are initialized, that is, the Write FIFO is "flushed."
		1	Write FIFO is enabled. If Write FIFO is to be enabled, it must be enabled prior to taking McASP out of reset.
15-8	WNUMEVT	0-FFh	Write word count per DMA event (32-bit). When the Write FIFO has space for at least WNUMEVT words of data, then an AXEVT (transmit DMA event) is generated to the host/DMA controller. This value should be set to a non-zero integer multiple of the number of serializers enabled as transmitters. This value must be set prior to enabling the Write FIFO.
		0	0 words
		1h	1 word
		2h	2 words
		3h-40h	3 to 64 words
		41h-FFh	Reserved
7-0	WNUMDMA	0-FFh	Write word count per transfer (32-bit words). Upon a transmit DMA event from the McASP, WNUMDMA words are transferred from the Write FIFO to the McASP. This value must equal the number of McASP serializers (not the number of channels) used as transmitters. This value must be set prior to enabling the Write FIFO.
		0	0 words
		1h	1 word
		2h	2 words
		3h-10h	3-16 words
		11h-FFh	Reserved

26.3.46 Write FIFO Status Register (WFIFOSTS)

The Write FIFO status register (WFIFOSTS) is shown in Figure 26-79 and described in Table 26-49.

Figure 26-79. Write FIFO Status Register (WFIFOSTS)

31	16
Reserved	
R-0	

15	8	7	0
Reserved		WLVL	
R-0		R-0	

LEGEND: R = Read only; -*n* = value after reset

Table 26-49. Write FIFO Status Register (WFIFOSTS) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved
7-0	WLVL	0-FFh	Write level (read-only). Number of 32-bit words currently in the Write FIFO.
		0	0 words currently in Write FIFO.
		1h	1 word currently in Write FIFO.
		2h	2 words currently in Write FIFO.
		3h-40h	3 to 64 words currently in Write FIFO.
		41h-FFh	Reserved

26.3.47 Read FIFO Control Register (RFIFOCTL)

The Read FIFO control register (RFIFOCTL) is shown in Figure 26-80 and described in Table 26-50.

NOTE: The RNUMEVT and RNUMDMA values must be set prior to enabling the Read FIFO.

If the Read FIFO is to be enabled, it must be enabled prior to taking the McASP out of reset.

Figure 26-80. Read FIFO Control Register (RFIFOCTL)

31	17	16
Reserved		RENA
R-0		R/W-0

15	8	7	0
RNUMEVT		RNUMDMA	
R/W-10h		R/W-4h	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 26-50. Read FIFO Control Register (RFIFOCTL) Field Descriptions

Bit	Field	Value	Description
31-17	Reserved	0	Reserved
16	RENA		Read FIFO enable bit.
		0	Read FIFO is disabled. The RLVL bit in the Read FIFO status register (RFIFOSTS) is reset to 0 and pointers are initialized, that is, the Read FIFO is “flushed.”
		1	Read FIFO is enabled. If Read FIFO is to be enabled, it must be enabled prior to taking McASP out of reset.
15-8	RNUMEVT	0-FFh	Read word count per DMA event (32-bit). When the Read FIFO contains at least RNUMEVT words of data, then an AREVT (receive DMA event) is generated to the host/DMA controller. This value should be set to a non-zero integer multiple of the number of serializers enabled as receivers. This value must be set prior to enabling the Read FIFO.
		0	0 words
		1h	1 word
		2h	2 words
		3h-40h	3 to 64 words
		41h-FFh	Reserved
7-0	RNUMDMA	0-FFh	Read word count per transfer (32-bit words). Upon a receive DMA event from the McASP, the Read FIFO reads RNUMDMA words from the McASP. This value must equal the number of McASP serializers used as receivers. This value must be set prior to enabling the Read FIFO.
		0	0 words
		1	1 word
		2	2 words
		3h-10h	3-16 words
		11h-FFh	Reserved

26.3.48 Read FIFO Status Register (RFIFOSTS)

The Read FIFO status register (RFIFOSTS) is shown in Figure 26-81 and described in Table 26-51.

Figure 26-81. Read FIFO Status Register (RFIFOSTS)

31	16
Reserved	
R-0	

15	8	7	0
Reserved		RLVL	
R-0		R-0	

LEGEND: R = Read only; -*n* = value after reset

Table 26-51. Read FIFO Status Register (RFIFOSTS) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved
7-0	RLVL	0-FFh	Read level (read-only). Number of 32-bit words currently in the Read FIFO.
		0	0 words currently in Read FIFO.
		1h	1 word currently in Read FIFO.
		2h	2 words currently in Read FIFO.
		3h-40h	3 to 64 words currently in Read FIFO.
		41h-FFh	Reserved

Multimedia Card (MMC)/Secure Digital (SD) Card Controller

This chapter describes the multimedia card (MMC)/secure digital (SD) card controller.

Topic **Page**

27.1 Introduction

27.1.1 Purpose of the Peripheral

A number of applications use the multimedia card (MMC)/secure digital (SD) card to provide removable data storage. The MMC/SD card controller provides an interface to external MMC and SD cards. The communication between the MMC/SD card controller and MMC/SD card(s) is performed according to the MMC/SD protocol.

27.1.2 Features

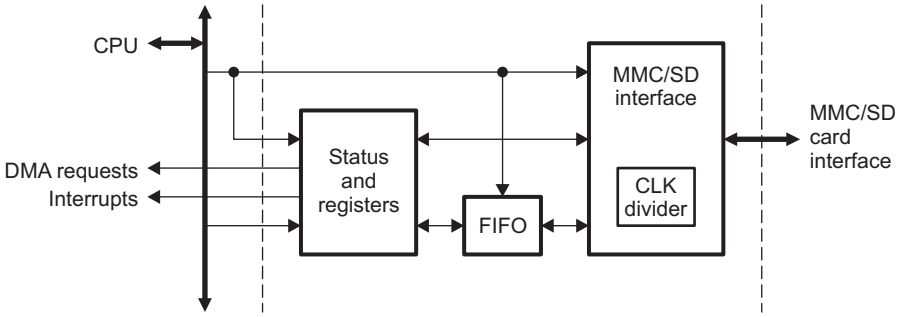
The MMC/SD card controller has the following features:

- Supports interface to multimedia cards (MMC)
- Supports interface to secure digital (SD) memory cards
- Ability to use the MMC/SD protocol and Secure Digital Input Output (SDIO) protocol
- Programmable frequency of the clock that controls the timing of transfers between the MMC/SD controller and memory card
- 512-bit read/write FIFO to lower system overhead
- Signaling to support enhanced direct memory access (EDMA) transfers (slave)
- Maximum clock to MMC varies based on core voltage (see your device-specific data manual)
- Maximum clock to SD varies based on core voltage (see your device-specific data manual)

27.1.3 Functional Block Diagram

The MMC/SD card controller transfers data between the CPU and the EDMA controller on one side and the MMC/SD card on the other side, as shown in Figure 27-1. This means you have a choice of performing data transfers using the CPU or EDMA as a mechanism to move data between the device memory and the FIFO. The CPU and the EDMA controller can read from or write to the data in the card by accessing the registers in the MMC/SD controller.

Figure 27-1. MMC/SD Card Controller Block Diagram



27.1.4 Supported Use Case Statement

The MMC/SD card controller supports the following user cases:

- MMC/SD card identification
- MMC/SD single-block read using CPU
- MMC/SD single-block read using EDMA
- MMC/SD single-block write using CPU
- MMC/SD single-block write using EDMA
- MMC/SD multiple-block read using CPU
- MMC/SD multiple-block read using EDMA

- MMC/SD multiple-block write using CPU
- MMC/SD multiple-block write using EDMA

27.1.5 Industry Standard(s) Compliance Statement

The MMC/SD card controller supports the following industry standards (with the exception noted below):

- MMC (Multimedia Card) Specification v4.0
- SD (Secure Digital) Physical Layer Specification v1.1
- SDIO (Secure Digital Input Output) Specification v2.0

The information in this chapter assumes that you are familiar with these standards.

The MMC/SD controller does not support the SPI mode of operation.

27.2 Architecture

The MMC/SD controller uses the MMC/SD protocol to communicate with the MMC/SD cards. You can configure the MMC/SD controller to work as an MMC or SD controller, based on the type of card the controller is communicating with. Figure 27-2 summarizes the MMC/SD mode interface. Figure 27-3 illustrates how the controller interfaces to the cards in MMC/SD mode.

In the MMC/SD mode, the MMC controller supports one or more MMC/SD cards. Regardless of the number of cards connected, the MMC/SD controller selects one by using identification broadcast on the data line. The following MMC/SD controller pins are used:

- MMCSD_CMD: This pin is used for two-way communication between the connected card and the MMC/SD controller. The MMC/SD controller transmits commands to the card and the memory card drives responses to the commands on this pin.
- MMCSD_DAT0, MMCSD_DAT0-3, or MMCSD_DAT0-7: MMC cards only use one data line (DAT0), four data lines (DAT0-3), or eight data lines (DAT0-7), and SD cards use one data line (DAT0) or four data lines (DAT0-3). The number of MMCSD_DAT pins (the data bus width) is set by the WIDTH bit in the MMC control register (MMCCTL), see Section 27.4.1).
- MMCSD_CLK: This pin provides the clock to the memory card from the MMC/SD controller.

Figure 27-2. MMC/SD Controller Interface Diagram

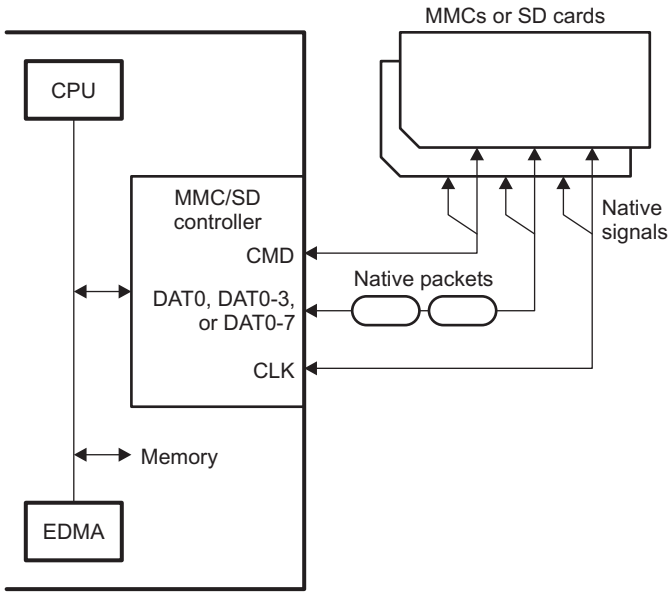
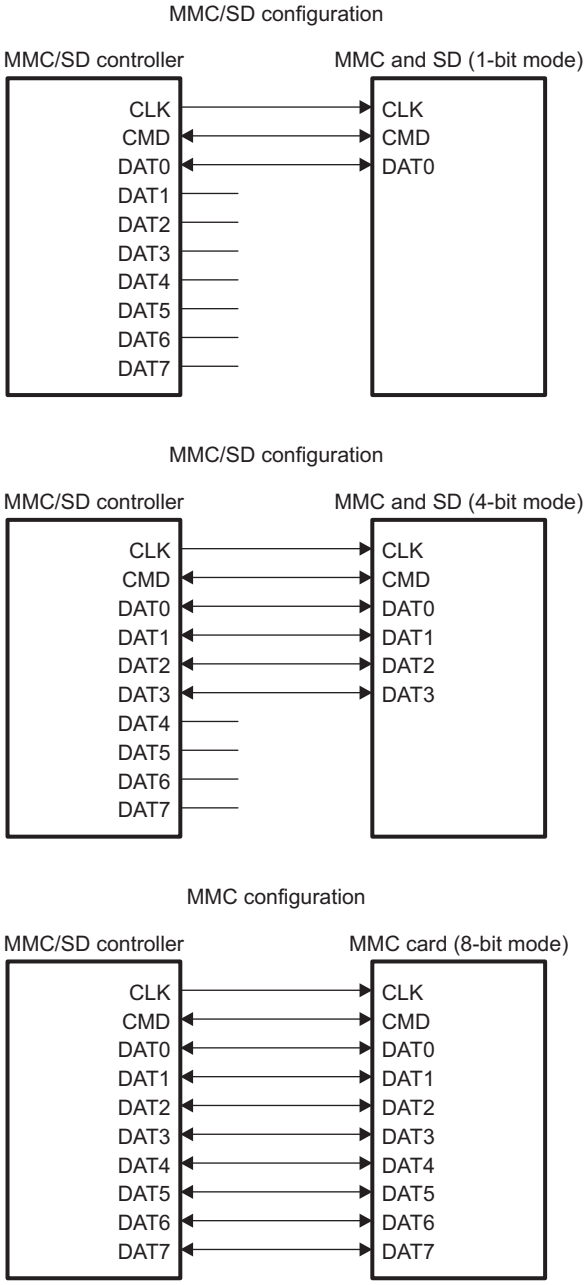


Figure 27-3. MMC Configuration and SD Configuration Diagram



27.2.1 Clock Control

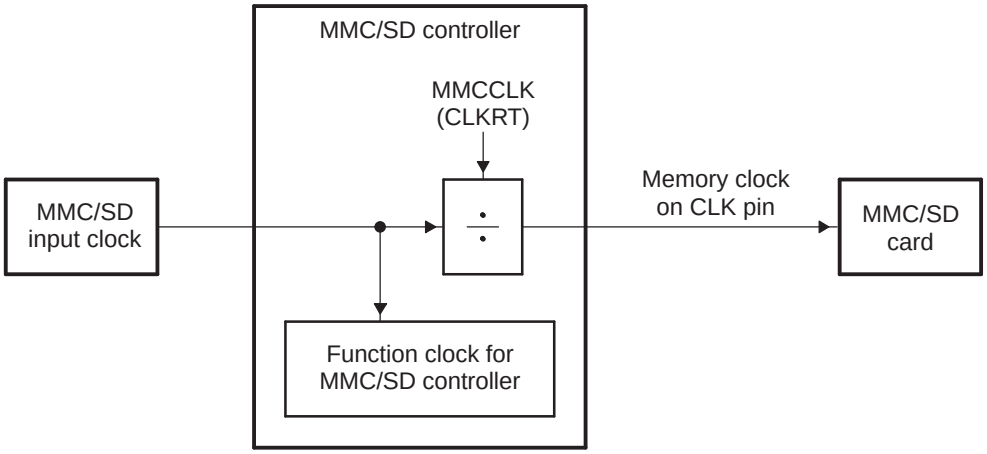
There are two clocks, the function clock and the memory clock, in the MMC/SD controller (Figure 27-4).

The function clock determines the operational frequency of the MMC/SD controller and is the input clock to the MMC/SD card(s).

The memory clock appears on the MMCSD_CLK pin of the MMC/SD controller interface. The memory clock controls the timing of communication between the MMC/SD controller and the connected memory card. The memory clock is generated by dividing the function clock in the MMC/SD controller. The divide-down value is set by CLKRT bits in the MMC memory clock control register (MMCCLK) and is determined by the following equation:

memory clock frequency = function clock frequency/(2 × (CLKRT + 1))

Figure 27-4. MMC/SD Controller Clocking Diagram



27.2.2 Signal Descriptions

Table 27-1 shows the MMC/SD controller pins that each mode uses. The MMC/SD protocol uses the clock, command (two-way communication between the MMC controller and memory card), and data (MMCSD_DAT0, MMCSD_DAT0-3, or MMCSD_DAT0-7 for MMC card; MMCSD_DAT0 or MMCSD_DAT0-3 for SD card) pins.

Table 27-1. MMC/SD Controller Pins Used in Each Mode

		Function		
Pin	**Type [1]**	**MMC and SD (1-bit mode) Communications**	**MMC and SD (4-bit mode) Communications**	**MMC (8-bit mode) Communication**
MMCSD_CLK	O	Clock line	Clock line	Clock line
MMCSD_CMD	I/O	Command line	Command line	Command line
MMCSD_DAT0	I/O	Data line 0	Data line 0	Data line 0
MMCSD_DAT1	I/O	(Not used)	Data line 1	Data line 1
MMCSD_DAT2	I/O	(Not used)	Data line 2	Data line 2
MMCSD_DAT3	I/O	(Not used)	Data line 3	Data line 3
MMCSD_DAT4	I/O		(Not used)	Data line 4
MMCSD_DAT5	I/O		(Not used)	Data line 5
MMCSD_DAT6	I/O		(Not used)	Data line 6
MMCSD_DAT7	I/O		(Not used)	Data line 7

(1) I = input to the MMC controller; O = output from the MMC controller.

27.2.3 Protocol Descriptions

The MMC/SD controller follows the MMC/SD protocol for completing any kind of transaction with the multimedia card and secure digital cards. For more detailed information, refer to the supported MMC and SD specifications in Section 27.1.5.

27.2.3.1 MMC/SD Mode Write Sequence

Figure 27-5 and Table 27-2 show the signal activity when the MMC/SD controller is in the MMC/SD mode and is writing data to a memory card. The same block length must be defined in the MMC/SD controller and in the memory card before initiating a data write. In a successful write protocol sequence, the following steps occur:

- The MMC/SD controller requests the CSD content.
- The card receives the command and sends the content of the CSD register as its response.
- If the desired block length, WRITE_BL_LEN value, is different from the default value determined from the response, the MMC/SD controller sends the block length command.
- The card receives the command and sends responses to the command.
- The MMC/SD controller requests the card to change states from standby to transfer.
- The card receives the command and sends responses to the command.
- The MMC/SD controller sends a write command to the card.
- The card receives the command and sends responses to the command.
- The MMC/SD controller sends a block of data to the card.
- The card sends the CRC status to the MMC/SD controller.
- The card sends a low BUSY bit until all of the data has been programmed into the flash memory inside the card.

Figure 27-5. MMC/SD Mode Write Sequence Timing Diagram

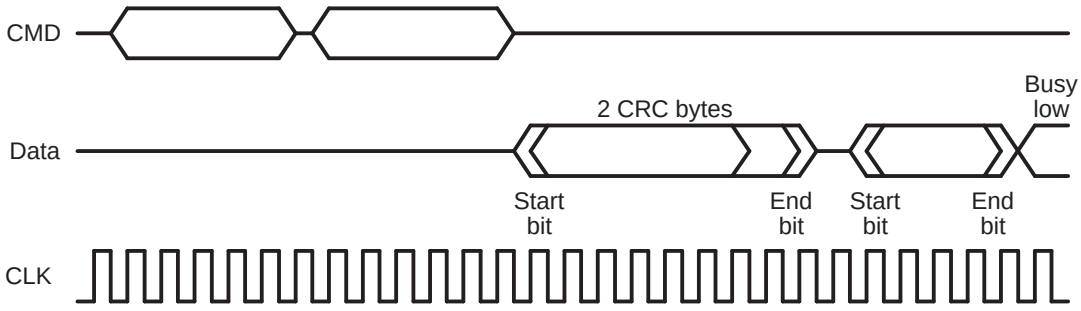


Table 27-2. MMC/SD Mode Write Sequence

Portion of the Sequence	Description
WR CMD	Write command: A 6-byte WRITE_BLOCK command token is sent from the CPU to the card.
CMD RSP	Command response: The card sends a 6-byte response of type R1 to acknowledge the WRITE_BLOCK to the CPU.
DAT BLK	Data block: The CPU writes a block of data to the card. The data content is preceded by one start bit and is followed by two CRC bytes and one end bit.
CRC STAT	CRC status: The card sends a one byte CRC status information, which indicates to the CPU whether the data has been accepted by the card or rejected due to a CRC error. The CRC status information is preceded by one start bit and is followed by one end bit.
BSY	BUSY bit: The CRC status information is followed by a continuous stream of low busy bits until all of the data has been programmed into the flash memory on the card.

27.2.3.2 MMC/SD Mode Read Sequence

Figure 27-6 and Table 27-3 show the signal activity when the MMC controller is in the MMC/SD mode and is reading data from a memory card. The same block length must be defined in the MMC controller and in the memory card before initiating a data read. In a successful read protocol sequence, the following steps occur:

- The MMC/SD controller requests for the CSD content.
- The card receives the command and sends the content of the CSD register as its response.
- If the desired block length, READ_BL_LEN value, is different from the default value determined from the response, the MMC/SD controller sends the block length command.
- The card receives the command and sends responses to the command.
- The MMC/SD controller requests the card to change state from stand-by to transfer.
- The card receives the command and sends responses to the command.
- The MMC/SD controller sends a read command to the card.
- The card drives responses to the command.
- The card sends a block of data to the CPU.

Figure 27-6. MMC/SD Mode Read Sequence Timing Diagram

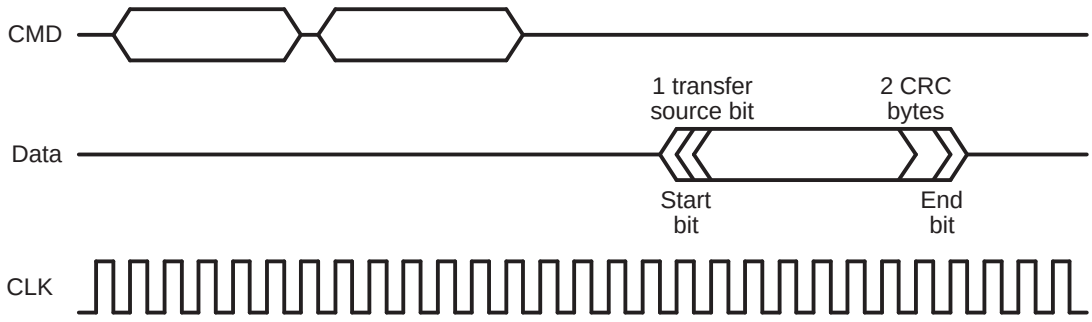


Table 27-3. MMC/SD Mode Read Sequence

Portion of the Sequence	Description
RD CMD	Read command: A 6-byte READ_SINGLE_BLOCK command token is sent from the CPU to the card.
CMD RSP	Command response: The card sends a response of type R1 to acknowledge the READ_SINGLE_BLOCK command to the CPU.
DAT BLK	Data block: The card sends a block of data to the CPU. The data content is preceded by a start bit and is followed by two CRC byte and an end bit.

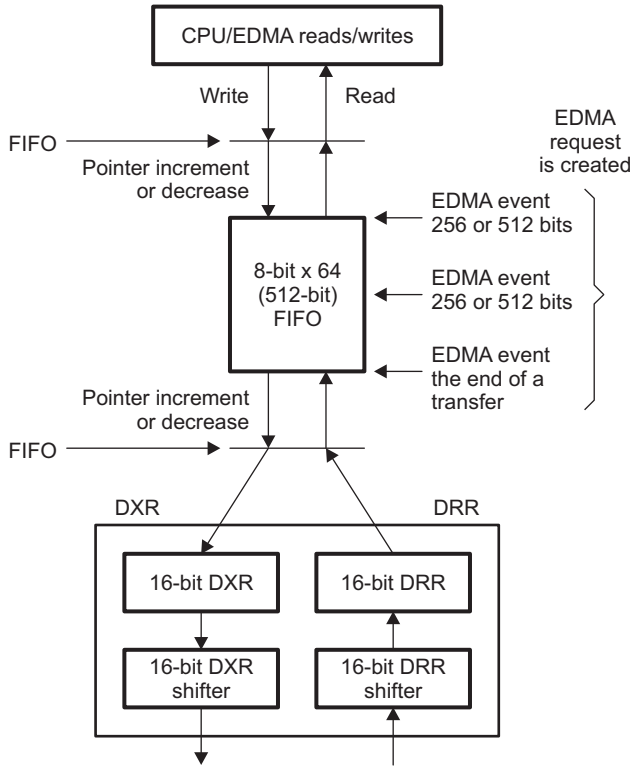
27.2.4 Data Flow in the Input/Output FIFO

The MMC/SD controller contains a single 512-bit FIFO, organized as 8-bit × 64 entries, that is used for both reading data from the memory card and writing data to the memory card (see Figure 27-7). The conversion from the 32-bit bus to the byte format of the FIFO follows the little-endian convention (details are provided in later sections). The read and write FIFOs act as an interim location to store data transferred from/to the card momentarily via the CPU or EDMA. The FIFO includes logic to generate EDMA events and interrupts based on the amount of data in the FIFO and a programmable number of bytes received/transmitted. Flags are set when the FIFO is full or empty.

A high-level operational description is as follows:

- Data is written to the FIFO through the MMC data transmit register (MMCDXR). Data is read from the FIFO through the MMC data receive register (MMCDRR). This is true for both the CPU and EDMA driven transactions; however, for the EDMA transaction, the EDMA access to the FIFO is transparent.
- The ACCWD bits in the MMC FIFO control register (MMCFIFOCTL) determines the behavior of the FIFO full (FIFOFUL) and FIFO empty (FIFOEMP) status flags in the MMC status register 1 (MMCST1):
  - If ACCWD = 00b:
    - FIFO full is active when the write pointer + 4 > read pointer
    - FIFO empty is active when the write pointer - 4 < read pointer
  - If ACCWD = 01b:
    - FIFO full is active when the write pointer + 3 > read pointer
    - FIFO empty is active when the write pointer - 3 < read pointer
  - If ACCWD = 10b:
    - FIFO full is active when the write pointer + 2 > read pointer
    - FIFO empty is active when the write pointer - 2 < read pointer
  - If ACCWD = 11b:
    - FIFO full is active when the write pointer + 1 > read pointer
    - FIFO empty is active when the write pointer - 1 < read pointer

Figure 27-7. FIFO Operation Diagram



Transmission of data

Step 1: Set FIFO reset
Step 2: Set FIFO direction
Step 3: EDMA driven transaction
Step 4: CPU driven transaction: Fill the FIFO by writing to MMCDXR (only first time) or every 256 or 512-bits transmitted and DXRDYINT interrupt is generated
Step 5: EDMA send xmit data
Step 6: If DXR ready is active, FIFO -> 16-bit DXR

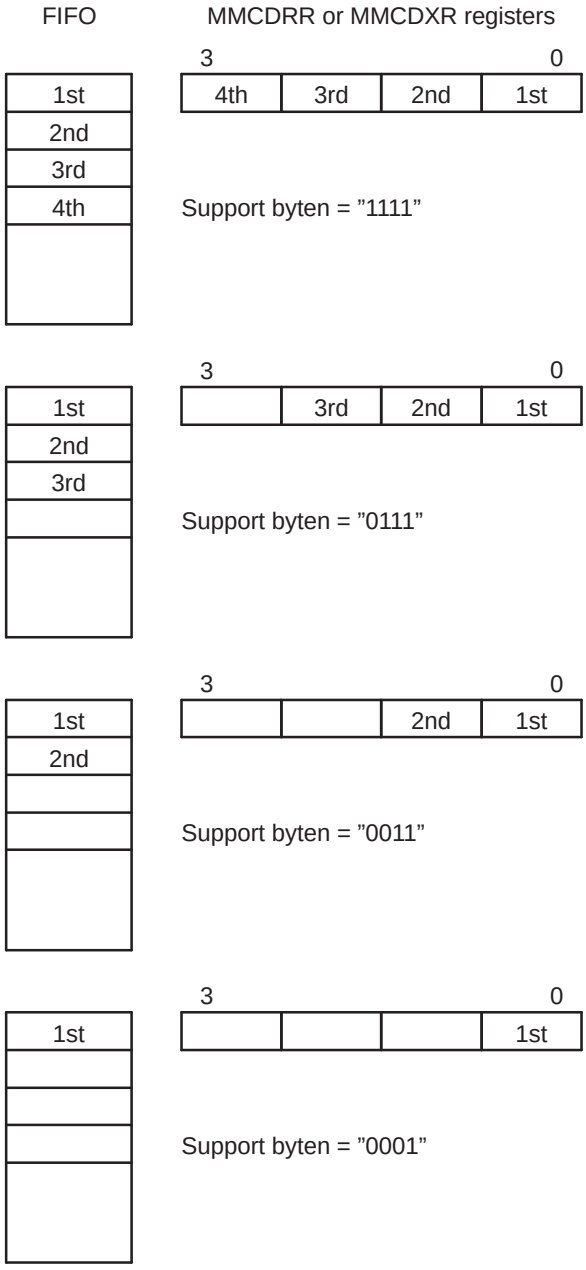
Reception of data

Step 1: Set FIFO reset
Step 2: Set FIFO direction
Step 3: If DRR ready is active, 16-bit DRR -> FIFO
Step 4: EDMA driven transaction
Step 5: DRRDYINT interrupt occur when FIFO every 256 or 512-bits of data received by FIFO
Step 6: EDMA read reception data

27.2.5 Data Flow in the Data Registers (MMCDRR and MMCDXR)

The CPU or EDMA controller can read 32 bits at a time from the FIFO by reading the MMC data receive register (MMCDRR) and write 32 bits at a time to the FIFO by writing to the MMC data transmit register (MMCDXR). However, since the memory card is an 8-bit device, it transmits or receives one byte at a time. Figure 27-8 shows how the data size is handled by the data registers in little-endian mode.

Figure 27-8. Little-Endian Access to MMCDXR/MMCDRR from the CPU or the EDMA



27.2.6 FIFO Operation During Card Read Operation

27.2.6.1 EDMA Reads

The FIFO controller manages the activities of reading the data in from the card and issuing EDMA read events. Each time an EDMA read event is issued, an EDMA read request interrupt generates.

Figure 27-9 provides details of the FIFO controllers operation. As data is received from the card, it is read into the FIFO. When the number of bytes of data received is equal to the level set by the FIFOLEV bits in MMCFIFOCTL, an EDMA read event is issued and new EDMA events are disabled until the EDMA is done with the transfer issued by the current event. Data is read from the FIFO by way of MMCDRR. The FIFO controller continues to read in data from the card while checking for the EDMA event to occur or for the FIFO to become full. Once the EDMA event finishes, new EDMA events are enabled. If the FIFO fills up, the FIFO controller stops the MMC/SD controller from reading any more data until the FIFO is no longer full.

An EDMA read event generates when the last data arrives, as determined by the MMC block length register (MMCBLEN) and the MMC number of blocks register (MMCNBLK) settings. This EDMA event flushes all of the data that was read from the card to the FIFO.

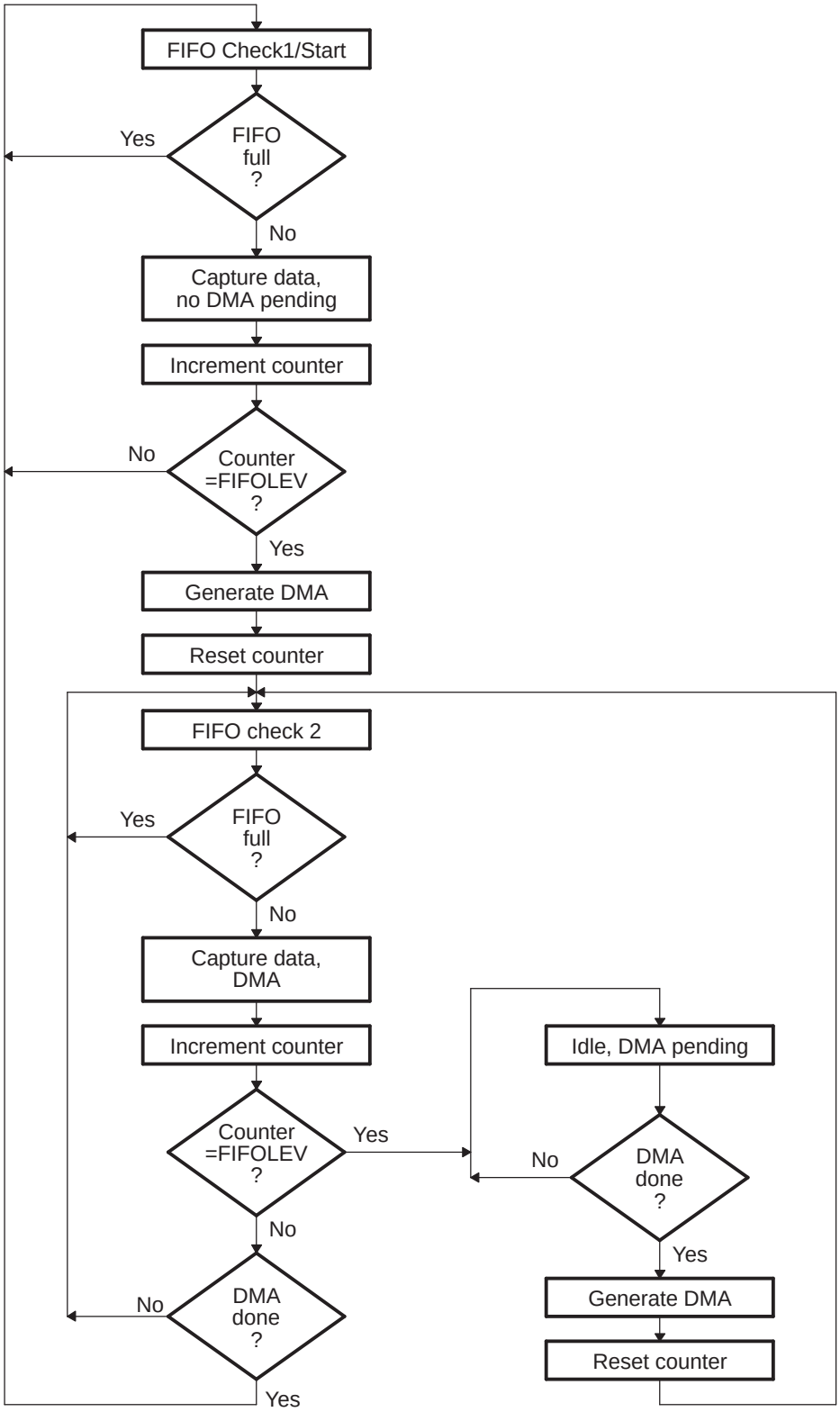
Each time an EDMA read event generates, an interrupt (DRRDYINT) generates and the DRRDY bit in the MMC status register 0 (MMCST0) is also set.

27.2.6.2 CPU Reads

The system CPU can also directly read the card data by reading the MMC data receive register (MMCDRR). The MMC/SD peripheral supports reads that are 1-, 2-, 3-, or 4-bytes wide as, shown in Figure 27-8.

As data is received from the card, it is read into the FIFO. When the number of bytes of data received is equal to the level set by the FIFOLEV bits in MMCFIFOCTL, a DRRDYINT interrupt is issued and the DRRDY bit in the MMC status register 0 (MMCST0) is set. Upon receiving the interrupt, the CPU quickly reads out the bytes received (equal to the level set by the FIFOLEV bits). A DRRDYINT interrupt also generates when the last data arrives as determined by the MMC block length register (MMCBLEN) and the MMC numbers of blocks register (MMCNBLK) settings.

Figure 27-9. FIFO Operation During Card Read Diagram



27.2.7 FIFO Operation During Card Write Operation

27.2.7.1 EDMA Writes

The FIFO controller manages the activities of accepting data from the CPU or EDMA and passing the data to the MMC/SD controller. The FIFO controller issues EDMA write events as appropriate. Each time an EDMA write event is issued, an EDMA write request interrupt generates. Data is written into the FIFO through MMCDXR. Note that the EDMA access to MMCDXR is transparent.

Figure 27-10 provides details of the FIFO controller's operation. The CPU or EDMA controller writes data into the FIFO. The FIFO passes the data to the MMC/SD controller which manages writing the data to the card. When the number of bytes of data in the FIFO is less than the level set by the FIFOLEV bits in MMCFIFOCTL, an EDMA write event is issued and new EDMA events are disabled. The FIFO controller continues to transfer data to the MMC/SD controller while checking for the EDMA event to finish or for the FIFO to become empty. Once the EDMA event finishes, new EDMA events are enabled. If the FIFO becomes empty, the FIFO controller informs the MMC/SD controller.

Each time an EDMA write event generates, an interrupt (DXRDYINT) generates and the DXRDY bit in the MMC status register 0 (MMCST0) is also set.

27.2.7.2 CPU Writes

The system CPU can also directly write the card data by writing the MMC data transmit register (MMCDXR). The MMC/SD peripheral supports writes that are 1-, 2-, 3-, or 4-bytes wide, as shown in Figure 27-8.

The CPU makes use of the FIFO to transfer data to the card via the MMC/SD controller. The CPU writes the data to be transferred into MMCDXR. As is the case with the EDMA driven transaction, when the number of data in the FIFO is less than the level set by the FIFOLEV bits in MMCFIFOCTL, a DXRDYINT interrupt generates and the DXRDY bit in the MMC status register 0 (MMCST0) is set to signify to the CPU that space is available for new data.

NOTE: When starting the write transaction, the CPU is responsible for getting the FIFO ready to start transferring data by filling up the FIFO with data prior to invoking/posting the write command to the card. Filling up the FIFO is a requirement since no interrupt/event generates at the start of the write transfer.

27.2.8 Reset Considerations

The MMC/SD peripheral has two reset sources: hardware reset and software reset.

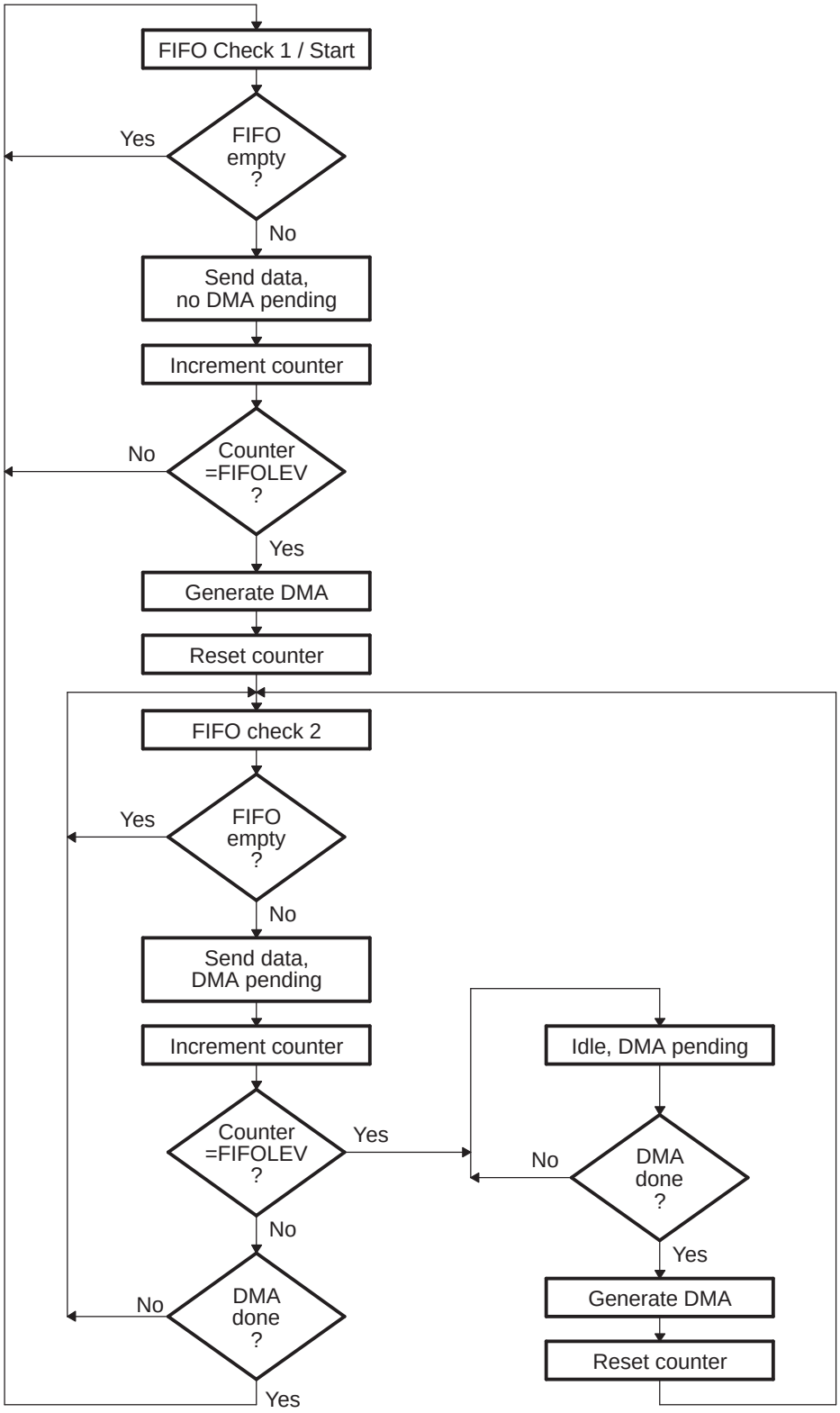
27.2.8.1 Software Reset Considerations

A software reset (such as a reset that the emulator generates) does not cause the MMC/SD controller registers to alter. After a software reset, the MMC/SD controller continues to operate as it was configured prior to the reset.

27.2.8.2 Hardware Reset Considerations

A hardware reset of the processor causes the MMC/SD controller registers to return to their default values after reset.

Figure 27-10. FIFO Operation During Card Write Diagram



27.2.9 Initialization

27.2.9.1 MMC/SD Controller Initialization

The general procedure for initializing the MMC/SD controller is given in the following steps. Details about the registers or register bit fields to be configured in the MMC/SD mode are in the subsequent subsections.

1. Place the MMC/SD controller in its reset state by setting the CMDRST bit and DATRST bit in the MMC control register (MMCCTL). You can set other bits in MMCCTL after reset.
2. Write the required values to other registers to complete the MMC/SD controller configuration.
3. Clear the CMDRST bit and the DATRST bit in MMCCTL to release the MMC/SD controller from its reset state. It is recommended not to rewrite the values that are written to the other bits of MMCCTL in .
4. Enable the MMCSD_CLK pin so that the memory clock is sent to the memory card by setting the CLKEN bit in the MMC memory clock control register (MMCCLK).

NOTE: The MMC/SD cards require a clock frequency of 400 kHz or less for the card initialization procedure. Make sure that the memory clock confirms this requirement. Once card initialization completes, you can adjust the memory clock up to the lower of the card capabilities or the maximum frequency that is supported.

27.2.9.2 Initializing the MMC Control Register (MMCCTL)

The bits in the MMC control register (MMCCTL) affect the operation of the MMC/SD controller. The subsections that follow help you decide how to initialize each of control register bits.

In the MMC/SD mode, the MMC/SD controller must know how wide the data bus must be for the memory card that is connected. If an MMC card is connected, specify a 1-bit data bus (WIDTH = 0 in MMCCTL); if an SD card is connected, specify a 4-bit data bus (WIDTH = 1 in MMCCTL).

To place the MMC/SD controller in its reset state and disable it, set the CMDRST bit and DATRST bit in MMCCTL. The first step of the MMC/SD controller initialization process is to disable both sets of logic. When initialization is complete, but before you enable the MMCSD_CLK pin, clear the CMDRST bit and DATRST bit in MMCCTL to enable the MMC/SD controller.

27.2.9.3 Initializing the Clock Controller Registers (MMCCLK)

A clock divider in the MMC/SD controller divides-down the function clock to produce the memory clock. Load the divide-down value into the CLKRT bits in the MMC memory clock control register (MMCCLK). The divide-down value is determined by the following equation:

memory clock frequency = function clock frequency/(2 × (CLKRT + 1)), when DIV4 = 0 in MMCCLK

memory clock frequency = function clock frequency/(4 × (CLKRT + 1)), when DIV4 = 1 in MMCCLK

The CLKEN bit in MMCCLK determines whether the memory clock appears on the MMCSD_CLK pin. If you clear the CLKEN to 0, the memory clock is not provided except when required.

27.2.9.4 Initialize the Interrupt Mask Register (MMCIM)

The bits in the MMC interrupt mask register (MMCIM) individually enable or disable the interrupt requests. To enable the associated interrupt request, set the corresponding bit in MMCIM. To disable the associated interrupt request, clear the corresponding bit. Load zeros into the bits that are not used in the MMC/SD mode.

27.2.9.5 Initialize the Time-Out Registers (MMCTOR and MMCTOD)

Specify the time-out period for responses using the MMC response time-out register (MMCTOR) and the time-out period for reading data using the MMC data read time-out register (MMCTOD).

When the MMC/SD controller sends a command to a memory card, it must often wait for a response. The MMC/SD controller can wait indefinitely or up to 255 memory clock cycles. If you load 0 into MMCTOR, the MMC/SD controller waits indefinitely for a response. If you load a nonzero value into MMCTOR, the MMC/SD controller stops waiting after the specified number of memory clock cycles and then sets a response time-out flag (TOUTRS) in the MMC status register 0 (MMCST0). If you enable the associated interrupt request, the MMC/SD controller also sends an interrupt request to the CPU.

When the MMC/SD controller requests data from a memory card, it can wait indefinitely for that data or it can stop waiting after a programmable number of cycles. If you load 0 into MMCTOD, the MMC/SD controller waits indefinitely. If you load a nonzero value into MMCTOD, the MMC/SD controller waits the specified number of memory clock cycles and then sets a read data time-out flag (TOUTRD) in MMCST0. If you enable the associated interrupt request, the MMC/SD controller also sends an interrupt request to the CPU.

27.2.9.6 Initialize the Data Block Registers (MMCBLEN and MMCNBLK)

Specify the number of bytes in a data block in the MMC block length register (MMCBLEN) and the number of blocks in a multiple-block transfer in the MMC number of blocks register (MMCNBLK).

You must define the size for each block of data transferred between the MMC/SD controller and a memory card in MMCBLEN. The valid size depends on the type of read/write operations. A length of 0 bytes is prohibited.

For multiple-block transfers, you must specify how many blocks of data are to be transferred between the MMC/SD controller and a memory card. You can specify an infinite number of blocks by loading 0 into MMCNBLK. When MMCNBLK = 0, the MMC/SD controller continues to transfer data blocks until the transferring is stopped with a STOP_TRANSMISSION command. To transfer a specific number of blocks, load MMCNBLK with a value from 1 to 65 535.

27.2.9.7 Monitoring Activity in the MMC/SD Mode

This section describes registers and specific register bits that you can use to obtain the status of the MMC/SD controller in the MMC/SD mode. You can determine the status of the MMC/SD controller by reading the bits in the MMC status register 0 (MMCST0) and MMC status register 1 (MMCST1).

27.2.9.7.1 Determining Whether New Data is Available in MMCDRR

The MMC/SD controller sets the DRRDY bit in MMCST0 when the data in the FIFO is greater than the threshold set in the MMC FIFO control register (MMCFIFOCTL). If the interrupt request is enabled (EDRRDY = 1 in MMCIM), the processor is notified of the event by an interrupt. A read of the MMC data receive register (MMCDDR) clears the DRRDY flag.

27.2.9.7.2 Verifying that MMCDXR is Ready to Accept New Data

The MMC/SD controller sets the DXRDY bit in MMCST0 when the amount of data in the FIFO is less than the threshold set in the MMC FIFO control register (MMCFIFOCTL). If the interrupt request is enabled (EDXRDY = 1 in MMCIM), the CPU is notified of the event by an interrupt.

27.2.9.7.3 Checking for CRC Errors

The MMC/SD controller sets the CRCRS, CRCRD, and CRCWR bits in MMCST0 in response to the corresponding CRC errors of command response, data read, and data write. If the interrupt request is enabled (ECRCRS/ECRCRD/ECRCWR = 1 in MMCIM), the CPU is notified of the CRC error by an interrupt.

27.2.9.7.4 Checking for Time-Out Events

The MMC/SD controller sets the TOUTRS and TOUTRD bits in MMCST0 in response to the corresponding command response or data read time-out event. If the interrupt request is enabled (ETOUTRS/ETOUTRD = 1 in MMCIM), the CPU is notified of the event by an interrupt.

27.2.9.7.5 Determining When a Response/Command is Done

The MMC/SD controller sets the RSPDNE bit in MMCST0 when the response is done; or in the case of commands that do not require a response, when the command is done. If the interrupt request is enabled (ERSPDNE = 1 in MMCIM), the CPU is also notified.

27.2.9.7.6 Determining Whether the Memory Card is Busy

The card sends a busy signal either when waiting for an R1b-type response or when programming the last write data into its flash memory. The MMC/SD controller has two flags to notify you whether the memory card is sending a busy signal. The two flags are complements of each other:

- The BSYDNE flag in MMCST0 is set if the card did not send or is not sending a busy signal when the MMC/SD controller is expecting a busy signal (BSYEXP = 1 in MMCCMD). The interrupt by this bit is enabled by a corresponding interrupt enable bit (EBSYDNE = 1 in MMCIM).
- The BUSY flag in MMCST1 is set when a busy signal is received from the card.

27.2.9.7.7 Determining Whether a Data Transfer is Done

The MMC/SD controller sets the DATDNE bit in MMCST0 when all of the bytes of a data transfer have been transmitted/received. The DATDNE bit is polled to determine when to stop writing to the data transmit register (for a write operation) or when to stop reading from the data receive register (for a read operation). The CPU is also notified of the time-out event by an interrupt if the interrupt request is enabled (EDATDNE = 1 in MMCIM).

27.2.9.7.8 Determining When Last Data has Been Written to Card (SanDisk SD cards)

Some SanDisk brand SD™ cards exhibit a behavior that requires a multiple-block write command to terminate with a STOP (CMD12) command before the data write sequence completes. To enable support of this function, the transfer done interrupt (TRNDNE) is provided. Set the ETRNDNE bit in MMCIM to enable the TRNDNE interrupt. This interrupt is issued when the last byte of data (as defined by MMCNBLK and MMCBLEN) is transferred from the FIFO to the output shift register. The CPU should respond to this interrupt by sending a STOP command to the card. This interrupt differs from DATDNE by timing. DATDNE does not occur until after the CRC and memory programming are complete.

27.2.9.7.9 Checking For a Data Transmit Empty Condition

During transmission, a data value is passed from the MMC data transmit register (MMCDXR) to the data transmit shift register. The data is then passed from the shift register to the memory card one bit at a time. The DXEMP bit in MMCST1 indicates when the shift register is empty.

Typically, the DXEMP bit is not used to control data transfers; rather, it is checked during recovery from an error condition. There is no interrupt associated with the DXEMP bit.

27.2.9.7.10 Checking for a Data Receive Full Condition

During reception, the data receive shift register accepts a data value one bit at a time. The entire value is then passed from the shift register to the MMC data receive register (MMCDRR). The DRFUL bit in MMCST1 indicates that when the shift register is full no new bits can be shifted in from the memory card.

The DRFUL bit is not typically used to control data transfers; rather, it is checked during recovery from an error condition. There is no interrupt associated with the DRFUL bit.

27.2.9.7.11 Checking the Status of the MMCSD_CLK Pin

Read the CLKSTP bit in MMCST1 to determine whether the memory clock has been stopped on the MMCSD_CLK pin.

27.2.9.7.12 Checking the Remaining Block Count During a Multiple-Block Transfer

During a transfer of multiple data blocks, the MMC number of blocks counter register (MMCNBLC) indicates how many blocks are remaining to be transferred. The MMCNBLC is a read-only register.

27.2.10 Interrupt Support

27.2.10.1 Interrupt Events and Requests

The MMC/SD controller generates the interrupt requests described in Table 27-4. When an interrupt event occurs, its flag bit is set in the MMC status register 0 (MMCST0). If the enable bits corresponding to each flag are set in the MMC interrupt mask register (MMCIM), an interrupt request generates. All such requests are multiplexed to a single MMC/SD interrupt request from the MMC/SD peripheral to the CPU.

The MMC/SD interrupts are part of the maskable CPU interrupts. One CPU interrupt is associated with MMC functions and one CPU interrupt is associated with SD functions (see your device-specific data manual for details). The interrupt service routine (ISR) for the MMC/SD interrupt can determine the event that caused the interrupt by checking the bits in MMCST0. When MMCST0 is read, all register bits automatically clear. During a middle of data transfer, the DXRDY and DRRDY bits are set during every 256-bit or 512-bit transfer, depending on the MMC FIFO control register (MMCFIFOCTL) setting. Performing a write and a read in response to the interrupt generated by the FIFO automatically clears the corresponding interrupt bit/flag.

NOTE: You must be aware that an emulation read of the status register clears the interrupt status flags. To avoid inadvertently clearing the flag, be careful while monitoring MMCST0 via the debugger.

Table 27-4. Description of MMC/SD Interrupt Requests

Interrupt Request	Interrupt Event
TRNDNEINT	**For read operations:** The MMC/SD controller has received the last byte of data (before CRC check).
	For write operations: The MMC/SD controller has transferred the last word of data to the output shift register.
DATEDINT	An edge was detected on the MMCSD_DAT3 pin.
DRRDYINT	MMCDRR is ready to be read (data in FIFO is above threshold).
DXRDYINT	MMCDXR is ready to transmit new data (data in FIFO is less than threshold).
CRCRSINT	A CRC error was detected in a response from the memory card.
CRCRDINT	A CRC error was detected in the data read from the memory card.
CRCWRINT	A CRC error was detected in the data written to the memory card.
TOUTRSINT	A time-out occurred while the MMC controller was waiting for a response to a command.
TOUTRDINT	A time-out occurred while the MMC controller was waiting for the data from the memory card.
RSPDNEINT	**For a command that requires a response:** The MMC controller has received the response without a CRC error.
	For a command that does not require a response: The MMC controller has finished sending the command.
BSYDNEINT	The memory card stops or is no longer sending a busy signal when the MMC controller is expecting a busy signal.
DATDNEINT	**For read operations:** The MMC controller has received data without a CRC error.
	For write operations: The MMC controller has finished sending data.

27.2.10.2 Interrupt Multiplexing

The interrupts from the MMC/SD peripheral to the CPU are not multiplexed with any other interrupt source.

27.2.11 DMA Event Support

The MMC/SD controller is capable of generating EDMA events for both read and write operations in order to request service from an EDMA controller. Based on the FIFO threshold setting, the EDMA event signals generate every time 256-bit or 512-bit data is transferred from the FIFO.

27.2.12 Power Management

You can put the MMC/SD peripheral in reduced-power modes to conserve power during periods of low activity. The processor power and sleep controller (PSC) controls the power management of the MMC/SD peripheral. The PSC acts as a master controller for power management for all of the peripherals on the device. For detailed information on power management procedures using the PSC, see the *Power and Sleep Controller (PSC)* chapter.

27.2.13 Emulation Considerations

The MMC/SD peripheral is not affected by emulation halt events (such as breakpoints).

27.3 Procedures for Common Operations

27.3.1 Card Identification Operation

Before the MMC/SD controller starts data transfers to or from memory cards in the MMC/SD native mode, it must first identify how many cards are present on the bus and configure them. For each card that responds to the ALL_SEND_CID broadcast command, the controller reads that card's unique card identification address (CID) and then assigns it a relative address (RCA). This address is much shorter than the CID and the MMC/SD controller uses this address to identify the card in all future commands that involve the card.

Only one card completes the response to ALL_SEND_CID at any one time. The absence of any response to ALL_SEND_CID indicates that all cards have been identified and configured.

NOTE: The following steps assume that the MMC/SD controller is configured to operate in MMC or SD mode, and the memory clock frequency on the MMCSD_CLK pin is set for 400 kHz or less.

The procedure for a card identification operation is issued in open-drain bus mode for both MMC and SD cards.

27.3.1.1 MMC Card Identification Procedure

The MMC card identification procedure is:

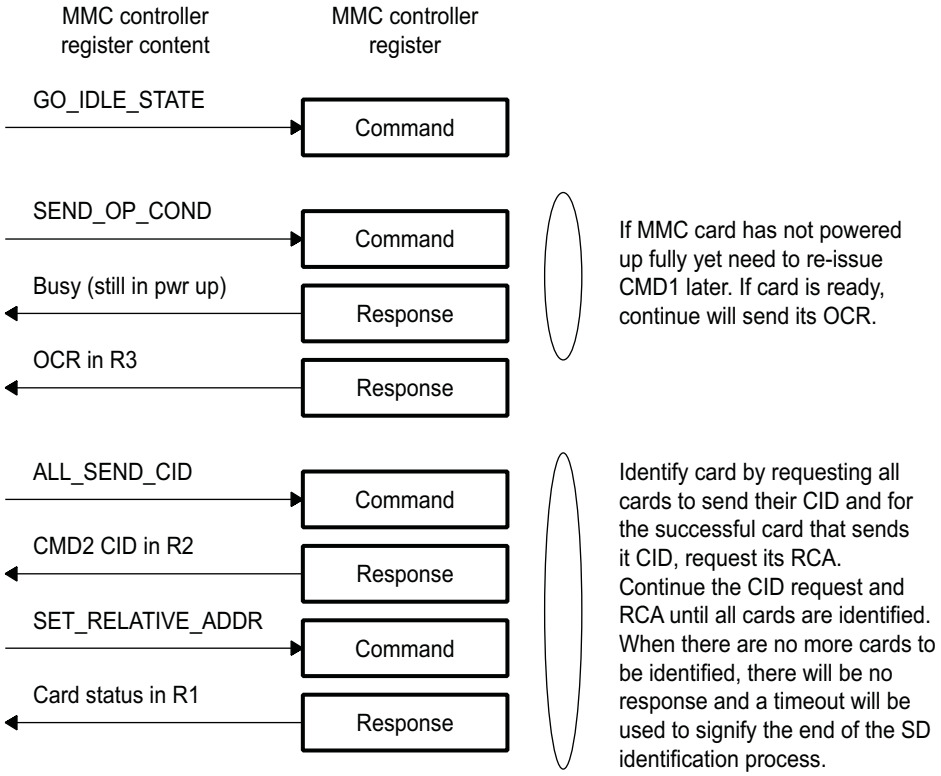
1. Use the MMC command register (MMCCMD) to issue the GO_IDLE_STATE (CMD0) command to the MMC cards. Using MMCCMD to issue the CMD0 command puts all cards (MMC and SD) in the idle state and no response from the cards is expected.
2. Use MMCCMD to issue the SEND_OP_CMD (CMD1) command with the voltage range supported (R3 response, if it is successful; R1b response, if the card is expected to be busy). Using MMCCMD to issue the CMD1 command allows the host to identify and reject cards that do not match the VDD range that the host supports.
3. If the response in Step 2 is R1b (that is, the card is still busy due to power up), then return to Step 2. If the card is not busy, go to Step 4.
4. Use MMCCMD to send the ALL_SEND_CID (CMD2) command (R2 response is expected) to the MMC cards. Using MMCCMD to send the CMD2 command notifies all cards to send their unique card identification (CID) number. There should only be one card that successfully sends its full CID number to the host. The successful card goes into the identification state and does not respond to this command again.
5. Use MMCMD to issue the SET_RELATIVE_ADDR (CMD3) command (R1 response is expected) in order to assign an address that is shorter than the CID number that will be used in the future to address the card in the future data transfer mode.

   NOTE: This command is only addressed to the card that successfully sent its CID number in step 4. This card now goes into standby mode. This card also changes its output drivers from open-drain to push-pull. It stops replying to the CMD2 command, allowing for the identification of other cards.

6. Repeat Step 4 and Step 5 to identify and assign relative addresses to all remaining cards until no card responds to the CMD1 command. No card responding within 5 memory clock cycles indicates that all cards have been identified and the MMC card identification procedure terminates.

The sequence of events in this operation is shown in Figure 27-11.

Figure 27-11. MMC Card Identification Procedure



27.3.1.2 SD Card Identification Procedure

The SD card identification procedure is:

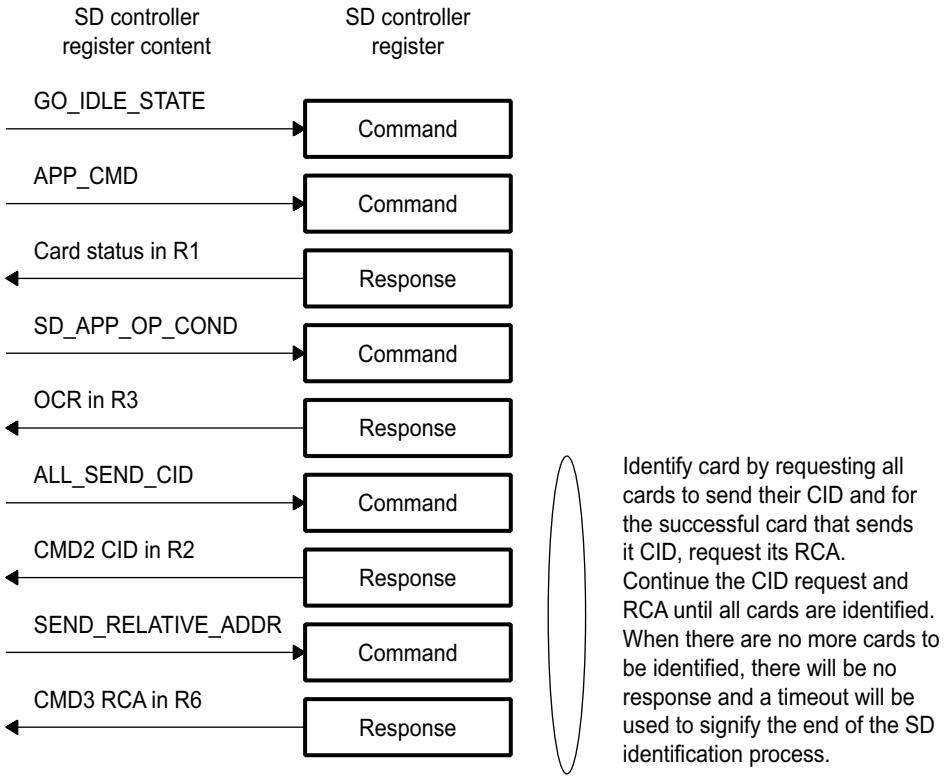
1. Use the MMC command register (MMCCMD) to issue the GO_IDLE_STATE (CMD0) command to the MMC cards. Using MMCMD to issue the CMD0 command puts all cards (MMC and SD) in the idle state and no response from the cards is expected.
2. Use MMCCMD to issue the APP_CMD (CMD55) command (R1 response is expected) to indicate that the command that follows is an application command.
3. Use MMCCMD to send the SD_SEND_OP_COND (ACMD41) command with the voltage range supported (R3 response is expected) to SD cards. Using MMCCMD to send the ACMD41 command allows the host to identify and reject cards that do not match the VDD range that the host supports.
4. Use MMCCMD to send the ALL_SEND_CID (CMD2) command (R2 response is expected) to the MMC cards. Using MMCCMD to send the CMD2 command notifies all cards to send their unique card identification (CID) number. There should only be one card that successfully sends its full CID number to the host. The successful card goes into identification state and does not respond to this command again.
5. Use MMCMD to issue the SEND_RELATIVE_ADDR (CMD3) command (R1 response is expected) in order to ask the card to publish a new relative address for future use to address the card in data transfer mode.

NOTE: This command is only addressed to the card that successfully sent its CID number in step 4. This card now goes into standby mode. This card also changes its output drivers from open-drain to push-pull. It stops replying to the CMD2 command, allowing for the identification of other cards.

6. Repeat Step 4 and Step 5 to identify and retrieve relative addresses from all remaining SD cards until no card responds to the CMD2 command. No card responding within 5 memory clock cycles indicates that all cards have been identified and the MMC card and the identification procedure terminates.

The sequence of events in this operation is shown in Figure 27-12.

Figure 27-12. SD Card Identification Procedure



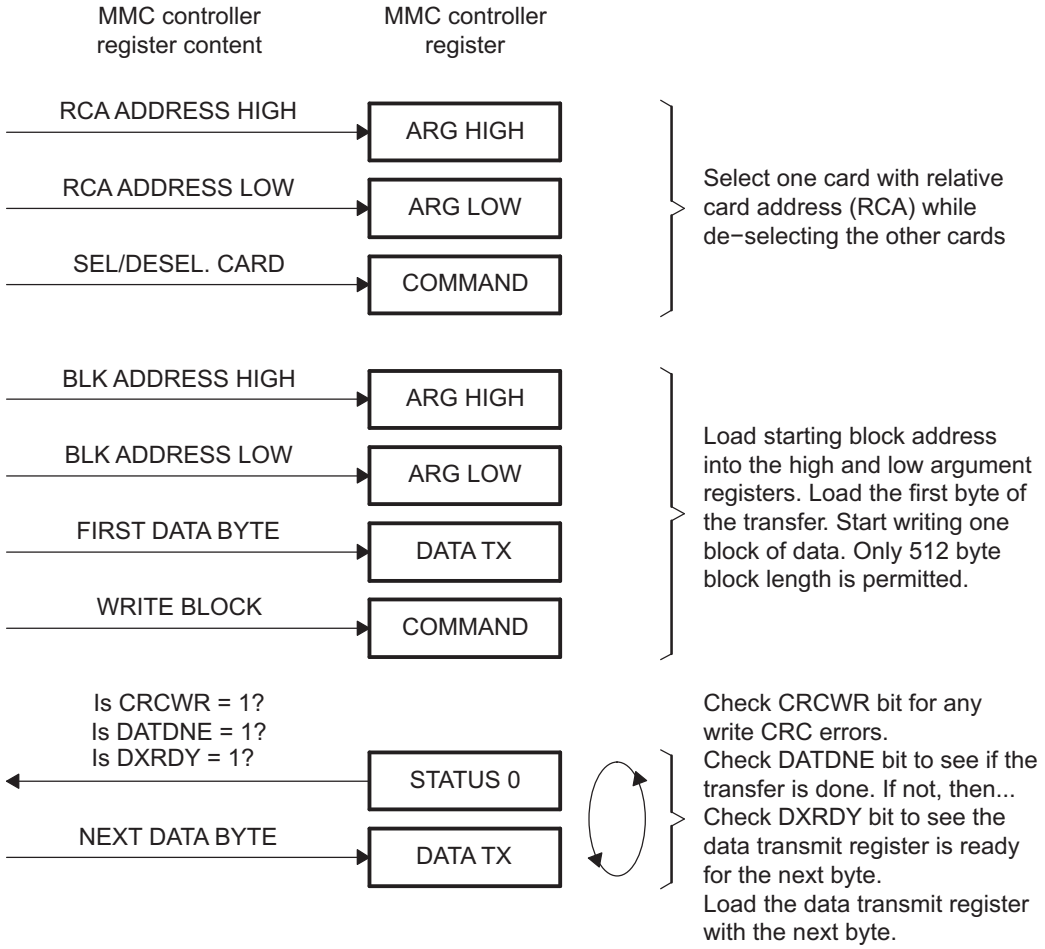
27.3.2 MMC/SD Mode Single-Block Write Operation Using CPU

To perform a single-block write, the block length must be 512 bytes and the same length needs to be set in both the MMC/SD controller and the memory card. The procedure for this operation is:

1. Write the card's relative address to the MMC argument registers (MMCARGH and MMCARGL). Load the higher part of the address to MMCARGH and the low part of the address to MMCARGL.
2. Use the MMC command register (MMCCMD) to send the SELECT/DESELECT_CARD broadcast command. This selects the addressed card and deselects the others.
3. Write the destination start address to the MMC argument registers. Load the high part to the MMCARGH register and the low part to MMCARGL.
4. Read the card CSD to determine the card's maximum block length.
5. Use MMCCMD to send the SET_BLOCKLEN command (if the block length is different than the length used in the previous operation). The block length must be a multiple of 512 bytes and less then the maximum block length specified in the CSD.
6. Reset the FIFO (FIFORST bit in MMCFIFOCTL).
7. Set the FIFO direction to transmit (FIFODIR bit in MMCFIFOCTL).
8. Set the access width (ACCWD bits in MMCFIFOCTL).
9. Enable the MMC interrupt.
10. Enable the DXRDYINT interrupt.
11. Write the first 32 bytes of the data block to the data transmit register (MMCDXR).
12. Use MMCCMD to send the WRITE_BLOCK command to the card.
13. Set the DMATRIG bit in MMCCMD to trigger the first data transfer.
14. Wait for the MMC interrupt.
15. Use the MMC status register 0 (MMCST0) to check for errors and the status of the FIFO. If all of the data has not been written and if the FIFO is not full, go to Step 16. If all of the data has been written, stop.
16. Write the next *n* bytes (this depends on the setting of the FIFOLEV bit in MMCFIFOCTL: 0 = 32 bytes, 1 = 64 bytes) of the data block to the MMC data transmit register (MMCDXR) and return to Step 14.

The sequence of events in this operation is shown in Figure 27-13.

Figure 27-13. MMC/SD Mode Single-Block Write Operation



27.3.3 MMC/SD Mode Single-Block Write Operation Using the EDMA

To perform a single-block write, the block length must be 512 bytes and the same length must be set in both the MMC/SD controller and the card.

The procedure for this operation is as follows:

1. Write the card's relative address to the MMC argument registers (MMCARGH and MMCARGL). Load the high part of the address to MMCARGH and the low part of the address to MMCARGL.
2. Read the card CSD to determine the card's maximum block length.
3. Use the MMC command register (MMCCMD) to send the SET_BLOCKLEN command (if the block length is different than the length used in the previous operation). The block length must be a multiple of 512 bytes and less then the maximum block length specified in the CSD.
4. Reset the FIFO (FIFORST bit in MMCFIFOCTL).
5. Set the FIFO direction to transmit (FIFODIR bit in MMCFIFOCTL).
6. Set the access width (ACCWD bits in MMCFIFOCTL).
7. Set the FIFO threshold (FIFOLEV bit in MMCFIFOCTL).
8. Set up the DMA (DMA size must be greater than or equal to the FIFOLEV setting).
9. Use MMCCMD to send the WRITE _BLOCK command to the card.
10. Set the DMATRIG bit in MMCCMD to trigger the first data transfer.
11. Wait for the DMA sequence to complete or for the DATADNE flag in the MMC status register 0 (MMCST0) to be set.
12. Use MMCST0 to check for errors.

27.3.4 MMC/SD Mode Single-Block Read Operation Using the CPU

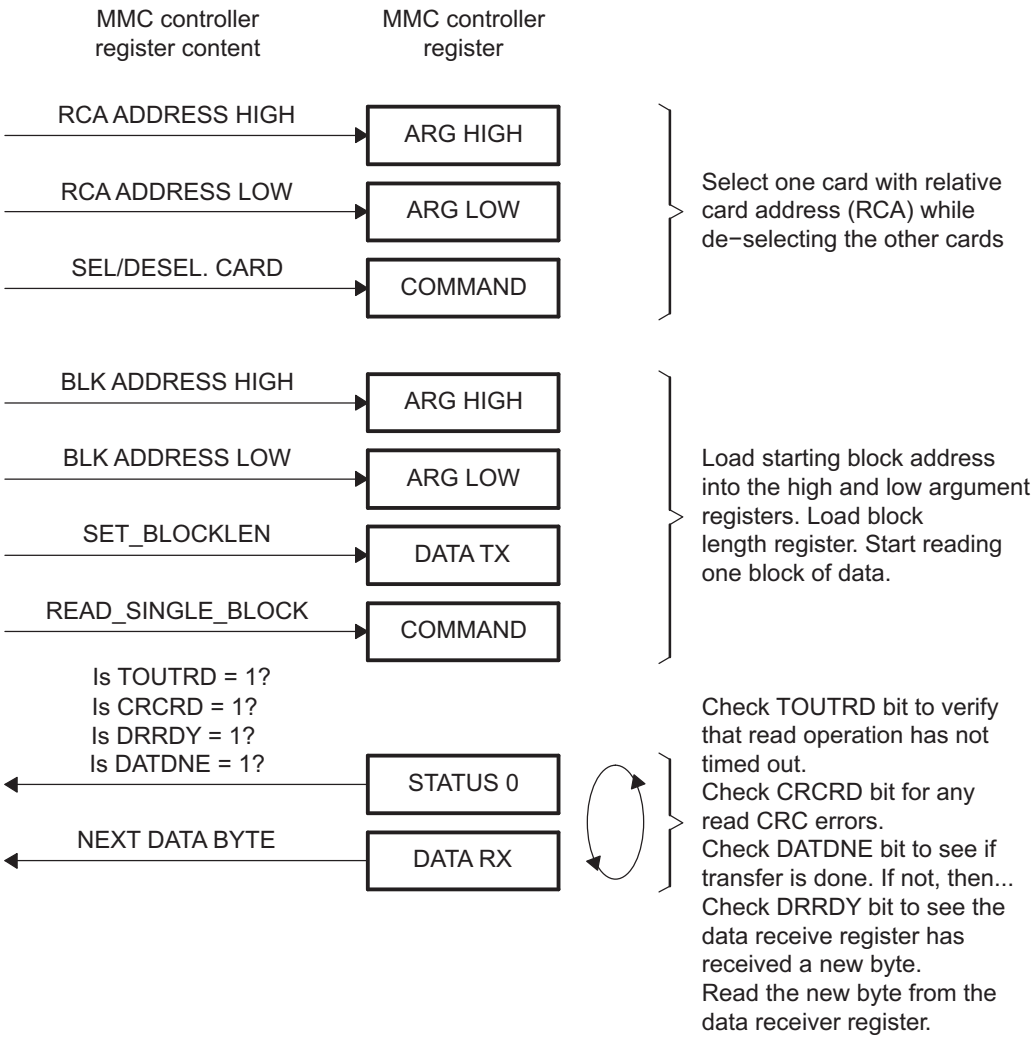
To perform a single-block read, the same block length must be set in both the MMC/SD controller and the card.

The procedure for this operation is as follows:

1. Write the card's relative address to the MMC argument registers (MMCARGH and MMCARGL). Load the high part of the address to MCARGH and the low part of the address to MMCARGL.
2. Use the MMC command register (MMCCMD) to send the SELECT/DESELECT_CARD broadcast command. This selects the addressed card and deselects the others.
3. Write the source start address to the MMC argument registers. Load the high part to MMCARGH and the low part to MMCARGL.
4. Read card CSD to determine the card's maximum block length.
5. Use MMCCMD to send the SET_BLOCKLEN command (if the block length is different than the length used in the previous operation). The block length must be a multiple of 512 bytes and less then the maximum block length specified in the CSD.
6. Reset the FIFO (FIFORST bit in MMCFIFOCTL).
7. Set the FIFO direction to receive (FIFODIR bit in MMCFIFOCTL).
8. Set the access width (ACCWD bits in MMCFIFOCTL).
9. Set the FIFO threshold (FIFOLEV bit in MMCFIFOCTL).
10. Enable the MMC interrupt.
11. Enable the DRRDYINT interrupt.
12. Use MMCCMD to send the READ_SINGLE_BLOCK command.
13. Set the DMATRIG bit in MMCCMD to trigger the first data transfer.
14. Wait for the MMC interrupt.
15. Use the MMC status register 0 (MMCST0) to check for errors and the status of the FIFO. If the FIFO is not empty, go to Step 16. If the all of the data has been read, stop.
16. Read the next *n* bytes of data (this depends on the setting of the FIFOLEV bit in MMCFIFOCTL: 0 = 32 bytes, 1 = 64 bytes) from the MMC data receive register (MMCDRR) and return to Step 14.

The sequence of events in this operation is shown in Figure 27-14.

Figure 27-14. MMC/SD Mode Single-Block Read Operation



27.3.5 MMC/SD Mode Single-Block Read Operation Using EDMA

To perform a single-block read, the same block length needs to be set in both the MMC/SD controller and the card. The procedure for this operation is:

1. Write the card's relative address to the MMC argument registers (MMCARGH and MMCARGL). Load the high part of the address to MMCARGH and the low part of the address to MMCARGL.
2. Read card CSD to determine the card's maximum block length.
3. Use the MMC command register (MMCCMD) to send the SET_BLOCKLEN command (if the block length is different than the length used in the previous operation). The block length must be a multiple of 512 bytes and less then the maximum block length specified in the CSD.
4. Reset the FIFO (FIFORST bit in MMCFIFOCTL).
5. Set the FIFO direction to receive (FIFODIR bit in MMCFIFOCTL).
6. Set the access width (ACCWD bits in MMCFIFOCTL).
7. Set the FIFO threshold (FIFOLEV bit in MMCFIFOCTL).
8. Set up DMA (DMA size needs to be greater than or equal to FIFOLEV setting).
9. Use MMCCMD to send the READ _BLOCK command to the card.
10. Set the DMATRIG bit in MMCCMD to trigger the first data transfer.
11. Wait for DMA sequence to complete.
12. Use the MMC status register 0 (MMCST0) to check for errors.

27.3.6 MMC/SD Mode Multiple-Block Write Operation Using CPU

NOTE: This procedure uses a STOP_TRANSMISSION command to end the block transfer. This assumes that the value in the MMC number of blocks counter register (MMCNBLK) is 0. A multiple-block operation terminates itself if you load MMCNBLK with the exact number of blocks you want transferred.

To perform a multiple-block write, the same block length needs to be set in both the MMC/SD controller and the card.

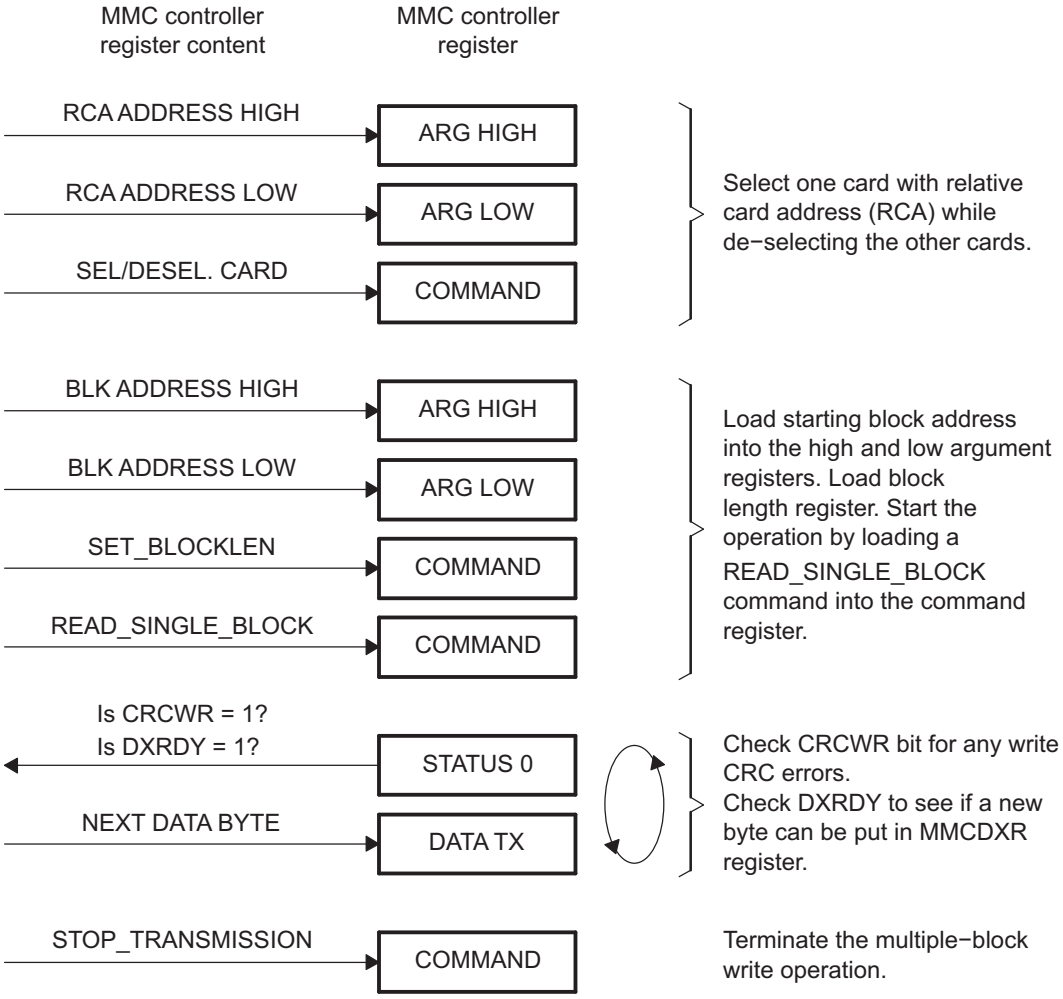
The procedure for this operation is:

1. Write the card's relative address to the MMC argument registers (MMCARGH and MMCARGL). Load the high part of the address to MMCARGH and the low part of the address to MMCARGL.
2. Read card CSD to determine the card's maximum block length.
3. Use the MMC command register (MMCCMD) to send the SET_BLOCKLEN command (if the block length is different than the length used in the previous operation). The block length must be a multiple of 512 bytes and less then the maximum block length specified in the CSD.
4. Reset the FIFO (FIFORST bit in MMCFIFOCTL).
5. Set the FIFO direction to transmit (FIFODIR bit in MMCFIFOCTL).
6. Set the access width (ACCWD bits in MMCFIFOCTL).
7. Set the FIFO threshold (FIFOLEV bit in MMCFIFOCTL).
8. Enable the MMC interrupt.
9. Enable DXRDYINT interrupt.
10. Write the first 32 bytes of the data block to the MMC data transmit register (MMCDXR).
11. Use MMCCMD to send the WRITE_MULTI_BLOCK command to the card.
12. Set the DMATRIG bit in MMCCMD to trigger the first data transfer.
13. Wait for MMC interrupt.
14. Use the MMC status register 0 (MMCST0) to check for errors and to determine the status of the FIFO. If more bytes are to be written and the FIFO is not full, go to Step 15. If the all of the data has been written, go to Step 16.

15. Write the next *n* bytes (depends on setting of FIFOLEV in MMCFIFOCTL: 0 = 32 bytes, 1 = 64 bytes) of the data block to MMCDXR, and return to Step 13.
16. Use MMCCMD to send the STOP_TRANSMISSION command.

The sequence of events in this operation is shown in Figure 27-15.

Figure 27-15. MMC/SD Multiple-Block Write Operation



27.3.7 MMC/SD Mode Multiple-Block Write Operation Using EDMA

To perform a multiple-block write, the same block length needs to be set in both the MMC/SD controller and the card. The procedure for this operation is:

1. Write the card's relative address to the MMC argument registers (MMCARGH and MMCARGL). Load the high part of the address to MMCARGH and the low part of the address to MMCARGL.
2. Read card CSD to determine the card's maximum block length.
3. Use the MMC command register (MMCCMD) to send the SET_BLOCKLEN command (if the block length is different than the length used in the previous operation). The block length must be a multiple of 512 bytes and less then the maximum block length specified in the CSD.
4. Reset the FIFO (FIFORST bit in MMCFIFOCTL).
5. Set the FIFO direction to transmit (FIFODIR bit in MMCFIFOCTL).
6. Set the FIFO threshold (FIFOLEV bit in MMCFIFOCTL).
7. Set the access width (ACCWD bits in MMCFIFOCTL).
8. Set up DMA (DMA size needs to be greater than or equal to FIFOLEV setting).
9. Use MMCCMD to send the WRITE_MULTI_BLOCK command to the card.
10. Set the DMATRIG bit in MMCCMD to trigger the first data transfer.
11. Wait for DMA sequence to complete or the DATADNE flag in the MMC status register 0 (MMCST0) is set.
12. Use MMCST0 to check for errors.
13. Use MMCCMD to send the STOP_TRANSMISSION command.

27.3.8 MMC/SD Mode Multiple-Block Read Operation Using CPU

NOTE: This procedure uses a STOP_TRANSMISSION command to end the block transfer. This assumes that the value in the MMC number of blocks counter register (MMCNBLK) is 0. A multiple-block operation terminates itself if you load MMCNBLK with the exact number of blocks you want transferred.

To perform a multiple-block read, the same block length needs to be set in both the MMC/SD controller and the card.

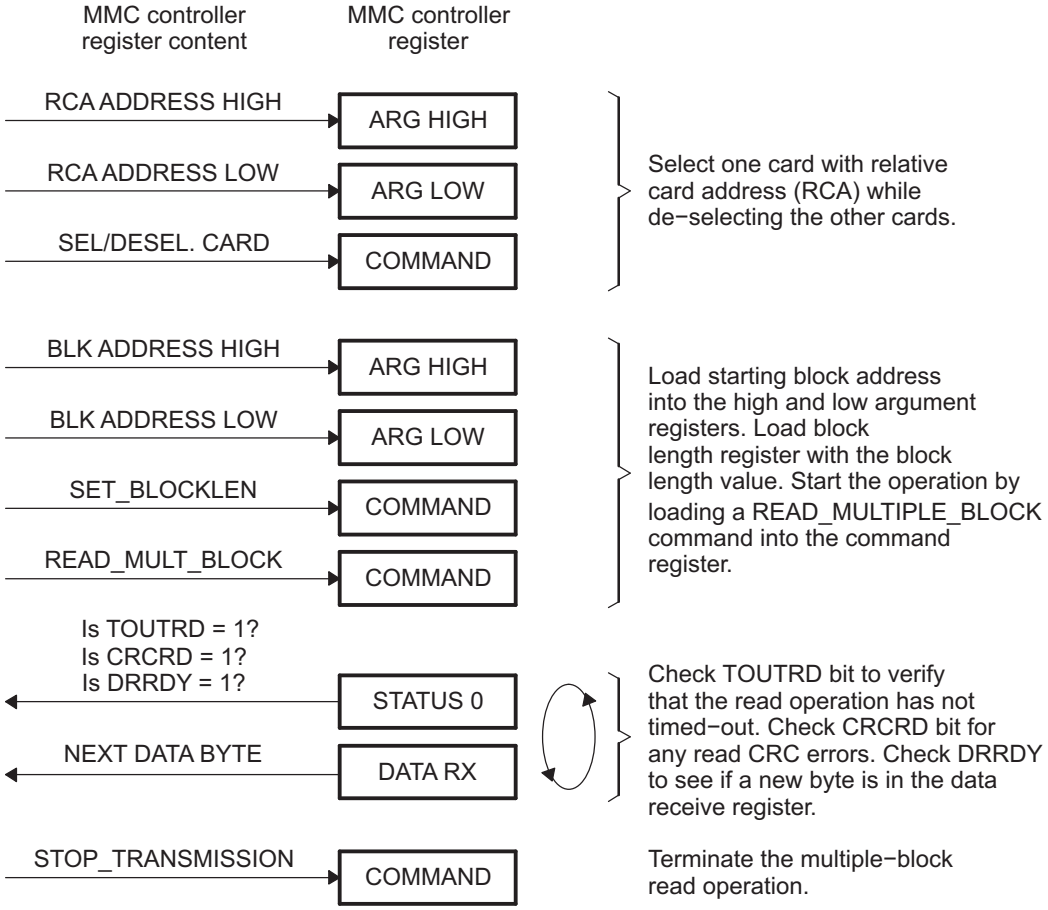
The procedure for this operation is:

1. Write the card's relative address to the MMC argument registers (MMCARGH and MMCARGL). Load the high part of the address to MMCARGH and the low part of the address to MMCARGL.
2. Read card CSD to determine the card's maximum block length.
3. Use the MMC command register (MMCCMD) to send the SET_BLOCKLEN command (if the block length is different than the length used in the previous operation). The block length must be a multiple of 512 bytes and less then the maximum block length specified in the CSD.
4. Reset the FIFO (FIFORST bit in MMCFIFOCTL).
5. Set the FIFO direction to receive (FIFODIR bit in MMCFIFOCTL).
6. Set FIFO threshold (FIFOLEV bit in MMCFIFOCTL).
7. Set the access width (ACCWD bits in MMCFIFOCTL).
8. Enable the MMC interrupt.
9. Enable DRRDYINT interrupt.
10. Use MMCCMD to send the READ_MULT_BLOCKS command.
11. Set the DMATRIG bit in MMCCMD to trigger the first data transfer.
12. Wait for MMC interrupt.
13. Use the MMC status register 0 (MMCST0) to check for errors and to determine the status of the FIFO. If FIFO is not empty and more bytes are to be read, go to Step 14. If the all of the data has been read, go to Step 15.

14. Read *n* bytes (depends on setting of FIFOLEV in MMCFIFOCTL: 0 = 32 bytes, 1 = 64 bytes) of data from the MMC data receive register (MMCDRR) and return to Step 10.
15. Use MMCCMD to send the STOP_TRANSMISSION command.

The sequence of events in this operation is shown in Figure 27-16.

Figure 27-16. MMC/SD Mode Multiple-Block Read Operation



27.3.9 MMC/SD Mode Multiple-Block Read Operation Using EDMA

To perform a multiple-block read, the same block length must be set in both the MMC/SD controller and the card.

The procedure for this operation is as follows:

1. Write the card's relative address to the MMC argument registers (MMCARGH and MMCARGL). Load the high part of the address to MMCARGH and the low part of the address to MMCARGL.
2. Read card CSD to determine the card's maximum block length.
3. Use the MMC command register (MMCCMD) to send the SET_BLOCKLEN command (if the block length is different than the length used in the previous operation). The block length must be a multiple of 512 bytes and less then the maximum block length specified in the CSD.
4. Reset the FIFO (FIFORST bit in MMCFIFOCTL).
5. Set the FIFO direction to receive (FIFODIR bit in MMCFIFOCTL).
6. Set the FIFO threshold (FIFOLEV bit in MMCFIFOCTL).
7. Set the access width (ACCWD bits in MMCFIFOCTL).
8. Set up DMA (DMA size needs to be greater than or equal to FIFOLEV setting).
9. Use MMCCMD to send the READ_MULTI_BLOCK command to the card.
10. Set the DMATRIG bit in MMCCMD to trigger the first data transfer.
11. Wait for DMA sequence to complete.
12. Use the MMC status register 0 (MMCST0) to check for errors.
13. Use MMCCMD to send the STOP_TRANSMISSION command.

27.3.10 SDIO Card Function

To support the SDIO card, the following features are available in the MMC/SD controller:

- Read wait operation request
- Interrupt to CPU at the start of read wait operation
- Interrupt to CPU at the detection of SDIO interrupt

When in 1-bit mode and the transfer clock (memory clock) is off, this peripheral cannot recognize an SDIO interrupt from SD_DATA1 line. Two options are available to deal with this situation:

1. Do not turn off the memory clock in 1-bit mode. The clock is enabled by the CLKEN bit in the MMC memory clock control register (MMCCLK).
2. If the memory clock needs to be turned off, physically connect a GPIO signal and SD_DATA1, and use the GPIO as an external interrupt input. When the memory clock is enabled, disable the GPIO interrupt and enable the SDIO interrupt. When the memory clock is disabled, enable the GPIO interrupt and disable the SDIO interrupt by software.

27.3.10.1 SDIO Control Register (SDIOCTL)

The SDIO card control register (SDIOCTL) is used to configure the read wait operation using the SD_DATA2 line.

27.3.10.2 SDIO Status Register 0 (SDIOST0)

The SDIO card status register 0 (SDIOST0) is used to check the status of the SD_DATA1 signal, check the status of being in an interrupt period, or check the status of being in a read wait operation.

27.3.10.3 SDIO Interrupt Control Registers (SDIOIEN, SDIOIST)

The SDIO card controller issues an interrupt to the CPU when the read wait operation starts or when an SDIO interrupt is detected on the SD_DATA1 line.

Interrupt flags of each case are checked with the SDIO interrupt status register (SDIOIST). To issue an actual interrupt to the CPU, enabling each interrupt in the SDIO interrupt enable register (SDIOIEN) is required.

When both interrupts are enabled, they are both reported to the CPU as an interrupt (whether one or both occurred). The interrupt(s) that occurred are determined by reading SDIOIST.

27.4 Registers

Table 27-5 lists the memory-mapped registers for the multimedia card/secure digital (MMC/SD) card controller. See your device-specific data manual for the memory address of these registers.

Table 27-5. Multimedia Card/Secure Digital (MMC/SD) Card Controller Registers

Offset	Acronym	Register Description	Section
0h	MMCCTL	MMC Control Register	Section 27.4.1
4h	MMCCLK	MMC Memory Clock Control Register	Section 27.4.2
8h	MMCST0	MMC Status Register 0	Section 27.4.3
Ch	MMCST1	MMC Status Register 1	Section 27.4.4
10h	MMCIM	MMC Interrupt Mask Register	Section 27.4.5
14h	MMCTOR	MMC Response Time-Out Register	Section 27.4.6
18h	MMCTOD	MMC Data Read Time-Out Register	Section 27.4.7
1Ch	MMCBLEN	MMC Block Length Register	Section 27.4.8
20h	MMCNBLK	MMC Number of Blocks Register	Section 27.4.9
24h	MMCNBLC	MMC Number of Blocks Counter Register	Section 27.4.10
28h	MMCDRR	MMC Data Receive Register	Section 27.4.11
2Ch	MMCDXR	MMC Data Transmit Register	Section 27.4.12
30h	MMCCMD	MMC Command Register	Section 27.4.13
34h	MMCARGHL	MMC Argument Register	Section 27.4.14
38h	MMCRSP01	MMC Response Register 0 and 1	Section 27.4.15
3Ch	MMCRSP23	MMC Response Register 2 and 3	Section 27.4.15
40h	MMCRSP45	MMC Response Register 4 and 5	Section 27.4.15
44h	MMCRSP67	MMC Response Register 6 and 7	Section 27.4.15
48h	MMCDRSP	MMC Data Response Register	Section 27.4.16
50h	MMCCIDX	MMC Command Index Register	Section 27.4.17
64h	SDIOCTL	SDIO Control Register	Section 27.4.18
68h	SDIOST0	SDIO Status Register 0	Section 27.4.19
6Ch	SDIOIEN	SDIO Interrupt Enable Register	Section 27.4.20
70h	SDIOIST	SDIO Interrupt Status Register	Section 27.4.21
74h	MMCFIFOCTL	MMC FIFO Control Register	Section 27.4.22

27.4.1 MMC Control Register (MMCCTL)

The MMC control register (MMCCTL) is used to enable or configure various modes of the MMC controller. Set or clear the DATRST and CMDRST bits at the same time to reset or enable the MMC controller.

The MMC control register (MMCCTL) is shown in Figure 27-17 and described in Table 27-6.

Figure 27-17. MMC Control Register (MMCCTL)

31	16
Reserved	
R-0	

15	11	10	9	8
Reserved		PERMDX	PERMDR	WIDTH1
R-0		R/W-0	R/W-0	R-0

7	6	5	3	2	1	0
DATEG		Reserved		WIDTH0	CMDRST	DATRST
R/W-0		R-0		R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 27-6. MMC Control Register (MMCCTL) Field Descriptions

Bit	Field	Value	Description
31-11	Reserved	0	Reserved
10	PERMDX		Endian select when writing.
		0	Little endian is selected.
		1	Big endian is selected.
9	PERMDR		Endian select when reading.
		0	Little endian is selected.
		1	Big endian is selected.
8	WIDTH1	0-3h	Data bus width 1 (MMC mode only). Used in conjunction with the WIDTH0 bit.
		0	Data bus has 1 bit (only MMCSD_DAT0 is used).
		1h	Data bus has 4 bits (only MMCSD_DAT0-3 are used).
		2h	Data bus has 8 bits (MMCSD_DAT0-7 are used).
		3h	Reserved
7-6	DATEG	0-3h	MMCSD_DAT3 edge detection select.
		0	MMCSD_DAT3 edge detection is disabled.
		1h	MMCSD_DAT3 rising-edge detection is enabled.
		2h	MMCSD_DAT3 falling-edge detection is enabled.
		3h	MMCSD_DAT3 rising-edge and falling-edge detections are enabled.
5-3	Reserved	0	Reserved
2	WIDTH0	0-3h	Data bus width 0 (MMC mode only). Used in conjunction with the WIDTH1 bit.
1	CMDRST		CMD logic reset.
		0	CMD line portion is enabled.
		1	CMD line portion is disabled and in reset state.
0	DATRST		DAT logic reset.
		0	DAT line portion is enabled.
		1	DAT line portion is disabled and in reset state.

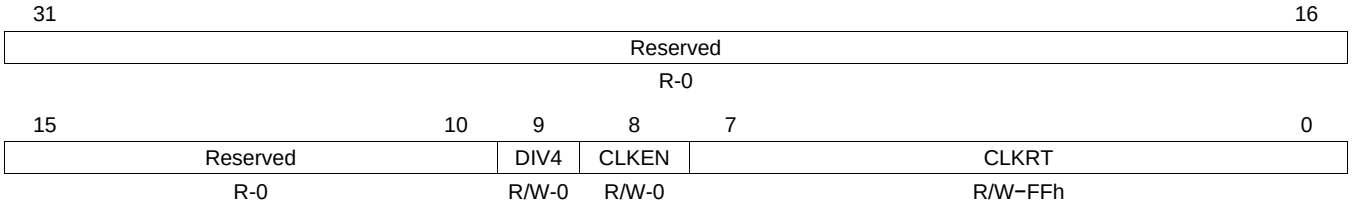
27.4.2 MMC Memory Clock Control Register (MMCCLK)

The MMC memory clock control register (MMCCLK) is used to:

- Select whether the MMCSD_CLK pin is enabled or disabled (CLKEN bit).
- Select how much the function clock is divided-down to produce the memory clock (CLKRT bits). When the MMCSD_CLK pin is enabled, the MMC controller drives the memory clock on this pin to control the timing of communications with attached memory cards. For more details about clock generation, see Section 27.2.1.

The MMC memory clock control register (MMCCLK) is shown in Figure 27-18 and described in Table 27-7.

Figure 27-18. MMC Memory Clock Control Register (MMCCLK)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 27-7. MMC Memory Clock Control Register (MMCCLK) Field Descriptions

Bit	Field	Value	Description
31-10	Reserved	0	Reserved
9	DIV4		DIV4 option
		0	MMC clock = function clock/2 × (CLKRT + 1)
		1	MMC clock = function clock/4 × (CLKRT + 1)
8	CLKEN		MMCSD_CLK pin enable
		0	MMCSD_CLK pin is disabled and fixed low
		1	The MMCSD_CLK pin is enabled; it shows the memory clock signal.
7-0	CLKRT	0−FFh	Clock rate. Use this field to set the divide-down value for the memory clock. The function clock is divided down as follows to produce the memory clock: memory clock frequency = function clock frequency/(2 × (CLKRT + 1))

27.4.3 MMC Status Register 0 (MMCST0)

The MMC status register 0 (MMCST0) records specific events or errors. The transition from 0 to 1 on each bit in MMCST0 can cause an interrupt signal to be sent to the CPU. If an interrupt is desired, set the corresponding interrupt enable bit in the MMC interrupt mask register (MMCIM).

In most cases, when a status bit is read, it is cleared. The two exceptions are the DRRDY bit and the DXRDY bit; these bits are cleared only in response to the functional events described for them in Table 27-8, or in response to a hardware reset.

The MMC status register 0 (MMCST0) is shown in Figure 27-19 and described in Table 27-8.

NOTE: 1) As the command portion and the data portion of the MMC/SD controller are independent, any command such as CMD0 (GO_IDLE_STATE) or CMD12 (STOP_TRANSMISSION) can be sent to the card, even during block transfer. In this situation, the data portion detects this and waits, releasing the busy state only when the command sent was R1b (to be specific, command with BSYEXP bit), otherwise it continues transferring data.

2) Bit 12 (TRNDNE) indicates that the last byte of a transfer has been completed. Bit 0 (DATDNE) occurs at end of a transfer, but not until the CRC check and programming has completed.

Figure 27-19. MMC Status Register 0 (MMCST0)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
R-0															

15	14	13	12	11	10	9	8
Reserved		CCS	TRNDNE	DATED	DRRDY	DXRDY	Reserved
R-0		R-0	R-0	RC-0	R-0	R-1	R-0

7	6	5	4	3	2	1	0
CRCRS	CRCRD	CRCWR	TOUTRS	TOUTRD	RSPDNE	BSYDNE	DATDNE
R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0

LEGEND: R = Read only; RC = Cleared to 0 when read; -*n* = value after reset

Table 27-8. MMC Status Register 0 (MMCST0) Field Descriptions

Bit	Field	Value	Description
31-14	Reserved	0	Reserved
13	CCS		Command completion signal
		0	Command completion signal is not completed.
		1	Command completion signal is completed.
12	TRNDNE		Transfer done.
		0	No data transfer is done.
		1	Data transfer of specified length is done.
11	DATED		MMCSD_DAT3 edge detected. DATED is cleared when read by CPU.
		0	An MMCSD_DAT3 edge has not been detected.
		1	An MMCSD_DAT3 edge has been detected.
10	DRRDY		Data receive ready. DRRDY is cleared to 0 when the DAT logic is reset (DATRST = 1 in MMCCTL), when a command is sent with data receive/transmit clear (DCLR = 1 in MMCCMD), or when data is read from the MMC data receive register (MMCDRR).
		0	MMCDRR is not ready.
		1	MMCDRR is ready. New data has arrived and can be read by the CPU or by the DMA controller.

Table 27-8. MMC Status Register 0 (MMCST0) Field Descriptions (continued)

Bit	Field	Value	Description
9	DXRDY		Data transmit ready. DXRDY is set to 1 when the DAT logic is reset (DATRST = 1 in MMCCTL), when a command is sent with data receive/transmit clear (DCLR = 1 in MMCCMD), or when data is written to the MMC data transmit register (MMCDXR).
		0	MMCDXR is not ready.
		1	MMCDXR is ready. The data in MMCDXR has been transmitted; MMCDXR can accept new data from the CPU or from the DMA controller.
8	Reserved	0	Reserved
7	CRCRS		Response CRC error.
		0	A response CRC error has not been detected.
		1	A response CRC error has been detected.
6	CRCRD		Read-data CRC error.
		0	A read-data CRC error has not been detected.
		1	A read-data CRC error has been detected.
5	CRCWR		Write-data CRC error.
		0	A write-data CRC error has not been detected.
		1	A write-data CRC error has been detected.
4	TOUTRS		Response time-out event.
		0	A response time-out event has not occurred.
		1	A time-out event has occurred while the MMC controller was waiting for a response to a command.
3	TOUTRD		Read-data time-out event.
		0	A read-data time-out event has not occurred.
		1	A time-out event has occurred while the MMC controller was waiting for data.
2	RSPDNE		Command/response done.
		0	No receiving response is done.
		1	Response successfully has received or command has sent without response.
1	BSYDNE		Busy done.
		0	No busy releasing is done.
		1	Released from busy state or expected busy is not detected.
0	DATDNE		Data done
		0	The data has not been fully transmitted.
		1	The data has been fully transmitted.

27.4.4 MMC Status Register 1 (MMCST1)

The MMC status register 1 (MMCST1) records specific events or errors. There are no interrupts associated with these events or errors.

The MMC status register 1 (MMCST1) is shown in Figure 27-20 and described in Table 27-9.

Figure 27-20. MMC Status Register 1 (MMCST1)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
R-0															

15	14	13	12	11	10	9	8
Reserved							
R-0							

7	6	5	4	3	2	1	0
Reserved	FIFOFUL	FIFOEMP	DAT3ST	DRFUL	DXEMP	CLKSTP	BUSY
R-0	R-0	R-0	R-0	R-0	R-0	R-1	R-0

LEGEND: R = Read only; -*n* = value after reset

Table 27-9. MMC Status Register 1 (MMCST1) Field Descriptions

Bit	Field	Value	Description
31-7	Reserved	0	Reserved
6	FIFOFUL		FIFO is full.
		0	FIFO is not full.
		1	FIFO is full.
5	FIFOEMP		FIFO is empty.
		0	FIFO is not empty.
		1	FIFO is empty.
4	DAT3ST		MMCSD_DAT3 status.
		0	The signal level on the MMCSD_DAT3 pin is a logic-low level.
		1	The signal level on the MMCSD_DAT3 pin is a logic-high level.
3	DRFUL		Data receive register (MMCDRR) is full.
		0	A data receive register full condition is not detected. The data receive shift register is not full.
		1	A data receive register full condition is detected. The data receive shift register is full. No new bits can be shifted in from the memory card.
2	DXEMP		Data transmit register (MMCDXR) is empty.
		0	A data transmit register empty condition is not detected. The data transmit shift register is not empty.
		1	A data transmit register empty condition is detected. The data transmit shift register is empty. No bits are available to be shifted out to the memory card.
1	CLKSTP		Clock stop status.
		0	MMCSD_CLK is active. The memory clock signal is being driven on the pin.
		1	MMCSD_CLK is held low because of a manual stop (CLKEN = 0 in MMCCLK), receive shift register is full, or transmit shift register is empty.
0	BUSY		Busy.
		0	No busy signal is detected.
		1	A busy signal is detected (the memory card is busy).

27.4.5 MMC Interrupt Mask Register (MMCIM)

The MMC interrupt mask register (MMCIM) is used to enable (bit = 1) or disable (bit = 0) status interrupts. If an interrupt is enabled, the transition from 0 to 1 of the corresponding interrupt bit in the MMC status register 0 (MMCST0) can cause an interrupt signal to be sent to the CPU.

The MMC interrupt mask register (MMCIM) is shown in Figure 27-21 and described in Table 27-10.

Figure 27-21. MMC Interrupt Mask Register (MMCIM)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
R-0															

15	14	13	12	11	10	9	8
Reserved		ECCS	ETRNDNE	EDATED	EDRRDY	EDXRDY	Reserved
R-0		R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R-0

7	6	5	4	3	2	1	0
ECRCRS	ECRCRD	ECRCWR	ETOUTRS	ETOUTRD	ERSPDNE	EBSYDNE	EDATDNE
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 27-10. MMC Interrupt Mask Register (MMCIM) Field Descriptions

Bit	Field	Value	Description
31-14	Reserved	0	Reserved
13	ECCS		Command completion signal interrupt enable.
		0	Command completion signal interrupt is disabled.
		1	Command completion signal interrupt is enabled.
12	ETRNDNE		Transfer done (TRNDNE) interrupt enable.
		0	Transfer done interrupt is disabled.
		1	Transfer done interrupt is enabled.
11	EDATED		MMCSD_DAT3 edge detect (DATED) interrupt enable.
		0	MMCSD_DAT3 edge detect interrupt is disabled.
		1	MMCSD_DAT3 edge detect interrupt is enabled.
10	EDRRDY		Data receive register ready (DRRDY) interrupt enable.
		0	Data receive register ready interrupt is disabled.
		1	Data receive register ready interrupt is enabled.
9	EDXRDY		Data transmit register (MMCDXR) ready interrupt enable.
		0	Data transmit register ready interrupt is disabled.
		1	Data transmit register ready interrupt is enabled.
8	Reserved	0	Reserved
7	ECRCRS		Response CRC error (CRCRS) interrupt enable.
		0	Response CRC error interrupt is disabled.
		1	Response CRC error interrupt is enabled.
6	ECRCRD		Read-data CRC error (CRCRD) interrupt enable.
		0	Read-data CRC error interrupt is disabled.
		1	Read-data CRC error interrupt is enabled.
5	ECRCWR		Write-data CRC error (CRCWR) interrupt enable.
		0	Write-data CRC error interrupt is disabled.
		1	Write-data CRC error interrupt is disabled.

Table 27-10. MMC Interrupt Mask Register (MMCIM) Field Descriptions (continued)

Bit	Field	Value	Description
4	ETOUTRS		Response time-out event (TOUTRS) interrupt enable.
		0	Response time-out event interrupt is disabled.
		1	Response time-out event interrupt is enabled.
3	ETOUTRD		Read-data time-out event (TOUTRD) interrupt enable.
		0	Read-data time-out event interrupt is disabled.
		1	Read-data time-out event interrupt is enabled.
2	ERSPDNE		Command/response done (RSPDNE) interrupt enable.
		0	Command/response done interrupt is disabled.
		1	Command/response done interrupt is enabled.
1	EBSYDNE		Busy done (BSYDNE) interrupt enable.
		0	Busy done interrupt is disabled.
		1	Busy done interrupt is enabled.
0	EDATDNE		Data done (DATDNE) interrupt enable.
		0	Data done interrupt is disabled.
		1	Data done interrupt is enabled.

27.4.6 MMC Response Time-Out Register (MMCTOR)

The MMC response time-out register (MMCTOR) defines how long the MMC controller waits for a response from a memory card before recording a time-out condition in the TOUTRS bit of the MMC status register 0 (MMCST0). If the corresponding ETOUTRS bit in the MMC interrupt mask register (MMCIM) is set, an interrupt is generated when the TOUTRS bit is set in MMCST0. If a memory card should require a longer time-out period than MMCTOR can provide, a software time-out mechanism can be implemented.

The MMC response time-out register (MMCTOR) is shown in Figure 27-22 and described in Table 27-11.

Figure 27-22. MMC Response Time-Out Register (MMCTOR)

31	18	17	16
Reserved		TOD_25_16	
R-0		R/W-0	

15	8	7	0
TOD_25_16		TOR	
R/W-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 27-11. MMC Response Time-Out Register (MMCTOR) Field Descriptions

Bit	Field	Value	Description
31-18	Reserved	0	Reserved
17-8	TOD_25_16	0-3FFh	Data read time-out count upper 10 bits. Used in conjunction with the TOD_15_0 bits in MMCTOD to form a 26-bit count (1 CLK clock cycle to 67 108 863 CLK clock cycles). See MMCTOD (Section 27.4.7).
		0	No time out
		1h-3FF FFFFh	1 CLK clock cycle to 67 108 863 CLK clock cycles
7-0	TOR	0-FFh	Time-out count for response.
		0	No time out
		1h-FFh	1 CLK clock cycle to 255 CLK clock cycles

27.4.7 MMC Data Read Time-Out Register (MMCTOD)

The MMC data read time-out register (MMCTOD) defines how long the MMC controller waits for the data from a memory card before recording a time-out condition in the TOUTRD bit of the MMC status register 0 (MMCST0). If the corresponding ETOUTRD bit in the MMC interrupt mask register (MMCIM) is set, an interrupt is generated when the TOUTRD bit is set in MMCST0. If a memory card should require a longer time-out period than MMCTOD can provide, a software time-out mechanism can be implemented.

The MMC data read time-out register (MMCTOD) is shown in Figure 27-23 and described in Table 27-12.

Figure 27-23. MMC Data Read Time-Out Register (MMCTOD)

31	16
Reserved	
R-0	

15	0
TOD_15_0	
R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 27-12. MMC Data Read Time-Out Register (MMCTOD) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	Reserved
15-0	TOD_15_0	0-FFFFh	Data read time-out count. Used in conjunction with the TOD_25_16 bits in MMCTOR to form a 26-bit count (1 CLK clock cycle to 67 108 863 CLK clock cycles). See MMCTOR (Section 27.4.6).
		0	No time out
		1h-3FF FFFFh	1 CLK clock cycle to 67 108 863 CLK clock cycles

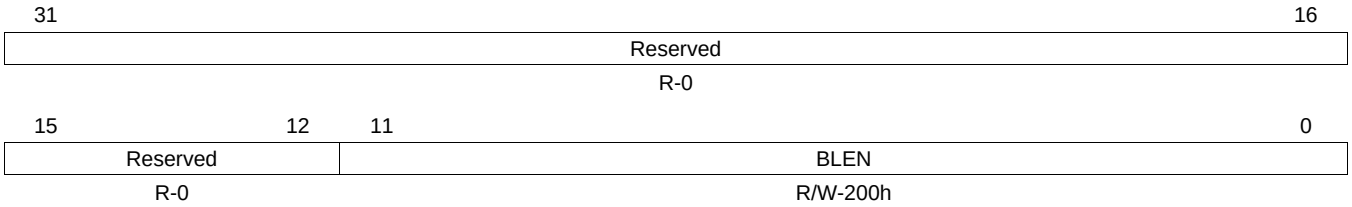
27.4.8 MMC Block Length Register (MMCBLEN)

The MMC block length register (MMCBLEN) specifies the data block length in bytes. This value must match the block length setting in the memory card.

The MMC block length register (MMCBLEN) is shown in Figure 27-24 and described in Table 27-13.

NOTE: The BLEN bits value must be the same as the CSD register settings in the MMC/SD card. To be precise, it should match the value of the READ_BL_LEN field for read, or WRITE_BL_LEN field for write.

Figure 27-24. MMC Block Length Register (MMCBLEN)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 27-13. MMC Block Length Register (MMCBLEN) Field Descriptions

Bit	Field	Value	Description
31-12	Reserved	0	Reserved
11−0	BLEN	1h−FFFh	Block length. This field is used to set the block length, which is the byte count of a data block. The value 0 is prohibited.

27.4.9 MMC Number of Blocks Register (MMCNBLK)

The MMC number of blocks register (MMCNBLK) specifies the number of blocks for a multiple-block transfer.

The MMC number of blocks register (MMCNBLK) is shown in Figure 27-25 and described in Table 27-14.

Figure 27-25. MMC Number of Blocks Register (MMCNBLK)

31	16
Reserved	
R-0	

15	0
NBLK	
R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 27-14. MMC Number of Blocks Register (MMCNBLK) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	Reserved
15-0	NBLK	0-FFFFh	Number of blocks. This field is used to set the total number of blocks to be transferred.
		0	Infinite number of blocks. The MMC controller reads/writes blocks of data until a STOP_TRANSMISSION command is written to the MMC command register (MMCCMD).
		1h−FFFFh	*n* blocks. The MMC controller reads/writes only *n* blocks of data, even if the STOP_TRANSMISSION command has not been written to the MMC command register (MMCCMD).

27.4.10 MMC Number of Blocks Counter Register (MMCNBLC)

The MMC number of blocks counter register (MMCNBLC) is a down-counter for tracking the number of blocks remaining to be transferred during a multiple-block transfer.

The MMC number of blocks counter register (MMCNBLC) is shown in Figure 27-26 and described in Table 27-15.

Figure 27-26. MMC Number of Blocks Counter Register (MMCNBLC)

31	16
Reserved	
R-0	

15	0
NBLC	
R-FFFFh	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 27-15. MMC Number of Blocks Counter Register (MMCNBLC) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	Reserved
15-0	NBLC	0−FFFFh	Read this field to determine the number of blocks remaining to be transferred.

27.4.11 MMC Data Receive Register (MMCDRR)

The MMC data receive register (MMCDRR) is used for storing the received data from the MMC controller. The CPU or the DMA controller can read data from this register. MMCDRR expects the data in little-endian format.

The MMC data receive register (MMCDRR) is shown in Figure 27-27 and described in Table 27-16.

Figure 27-27. MMC Data Receive Register (MMCDRR)

31	0
DRR	
R/W-0	

LEGEND: R/W = Read/Write; *-n* = value after reset

Table 27-16. MMC Data Receive Register (MMCDRR) Field Descriptions

Bit	Field	Value	Description
31-0	DRR	0-FFFF FFFFh	Data receive.

27.4.12 MMC Data Transmit Register (MMCDXR)

The MMC data transmit register (MMCDXR) is used for storing the data to be transmitted from the MMC controller to the memory card. The CPU or the DMA controller can write data to this register to be transmitted. MMCDXR expects the data in little-endian format.

The MMC data transmit register (MMCDXR) is shown in Figure 27-28 and described in Table 27-17.

Figure 27-28. MMC Data Transmit Register (MMCDXR)

31	0
DXR	
R/W-0	

LEGEND: R/W = Read/Write; *-n* = value after reset

Table 27-17. MMC Data Transmit Register (MMCDXR) Field Descriptions

Bit	Field	Value	Description
31-0	DXR	0-FFFF FFFFh	Data transmit.

27.4.13 MMC Command Register (MMCCMD)

NOTE: Writing to the MMC command register (MMCCMD) causes the MMC controller to send the programmed command. Therefore, the MMC argument register (MMCARGHL) must be loaded properly before a write to MMCCMD.

The MMC command register (MMCCMD) specifies the type of command to be sent and defines the operation (command, response, additional activity) for the MMC controller. The content of MMCCMD is kept after the transfer to the transmit shift register. The MMC command register (MMCCMD) is shown in Figure 27-29 and described in Table 27-18.

When the CPU writes to MMCCMD, the MMC controller sends the programmed command, including any arguments in the MMC argument register (MMCARGHL). For the format of a command (index, arguments, and other bits), see Figure 27-30 and Table 27-19.

Figure 27-29. MMC Command Register (MMCCMD)

31	30	29	28	27	26	25	24
Reserved							
R-0							

23	22	21	20	19	18	17	16
Reserved							DMATRIG
R-0							R/W-0

15	14	13	12	11	10	9	8
DCLR	INITCK	WDATX	STRMTP	DTRW	RSPFMT		BSYEXP
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0		R/W-0

7	6	5	4	3	2	1	0
PPLEN	Reserved	CMD					
R/W-0	R-0	R/W-0					

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 27-18. MMC Command Register (MMCCMD) Field Descriptions

Bit	Field	Value	Description
31-17	Reserved	0	Reserved
16	DMATRIG		Data transfer triggering. (Read back as 0.)
		0	Data transfer has not been triggered.
		1	Data transfer is triggered.
15	DCLR		Data receive/transmit clear. Use this bit to clear the data receive ready (DRRDY) bit and the data transmit ready (DXRDY) bit in the MMC status register 0 (MMCST0) before a new read or write sequence. This clears any previous status.
		0	Do not clear DRRDY and DXRDY bits in MMCST0.
		1	Clear DRRDY and DXRDY bits in MMCST0.
14	INITCK		Initialization clock cycles.
		0	Do not insert initialization clock cycles.
		1	Insert initialization clock cycles; insert 80 CLK cycles before sending the command specified in the CMD bits. These dummy clock cycles are required for resetting a card after power on.
13	WDATX		Data transfer indicator.
		0	There is no data transfer.
		1	There is a data transfer associated with the command.

Table 27-18. MMC Command Register (MMCCMD) Field Descriptions (continued)

Bit	Field	Value	Description
12	STRMTP		Stream enable.
		0	If WDATX = 1, the data transfer is a block transfer. The data transfer stops after the movement of the programmed number of bytes (defined by the programmed block size and the programmed number of blocks).
		1	If WDATX = 1, the data transfer is a stream transfer. Once the data transfer is started, the data transfer does not stop until the MMC controller issues a stop command to the memory card.
11	DTRW		Write enable.
		0	If WDATX = 1, the data transfer is a read operation.
		1	If WDATX = 1, the data transfer is a write operation.
10-9	RSPFMT	0-3h	Response format (expected type of response to the command).
		0	No response.
		1h	R1, R4, R5, or R6 response. 48 bits with CRC.
		2h	R2 response. 136 bits with CRC.
		3h	R3 response. 48 bits with no CRC.
8	BSYEXP		Busy expected. If an R1b (R1 with busy) response is expected, set RSPFMT = 1h and BSYEXP = 1.
		0	A busy signal is not expected.
		1	A busy signal is expected.
7	PPLEN		Push pull enable.
		0	Push pull driver of CMD line is disabled (open drain).
		1	Push pull driver of CMD line is enabled.
6	Reserved	0	Reserved.
5-0	CMD	0-3Fh	Command index. This field contains the command index for the command to be sent to the memory card.

Figure 27-30. Command Format

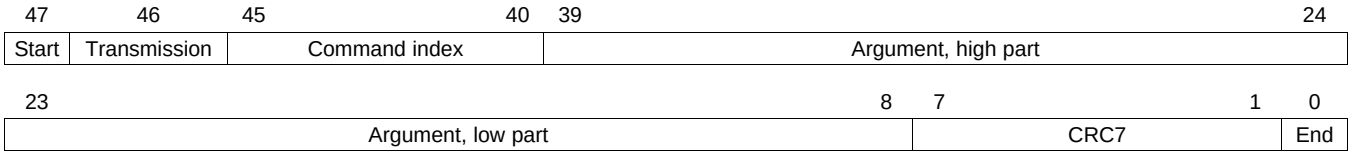


Table 27-19. Command Format

Bit Position of Command	Register	Description
47	-	Start bit
46	-	Transmission bit
45-40	MMCCMD(5-0)	Command index (CMD)
39-24	MMCARGHL	Argument, high part (ARGH)
23-8	MMCARGHL	Argument, low part (ARGL)
7-1	-	CRC7
0	-	End bit

27.4.14 MMC Argument Register (MMCARGHL)

NOTE: Do not modify the MMC argument register (MMCARGHL) while it is being used for an operation.

The MMC argument register (MMCARGHL) specifies the arguments to be sent with the command specified in the MMC command register (MMCCMD). Writing to MMCCMD causes the MMC controller to send a command; therefore, MMCARGHL must be configured before writing to MMCCMD. The content of MMCARGHL is kept after the transfer to the shift register; however, modification to MMCARGHL is not allowed during a sending operation. For the format of a command, see Figure 27-30 and Table 27-19.

The MMC argument register (MMCARGHL) is shown in Figure 27-31 and described in Table 27-20.

Figure 27-31. MMC Argument Register (MMCARGHL)

31															16
ARGH															
R/W-0															
15															0
ARGL															
R/W-0															

LEGEND: R/W = Read/Write; *-n* = value after reset

Table 27-20. MMC Argument Register (MMCARGHL) Field Descriptions

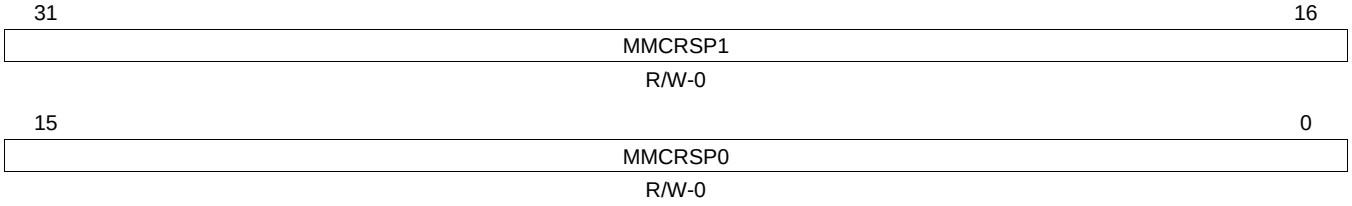
Bit	Field	Value	Description
31-16	ARGH	0-FFFFh	Argument, high part.
15-0	ARGL	0-FFFFh	Argument, low part.

27.4.15 MMC Response Registers (MMCRSP0-MMCRSP7)

Each command has a preset response type. When the MMC controller receives a response, it is stored in some or all of the eight MMC response registers (MMCRSP7-MMCRSP0). The response registers are updated as the responses arrive, even if the CPU has not read the previous contents.

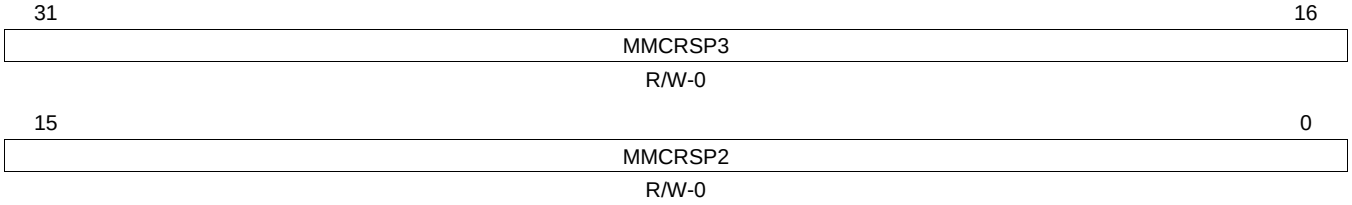
As shown in Figure 27-32, Figure 27-33, Figure 27-34, and Figure 27-35 each of the MMC response registers holds up to 16 bits. Table 27-21 and Table 27-22 show the format for each type of response and which MMC response registers are used for the bits of the response. The first byte of the response is a command index byte and is stored in the MMC command index register (MMCCIDX).

Figure 27-32. MMC Response Register 0 and 1 (MMCRSP01)



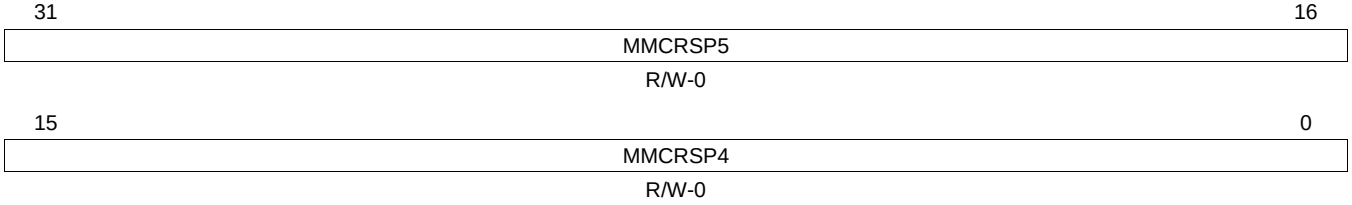
LEGEND: R/W = Read/Write; -*n* = value after reset

Figure 27-33. MMC Response Register 2 and 3 (MMCRSP23)



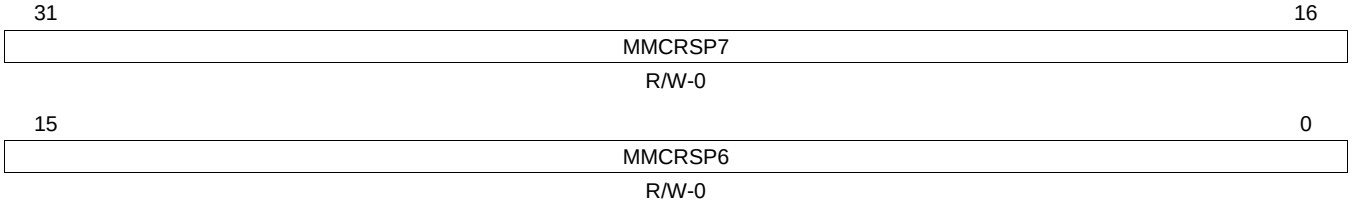
LEGEND: R/W = Read/Write; -*n* = value after reset

Figure 27-34. MMC Response Register 4 and 5 (MMCRSP45)



LEGEND: R/W = Read/Write; -*n* = value after reset

Figure 27-35. MMC Response Register 6 and 7 (MMCRSP67)



LEGEND: R/W = Read/Write; -*n* = value after reset

Table 27-21. R1, R3, R4, R5, or R6 Response (48 Bits)

Bit Position of Response	Register
47-40	MMCCIDX
39-24	MMCRSP7
23-8	MMCRSP6
7-0	MMCRSP5[(1)]
-	MMCRSP4-0

(1) Bits 7-0 of the response are stored to bits 7-0 of MMCRSP5.

Table 27-22. R2 Response (136 Bits)

Bit Position of Response	Register
135-128	MMCCIDX
127-112	MMCRSP7
111-96	MMCRSP6
95-80	MMCRSP5
79-64	MMCRSP4
63-48	MMCRSP3
47-32	MMCRSP2
31-16	MMCRSP1
15-0	MMCRSP0

27.4.16 MMC Data Response Register (MMCDRSP)

After the MMC controller sends a data block to a memory card, the return byte from the memory card is stored in the MMC data response register (MMCDRSP).

The MMC data response register (MMCDRSP) is shown in Figure 27-36 and described in Table 27-23.

Figure 27-36. MMC Data Response Register (MMCDRSP)

31	16
Reserved	
R-0	

15	8	7	0
Reserved		DRSP	
R-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 27-23. MMC Data Response Register (MMCDRSP) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved
7-0	DRSP	0-FFh	During a write operation (see Section 27.2.3.1), the CRC status token is stored in DRSP.

27.4.17 MMC Command Index Register (MMCCIDX)

The MMC command index register (MMCCIDX) stores the first byte of a response from a memory card. Table 27-21 and Table 27-22 show the format for each type of response.

The MMC command index register (MMCCIDX) is shown in Figure 27-37 and described in Table 27-24.

Figure 27-37. MMC Command Index Register (MMCCIDX)

31	16
Reserved	
R-0	

15	8	7	6	5	0
Reserved		STRT	XMIT	CIDX	
R-0		R/W-0	R/W-0	R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 27-24. MMC Command Index Register (MMCCIDX) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved
7	STRT	0-1	Start bit. When the MMC controller receives a response, the start bit is stored in STRT.
6	XMIT	0-1	Transmission bit. When the MMC controller receives a response, the transmission bit is stored in XMIT.
5-0	CIDX	0-3Fh	Command index. When the MMC controller receives a response, the command index is stored in CIDX.

27.4.18 SDIO Control Register (SDIOCTL)

The SDIO control register (SDIOCTL) is shown in Figure 27-38 and described in Table 27-25.

Figure 27-38. SDIO Control Register (SDIOCTL)

31	16
Reserved	
R-0	

15	2	1	0
Reserved		RDWTCR	RDWTRQ
R-0		R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 27-25. SDIO Control Register (SDIOCTL) Field Descriptions

Bit	Field	Value	Description
31-2	Reserved	0	Reserved
1	RDWTCR		Read wait enable for CRC error. To end the read wait operation, write 0 to RDWTRQ. (No need to clear RDWTCR).
		0	Read wait is disabled.
		1	Automatically start read wait on CRC error detection during multiple block read access and not the last block to be transferred. RDWTRQ is automatically set to 1.
0	RDWTRQ		Read wait request. To end the read wait operation, write 0 to RDWTRQ.
		0	End read wait operation and release MMCSD_DAT2.
		1	Set a read wait request. Read wait operation starts 2 clocks after the end of the read data block. MMCIF asserts low level on MMCSD_DAT2 until RDWTRQ is cleared to 0.

27.4.19 SDIO Status Register 0 (SDIOST0)

The SDIO status register 0 (SDIOST0) is shown in Figure 27-39 and described in Table 27-26.

Figure 27-39. SDIO Status Register 0 (SDIOST0)

31	16
Reserved	
R-0	

15	3	2	1	0
Reserved		RDWTST	INTPRD	DAT1
R-0		R-0	R-0	R-1

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 27-26. SDIO Status Register 0 (SDIOST0) Field Descriptions

Bit	Field	Value	Description
31-3	Reserved	0	Reserved
2	RDWTST		Read wait status.
		0	Read wait operation not in progress.
		1	Read wait operation in progress.
1	INTPRD		Interrupt period.
		0	Interrupt not in progress.
		1	Interrupt in progress.
0	DAT1		This bit reflects the external state of the SD_DATA1 pin.
		0	Logic-low level on the SD_DATA1 pin.
		1	Logic-high level on the SD_DATA1 pin.

27.4.20 SDIO Interrupt Enable Register (SDIOIEN)

The SDIO interrupt enable register (SDIOIEN) is shown in Figure 27-40 and described in Table 27-27.

Figure 27-40. SDIO Interrupt Enable Register (SDIOIEN)

31	16
Reserved	
R-0	

15	2	1	0
Reserved		RWSEN	IOINTEN
R-0		R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 27-27. SDIO Interrupt Enable Register (SDIOIEN) Field Descriptions

Bit	Field	Value	Description
31-2	Reserved	0	Reserved
1	RWSEN		Read wait interrupt enable.
		0	Read wait interrupt is disabled.
		1	Read wait interrupt is enabled.
0	IOINTEN		SDIO card interrupt enable.
		0	SDIO card interrupt is disabled.
		1	SDIO card interrupt is enabled.

27.4.21 SDIO Interrupt Status Register (SDIOIST)

The SDIO interrupt status register (SDIOIST) is shown in Figure 27-41 and described in Table 27-28.

Figure 27-41. SDIO Interrupt Status Register (SDIOIST)

31	16
Reserved	
R-0	

15	2	1	0
Reserved		RWS	IOINT
R-0		R/W1C-0	R/W1C-0

LEGEND: R/W = Read/Write; R = Read only; W1C = Write 1 to clear (writing 0 has no effect); -*n* = value after reset

Table 27-28. SDIO Interrupt Status Register (SDIOIST) Field Descriptions

Bit	Field	Value	Description
31-2	Reserved	0	Reserved
1	RWS		Read wait interrupt status. Write a 1 to clear this bit.
		0	Read wait interrupt did not occur.
		1	Read wait interrupt occurred. Read wait operation starts and read wait interrupt is enabled (RWSEN = 1 in SDIOIEN).
0	IOINT		SDIO card interrupt status. Write a 1 to clear this bit.
		0	SDIO card interrupt did not occur.
		1	SDIO card interrupt occurred. SDIO card interrupt is detected and SDIO card interrupt is enabled (IOINTEN = 1 in SDIOIEN).

27.4.22 MMC FIFO Control Register (MMCFIFOCTL)

The MMC FIFO control register (MMCFIFOCTL) is shown in Figure 27-42 and described in Table 27-29.

Figure 27-42. MMC FIFO Control Register (MMCFIFOCTL)

31	16
Reserved	
R-0	

15	5	4	3	2	1	0
Reserved		ACCWD		FIFOLEV	FIFODIR	FIFORST
R-0		R/W-0		R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 27-29. MMC FIFO Control Register (MMCFIFOCTL) Field Descriptions

Bit	Field	Value	Description
31-5	Reserved	0	Reserved
4-3	ACCWD	0-3h	Access width. Used by FIFO control to determine full/empty flag.
		0	CPU/EDMA access width of 4 bytes.
		1h	CPU/EDMA access width of 3 bytes.
		2h	CPU/EDMA access width of 2 bytes.
		3h	CPU/EDMA access width of 1 byte.
2	FIFOLEV		FIFO level. Sets the threshold level that determines when the EDMA request and the FIFO threshold interrupt are triggered.
		0	EDMA request every 256 bits (32 bytes) sent/received.
		1	EDMA request every 512 bits (64 bytes) sent/received.
1	FIFODIR		FIFO direction. Determines if the FIFO is being written to or read from.
		0	Read from FIFO.
		1	Write to FIFO.
0	FIFORST		FIFO reset. Resets the internal state of the FIFO.
		0	FIFO reset is disabled.
		1	FIFO reset is enabled.

Real-Time Clock (RTC)

This chapter describes the real-time clock (RTC).

Topic **Page**

28.1 Introduction

28.1.1 Purpose of the Peripheral

The real-time clock (RTC) provides a time reference to an application running on the device. The current date and time is tracked in a set of counter registers that update once per second. The time can be represented in 12-hour or 24-hour mode. The calendar and time registers are buffered during reads and writes so that updates do not interfere with the accuracy of the time and date.

Alarms are available to interrupt the CPU at a particular time, or at periodic time intervals, such as once per minute or once per day. In addition, the RTC can interrupt the CPU every time the calendar and time registers are updated, or at programmable periodic intervals.

28.1.2 Features

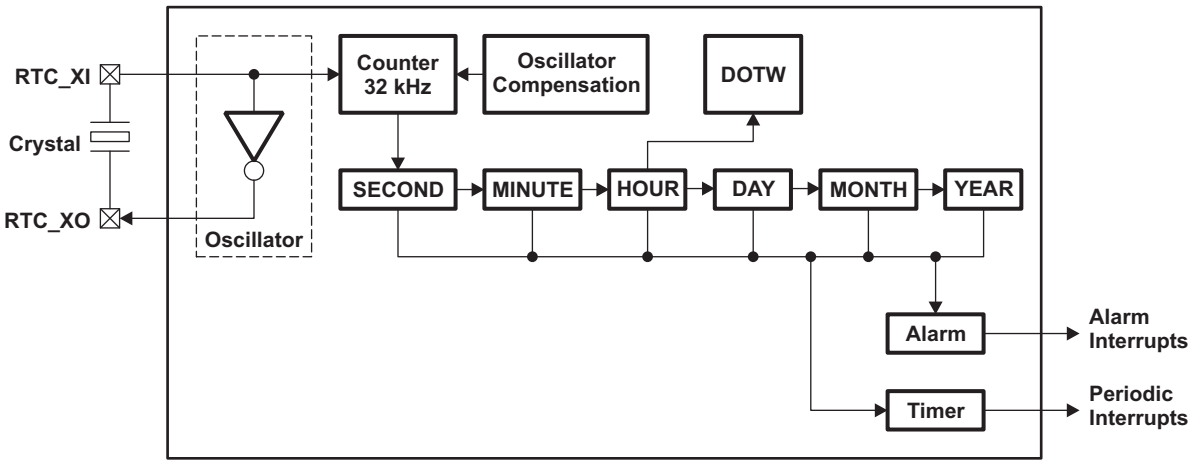
The real-time clock (RTC) provides the following features:

- 100-year calendar (xx00 to xx99)
- Counts seconds, minutes, hours, day of the week, date, month, and year with leap year compensation
- Binary-coded-decimal (BCD) representation of time, calendar, and alarm
- 12-hour clock mode (with AM and PM) or 24-hour clock mode
- Alarm interrupt
- Periodic interrupt
- Single interrupt to the CPU
- Supports external 32.768-kHz crystal or external clock source of the same frequency
- Isolated power supply

28.1.3 Block Diagram

Figure 28-1 shows a block diagram of the RTC.

Figure 28-1. Real-Time Clock Block Diagram



28.2 Architecture

28.2.1 Clock Source

The clock reference for the RTC is an external 32.768-kHz crystal or an external clock source of the same frequency. The RTC also has a separate power supply that is isolated from the rest of the system. When the CPU and other peripherals are without power, the RTC can remain powered to preserve the current time and calendar information.

The source for the RTC reference clock may be provided by a crystal or by an external clock source. The RTC has an internal oscillator buffer to support direct operation with a crystal. The crystal is connected between pins RTC_XI and RTC_XO. RTC_XI is the input to the on-chip oscillator and RTC_XO is the output from the oscillator back to the crystal. For more information about the RTC crystal connection, see your device-specific data manual.

An external 32.768-kHz clock source may be used instead of a crystal. In such a case, the clock source is connected to RTC_XI, and RTC_XO is left unconnected.

If the RTC is not used, the RTC_XI pin should be held low and RTC_XO should be left unconnected. The RTCDISABLE bit in the control register (CTRL) can be set to save power; however, the RTCDISABLE bit should not be cleared once it has been set. If the application requires the RTC module to stop and continue, the RUN bit in CTRL should be used instead.

28.2.2 Signal Descriptions

The RTC signals are listed in Table 28-1.

Table 28-1. Real-Time Clock Signals

Signal	I/O	Description
RTC_XI	I	RTC time base input signal. RTC_XI can either be driven with a 32.768-kHz reference clock, or RTC_XI and RTC_XO can be connected to an external crystal. This signal is the input to the RTC internal oscillator.
RTC_XO	O	RTC time base output signal. RTC_XO is the output from the RTC internal oscillator. If a crystal is not used as the time base for RTC_XI, RTC_XO should be left unconnected.

28.2.3 Isolated Power Supply

The RTC has a power supply that is isolated from the rest of the system. This allows the RTC to continue to run while the rest of the system is not powered. In this state, the RTC time and calendar counters continue to run, but the powered down CPU is not able to receive RTC interrupts. Separate power supply pins for the RTC are provided on the device package.

28.2.3.1 Split-Power Circuitry

To decrease power consumption, RTC includes leakage-isolation circuitry that is activated by setting the SPLITPOWER bit in the control register (CTRL). Because of its isolated power supply, RTC does not have a power-on hardware reset signal. Therefore, upon initial device power-on, the RTC is in an unknown state until it has been properly configured. After the RTC module has been configured once, it functions as programmed as long as its power supply and clock source are provided.

28.2.3.2 Power Considerations

The RTC leakage-isolation circuitry requires that the CPU supply be powered down to VSS when the RTC is powered on while the rest of the device is powered off. A floating CPU supply creates undesired RTC leakage current. Also, the RTC power consumption is higher when the CPU is powered on versus the RTC power consumption when the CPU is powered off. Therefore, if the RTC module is expected to run from a small-capacity power supply (ex. watch battery) while the rest of the device is powered off, a power system should be implemented such that the RTC is powered from a high-capacity power supply when the CPU is powered on.

28.2.4 Operation

28.2.4.1 Using the Real-Time Clock Time and Calendar Registers

The current time and date are maintained in the RTC time and calendar registers.

28.2.4.1.1 Time/Calendar Data Format

The time and calendar data in the RTC is stored as binary-coded decimal (BCD) format. In BCD format, the decimal numbers 0 through 9 are encoded with their binary equivalent. Although most of the time/calendar registers have 4 bits assigned to each BCD digit, some of the register fields are shorter since the range of valid numbers may be limited. For example, only 3 bits are required to represent the day since only BCD numbers 1 though 7 are required.

The following time and calendar registers are supported (BCD Format):

- SECOND - Second Count (00-59)
- MINUTE - Minute Count (00-59)
- HOUR - Hour Count (12HR: 01-12; 24HR: 00-23)
- DAY - Day of the Month Count (01-31)
- MONTH - Month Count (01-12; JAN = 1)
- YEAR - Year Count (00-99)
- DOTW - Day of the Week Count (0-6; SUN = 0)

Note that the ALARM registers which share the names above also share the same BCD formatting.

28.2.4.1.2 12-Hour and 24-Hour Modes

The current time can be represented in 12-hour or 24-hour mode by configuring the HOURMODE bit in the control register (CTRL):

- When HOURMODE = 0, 24-hour mode is selected. The hours are represented as 00 through 23. The MERIDIEM bit in the HOURS register has no function and should be cleared.
- When HOURMODE = 1, 12-hour mode is selected. The hours are represented as 00 through 12. MERIDIEM = 0 indicates ante meridiem (AM), and MERIDIEM = 1 indicates post meridiem (PM).

28.2.4.1.3 Reading from Time/Calendar Registers

The time/calendar registers are updated every second as the time changes. During a read of the SECOND register, the RTC copies the current values of the time/date registers into shadow read registers. This isolation assures that the CPU can capture all the time/date values at the moment of the SECOND read request and not be subject to changing register values from time updates.

If desired, the RTC also provides a one-time-triggered minute-rounding feature to round the MINUTE:SECOND registers to the nearest minute (with zero seconds). This feature is enabled by setting the ROUNDMIN bit in the control register (CTRL); the RTC automatically rounds the time values to the nearest minute upon the next read of the SECOND register.

28.2.4.1.4 Writing to Time/Calendar Registers

When setting the RTC time and date, values are written directly to the time/calendar registers. Therefore, care must be taken to avoid writing to the time/calendar registers while the time is updating to the next second. This can be accomplished in one of two ways:

1. The RTC can be stopped by clearing the RUN bit in the control register (CTRL). When stopped, there is no danger of contention during writes because the registers do not auto-update.
2. The BUSY bit in the status register (STATUS) is low when a time update does not take place for at least 15 µs. By checking for a low BUSY bit before writing to registers, the CPU is assured of a 15 µs window of time during which multiple accesses to the time/calendar registers can be performed.

After writing to a time/calendar register, the RTC requires four peripheral clock cycles to update the register value. Any reads that take place within four peripheral clock cycles of a write returns old data.

Note that all registers in the RTC except for KICK*n*R have write-protection. See Section 28.2.6 for information on unlocking registers.

28.2.4.2 Real-Time Clock Update Cycle

The RTC executes an update cycle once per second to update the current time in the time/calendar registers. The update cycle also compares each alarm register with the corresponding time register. These comparisons are done to determine when to trigger an alarm. The BUSY bit in the status register (STATUS) provides a mechanism to indicate when the time/calendar registers are updated. When the BUSY bit is high, an update takes place within 15 µs. When BUSY returns low again, the update has been completed.

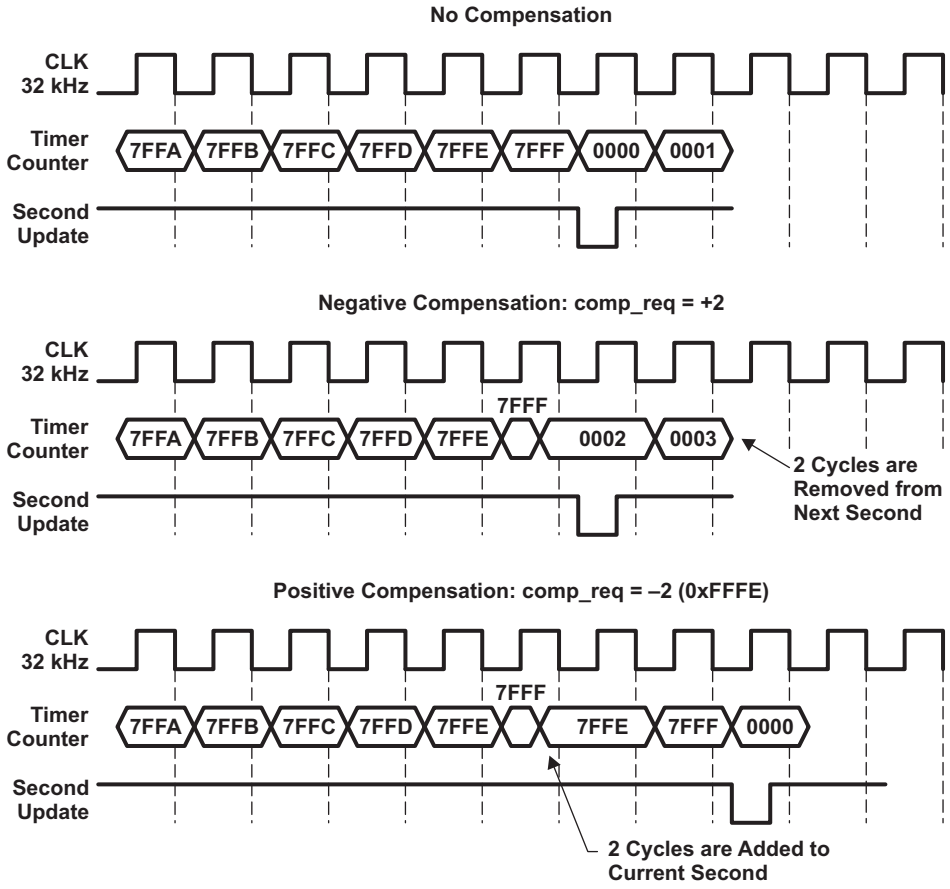
The BUSY bit should be checked when writing to any of the following registers while RTC is running:

- SECOND
- MINUTE
- HOUR
- DAY
- MONTH
- YEAR
- DOTW
- ALARMSECOND (when ALARM interrupt is enabled)
- ALARMMINUTE (when ALARM interrupt is enabled)
- ALARMHOUR (when ALARM interrupt is enabled)
- ALARMDAY (when ALARM interrupt is enabled)
- ALARMMONTH (when ALARM interrupt is enabled)
- ALARMYEAR (when ALARM interrupt is enabled)
- CTRL (SET32COUNTER field only -- the other fields in CTRL do not require BUSY to be low)
- INTERRUPT
- COMPLSB (when oscillator drift compensation is enabled)
- COMPMSB (when oscillator drift compensation is enabled)

28.2.4.3 Oscillator Drift Compensation

If the RTC 32.768-kHz reference clock is susceptible to oscillator drift, the RTC provides the ability to compensate the update cycle by subtracting oscillator periods. The COMPMSB and COMPLSB registers hold the number of two's complement reference periods to subtract from the update cycle every hour. For example, Figure 28-2 shows how programming the value of 2h into the compensation registers shortens the update cycle by two 32.786-kHz reference periods every hour. Figure 28-2 also shows how programming the value of FFFEh (decimal negative 2) into the compensation register lengthens the update cycle by two reference periods every hour. To enable the oscillator compensation, the AUTOCOMP bit in the control register (CTRL) must be set.

Figure 28-2. 32-kHz Oscillator Counter Compensation



28.2.5 Interrupt Requests

The RTC provides the ability to interrupt the CPU based on two events: a periodic interrupt and an alarm interrupt. Although two interrupt sources are available, the RTC makes a single interrupt request to the CPU.

When the device is initially powered on, the RTC may issue spurious interrupt signals to the CPU. To avoid issues, a software reset should be performed on the RTC module before the CPU interrupt controller is initialized. See Section 28.2.10 for more information on reset considerations.

28.2.5.1 Alarm Interrupt Enable and Status Bits

The ALARM bit in the interrupt register (INTERRUPT) enables the alarm interrupt. When the current time and date match the ALARMSECOND, ALARMMINUTE, ALARMHOUR, ALARMDAY, ALARMMONTH, and ALARMYEAR registers, the RTC issues an interrupt to the CPU and sets the ALARM bit in the status register (STATUS). Once set, the ALARM status bit stays high until cleared by a write of 1 to the ALARM bit.

As with writing to time and calendar registers (Section 28.2.4.1.4), writes to the INTERRUPT and STATUS registers should only be done when the RTC is stopped or when the BUSY bit is low.

Note that all registers in the RTC except for KICK*n*R have write-protection. See Section 28.2.6 for information on unlocking registers.

28.2.5.2 Periodic Interrupt Enable and Status Bits

The TIMER bit and EVERY field in the interrupt register (INTERRUPT) work together to enable periodic interrupts. When the TIMER bit is enabled, interrupts are issued at a time period indicated by the EVERY field (0 = Second, 1h = Minute, 2h = Hour, 3h = Day). Regardless of the period selected in the EVERY field, the periodic timer status bits (DAYEVT, HREVT, MINEVT, SECEVT) are set in the status register (STATUS) whenever they are valid. Note that the appropriate status bits are set when the TIME bit is enabled, not when the desired interrupt is generated. Active periodic status bits remain high as long as the TIMER bit is enabled.

For example, if daily periodic interrupts are enabled and the time (in HH:MM:SS format) transitions from 23:59:59 to 00:00:00, the STATUS register sets all four periodic status bits (DAYEVT, HREVT, MINEVT, and SECEVT) because all four time periods were incremented. These bits all remain high until:

1. The TIME bit is cleared and all four status bits clear to zero until TIME is set again **OR**
2. The current time reaches 00:00:01. At that point, the SECEVT remains set while the DAYEVT, HREVT, and MINEVT bits are cleared. The next interrupt is not generated until the next day transition.

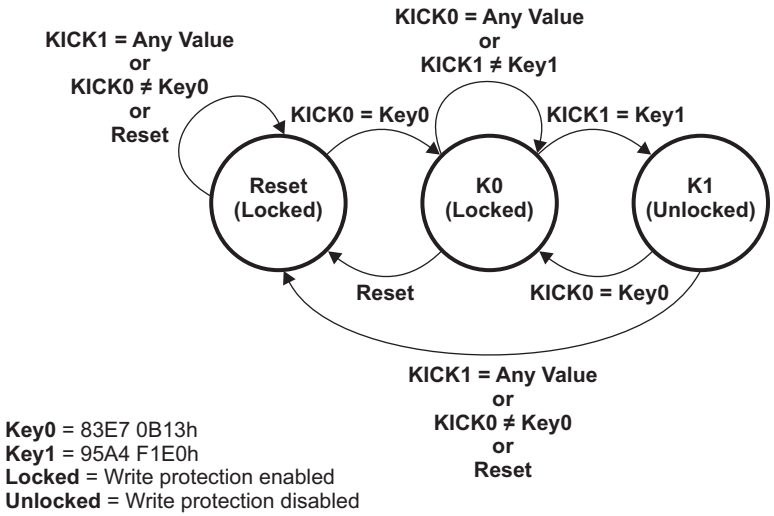
As with writing to time and calendar registers (Section 28.2.4.1.4), writes to the INTERRUPT and STATUS registers should only be done when the RTC is stopped or when the BUSY bit is low.

Note that all registers in the RTC except for KICK*n*R have write-protection. See Section 28.2.6 for information on unlocking registers.

28.2.6 Register Protection Against Spurious Writes

All registers in the RTC except for the KICK*n*R registers are protected from spurious writes. Out of reset, writes to protected registers are disabled until the registers are unlocked using the KICK*n*R registers. To unlock the registers, a key of 83E7 0B13h needs to be written to KICK0R, followed by a write of 95A4 F1E0h to KICK1R. Registers remain unlocked until write protection is enabled again by writing any value to KICK0R or KICK1R. The write protection state machine is shown in Figure 28-3.

Figure 28-3. Kick State Machine



28.2.7 General-Purpose Scratch Registers

The RTC provides three general-purpose registers (SCRATCH*n*) that can be used to store 32-bit words -- these registers have no functional purpose for the RTC. Software using the RTC may find the SCRATCH*n* registers to be useful in indicating RTC states. For example, the SCRATCH*n* registers may be used to indicate write-protection lock status or unintentional power downs.

To indicate write-protection, the software should write a unique value to one of the SCRATCH*n* registers when write-protection is disabled and another unique value when write-protection is enabled again. In this way, the lock-status of the registers can be determined quickly by reading the SCRATCH register.

To indicate unintentional power downs, the software should write a unique value to one of the SCRATCH*n* registers when RTC is configured and enabled. If the RTC is unintentionally powered down, the value written to the SCRATCH register is cleared.

28.2.8 Real-Time Clock Response to Low Power Modes (Idle Configurations)

The device is divided into idle domains that can be programmed to be idle or active. The state of all domains is called the idle configuration. The RTC runs on its own external clock source and is not affected by any of the other device idle domains.

28.2.9 Emulation Modes of the Real-Time Clock

The RTC always continues to run regardless of the state (running/halted) of the emulation debugger software.

28.2.10 Reset Considerations

When the device is initially powered on, the RTC may issue spurious interrupt signals to the CPU. To avoid issues, a software reset should be performed on the RTC module before the CPU interrupt controller is initialized.

As the RTC is configured, the SPLITPOWER bit in the control register (CTRL) should be set.

A software reset is performed on the RTC by setting the SWRESET bit in the oscillator register (OSC). The software reset applies to all registers except the oscillator (OSC) and kick (KICK*n*R) registers. The RTC requires three 32.768-kHz reference clocks to pass before RTC registers can be accessed.

28.3 Registers

Table 28-2 lists the memory-mapped registers for the RTC. See your device-specific data manual for the memory address of these registers.

Table 28-2. Real-Time Clock (RTC) Registers

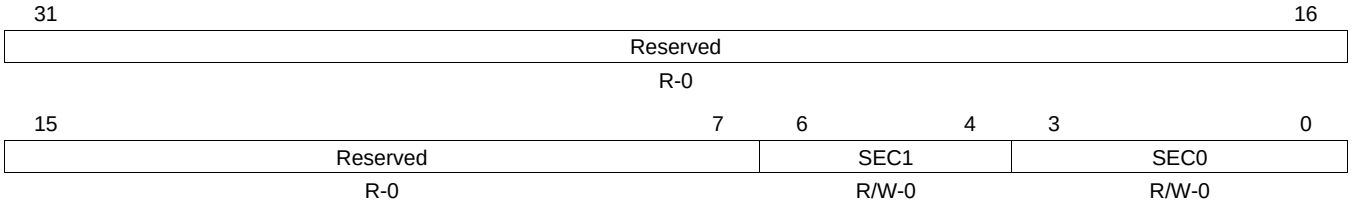
Address Offset	Acronym	Register Description	Section
0h	SECOND	Seconds Register	Section 28.3.1
4h	MINUTE	Minutes Register	Section 28.3.2
8h	HOUR	Hours Register	Section 28.3.3
Ch	DAY	Day of the Month Register	Section 28.3.4
10h	MONTH	Month Register	Section 28.3.5
14h	YEAR	Year Register	Section 28.3.6
18h	DOTW	Day of the Week Register	Section 28.3.7
20h	ALARMSECOND	Alarm Seconds Register	Section 28.3.8
24h	ALARMMINUTE	Alarm Minutes Register	Section 28.3.9
28h	ALARMHOUR	Alarm Hours Register	Section 28.3.10
2Ch	ALARMDAY	Alarm Days Register	Section 28.3.11
30h	ALARMMONTH	Alarm Months Register	Section 28.3.12
34h	ALARMYEAR	Alarm Years Register	Section 28.3.13
40h	CTRL	Control Register	Section 28.3.14
44h	STATUS	Status Register	Section 28.3.15
48h	INTERRUPT	Interrupt Enable Register	Section 28.3.16
4Ch	COMPLSB	Compensation (LSB) Register	Section 28.3.17
50h	COMPMSB	Compensation (MSB) Register	Section 28.3.18
54h	OSC	Oscillator Register	Section 28.3.19
60h	SCRATCH0	Scratch 0 Register (General-Purpose)	Section 28.3.20
64h	SCRATCH1	Scratch 1 Register (General-Purpose)	Section 28.3.20
68h	SCRATCH2	Scratch 2 Register (General-Purpose)	Section 28.3.20
6Ch	KICK0R	Kick 0 Register (Write Protect)	Section 28.3.21
70h	KICK1R	Kick 1 Register (Write Protect)	Section 28.3.21

28.3.1 Second Register (SECOND)

NOTE: Out of reset, the second register (SECOND) is write-protected. To disable write protection, correct keys must be written to the KICK*n*R registers (see Section 28.2.6).

The second register (SECOND) sets the second value of the current time. Seconds are stored as binary-coded decimal (BCD) format. In BCD format, the decimal numbers 0 through 9 are encoded with their binary equivalent. The SECOND register is shown in Figure 28-4 and described in Table 28-3.

Figure 28-4. Second Register (SECOND)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 28-3. Second Register (SECOND) Field Descriptions

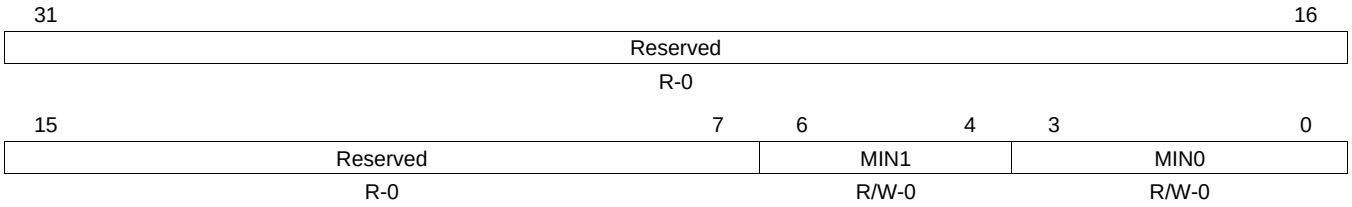
Bit	Field	Value	Description
31-7	Reserved	0	Reserved.
6-4	SEC1	0-5h	Most significant digit of second value. Range for SEC1:SEC0 is 00-59.
3-0	SEC0	0-9h	Least significant digit of second value. Range for SEC1:SEC0 is 00-59.

28.3.2 Minute Register (MINUTE)

NOTE: Out of reset, the minute register (MINUTE) is write-protected. To disable write protection, correct keys must be written to the KICK*n*R registers (see Section 28.2.6).

The minute register (MINUTE) sets the minute value of the current time. Minutes are stored as binary-coded decimal (BCD) format. In BCD format, the decimal numbers 0 through 9 are encoded with their binary equivalent. The MINUTE register is shown in Figure 28-5 and described in Table 28-4.

Figure 28-5. Minute Register (MINUTE)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 28-4. Minute Register (MINUTE) Field Descriptions

Bit	Field	Value	Description
31-7	Reserved	0	Reserved.
6-4	MIN1	0-5h	Most significant digit of minute value. Range for MIN1:MIN0 is 00-59.
3-0	MIN0	0-9h	Least significant digit of minute value. Range for MIN1:MIN0 is 00-59.

28.3.3 Hour Register (HOUR)

NOTE: Out of reset, the hour register (HOUR) is write-protected. To disable write protection, correct keys must be written to the KICK*n*R registers (see Section 28.2.6).

The hour register (HOUR) sets the hour value of the current time. Hours are stored as binary-coded decimal (BCD) format. In BCD format, the decimal numbers 0 through 9 are encoded with their binary equivalent. The HOUR register is shown in Figure 28-6 and described in Table 28-5.

Figure 28-6. Hour Register (HOUR)

31	16
Reserved	
R-0	

15	8	7	6	5	4	3	0
Reserved		MERIDIEM	Rsvd	HOUR1		HOUR0	
R-0		R/W-0	R-0	R/W-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 28-5. Hour Register (HOUR) Field Descriptions

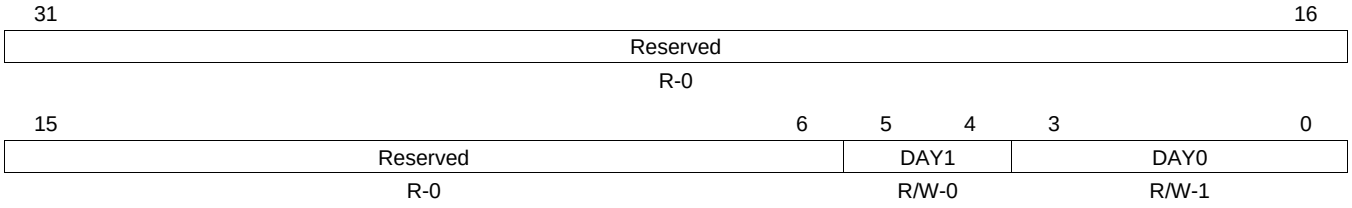
Bit	Field	Value	Description
31-8	Reserved	0	Reserved.
7	MERIDIEM		Determines whether the hour is ante meridiem (AM) or post meridiem (PM) when 12-hour mode is enabled.
		0	Hour is AM
		1	Hour is PM
6	Reserved	0	Reserved.
5-4	HOUR1	0-2h	Most significant digit of hours value. Range for HOUR1:HOUR0 is 00-24.
3-0	HOUR0	0-9h	Least significant digit of hours value. Range for HOUR1:HOUR0 is 00-24.

28.3.4 Day of the Month Register (DAY)

NOTE: Out of reset, the day of the month register (DAY) is write-protected. To disable write protection, correct keys must be written to the KICK*n*R registers (see Section 28.2.6).

The day of the month register (DAY) sets the day of the month value of the current date. Days are stored as binary-coded decimal (BCD) format. In BCD format, the decimal numbers 0 through 9 are encoded with their binary equivalent. The DAY register is shown in Figure 28-7 and described in Table 28-6.

Figure 28-7. Days Register (DAY)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 28-6. Day Register (DAY) Field Descriptions

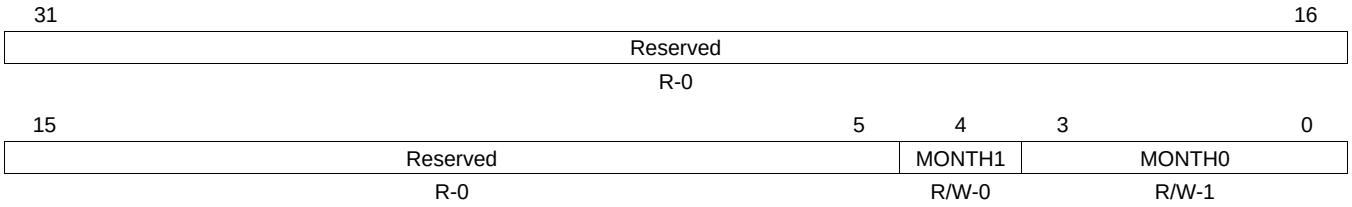
Bit	Field	Value	Description
31-6	Reserved	0	Reserved.
5-4	DAY1	0-3h	Most significant digit of day of the month value. Range for DAY1:DAY0 is 01-31.
3-0	DAY0	0-9h	Least significant digit of day of the month value. Range for DAY1:DAY0 is 01-31.

28.3.5 Month Register (MONTH)

NOTE: Out of reset, the month register (MONTH) is write-protected. To disable write protection, correct keys must be written to the KICK*n*R registers (see Section 28.2.6).

The month register (MONTH) sets the month in the year value of the current date. The month is stored as binary-coded decimal (BCD) format. In BCD format, the decimal numbers 0 through 9 are encoded with their binary equivalent. The MONTH register is shown in Figure 28-8 and described in Table 28-7.

Figure 28-8. Month Register (MONTH)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 28-7. Month Register (MONTH) Field Descriptions

Bit	Field	Value	Description
31-5	Reserved	0	Reserved.
4	MONTH1	0-1h	Most significant digit of months value. For MONTH1:MONTH0, JAN = 01 and DEC = 12.
3-0	MONTH0	0-9h	Least significant digit of months value. For MONTH1:MONTH0, JAN = 01 and DEC = 12.

28.3.6 Year Register (YEAR)

NOTE: Out of reset, the year register (YEAR) is write-protected. To disable write protection, correct keys must be written to the KICK*n*R registers (see Section 28.2.6).

The year register (YEAR) sets the year value of the current date. The year is stored as binary-coded decimal (BCD) format. In BCD format, the decimal numbers 0 through 9 are encoded with their binary equivalent. The YEAR register is shown in Figure 28-9 and described in Table 28-8.

Figure 28-9. Year Register (YEAR)

31	16
Reserved	
R-0	

15	8	7	4	3	0
Reserved		YEAR1		YEAR0	
R-0		R/W-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 28-8. Year Register (YEAR) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved.
7-4	YEAR1	0-9h	Most significant digit of years value. Range for YEAR1:YEAR0 is 00-99.
3-0	YEAR0	0-9h	Least significant digit of years value. Range for YEAR1:YEAR0 is 00-99.

28.3.7 Day of the Week Register (DOTW)

NOTE: Out of reset, the day of the week register (DOTW) is write-protected. To disable write protection, correct keys must be written to the KICK*n*R registers (see Section 28.2.6).

The day of the week register (DOTW) sets the day of the week value of the current date. The day of the week is stored as binary-coded decimal (BCD) format. In BCD format, the decimal numbers 0 through 9 are encoded with their binary equivalent. The DOTW register is shown in Figure 28-10 and described in Table 28-9.

Figure 28-10. Day of the Week Register (DOTW)

31	16
Reserved	
R-0	

15	3	2	0
Reserved		DOTW	
R-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 28-9. Day of the Week Register (DOTW) Field Descriptions

Bit	Field	Value	Description
31-3	Reserved	0	Reserved.
2-0	DOTW	0-6h	Day of the week. Sunday = 0, Saturday = 6h.

28.3.8 Alarm Second Register (ALARMSECOND)

NOTE: Out of reset, the alarm second register (ALARMSECOND) is write-protected. To disable write protection, correct keys must be written to the KICK*n*R registers (see Section 28.2.6).

The alarm second register (ALARMSECOND) sets the second value for the alarm interrupt. Seconds are stored as binary-coded decimal (BCD) format. In BCD format, the decimal numbers 0 through 9 are encoded with their binary equivalent. The ALARMSECOND register is shown in Figure 28-11 and described in Table 28-10.

Figure 28-11. Alarm Second Register (ALARMSECOND)

31	16
Reserved	
R-0	

15	7	6	4	3	0
Reserved		SEC1		SEC0	
R-0		R/W-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 28-10. Alarm Second Register (ALARMSECOND) Field Descriptions

Bit	Field	Value	Description
31-7	Reserved	0	Reserved.
6-4	SEC1	0-5h	Most significant digit of alarm seconds value. Range for SEC1:SEC0 is 00-59.
3-0	SEC0	0-9h	Least significant digit of alarm seconds value. Range for SEC1:SEC0 is 00-59.

28.3.9 Alarm Minute Register (ALARMMINUTE)

NOTE: Out of reset, the alarm minute register (ALARMMINUTE) is write-protected. To disable write protection, correct keys must be written to the KICK*n*R registers (see Section 28.2.6).

The alarm minute register (ALARMMINUTE) sets the minute value for the alarm interrupt. Minutes are stored as binary-coded decimal (BCD) format. In BCD format, the decimal numbers 0 through 9 are encoded with their binary equivalent. The ALARMMINUTE register is shown in Figure 28-12 and described in Table 28-11.

Figure 28-12. Alarm Minute Register (ALARMMINUTE)

31	16
Reserved	
R-0	

15	7	6	4	3	0
Reserved		MIN1		MIN0	
R-0		R/W-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 28-11. Alarm Minute Register (ALARMMINUTE) Field Descriptions

Bit	Field	Value	Description
31-7	Reserved	0	Reserved.
6-4	MIN1	0-5h	Most significant digit of alarm minutes value. Range for MIN1:MIN0 is 00-59.
3-0	MIN0	0-9h	Least significant digit of alarm minutes value. Range for MIN1:MIN0 is 00-59.

28.3.10 Alarm Hour Register (ALARMHOUR)

NOTE: Out of reset, the alarm hour register (ALARMHOUR) is write-protected. To disable write protection, correct keys must be written to the KICK*n*R registers (see Section 28.2.6).

The alarm hour register (ALARMHOUR) sets the hour value for the alarm interrupt. Hours are stored as binary-coded decimal (BCD) format. In BCD format, the decimal numbers 0 through 9 are encoded with their binary equivalent. The ALARMHOUR register is shown in Figure 28-13 and described in Table 28-12.

Figure 28-13. Alarm Hour Register (ALARMHOUR)

31	16
Reserved	
R-0	

15	8	7	6	5	4	3	0
Reserved		MERIDIEM	Rsvd	HOUR1		HOUR0	
R-0		R/W-0	R-0	R/W-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 28-12. Alarm Hour Register (ALARMHOUR) Field Descriptions

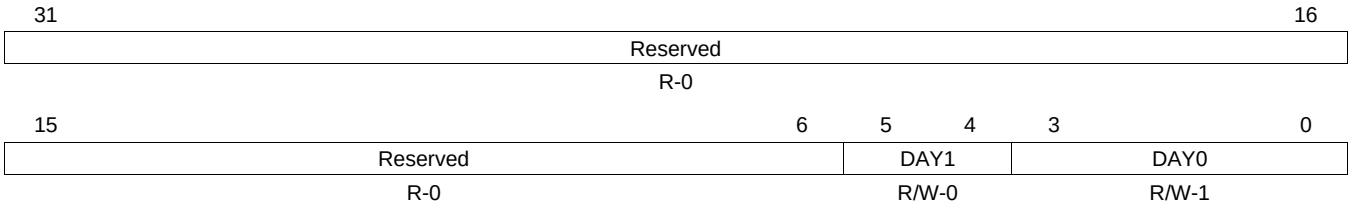
Bit	Field	Value	Description
31-8	Reserved	0	Reserved.
7	MERIDIEM		Determines whether the hour is ante meridiem (AM) or post meridiem (PM) when 12-hour mode is enabled.
		0	Hour is AM
		1	Hour is PM
6	Reserved	0	Reserved.
5-4	HOUR1	0-2h	Most significant digit of hours value. Range for HOUR1:HOUR0 is 00-24.
3-0	HOUR0	0-9h	Least significant digit of hours value. Range for HOUR1:HOUR0 is 00-24.

28.3.11 Alarm Day of the Month Register (ALARMDAY)

NOTE: Out of reset, the alarm day of the month register (ALARMDAY) is write-protected. To disable write protection, correct keys must be written to the KICK*n*R registers (see Section 28.2.6).

The alarm day of the month register (ALARMDAY) sets the day of the month value for the alarm interrupt. Days are stored as binary-coded decimal (BCD) format. In BCD format, the decimal numbers 0 through 9 are encoded with their binary equivalent. The ALARMDAYS register is shown in Figure 28-14 and described in Table 28-13.

Figure 28-14. Alarm Day Register (ALARMDAY)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 28-13. Alarm Day Register (ALARMDAY) Field Descriptions

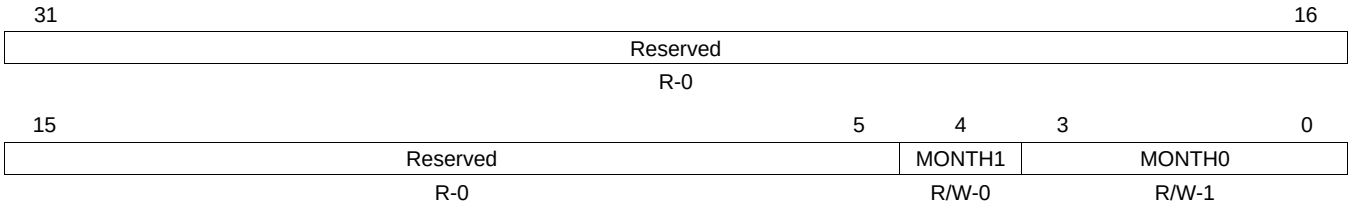
Bit	Field	Value	Description
31-6	Reserved	0	Reserved.
5-4	DAY1	0-3h	Most significant digit of day of the month value. Range for DAY1:DAY0 is 01-31.
3-0	DAY0	0-9h	Least significant digit of day of the month value. Range for DAY1:DAY0 is 01-31.

28.3.12 Alarm Month Register (ALARMMONTH)

NOTE: Out of reset, the alarm month register (ALARMMONTH) is write-protected. To disable write protection, correct keys must be written to the KICK*n*R registers (see Section 28.2.6).

The alarm month register (ALARMMONTH) sets the month in the year value for the alarm interrupt. The month is stored as binary-coded decimal (BCD) format. In BCD format, the decimal numbers 0 through 9 are encoded with their binary equivalent. The ALARMMONTH register is shown in Figure 28-15 and described in Table 28-14.

Figure 28-15. Alarm Month Register (ALARMMONTH)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 28-14. Alarm Month Register (ALARMMONTH) Field Descriptions

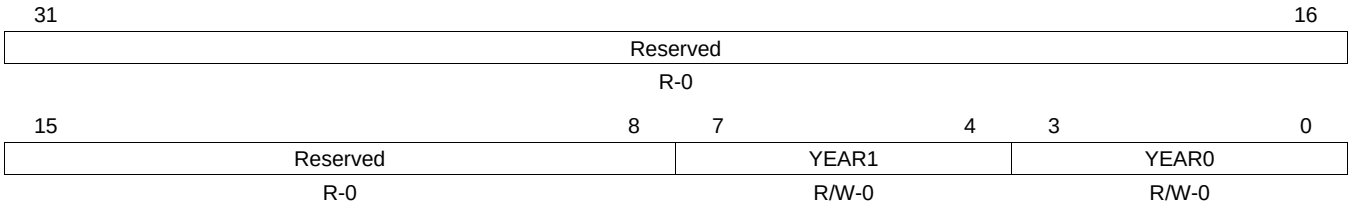
Bit	Field	Value	Description
31-5	Reserved	0	Reserved.
4	MONTH1	0-1h	Most significant digit of months value. For MONTH1:MONTH0, JAN = 01 and DEC = 12.
3-0	MONTH0	0-9h	Least significant digit of months value. For MONTH1:MONTH0, JAN = 01 and DEC = 12.

28.3.13 Alarm Year Register (ALARMYEAR)

NOTE: Out of reset, the alarm year register (ALARMYEAR) is write-protected. To disable write protection, correct keys must be written to the KICK*n*R registers (see Section 28.2.6).

The alarm year register (ALARMYEAR) sets the year for the alarm interrupt. The year is stored as binary-coded decimal (BCD) format. In BCD format, the decimal numbers 0 through 9 are encoded with their binary equivalent. The ALARMYEAR register is shown in Figure 28-16 and described in Table 28-15.

Figure 28-16. Alarm Year Register (ALARMYEAR)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 28-15. Alarm Years Register (ALARMYEARS) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved.
7-4	YEAR1	0-9h	Most significant digit of years value. Range for YEAR1:YEAR0 is 00-99.
3-0	YEAR0	0-9h	Least significant digit of years value. Range for YEAR1:YEAR0 is 00-99.

28.3.14 Control Register (CTRL)

NOTE: Out of reset, the control register (CTRL) is write-protected. To disable write protection, correct keys must be written to the KICK*n*R registers (see Section 28.2.6).

The control register (CTRL) is shown in Figure 28-17 and described in Table 28-16.

Figure 28-17. Control Register (CTRL)

31							8
Reserved							
R-0							

7	6	5	4	3	2	1	0
SPLITPOWER	RTCDISABLE	SET32COUNTER	Reserved	HOURMODE	AUTOCOMP	ROUNDMIN	RUN
W-0	R/W-0	R/W-0	R-0	R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; W = Write only; -*n* = value after reset

Table 28-16. Control Register (CTRL) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved.
7	SPLITPOWER		Enable leakage-isolation circuitry used for isolated power schemes. **Write-only bit. Read-modify-write updates to the control register may unintentionally clear the SPLITPOWER bit because the bit always reads back 0.**
		0	Disable split power.
		1	Enable split power.
6	RTCDISABLE		Disable RTC module and gate 32-kHz reference clock. RTC should only be disabled using this bit if the module will never be used and saving power is desired.
		0	RTC is functional.
		1	RTC is disabled and 32-kHz reference clock is gated.
5	SET32COUNTER		Set the 32-kHz counter with the value stored in the compensation registers when the SET32COUNTER bit is set. RTC does not run normally when the SET32COUNTER bit is high so this bit should be toggled low-high-low when used.
		0	No action.
		1	Set 32-kHz counter with compensation register value.
4	Reserved	0	Reserved.
3	HOURMODE		Enable 12-hour mode for HOURS and ALARMHOURS registers.
		0	24 Hour Mode (Valid hours 00-24).
		1	12 Hour Mode (Valid hours 00-12; MERIDIEM bit in HOURS and ALARMHOURS must be used to denote AM or PM).
2	AUTOCOMP		Enable oscillator compensation mode. Compensation takes place once every hour.
		0	Auto compensation is disabled.
		1	Auto compensation is enabled.
1	ROUNDMIN		Enable one-time rounding to nearest minute on next time register read.
		0	Minute rounding disabled.
		1	Rounding to nearest minute enabled.
0	RUN		Stop the RTC 32-kHz counter. RTC should be stopped using this bit for stopping and resuming the counter.
		0	Stop RTC counter.
		1	Run RTC counter.

28.3.15 Status Register (STATUS)

The STATUS register is shown in Figure 28-18 and described in Table 28-17.

NOTE: Out of reset, the STATUS register is write-protected. To disable write protection, correct keys must be written to the KICK*n*R registers (see Section 28.2.6).

Figure 28-18. Status Register (STATUS)

31							16
Reserved							
R-0							

15	7	6	5	4	3	2	1	0
Reserved		ALARM	DAYEVT	HREVT	MINEVT	SECEVT	RUN	BUSY
R-1		R/W1C-0	R-0	R-0	R-0	R-0	R-0	R-0

LEGEND: R = Read only; W1C = Write 1 to clear bit; -*n* = value after reset

Table 28-17. Status Register (STATUS) Field Descriptions

Bit	Field	Value	Description
31-7	Reserved	1	Reserved
6	ALARM		Indicates if an alarm interrupt has been generated. Write a 1 to clear the ALARM status.
		0	No new alarm interrupt was generated.
		1	New alarm interrupt was generated.
5	DAYEVT		When the (TIMER = 1) in the INTERRUPTS register, DAYEVT indicates if the DAYS register incremented during the most recent time update.
		0	DAYS register did not increment during the last time update.
		1	DAYS register incremented during the last time update.
4	HREVT		When the (TIMER = 1) in the INTERRUPTS register, HREVT indicates if the HOURS register incremented during the most recent time update.
		0	HOURS register did not increment during the last time update.
		1	HOURS register incremented during the last time update.
3	MINEVT		When the (TIMER = 1) in the INTERRUPTS register, MINEVT indicates if the MINUTES register incremented during the most recent time update.
		0	MINUTES register did not increment during the last time update.
		1	MINUTES register incremented during the last time update.
2	SECEVT		When the (TIMER = 1) in the INTERRUPTS register, SECEVT indicates if the SECONDS register incremented during the most recent time update.
		0	SECONDS register did not increment during the last time update.
		1	SECONDS register incremented during the last time update.
1	RUN		Indicates if RTC is running or stopped.
		0	RTC is stopped.
		1	RTC is running.
0	BUSY		Indicates if RTC is busy updating or is within 15 µs of updating the time and calendar registers.
		0	RTC is free. The time, calendar, and control registers can be written to without contention.
		1	RTC is or will soon be busy updating the time and calendar registers.

28.3.16 Interrupt Register (INTERRUPT)

The INTERRUPT register is shown in Figure 28-19 and described in Table 28-18.

NOTE: Out of reset, the INTERRUPT register is write-protected. To disable write protection, correct keys must be written to the KICK*n*R registers (see Section 28.2.6).

Figure 28-19. Interrupt Register (INTERRUPT)

31	16
Reserved	
R-0	

15	4	3	2	1	0
Reserved		ALARM	TIMER	EVERY	
R-0		R/W-0	R/W-0	R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 28-18. Interrupt Register (INTERRUPT) Field Descriptions

Bit	Field	Value	Description
31-4	Reserved	0	Reserved.
3	ALARM		Enable interrupt generation for when the alarm time and date match the current time and date
		0	Alarm interrupt is disabled.
		1	Alarm interrupt is enabled.
2	TIMER		Enable periodic timer interrupt generation. Period is determined by the EVERY field.
		0	Periodic timer interrupt is disabled.
		1	Periodic timer interrupt is enabled.
1-0	EVERY	0-3h	Selects the time period desired when periodic timer interrupts are enabled by the TIMER bit.
		0	Second
		1h	Minute
		2h	Hour
		3h	Day

28.3.17 Compensation (LSB) Register (COMPLSB)

NOTE: Out of reset, the compensation (LSB) register (COMPLSB) is write-protected. To disable write protection, correct keys must be written to the KICK*n*R registers (see Section 28.2.6).

The compensation (LSB) register (COMPLSB) works together with the COMPMSB register to set the hourly oscillator compensation value. The AUTOCOMP bit in the control register (CTRL) must be enabled for compensation to take place. The COMPLSB register is shown in Figure 28-20 and described in Table 28-19.

Figure 28-20. Compensation (LSB) Register (COMPLSB)

31	16
Reserved	
R-0	

15	8	7	0
Reserved		COMPLSB	
R-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 28-19. Compensations Register (COMPLSB) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved.
7-0	COMPLSB	0-FFh	Lower bits of the 16-bit compensation value. The COMPMSB:COMPLSB register value is subtracted from the 32-kHz period. Compensation values are two's complement. The COMPMSB:COMPLSB value of 7F:FFh is not allowed.

28.3.18 Compensation (MSB) Register (COMPMSB)

NOTE: Out of reset, the compensation (MSB) register (COMPMSB) is write-protected. To disable write protection, correct keys must be written to the KICK*n*R registers (see Section 28.2.6).

The compensation (MSB) register (COMPMSB) works together with the COMPLSB register to set the hourly oscillator compensation value. The AUTOCOMP bit in the control register (CTRL) must be enabled for compensation to take place. The COMPMSB register is shown in Figure 28-21 and described in Table 28-20.

Figure 28-21. Compensation (MSB) Register (COMPMSB)

31	16
Reserved	
R-0	

15	8	7	0
Reserved		COMPMSB	
R-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 28-20. Compensations Register (COMPMSB) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved.
7-0	COMPMSB	0-FFh	Lower bits of the 16-bit compensation value. The COMPMSB:COMPLSB register value is subtracted from the 32-kHz period. Compensation values are two's complement. The COMPMSB:COMPLSB value of 7F:FFh is not allowed.

28.3.19 Oscillator Register (OSC)

NOTE: Out of reset, the oscillator register (OSC) is write-protected. To disable write protection, correct keys must be written to the KICK*n*R registers (see Section 28.2.6).

The oscillator register (OSC) is shown in Figure 28-22 and described in Table 28-21.

Figure 28-22. Oscillator Register (OSC)

31	16
Reserved	
R-0	

15	6	5	4	0
Reserved		SWRESET	Reserved	
R-0		W-0	R/W-7h	

LEGEND: R/W = Read/Write; R = Read only; W = Write only; -*n* = value after reset

Table 28-21. Oscillator Register (OSC) Field Descriptions

Bit	Field	Value	Description
31-6	Reserved	0	Reserved.
5	SWRESET		Software reset. Always reads back 0.
		0	No action.
		1	Reset RTC module and registers (except for OSC and KICK*n*R registers). Registers must not be accessed for three 32-kHz reference periods after reset is asserted.
4-0	Reserved	7h	Reserved. This field is writeable, but should only be programmed to the value of 7h.

28.3.20 Scratch Registers (SCRATCH0-SCRATCH2)

NOTE: Out of reset, the scratch registers (SCRATCH*n*) are write-protected. To disable write protection, correct keys must be written to the KICK*n*R registers (see Section 28.2.6).

The scratch registers (SCRATCH*n*) are 32-bit general-purpose registers that have no effect on RTC functionality. They can be used by the user arbitrarily. The SCRATCH*n* register is shown in Figure 28-23 and described in Table 28-22.

Figure 28-23. Scratch Registers (SCRATCH*n*)

31	0
SCRATCH*n*	
R/W-0	

LEGEND: R/W = Read/Write; -*n* = value after reset

Table 28-22. Scratch Registers (SCRATCH*n*) Field Descriptions

Bit	Field	Value	Description
31-0	SCRATCH*n*	0-FFFF FFFFh	General-purpose 32-bit registers that have no effect on RTC functionality.

28.3.21 Kick Registers (KICK0R, KICK1R)

The kick registers (KICK*n*R) are used to enable and disable write protection on the RTC registers. Out of reset, the RTC registers are write-protected. To disable write protection, correct keys must be written to the KICK*n*R registers (see Section 28.2.6). The KICK*n*R register is shown in Figure 28-24 and described in Table 28-23.

Figure 28-24. Kick Registers (KICK*n*R)

31	0
KICK*n*	
R/W-0	

LEGEND: R/W = Read/Write; -*n* = value after reset

Table 28-23. Kick Registers (KICK*n*R) Field Descriptions

Bit	Field	Value	Description
31-0	KICK*n*	0-FFFF FFFFh	To disable RTC register write protection, the value of 83E7 0B13h must be written to KICK0R, followed by the value of 95A4 F1E0h written to KICK1R. RTC register write protection is enabled when any value is written to KICK0R.

Serial Peripheral Interface (SPI)

This chapter describes the serial peripheral interface (SPI) module. See your device-specific data manual to determine how many SPIs are available on your device.

Topic **Page**

29.1 Introduction

29.1.1 Purpose of the Peripheral

The SPI is a high-speed synchronous serial input/output port that allows a serial bit stream of programmed length (2 to 16 bits) to be shifted into and out of the device at a programmed bit-transfer rate. The SPI is normally used for communication between the device and external peripherals. Typical applications include interface to external I/O or peripheral expansion via devices such as shift registers, display drivers, SPI EPROMS and analog-to-digital converters.

29.1.2 Features

The SPI has the following features:

- 16-bit shift register
- 16-bit Receive buffer register (SPIBUF) and 16-bit Receive buffer emulation 'alias' register (SPIEMU)
- 16-bit Transmit data register (SPIDAT0) and 16-bit Transmit data and format selection register (SPIDAT1)
- 8-bit baud clock generator
- Serial clock (SPIx_CLK) I/O pin
- Slave in, master out (SPIx_SIMO) I/O pin
- Slave out, master in (SPIx_SOMI) I/O pin
- SPI enable ($\overline{\text{SPIx\_ENA}}$) I/O pin (4-pin or 5-pin mode only)
- Multiple slave chip select ($\overline{\text{SPIx\_SCS[n]}}$) I/O pins (4-pin or 5-pin mode only)
- Programmable SPI clock frequency range
- Programmable character length (2 to 16 bits)
- Programmable clock phase (delay or no delay)
- Programmable clock polarity (high or low)
- Interrupt capability
- DMA support (read/write synchronization events)

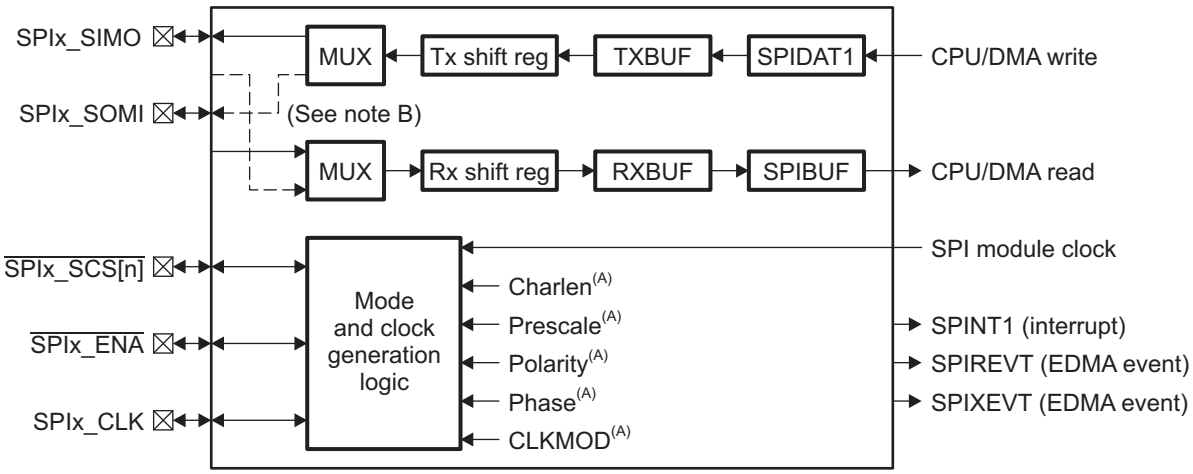
The SPI allows software to program the following options:

- SPI pins as functional or digital I/O pins
- SPI Master or Slave mode
- SPIx_CLK frequency (SPI module clock/3 through SPI module clock/256)
- 3-pin, 4-pin, and 5-pin options
- Character length (2 to 16 bits) and shift direction (MSB/LSB first)
- Clock phase (delay or no delay) and polarity (high or low)
- Delay between transmissions in master mode.
- Chip select setup and hold times in master mode
- Chip select hold in master mode

29.1.3 Functional Block Diagram

The Figure 29-1 shows the SPI block diagram.

Figure 29-1. SPI Block Diagram



NOTE: The value *x* indicates the applicable SPI; that is, SPI0, SPI1, etc. See your device-specific data manual to determine how many SPIs are available on your device. The value *n* indicates the SPI pins available. See your device-specific data manual to determine how many SPI pins are available on your device.

A Indicates the log controlled by SPI register bits.

B Solid line represents data flow for SPI master mode. Dashed line represents data flow for SPI slave mode.

29.1.4 Industry Standard(s) Compliance Statement

The programmable configuration capability of the SPI allows it to gluelessly interface to a variety of SPI format devices. The SPI does not conform to a specific industry standard.

29.2 Architecture

This section describes the SPI operation modes. It gives an overview of SPI operation and then provides details on the 3-pin, 4-pin, and 5-pin options, as well as more specific details on the supported data formats.

29.2.1 Clock

The SPI clock (SPIx_CLK) is derived from the SPI module clock. The maximum clock bit rate supported is SPI module clock/3, as determined by the PRESCALE field in the SPI data format register *n* (SPIFMT*n*). The SPIx_CLK frequency is calculated as:

SPIx_CLK frequency = [SPI module clock] / [SPIFMT*n*.PRESCALE + 1]

29.2.2 Signal Descriptions

Table 29-1 shows the SPI pins used to interface to external devices.

Table 29-1. SPI Pins

Pin [1]	Type	Function
SPIx_SIMO	Input/Output	Serial data input in slave mode, serial data output in master mode
SPIx_SOMI	Input/Output	Serial data output in slave mode, serial data input in master mode
SPIx_CLK	Input/Output	Serial clock input in slave mode, serial clock output in master mode
$\overline{\text{SPIx\_SCS[n]}}$ [2]	Input/Output	Slave chip select output in master mode, input in slave mode
$\overline{\text{SPIx\_ENA}}$	Input/Output	Input in master mode, output in slave mode indicates slave is ready

(1) The value *x* indicates the applicable SPI; that is, SPI0, SPI1, etc. See your device-specific data manual to determine how many SPIs are available on your device.

(2) The value *n* indicates the SPI pins available; that is, $\overline{\text{SPIx\_SCS[0]}}$, $\overline{\text{SPIx\_SCS[1]}}$, etc. See your device-specific data manual to determine how many SPI pins are available on your device.

29.2.3 Operation Modes

The SPI operates in master or slave mode. The SPI bus master is the device that drives the SPIx_CLK, SPIx_SIMO, and optionally the $\overline{\text{SPIx\_SCS[n]}}$ signals, and therefore initiates SPI bus transfers. The CLKMOD and MASTER bits in the SPI global control register 1 (SPIGCR1) select between master and slave mode. In both master and slave mode, the SPI supports four options:

- 3-pin option
- 4-pin with chip select option
- 4-pin with enable option
- 5-pin with enable and chip select option

The 3-pin option is the basic clock, data in, and data out SPI interface and uses the SPIx_CLK, SPIx_SIMO, and SPIx_SOMI pins. The 4-pin with chip select option adds the $\overline{\text{SPIx\_SCS[n]}}$ pin that is used to support multiple SPI slave devices on a single SPI bus. The 4-pin with enable option adds the $\overline{\text{SPIx\_ENA}}$ pin that is used to increase the overall throughput by adding hardware handshaking. The 5-pin option uses all the SPI pins and is a superset of the different options.

29.2.4 Programmable Registers

A general representation of the SPI programmable registers is shown in Table 29-2. For details on registers, see Section 29.3.

Table 29-2. SPI Registers

Offset Address [1]	Acronym	Name	Description	Section
0h	SPIGCR0	Global control register 0	Contains the software reset bit for the module	Section 29.3.1
4h	SPIGCR1	Global control register 1	Controls basic configurations of the module	Section 29.3.2
8h	SPIINT0	Interrupt register	Enable bits for interrupts, error, DMA and other functionality.	Section 29.3.3
Ch	SPILVL	Level register	SPI interrupt levels are set in this register.	Section 29.3.4
10h	SPIFLG	Flag register	Shows the status of several events during the operation.	Section 29.3.5
14h	SPIPC0	Pin control register 0	Determines if pins operate as general I/O or SPI functional pin	Section 29.3.6
18h	SPIPC1	Pin control register 1	Controls the direction of data on the I/O pins	Section 29.3.7
1Ch	SPIPC2	Pin control register 2	Reflects the values on the I/O pins	Section 29.3.8
20h	SPIPC3	Pin control register 3	Controls the values sent to the I/O pins	Section 29.3.9
24h	SPIPC4	Pin control register 4	Sets data values in the SPIPC3 register	Section 29.3.10
28h	SPIPC5	Pin control register 5	Clears values in the SPIPC3 register	Section 29.3.11
38h	SPIDAT0	Transmit data register 0	Transmit data register	Section 29.3.12
3Ch	SPIDAT1	Transmit data register 1	Transmit data with format selection register	Section 29.3.13
40h	SPIBUF	Receive buffer register	Holds received word	Section 29.3.14
44h	SPIEMU	Receive buffer emulation register	Mirror of SPIBUF. Read does not clear flags	Section 29.3.15
48h	SPIDELAY	Delay register	Sets $\overline{\text{SPIx\_SCS[n]}}$ mode, $\overline{\text{SPIx\_SCS[n]}}$ pre-/post-transfer delay time and $\overline{\text{SPIx\_ENA}}$ time-out	Section 29.3.16
4Ch	SPIDEF	Chip select default register	In $\overline{\text{SPIx\_SCS[n]}}$ decoded mode only: sets high low/active $\overline{\text{SPIx\_SCS[n]}}$ signal	Section 29.3.17
50h	SPIFMT0	Format 0 register	Configuration of data word format 0	Section 29.3.18
54h	SPIFMT1	Format 1 register	Configuration of data word format 1	Section 29.3.18
58h	SPIFMT2	Format 2 register	Configuration of data word format 2	Section 29.3.18
5Ch	SPIFMT3	Format 3 register	Configuration of data word format 3	Section 29.3.18
64h	INTVEC1	Interrupt vector register 1	Interrupt vector for line INT1	Section 29.3.19

(1) The actual address of these registers is device specific and CPU specific. See your device-specific data manual to verify the SPI register addresses.

29.2.5 Master Mode Settings

The four master mode options are defined by the configuration bit settings listed in Table 29-3. Other configuration bits may take any value in the range listed in Table 29-4. The values listed in Table 29-3 and Table 29-4 should not be changed while the ENABLE bit in the SPI global control register 1 (SPIGCR1) is set to 1. Note that in certain cases the allowed values may still be ignored. For example, Table 29-4 indicates that SPIDELAY may take a range of values in Master 3-pin mode; however, SPIDELAY has no effect in Master 3-pin mode. For complete details on each mode, see the following sections that explain the SPI operation for each of the master modes.

Table 29-3. SPI Register Settings Defining Master Modes

Register	Bit(s)	Master 3-pin	Master 4-pin Chip Select	Master 4-pin Enable	Master 5-pin
SPIGCR0	RESET	1	1	1	1
SPIGCR1	ENABLE	1	1	1	1
SPIGCR1	LOOPBACK	0	0	0	0
SPIGCR1	CLKMOD	1	1	1	1
SPIGCR1	MASTER	1	1	1	1
SPIPC0	SOMIFUN	1	1	1	1
SPIPC0	SIMOFUN	1	1	1	1
SPIPC0	CLKFUN	1	1	1	1
SPIPC0	ENAFUN	0	0	1	1
SPIPC0	SCS0FUN	0	1	0	1

Table 29-4. Allowed SPI Register Settings in Master Modes

Register	Bit(s)	Master 3-pin	Master 4-pin Chip Select	Master 4-pin Enable	Master 5-pin
SPIINT0	ENABLEHIGHZ	0,1	0,1	0,1	0,1
SPIFMT*n*	WDELAY	0 to 3Fh	0 to 3Fh	0 to 3Fh	0 to 3Fh
SPIFMT*n*	PARPOL	0,1	0,1	0,1	0,1
SPIFMT*n*	PARENA	0,1	0,1	0,1	0,1
SPIFMT*n*	WAITENA	0	0	1	1
SPIFMT*n*	SHIFTDIR	0,1	0,1	0,1	0,1
SPIFMT*n*	DISCSTIMERS	0,1	0,1	0,1	0,1
SPIFMT*n*	POLARITY	0,1	0,1	0,1	0,1
SPIFMT*n*	PHASE	0,1	0,1	0,1	0,1
SPIFMT*n*	PRESCALE	2 to FFh	2 to FFh	2 to FFh	2 to FFh
SPIFMT*n*	CHARLEN	2 to 10h	2 to 10h	2 to 10h	2 to 10h
SPIDELAY	C2TDELAY	0 to FFh	0 to FFh	0 to FFh	0 to FFh
SPIDELAY	T2CDELAY	0 to FFh	0 to FFh	0 to FFh	0 to FFh
SPIDELAY	T2EDELAY	0 to FFh	0 to FFh	0 to FFh	0 to FFh
SPIDELAY	C2EDELAY	0 to FFh	0 to FFh	0 to FFh	0 to FFh

29.2.5.1 Master Mode Timing Options

The SPI in master mode supports several options to modify the timing of its generation of the chip select signal ($\overline{\text{SPIx\_SCS[n]}}$). This allows the SPI to support the timing requirements of various slave devices without adding additional overhead to the CPU by generating the appropriate delays automatically.

29.2.5.1.1 Chip Select Setup Time

The master can be configured to provide a (slow) slave device a certain chip select setup time to the first edge on SPIx_CLK. This delay is controlled by the C2TDELAY field in the SPI delay register (SPIDELAY) and can be configured between 3 and 257 SPI module clock cycles. The C2TDELAY is applicable only in 4-pin with chip select and 5-pin SPI master modes. The C2TDELAY begins when the SPI master asserts SPIx_SCS[n]. The C2T delay period is specified by:

Maximum duration of C2TDELAY period = SPIDELAY.C2TDELAY + 2 (SPI module clock cycles)

Note that if SPIDELAY.C2TDELAY = 0, then the C2TDELAY period = 0.

The previous value of the CSHOLD bit in the SPI transmit data register (SPIDAT1) must be cleared to 0 for the C2T delay to be enabled.

NOTE: If the SPIDAT1.CSHOLD bit is set within the control field, the current hold time and the following setup time will not be applied in between transaction.

29.2.5.1.2 Chip Select Hold Time

The master can be configured to provide a (slow) slave device a certain chip select hold time after the last edge on SPIx_CLK. This delay is controlled by the T2CDELAY bit in the SPI delay register (SPIDELAY) and can be configured between 2 and 256 SPI module clock cycles. The T2CDELAY is applicable only in 4-pin with chip select and 5-pin SPI master modes. The T2CDELAY begins after the data shifting period ends. The T2C delay period is specified by:

Maximum duration of T2CDELAY period = SPIDELAY.T2CDELAY + 1 (SPI module clock cycle)

Note that if SPIDELAY.T2CDELAY = 0, then the T2CDELAY period = 0. If the PHASE bit in the SPI data format register *n* (SPIFMT*n*) is 0, then the T2CDELAY period lasts for an additional 1/2 SPIx_CLK time over that specified by the above equation.

The current value of the CSHOLD bit in the SPI transmit data register (SPIDAT1) must be cleared to 0 for T2C delay to be enabled.

NOTE: If the SPIDAT1.CSHOLD bit is set within the control field, the current hold time and the following setup time will not be applied in between transaction.

29.2.5.1.3 Automatic Delay Between Transfers

The SPI master can automatically insert a delay of between 2 and 65 SPI module clock cycles between transmissions. This delay is controlled by the WDELAY field in the SPI data format register *n* (SPIFMT*n*) and is enabled by setting the WDEL bit in the SPI transmit data register (SPIDAT1) to 1. The WDELAY period begins when the T2EDELAY period terminates (if T2E delay period is enabled) or when the T2CDELAY period terminates (if T2E delay period was disabled and T2C delay period was enabled) or when the master deasserts SPIx_SCS[n] (if T2E and T2C delay periods are disabled). If a transfer is initiated by writing a 32-bit value to SPIDAT1, then the new values of SPIDAT1.WDEL and SPIFMT*n*.WDELAY are used; otherwise, the old values of SPIDAT1.WDEL and SPIFMT*n*.WDELAY are used. The WDELAY delay period is specified by:

Maximum duration of WDELAY period = SPIFMTn.WDELAY + 2 (SPI module clock cycles)

29.2.5.1.4 Chip Select Hold Option

There are slave devices available that require the chip select signal to be held continuously active during several consecutive data word transfers. Other slave devices require the chip select signal to be deactivated between consecutive data word transfers. The SPI can support both types of slave devices. The CSHOLD bit in the SPI transmit data register (SPIDAT1) selects between the two options.

If the chip select hold option is enabled, the chip select will not toggle between two consecutive accesses; therefore, the SPIDELAY.T2CDELAY of the first transfer and the SPIDELAY.C2TDELAY of the second transfer will not be applied. However, the wait delay could still be applied between the two transactions, if the WDEL bit in SPIDAT1 is set to 1.

The current and previous values of the CSHOLD bit are retained. Though the current value of the CSHOLD bit is initialized to 0 when the RESET bit in the SPI global control register 0 (SPIGCR0) is cleared to 0, the previous value of the CSHOLD bit is not initialized. The previous value of the CSHOLD bit must be explicitly initialized by writing twice to the CSHOLD bit.

29.2.6 Slave Mode Settings

The four slave mode options are defined by the configuration bit settings listed in Table 29-5. Other configuration bits may take any value in the range listed in Table 29-6. The values listed in Table 29-5 and Table 29-6 should not be changed while the ENABLE bit in the SPI global control register 1 (SPIGCR1) is set to 1. Note that in certain cases the allowed values may still be ignored. For complete details on each mode, see the following sections that explain the SPI operation for each of the slave modes.

Table 29-5. SPI Register Settings Defining Slave Modes

Register	Bit(s)	Slave 3-pin	Slave 4-pin Chip Select	Slave 4-pin Enable	Slave 5-pin
SPIGCR0	RESET	1	1	1	1
SPIGCR1	ENABLE	1	1	1	1
SPIGCR1	LOOPBACK	0	0	0	0
SPIGCR1	CLKMOD	0	0	0	0
SPIGCR1	MASTER	0	0	0	0
SPIPC0	SOMIFUN	1	1	1	1
SPIPC0	SIMOFUN	1	1	1	1
SPIPC0	CLKFUN	1	1	1	1
SPIPC0	ENAFUN	0	0	1	1
SPIPC0	SCS0FUN	0	1	0	1

Table 29-6. Allowed SPI Register Settings in Slave Modes

Register	Bit(s)	Slave 3-pin	Slave 4-pin Chip Select	Slave 4-pin Enable	Slave 5-pin
SPIINT0	ENABLEHIGHZ	0,1	0,1	0,1	0,1
SPIFMT*n* (1)	WDELAY	0 to 3Fh	0 to 3Fh	0 to 3Fh	0 to 3Fh
SPIFMT*n* (1)	PARPOL	0,1	0,1	0,1	0,1
SPIFMT*n* (1)	PARENA	0,1	0,1	0,1	0,1
SPIFMT*n* (1)	WAITENA	0,1	0,1	0,1	0,1
SPIFMT*n* (1)	SHIFTDIR	0,1	0,1	0,1	0,1
SPIFMT*n* (1)	DISCSTIMERS	0,1	0,1	0,1	0,1
SPIFMT*n* (1)	POLARITY	0,1	0,1	0,1	0,1
SPIFMT*n* (1)	PHASE	0,1	0,1	0,1	0,1
SPIFMT*n* (1)	PRESCALE	2 to FFh	2 to FFh	2 to FFh	2 to FFh
SPIFMT*n* (1)	CHARLEN	2 to 10h	2 to 10h	2 to 10h	2 to 10h
SPIDELAY	C2TDELAY	0 to FFh	0 to FFh	0 to FFh	0 to FFh
SPIDELAY	T2CDELAY	0 to FFh	0 to FFh	0 to FFh	0 to FFh
SPIDELAY	T2EDELAY	0 to FFh	0 to FFh	0 to FFh	0 to FFh
SPIDELAY	C2EDELAY	0 to FFh	0 to FFh	0 to FFh	0 to FFh

(1) In slave mode, only SPIFMT0 is used. When SPIDAT1 is written, the DFSEL field in SPIDAT1 is cleared to 0 to select SPIFMT0.

29.2.7 SPI Operation: 3-Pin Mode

NOTE: If only unidirectional communication is required, the SPIx_CLK pin and the two data pins (SPIx_SOMI and SPIx_SIMO) must all be configured as functional pins. A 2-pin unidirectional mode is not supported.

The SPI 3-pin mode uses only the clock (SPIx_CLK) and data (SPIx_SOMI and SPIx_SIMO) pins for bidirectional communication between master and slave devices. Figure 29-2 shows the basic 3-pin SPI option.

To select the 3-pin SPI option, the SPIx_CLK, SPIx_SOMI, and SPIx_SIMO pins should be configured as functional pins by configuring the SPI pin control register 0 (SPIPC0). The $\overline{\text{SPIx\_SCS[n]}}$ and $\overline{\text{SPIx\_ENA}}$ pins can be used as general-purpose I/O pins by configuring the SPIPC1 through SPIPC5 registers.

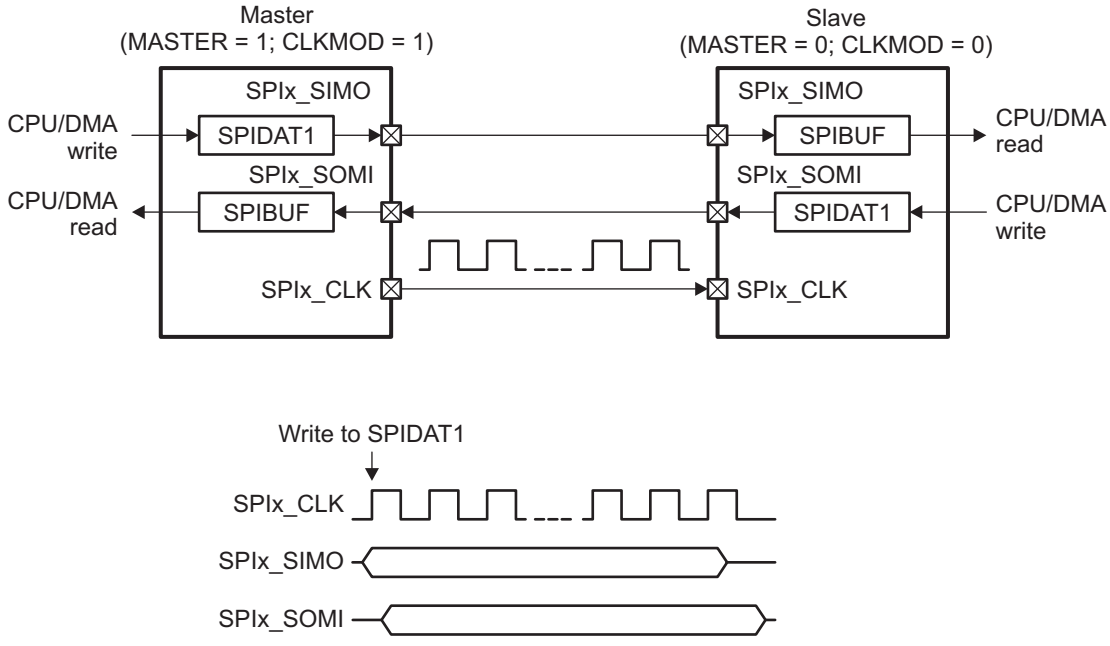
The SPI operates in either master or slave mode. The CLKMOD and MASTER bits in the SPI global control register 1 (SPIGCR1) select between master and slave mode; both must be programmed to 1 to configure the SPI for master mode or to 0 to configure the SPI for slave mode. The SPI bus master is the device that drives the SPIx_CLK signal and initiates SPI bus transfers. In SPI master mode, the SPIx_SOMI pin output buffer is in a high-impedance state and the SPIx_CLK and the SPIx_SIMO pin output buffer is enabled. In SPI slave mode, the SPIx_SIMO and SPIx_CLK pin output buffer is in a high-impedance state and the SPIx_SOMI pin output buffer is enabled.

In master mode with the 3-pin option, the DSP writes transmit data to the SPI transmit data registers (SPIDAT0[15:0] or SPIDAT1[15:0]). This initiates a transfer. A series of clocks pulses will be driven out on the SPIx_CLK pin to complete the transfer. Each clock pulse on the SPIx_CLK pin causes the simultaneous transfer (in both directions) of one bit by both the master and slave SPI devices. CPU writes to the configuration bits in SPIDAT1 (not writing to SPIDAT1[15:0]) do not result in a new transfer. When the selected number of bits has been transmitted, the received data is transferred to the SPI receive buffer register (SPIBUF) for the CPU to read. Data is stored right-justified in SPIBUF.

In slave mode with 3-pin option, CPU writes to SPIDAT0[15:0] or SPIDAT1[15:0] makes the slave ready to transmit. CPU writes to the configuration bits in SPIDAT1 (not writing to SPIDAT1[15:0]) do not make the slave ready to transmit.

NOTE: Either SPIDAT0 or SPIDAT1 can be used on both master and slaves sides.

Figure 29-2. SPI 3-Pin Option



29.2.8 SPI Operation: 4-Pin with Chip Select Mode

NOTE: The SPI only supports a single $\overline{\text{SPIx\_SCS[n]}}$ pin and so the usefulness of the $\overline{\text{SPIx\_SCS[n]}}$ pin in master mode is limited. In practice, general-purpose I/O pins are needed to support multiple slave device chip selects.

The 4-pin with chip select option is a superset of the 3-pin option and uses the chip select ($\overline{\text{SPIx\_SCS[n]}}$) pin in addition to the clock (SPIx_CLK) and data (SPIx_SOMI and SPIx_SIMO) pins. Figure 29-3 shows the SPI 4-pin chip select option.

To select the 4-pin with chip select option, the SPIx_CLK, SPIx_SOMI, SPIx_SIMO, and $\overline{\text{SPIx\_SCS[n]}}$ pins should be configured as functional pins by configuring the SPI pin control register 0 (SPIPC0). The $\overline{\text{SPIx\_ENA}}$ pin can be used as a general-purpose I/O pin by configuring the SPIPC1 through SPIPC5 registers.

In SPI master mode, the SPIx_SOMI pin output buffer is in a high-impedance state and the SPIx_CLK, SPIx_SIMO, and $\overline{\text{SPIx\_SCS[n]}}$ pin output buffer is enabled. In SPI slave mode, the SPIx_CLK, SPIx_SIMO, and $\overline{\text{SPIx\_SCS[n]}}$ pin output buffer is in a high-impedance state, and the SPIx_SOMI pin output buffer is enabled when $\overline{\text{SPIx\_SCS[n]}}$ is asserted and in a high-impedance state when $\overline{\text{SPIx\_SCS[n]}}$ is deasserted.

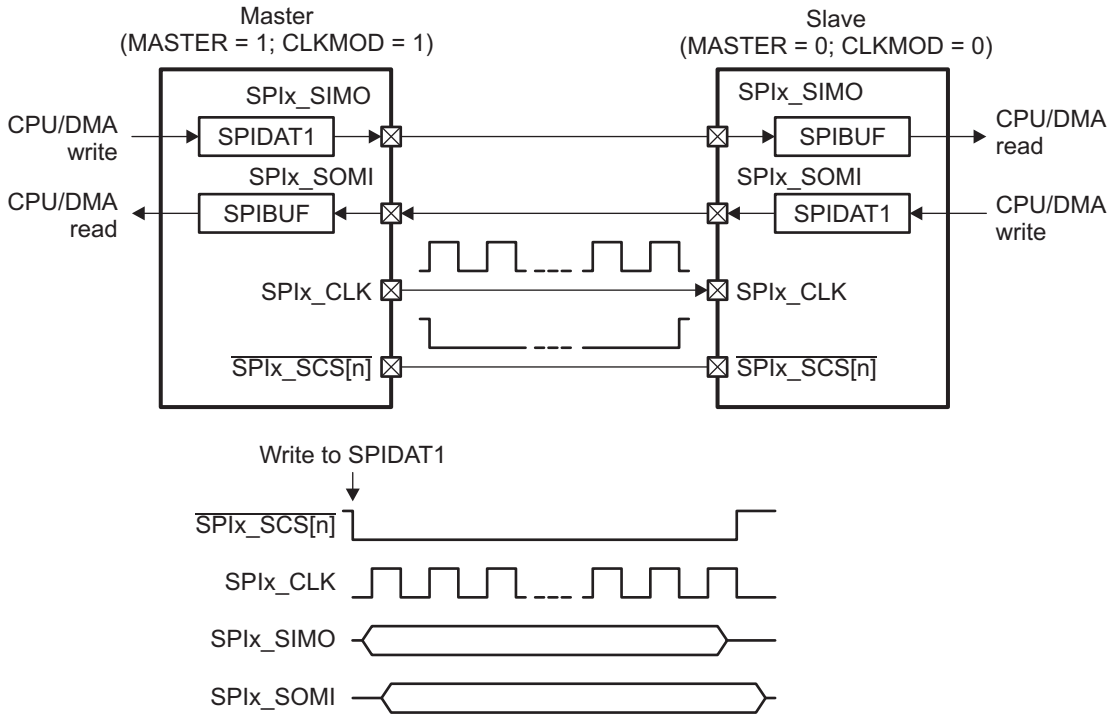
In slave mode with the chip select option enabled, the SPI ignores all transactions on the bus unless $\overline{\text{SPIx\_SCS[n]}}$ is asserted by the bus master. It also 3-states its output pin when $\overline{\text{SPIx\_SCS[n]}}$ is deasserted by the master to avoid conflicting with the active slave device on the bus.

In master mode, the $\overline{\text{SPIx\_SCS[n]}}$ pin functions as an output, and toggles when a specific slave device is selected. However, this is most useful on devices that support multiple $\overline{\text{SPIx\_SCS[n]}}$ pins.

However, one reason to use the $\overline{\text{SPIx\_SCS[n]}}$ pin as a functional pin for the SPI master is to take advantage of the timing parameters that can be set using the SPI delay register (SPIDELAY). The SPIDELAY allows delays to be added automatically so that the slave timing requirements between clock and chip select may be more easily met. Another reason would be to make use of the error detection built into the SPI.

NOTE: Either SPIDAT0 or SPIDAT1 can be used on both master and slaves sides.

Figure 29-3. SPI 4-Pin Option with $\overline{\text{SPIx\_SCS[n]}}$



NOTE: During an SPI transfer, if the slave mode SPI detects a deassertion of its chip select even before its internal character length counter overflows, then it 3-states its SPIx_SOMI pin. Once this condition has occurred, if a SPIx_CLK edge is detected while the chip select is deasserted, the SPI stops the transfer and sets an error flag DLENERR (data length) and generates an interrupt if enabled.

29.2.9 SPI Operation: 4-Pin with Enable Mode

The 4-pin with enable option is a superset of the 3-pin option and uses the enable ($\overline{\text{SPIx\_ENA}}$) pin in addition to the clock (SPIx_CLK) and data (SPIx_SOMI and SPIx_SIMO) pins. Figure 29-4 shows the SPI 4-pin enable option.

To select the 4-pin with enable option, the SPIx_CLK, SPIx_SOMI, SPIx_SIMO, and $\overline{\text{SPIx\_ENA}}$ pins should be configured as functional pins by configuring the SPI pin control register 0 (SPIPC0). The $\overline{\text{SPIx\_SCS[n]}}$ pins can be used as general-purpose I/O pins by configuring the SPIPC1 through SPIPC5 registers.

In SPI master mode, the SPIx_SOMI and $\overline{\text{SPIx\_ENA}}$ pin output buffer is in a high-impedance state and the SPIx_CLK and SPIx_SIMO pin output buffer is enabled. In SPI slave mode, the SPIx_CLK and SPIx_SIMO pin output buffer is in a high-impedance state, and the SPIx_SOMI pin output buffer is enabled. In SPI slave mode, the $\overline{\text{SPIx\_ENA}}$ pin output buffer enable depends upon the status of the transmit buffer and the configuration of the ENABLEHIGHZ bit in the SPI interrupt register (SPIINT0).

The handshake operation works this way:

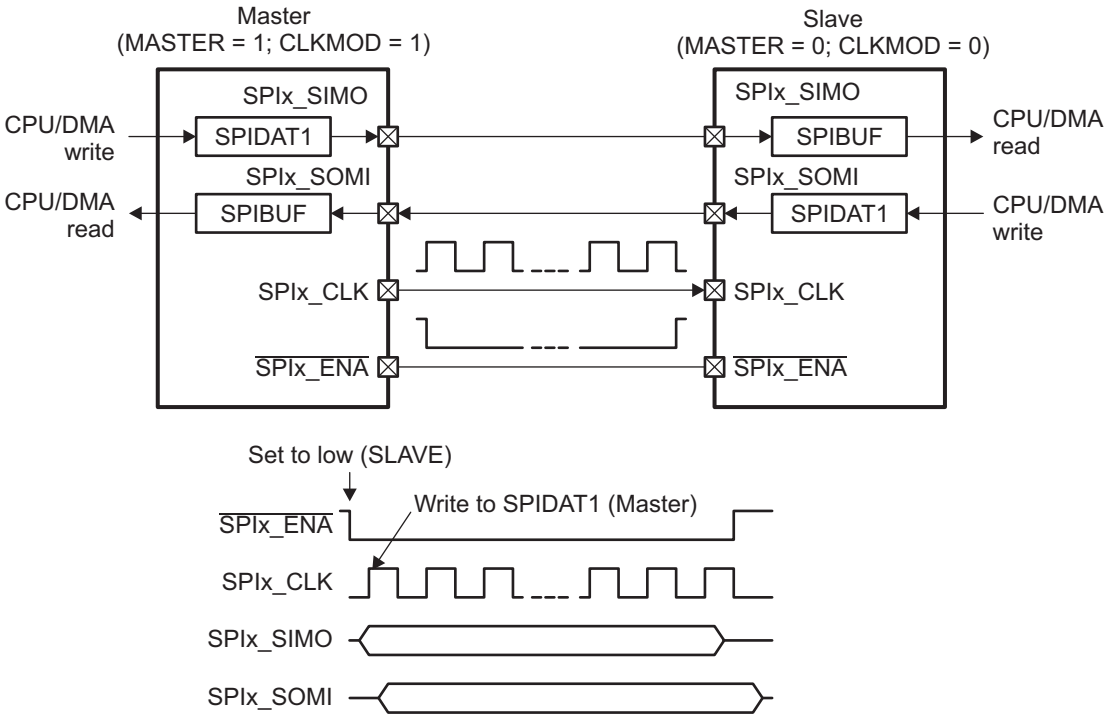
- After a transfer completes, both the master and slave SPI modules need to be serviced.
- The slave SPI deasserts $\overline{\text{SPIx\_ENA}}$ after the transfer, indicating it requires servicing and is not ready.
- The slave should begin servicing its SPI by first reading receive data from the SPI receive buffer register (SPIBUF).
- Next, the slave device should write transmit data to the SPI transmit data registers (SPIDAT0 or SPIDAT1). This causes the slave SPI to assert $\overline{\text{SPIx\_ENA}}$ indicating it is ready for the next transmission.
- In parallel, the master device can service its SPI at any time. It does not need to insert a delay before writing to its SPIDAT0 or SPIDAT1 in order to avoid overrunning the slave device. Instead, the master SPI module will automatically delay the next transfer until the slave has asserted $\overline{\text{SPIx\_ENA}}$ again to indicate it is ready for the transmission.

This handshake allows the two SPIs to communicate at the maximum rate possible. Without the handshake pin, the master must insert a delay between each transfer long enough to support the worst case response time of the slave servicing its SPI or risk an overrun condition. With the handshake, the throughput is determined by the average response time of the two devices servicing their SPI ports.

The $\overline{\text{SPIx\_ENA}}$ pin can be driven in a push-pull or open-drain mode, depending upon the setting of the ENABLEHIGHZ bit.

NOTE: Either SPIDAT0 or SPIDAT1 can be used on both master and slaves sides.

Figure 29-4. SPI 4-Pin Option with $\overline{\text{SPIx\_ENA}}$



29.2.10 SPI Operation: 5-Pin Mode

NOTE: The SPI only supports a single $\overline{\text{SPIx\_SCS[n]}}$ pin and so the usefulness of the $\overline{\text{SPIx\_SCS[n]}}$ pin in master mode is limited. In practice, general-purpose I/O pins are needed to support multiple slave device chip selects.

The 5-pin mode is a superset of both 4-pin modes. To use the 5-pin mode, both the $\overline{\text{SPIx\_ENA}}$ and the $\overline{\text{SPIx\_SCS[n]}}$ pins must be configured as functional pins, in addition to the SPIx_CLK, SPIx_SIMO, and SPIx_SOMI pins by configuring the SPI pin control register 0 (SPIPC0). Figure 29-5 shows the SPI 5-pin option.

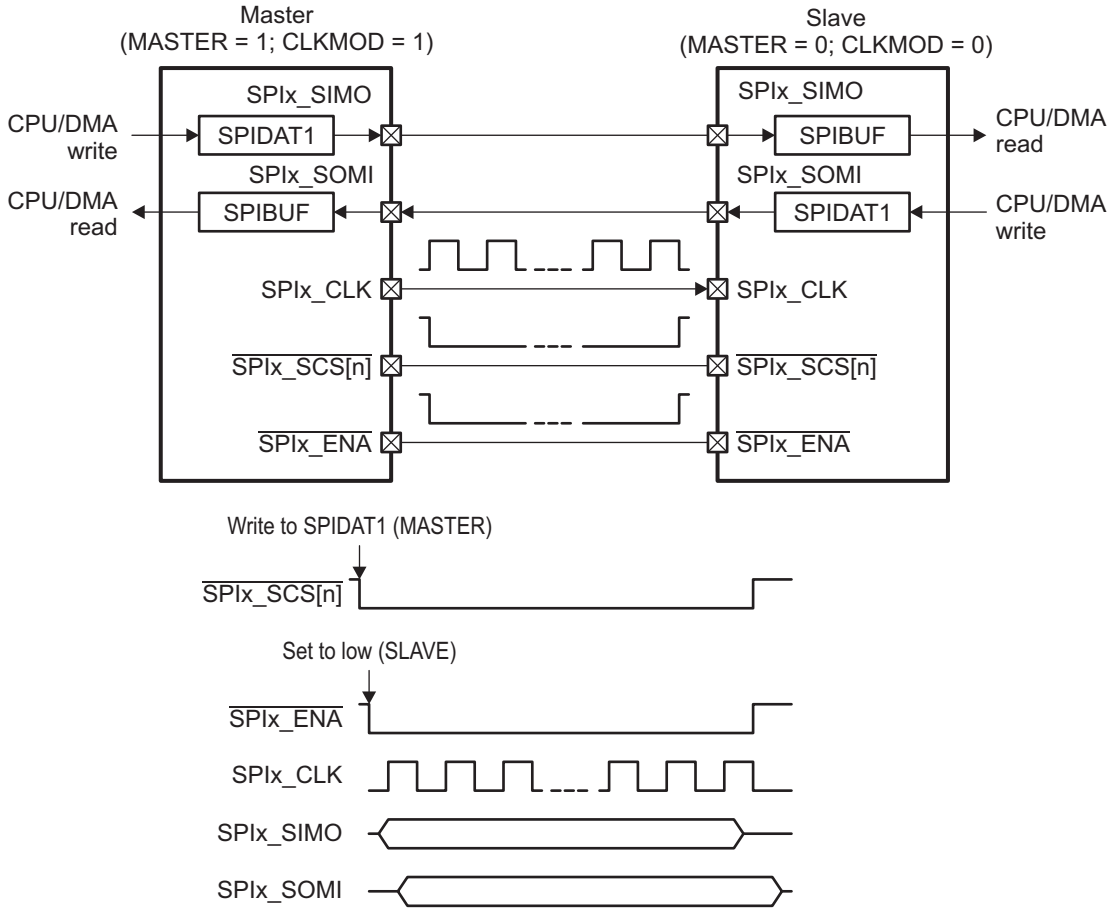
In SPI master mode, the SPIx_SOMI and $\overline{\text{SPIx\_ENA}}$ pin output buffer is in a high-impedance state and the SPIx_CLK, SPIx_SIMO, and $\overline{\text{SPIx\_SCS[n]}}$ pin output buffer is enabled. In SPI slave mode, the SPIx_CLK, SPIx_SIMO, and $\overline{\text{SPIx\_SCS[n]}}$ pin output buffer is in a high-impedance state, and the SPIx_SOMI pin output buffer is enabled and disabled asynchronously by the $\overline{\text{SPIx\_SCS[n]}}$ input and the $\overline{\text{SPIx\_ENA}}$ pin output buffer enable depends upon the status of the transmit buffer and the state of the $\overline{\text{SPIx\_SCS[n]}}$ input. In SPI slave mode, the assertion of the $\overline{\text{SPIx\_ENA}}$ pin by the slave is delayed until the master asserts $\overline{\text{SPIx\_SCS[n]}}$, thereby, allowing multiple SPI slaves on a single SPI bus, each slave with its own enable pin.

If the $\overline{\text{SPIx\_ENA}}$ pin is in high-impedance mode (ENABLEHIGHZ = 1 in the SPI interrupt register (SPIINT0)), the slave SPI will put this signal into the high-impedance state by default. The slave SPI will drive the $\overline{\text{SPIx\_ENA}}$ signal low when new data is written to the slave transmit shift register and the slave has been selected by the master ($\overline{\text{SPIx\_SCS[n]}}$ is low).

If the $\overline{\text{SPIx\_ENA}}$ pin is in push-pull mode (ENABLEHIGHZ = 0), the slave SPI will drive this pin high by default when it is in functional mode. The slave SPI will drive the $\overline{\text{SPIx\_ENA}}$ signal low when new data is written to the slave transmit shift register and the slave is selected by the master ($\overline{\text{SPIx\_SCS[n]}}$ is low). If the slave is deselected by the master ($\overline{\text{SPIx\_SCS[n]}}$ goes high), the slave $\overline{\text{SPIx\_ENA}}$ signal is driven high automatically.

NOTE: Either SPIDAT0 or SPIDAT1 can be used on both master and slaves sides.

Figure 29-5. SPI 5-Pin Option with $\overline{\text{SPIx\_ENA}}$ and $\overline{\text{SPIx\_SCS[n]}}$



NOTE: Push-Pull mode of the $\overline{\text{SPIx\_ENA}}$ pin can be used only when there is a single slave in the system. When there are multiple SPI slave devices connected to the common $\overline{\text{SPIx\_ENA}}$ pin, all the slaves should configure their $\overline{\text{SPIx\_ENA}}$ pins in high-impedance mode.

During an SPI transfer, if slave mode SPI detects a deassertion of its chip select even before its internal character length counter overflows, then it 3-states its SPIx_SOMI and $\overline{\text{SPIx\_ENA}}$ (if SPIINT0.ENABLEHIGHZ bit is set to 1) pins. Once this condition has occurred, if a SPIx_CLK edge is detected while the chip select is deasserted, then the SPI stops that transfer and sets an error flag DLENERR (data length) and generates an interrupt if enabled.

29.2.11 Data Formats

The SPI provides the capability to configure four independent data formats. These formats are configured by programming the corresponding SPI data format registers (SPIFMT*n*). In each data format, the following characteristics of the SPI operation are selected:

- Character length from 2 to 16 bits: The character length is configured by the SPIFMT*n*.CHARLEN field.
- Shift direction (MSB first or LSB first): The shift out direction is configured by the SPIFMT*n*.SHIFTDIR bit.
- Clock polarity: The clock polarity is configured by the SPIFMT*n*.POLARITY bit.
- Clock phase: The clock phase is configured by the SPIFMT*n*.PHASE bit.

The data format is chosen on each transaction. Transmit data is written to the SPI transmit data register 1 (SPIDAT1) and in the same write the data word format select (DFSEL) bit in SPIDAT1 indicates which data format is to be used for the next transaction. Alternatively, the data format can be configured once and applies to all transactions that follow until the data format is changed.

29.2.11.1 Character Length

The character length is configured by the SPIFMT*n*.CHARLEN bit. Legal values are 2 bits (2h) to 16 bits (10h). The character length is independently configured for each of the four data formats; and it must be programmed in both master mode and slave mode.

Transmit data is written to SPIDAT1. The transmit data must be written right-justified irrespective of the character length. The SPI automatically sends out the data correctly based on the chosen data format.

Figure 29-6 shows how a 12-bit word (EC9h) needs to be written to the transmit buffer in order to be transmitted correctly.

Figure 29-6. Format for Transmitting 12-Bit Word

D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
x	x	x	x	1	1	1	0	1	1	0	0	1	0	0	1

The data received in SPIBUF is right-justified irrespective of the character length and is padded with 0s when character length is less than 16.

Figure 29-7 shows how a 10-bit word (3A2h) is stored in the buffer once it is received.

Figure 29-7. Format for 10-Bit Received Word

D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
0	0	0	0	0	0	1	1	1	0	1	0	0	0	1	0

29.2.11.2 Shift Direction

The shift out direction is configured as most-significant bit (MSB) first or least significant bit (LSB) first. The shift out direction is selected by the SPIFMT*n*.SHIFTDIR bit. The shift out direction is independently configured for each of the four data formats.

- When SPIFMT*n*.SHIFTDIR is 0, the transmit data is shifted out MSB first.
- When SPIFMT*n*.SHIFTDIR is 1, the transmit data is shifted out LSB first.

29.2.11.3 Clock Phase and Polarity

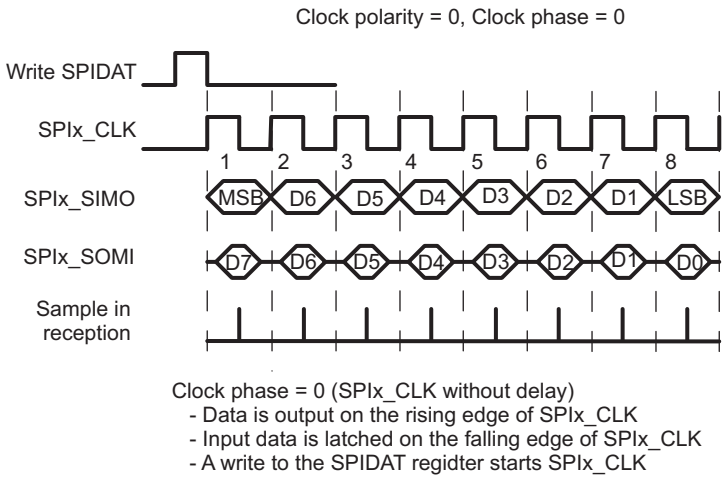
The SPI provides the flexibility to program four different clock mode combinations that SPIx_CLK may operate, enabling a choice of the clock phase (delay or no delay) and the clock polarity (rising edge or falling edge). When operating with PHASE active, the SPI makes the first bit of data available after SPIDAT1 is written and before the first edge of SPIx_CLK. The data input and output edges depend on the values of both the POLARITY and PHASE bits as shown in Table 29-7.

Table 29-7. Clocking Modes

POLARITY	PHASE	Action
0	0	Data is output on the rising edge of SPIx_CLK. Input data is latched on the falling edge.
0	1	Data is output one half-cycle before the first rising edge of SPIx_CLK and on subsequent falling edges. Input data is latched on the rising edge of SPIx_CLK.
1	0	Data is output on the falling edge of SPIx_CLK. Input data is latched on the rising edge.
1	1	Data is output one half-cycle before the first falling edge of SPIx_CLK and on subsequent rising edges. Input data is latched on the falling edge of SPIx_CLK.

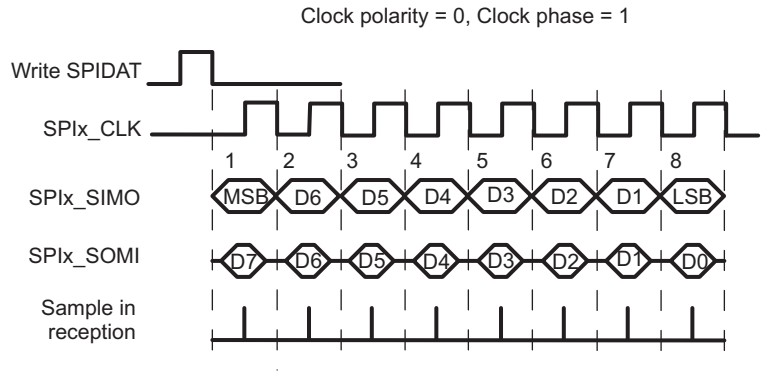
Figure 29-8 to Figure 29-11 illustrate the four possible signals of SPIx_CLK corresponding to each mode. Having four signal options allows the SPI to interface with different types of serial devices. Also shown are the SPIx_CLK control bit polarity and phase values corresponding to each signal.

Figure 29-8. Clock Mode with POLARITY = 0 and PHASE = 0



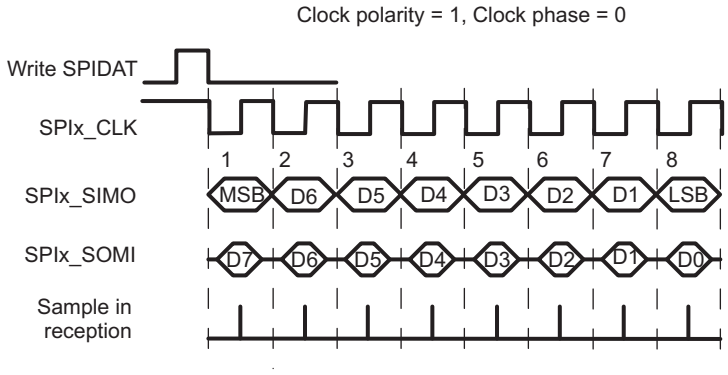
Clock phase = 0 (SPIx_CLK without delay)
- Data is output on the rising edge of SPIx_CLK
- Input data is latched on the falling edge of SPIx_CLK
- A write to the SPIDAT regidter starts SPIx_CLK

Figure 29-9. Clock Mode with POLARITY = 0 and PHASE = 1



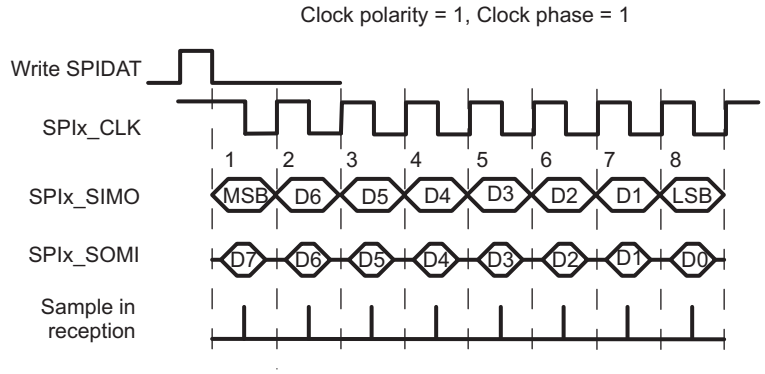
Clock phase = 1 (SPIx_CLK with delay)
- Data is output one-half cycle before the first rising of SPIx_CLK and on subsequent falling edges of SPIx_CLK
- Input data is latched on the rising edge of SPIx_CLK

Figure 29-10. Clock Mode with POLARITY = 1 and PHASE = 0



Clock phase = 0 (SPIx_CLK without delay)
- Data is output on the falling edge of SPIx_CLK
- Input data is latched on the rising edge of SPIx_CLK
- A write to the SPIDAT register starts SPIx_CLK

Figure 29-11. Clock Mode with POLARITY = 1 and PHASE = 1

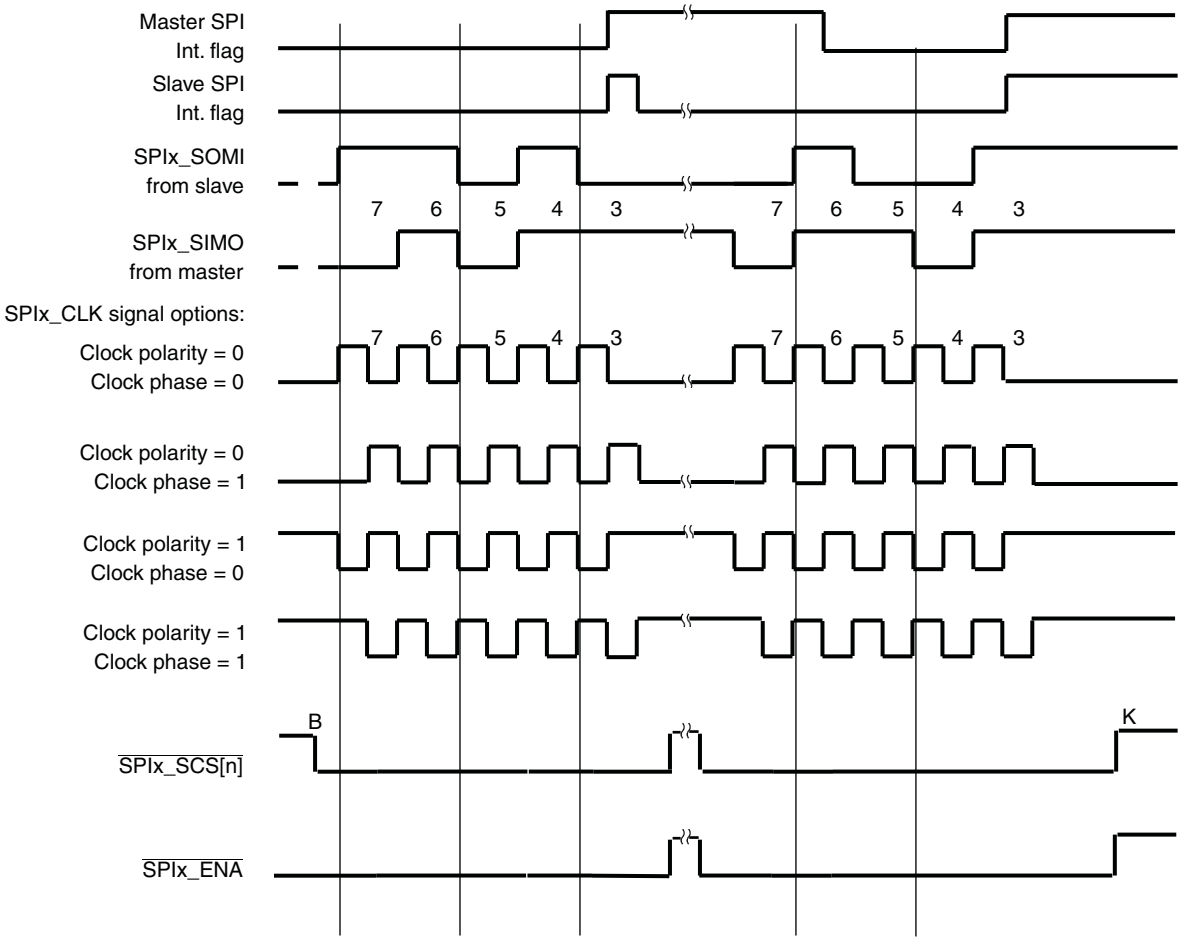


Clock phase = 1 (SPIx_CLK with delay)
- Data is output one-half cycle before the first falling edge of SPIx_CLK and on the subsequent rising edges of SPIx_CLK
- Input data is latched on the falling edge of SPIx_CLK

29.2.11.4 SPI Data Transfer Example

Figure 29-12 illustrates an SPI data transfer between two devices using a character length of five bits.

Figure 29-12. Five Bits per Character (5-Pin Option)



29.2.12 Interrupt Support

The SPI interrupt system is controlled by three registers:

- The SPI interrupt level register (SPILVL) controls the interrrupt level. The interrupt level must be set to select the level one interrupt (INT1).
- The SPI interrupt register (SPIINT) contains bits to selectively enable/disable each interrupt event.
- The SPI flag register (SPIFLG) contains flags indicating the interrupt conditions that have occurred.

To identify the interrupt source in the SPI peripheral, the CPU reads the SPI flag status register (SPIFLG) or the INTVECT1 code in the SPI interrupt vector register 1 (INTVEC1).

Check your device-specific data manual for details on the exact CPU interrupt numbers assigned to the SPI interrupts.

29.2.13 DMA Events Support

If handling the SPI message traffic on a character-by-character basis requires too much CPU overhead, then the CPU can configure the system DMA to handle the SPI data transfer.

The SPI module has two DMA synchronization event outputs for receive (REVT) and transmit (XEVT), allowing DMA transfers to be triggered by SPI read receive and write transmit events. The SPI module enables DMA requests by enabling the DMA request enable (DMAREQEN) bit in the SPI interrupt register (SPIINT0).

When a character is to be transmitted the SPI module signals the DMA via the XEVT signal. The DMA controller then transfers the data from the source buffer into the SPI transmit data register (SPIDAT1). When a character is received, the SPI module signals the DMA via the REVT signal. The DMA controller then reads the data from the SPI receive buffer register (SPIBUF) and transfers it to a destination buffer for ready access.

In most cases, if the DMA is being used to service received data from the SPI, the receive interrupt enable (RXINTEN) bit in SPIINT0 should be cleared to 0. This prevents the CPU from responding to the received data in addition to the DMA. For specific SPI synchronization event number assignments and detailed DMA features, see your device-specific data manual.

29.2.14 Robustness Features

The SPI module includes many features to make the SPI communication link robust. A internal loopback test mode can be used to facilitate a power on self test routine. Additionally, the SPI master continually monitors the bus for faults on its data line. The handshaking between master and slave can be monitored as well, and appropriate actions can be taken (interrupt, timeout) when the handshake breaks down. The following sections describe these robustness features in more detail.

29.2.14.1 SPI Internal Loopback Test Mode (Master Only)

CAUTION

The internal loop-back self-test mode should not be entered during a normal data transaction or unpredictable operation may occur.

To select the loopback mode, the SPIx_CLK, SPIx_SOMI, SPIx_SIMO pins should be configured as functional pins by configuring the SPI pin control register 0 (SPIPC0) and by setting the LOOPBACK bit in the SPI global control register 1 (SPIGCR1). The $\overline{\text{SPIx\_ENA}}$ and $\overline{\text{SPIx\_SCS[n]}}$ pins can be used as general-purpose I/O pins by configuring the SPIPC1 through SPIPC5 registers. The internal loop-back self-test mode can be utilized to test the SPI transmit path and receive path including the transmit and receive buffers. In this mode, the transmit signal is internally fed back to the receiver and the SPIx_SIMO, SPIx_SOMI, and SPIx_CLK pins are in a high-impedance state. This mode allows the CPU to write into the transmit buffer, and check that the receive buffer contains the correct transmit data. If an error occurs the corresponding error is set within the status field.

29.2.14.2 SPI Transmission Continuous Self-Test

During a data transfer, the SPI inputs the value from its data output pin on the appropriate SPIx_CLK edge. This value is compared against the expected value and any difference indicates a fault on the SPI bus. If a fault is detected, then the BITERR bit in the SPI receive buffer register (SPIBUF) and the BITERRFLG bit in the SPI flag register (SPIFLG) are set and an error interrupt is generated if enabled. The SPI continuous self-test mode is not available in SPI loopback mode.

29.2.14.3 SPI Detection of Slave Desynchronization

In the 4-pin with enable and 5-pin modes, the SPI master can monitor the slave $\overline{\text{SPIx\_ENA}}$ activity to detect a desynchronization event.

Some conditions that may cause a desynchronization event are:

- Master or slave device being reset during a transmission.
- Asserting a software reset of the SPI module during transmission.
- Having an incorrect SPI pin configuration, causing the $\overline{\text{SPIx\_ENA}}$ pin to behave incorrectly.
- Signal integrity problem causing additional clocks to be recognized by the slave.

The master can detect two desynchronization error conditions on the $\overline{\text{SPIx\_ENA}}$ pin:

1. Slave deasserts $\overline{\text{SPIx\_ENA}}$ after a transmission has begun, but before it completes.
2. Slave fails to deassert $\overline{\text{SPIx\_ENA}}$ within a certain time period after the completion of the last bit of the transmission.

The first error condition is straightforward to detect. To detect the second error condition, the SPI module includes an eight-bit counter with a timeout count that can be configured through the T2EDELAY field in the SPI delay register (SPIDELAY).

When a desynchronization event is detected, the DESYNC bit in the SPI receive buffer register (SPIBUF) and the DESYNCFLG bit in the SPI flag register (SPIFLG) are set and a desynchronization error interrupt is asserted if enabled.

NOTE: Remember that even though the desynchronization is detected by the master device, the problem causing the desynchronization event can be on either the master or the slave device.

The T2EDELAY period begins once the T2CDELAY period terminates or after the data shifting period in case the T2CDELAY is disabled. It defines the maximum time for the slave to deassert the $\overline{\text{SPIx\_ENA}}$ signal. If the slave device does not deassert the $\overline{\text{SPIx\_ENA}}$ signal before the T2EDELAY timeout value expires, the SPIFLG.DESYNC flag is set and a desynchronization interrupt is asserted if enabled. The T2E delay period does not always complete, sometimes it is skipped or terminated early. The T2E delay period terminates immediately after the $\overline{\text{SPIx\_ENA}}$ input is sampled (using the SPI module clock at intervals of SPIFMT*n*.PRESCALE + 2) as deasserted. However, assuming the T2E period completes its duration is specified by:

Maximum duration of T2EDELAY period = SPIDELAY.T2EDELAY + SPIFMTn.PRESCALE + 2 (SPI module clock cycles)

The T2EDELAY period is enabled only when the $\overline{\text{SPIx\_ENA}}$ is asserted at the beginning of the T2E delay period, the SPIDELAY.T2EDELAY field has a non-zero value, and SPIFMT*n*.WAITENA bit is set to 1.

29.2.14.4 $\overline{\text{SPIx\_ENA}}$ Signal Time-Out

In 5-pin mode, in addition to the slave desynchronization detection, the master can also detect whether the slave fails to respond to the $\overline{\text{SPIx\_SCS[n]}}$ signal by asserting $\overline{\text{SPIx\_ENA}}$ in a timely manner.

This condition could be the result of a serious error, or it could simply be the result of the slave device taking too long to service its SPI.

To detect this condition, the C2EDELAY field in the SPI delay register (SPIDELAY) is used. The C2EDELAY period begins once the C2TDELAY period terminates or when the master asserts $\overline{\text{SPIx\_SCS[n]}}$ (if C2TDELAY is disabled). It defines the maximum time for the addressed slave to respond by activating the $\overline{\text{SPIx\_ENA}}$ signal. If the slave does not respond with the $\overline{\text{SPIx\_ENA}}$ signal before the timeout value expires, then the TIMEOUT bit in the SPI receive buffer register (SPIBUF) and the TIMEOUTFLG bit in the SPI flag register (SPIFLG) are set, an interrupt is asserted if enabled, and the current transfer is terminated. The C2E delay period does not always complete, sometimes it is skipped or terminated early. The C2E delay period terminates immediately after the $\overline{\text{SPIx\_ENA}}$ input is sampled (using the SPI module clock at intervals of SPIFMT*n*.PRESCALE + 2) as asserted. However, assuming the C2E period completes its duration is specified by:

Maximum duration of C2EDELAY period = SPIDELAY.C2EDELAY + SPIFMTn.PRESCALE + 2 (SPI module clock cycles)

The C2EDELAY period is enabled only when the $\overline{\text{SPIx\_ENA}}$ is deasserted at the beginning of the C2E delay period and SPIFMT*n*.WAITENA bit is set to 1. If SPIFMT*n*.WAITENA bit is set to 1 and C2EDELAY is cleared to 0, then the master waits indefinitely for the slave to assert $\overline{\text{SPIx\_ENA}}$.

29.2.14.5 SPI Data Length Error

An SPI can generate an error flag by detecting any mismatch in length of received/transmitted data with the programmed character length under certain conditions.

Master Mode: During a data transfer, if the SPI detects a deassertion of the $\overline{\text{SPIx\_ENA}}$ pin (by the slave) while the character counter is not overflowed, then an error flag is set indicating the data length error. This can be caused by a slave receiving extra clocks (because of noise on the SPIx_CLK line).

NOTE: In SPI master mode, the data length error will be generated only if the $\overline{\text{SPIx\_ENA}}$ pin is used as a functional pin.

Slave Mode: During a transfer, if the SPI detects a deassertion of the $\overline{\text{SPIx\_SCS[n]}}$ pin before its character length counter overflows, then an error flag is set indicating the data length error. If the slave SPI misses one or more SPIx_CLK pulses from the master, this situation can occur. This error in slave mode would mean that both the transmitted and received data were not complete.

NOTE: In SPI slave mode, the data length error flag will be generated only if the $\overline{\text{SPIx\_SCS[n]}}$ pin is configured as a functional pin.

29.2.15 Reset Considerations

This section describes the software and hardware reset considerations.

29.2.15.1 Software Reset Considerations

The SPI module contains a software reset (RESET) bit in the SPI global control register 0 (SPIGCR0) that is used to reset the SPI module. As a result of a reset, the SPI module register values go to their reset state. The RESET bit must be set before any operation on the SPI is done.

29.2.15.2 Hardware Reset Considerations

In the event of a hardware reset, the SPI module register values go to their reset state and the application software needs to reprogram the registers to the desired values.

29.2.16 Power Management

The SPI module can be put in either local or global low-power mode. Global low-power mode is asserted by the system and is not controlled by the SPI. During global low-power mode, all clocks to the SPI are turned off so the module is completely inactive.

The SPI local low-power mode is asserted by setting the POWERDOWN bit in the SPI global control register 1 (SPIGCR1). Setting this bit stops the clocks to the SPI internal logic and the SPI registers. Setting the POWERDOWN bit causes the SPI to enter local low-power mode and clearing the POWERDOWN bit causes SPI to exit from local low-power mode. All the registers are accessible during local power-down mode as any register access enables the clock to SPI for that particular access alone.

Since entering a low-power mode has the effect of suspending all state machine activities, care must be taken when entering such modes to ensure that a valid state is entered when low-power mode is active. As a result, application software must ensure that a low-power mode is not entered during a transmission or reception of data.

29.2.17 General-Purpose I/O Pin

Each of the SPI pins may be programmed via the SPI pin control registers (SPIPC0 to SPIPC5) to be a general-purpose I/O (GPIO) pin.

When the SPI pins are not used as functional pins, they may be programmed to be either general input or general output pins by configuring SPIPC0. For example, in 3-pin mode, SPIx_SOMI, SPIx_SIMO, and SPIx_CLK must be configured as SPI pins, while the $\overline{\text{SPIx\_SCS[n]}}$ and $\overline{\text{SPIx\_ENA}}$ pins should be configured as GPIO pins. The direction is controlled by configuring SPIPC1.

If configured as a general-purpose output, then SPIPC3 controls the output value. There is also a write 1 to set (SPIPC4) and a write 1 to clear (SPIPC5) for the data out value. These registers allow different tasks running on the CPU to manipulate the SPI I/O pins without read-modify-write hazards.

SPIPC2 reflects the current value on the pin when the particular pin is configured as a functional or general-purpose input pin. When the pin is configured as a functional or general-purpose output pin, SPIPC2 indicates the value that is attempted to be driven on the pin.

29.2.18 Emulation Considerations

CAUTION

Viewing or otherwise reading the following SPI registers: SPIBUF, SPIFLG, and INTVEC1 through the JTAG debugger causes their contents to change, possibly invalidating the results of the debug session. Be sure to set up the debugger to avoid reading these registers.

The SPI module does not support soft or hard stop during emulation breakpoints. The SPI module will continue to run if an emulation breakpoint is encountered.

In addition, any status registers that are cleared after reading will be affected if viewed in a memory or watch window of the debugger; since the emulator will read these registers to update the value displayed in the window.

29.2.19 Initialization

Perform the following procedure for initializing the SPI:

1. Reset the SPI by clearing the RESET bit in the SPI global control register 0 (SPIGCR0) to 0.
2. Take the SPI out of reset by setting SPIGCR0.RESET to 1.
3. Configure the SPI for master or slave mode by configuring the CLKMOD and MASTER bits in the SPI global control register 1 (SPIGCR1).
4. Configure the SPI for 3-pin, 4-pin with chip select, 4-pin with enable, or 5-pin mode by configuring the SPI pin control register 0 (SPIPC0).
5. Chose the SPI data format register *n* (SPIFMT*n*) to be used by configuring the DFSEL bit in the SPI transmit data register (SPIDAT1). In slave mode, only SPIFMT0 is supported.
6. Configure the SPI data rate, character length, shift direction, phase, polarity and other format options using SPIFMT*n* selected in step 5.
7. If SPI master, then configure the master delay options using the SPI delay register (SPIDELAY). In slave mode, SPIDELAY is not relevant.
8. Select the error interrupt notifications by configuring the SPI interrupt register (SPIINT0) and the SPI interrupt level register (SPILVL).
9. Enable the SPI communication by setting the SPIGCR1.ENABLE to 1.
10. Setup and enable the DMA for SPI data handling and then enable the DMA servicing for the SPI data requests by setting the SPIINT0.DMAREQEN to 1.
11. Handle SPI data transfer requests using DMA and service any SPI error conditions using the interrupt service routine.

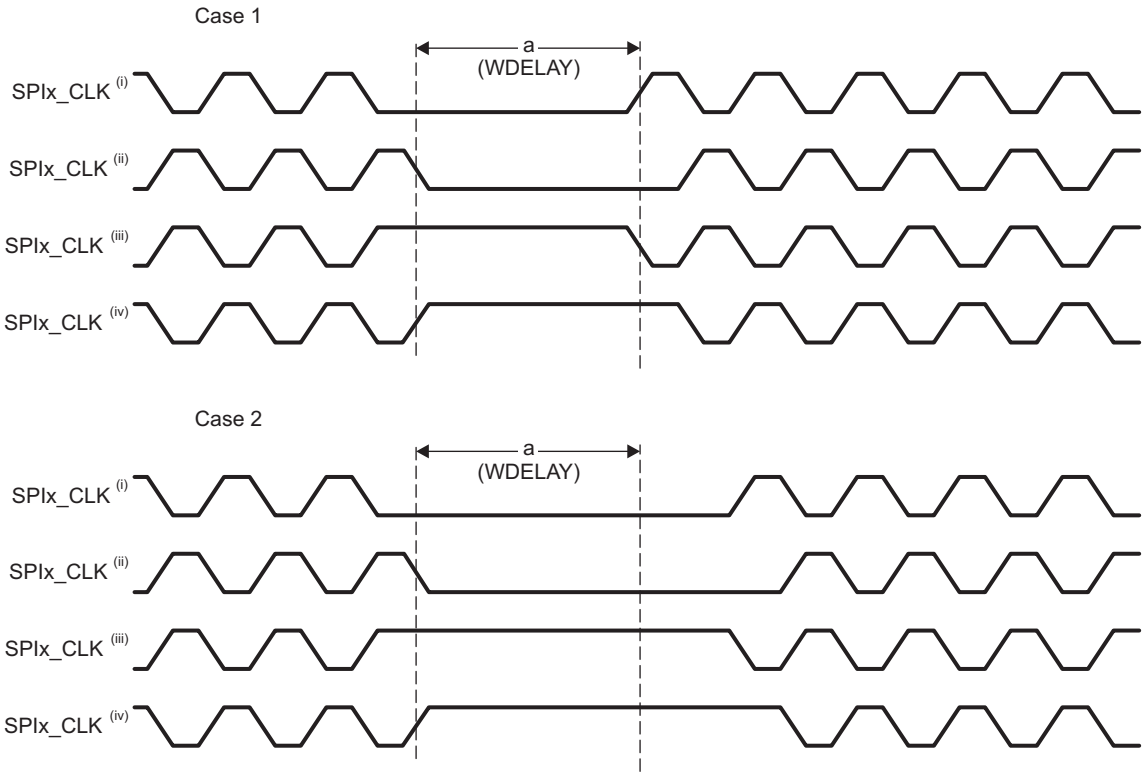
29.2.20 Timing Diagrams

This section contains timing diagrams illustrating the C2TDELAY, C2EDELAY, T2CDELAY, T2EDELAY, and WDELAY delays and their interaction with the SPIx_SCS[n] and SPIx_ENA pins for all SPI modes.

29.2.20.1 SPI 3-Pin Mode

Figure 29-13 illustrates the WDELAY option in SPI 3-pin master mode. This is the only delay available in this mode. In CASE1, a new transfer is initiated during the WDELAY period and the transfer begins immediately after the WDELAY period ends. In CASE2, while WDELAY has completed, a new transfer will not begin until SPIDAT0/SPIDAT1 have been written with new data.

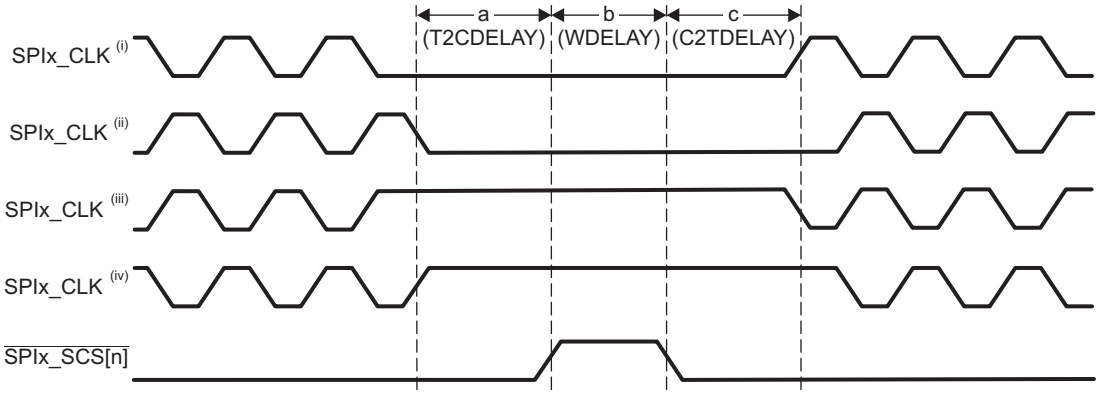
Figure 29-13. SPI 3-Pin Master Mode with WDELAY



29.2.20.2 SPI 4-Pin with $\overline{\text{SPIx\_SCS[n]}}$ Mode

Figure 29-14 illustrates the T2CDELAY, WDELAY and C2TDELAY delays in SPI 4-pin with $\overline{\text{SPIx\_SCS[n]}}$ master mode. C2EDELAY and T2EDELAY are not available in this mode. All the three delay periods T2CDELAY, WDELAY, and C2TDELAY proceed to completion when enabled.

Figure 29-14. SPI 4-Pin with $\overline{\text{SPIx\_SCS[n]}}$ Mode with T2CDELAY, WDELAY, and C2TDELAY



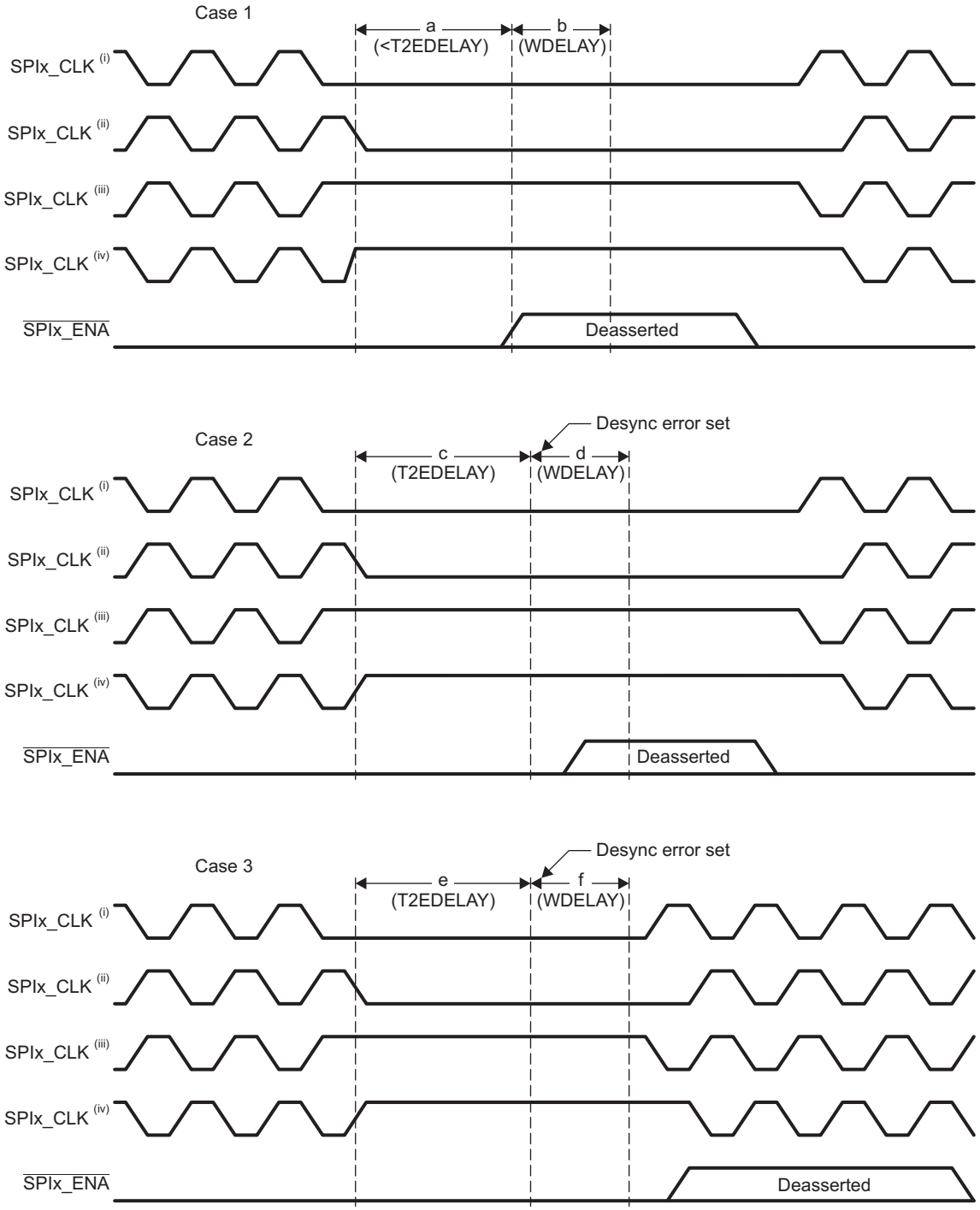
29.2.20.3 SPI 4-Pin with $\overline{\text{SPIx\_ENA}}$ Mode

Figure 29-15 shows the T2EDELAY and WDELAY delays in SPI 4-pin with $\overline{\text{SPIx\_ENA}}$ master mode. T2CDELAY, C2TDELAY, and C2EDELAY are not available in this mode.

- In CASE1, the $\overline{\text{SPIx\_ENA}}$ is deasserted during the T2EDELAY period. Consequently the T2EDELAY period is terminated early (a) and the WDELAY period begins immediately (b) if enabled. The next transfer is initiated as soon as the slave asserts $\overline{\text{SPIx\_ENA}}$ again.
- In CASE2, the T2EDELAY period (c) completes before the $\overline{\text{SPIx\_ENA}}$ is deasserted. As a result the DESYNC error is set. However since the $\overline{\text{SPIx\_ENA}}$ is deasserted during the WDELAY period (d), the master delays the next transfer until the $\overline{\text{SPIx\_ENA}}$ is asserted again.
- In CASE3, the T2EDELAY (e) and WDELAY (f) period (if enabled) both expire before the $\overline{\text{SPIx\_ENA}}$ input is deasserted. The DESYNC error is set at the end of the T2EDELAY period (e). However in this case the master begins the next transfer immediately after it is initiated and ignores the $\overline{\text{SPIx\_ENA}}$ during the transfer even if it is subsequently deasserted.

  If the T2EDELAY delay period is disabled then the DESYNC error is not set. The SPI master behavior in this case depends on whether the $\overline{\text{SPIx\_ENA}}$ gets deasserted during the WDELAY period (CASE2) or $\overline{\text{SPIx\_ENA}}$ gets deasserted after the WDELAY period completes (CASE3).

Figure 29-15. SPI 4-Pin with $\overline{\text{SPIx\_ENA}}$ Mode Demonstrating T2EDELAY and WDELAY



29.2.20.4 SPI 5-Pin Mode

Figure 29-16 shows the T2CDELAY, T2EDELAY, and WDELAY delays in SPI 5-pin master mode.

- In CASE1, the SPIx_ENA is deasserted during the T2CDELAY period. However the T2CDELAY period proceeds to completion(a), the T2EDELAY period is skipped (if enabled) and the WDELAY period begins immediately (b) (if enabled). The next transfer is initiated as soon as the slave asserts SPIx_ENA again.
- In CASE2, the SPIx_ENA signal is deasserted by the slave during the T2EDELAY period (d) which begins upon the completion of the T2CDELAY period (c). The deassertion of the SPIx_ENA causes the T2EDELAY period to terminate early and the WDELAY period (e) begins immediately (if enabled) after the T2EDELAY period terminates. The next transfer is initiated as soon as the slave asserts SPIx_ENA again.
- In CASE3, the SPIx_ENA signal is deasserted by the slave during the WDELAY period (h) which begins upon the completion of the T2CDELAY period (f) and T2EDELAY period (g). As a result the DESYNC error is set at the end of the T2EDELAY period (g). However since the SPIx_ENA is deasserted during the WDELAY period (h), the master delays the next transfer until the SPIx_ENA is asserted again.
- In CASE4, the SPIx_ENA signal is not deasserted until after the completion of the T2CDELAY (j), T2EDELAY (k) and WDELAY (m) (if enabled) periods. The DESYNC error is set at the end of the T2EDELAY period (k). However in this case the master begins the next transfer immediately after it is initiated and ignores the SPIx_ENA during the transfer even if it is subsequently deasserted.

  If the T2EDELAY delay period is disabled then the DESYNC error is not set. The SPI master behavior in this case depends on whether the SPIx_ENA gets deasserted during the T2CDELAY period (CASE1), WDELAY period (CASE3) or after the WDELAY period completes (CASE4).

  If the slave deasserts the SPIx_ENA signal before the completion of the configured master delays (T2CDELAY, T2EDELAY, WDELAY) then the master delays the next transfer until the slave asserts the SPIx_ENA again. However if the slave delays the SPIx_ENA deassertion until after the completion of the configured master delays then the master begins the next transfer immediately after it is initiated and ignores the SPIx_ENA during the transfer even if it is subsequently deasserted.

Figure 29-17 shows the C2TDELAY and C2EDELAY in SPI 5-pin master mode.

- In CASE1, the SPIx_ENA signal is asserted during the C2TDELAY period (a). However the C2TDELAY period proceeds to completion(a), the C2EDELAY period is skipped (if enabled) and the master begins generating the SPI clock for transmission.
- In CASE2, the SPIx_ENA signal is asserted during the C2EDELAY period (d) which begins upon the completion of C2TDELAY period (c). The assertion of the SPIx_ENA causes the C2EDELAY period to terminate early and the master begins generating the SPI clock for transmission.
- In CASE3, the SPIx_ENA signal is not asserted until after the completion of the C2TDELAY (f) and C2EDELAY (g) periods. The TIMEOUT error is set at the end of the C2EDELAY period (g). The master deasserts the SPIx_SCS[n] signal immediately and clears the current transmit request.

  If the C2EDELAY delay period is disabled then the SPI master behavior depends on whether the SPIx_ENA gets asserted during the C2TDELAY period (CASE1) or after the C2TDELAY period completes (CASE2). In latter case there is no limit on how long the master will wait for the slave to respond with SPIx_ENA asserted and hence there is no limit on period 'd' shown in CASE2. Thus when C2EDELAY period is disabled the TIMEOUT error is not set.

Figure 29-16. SPI 5-Pin Mode Demonstrating T2CDELAY, T2EDELAY, and WDELAY

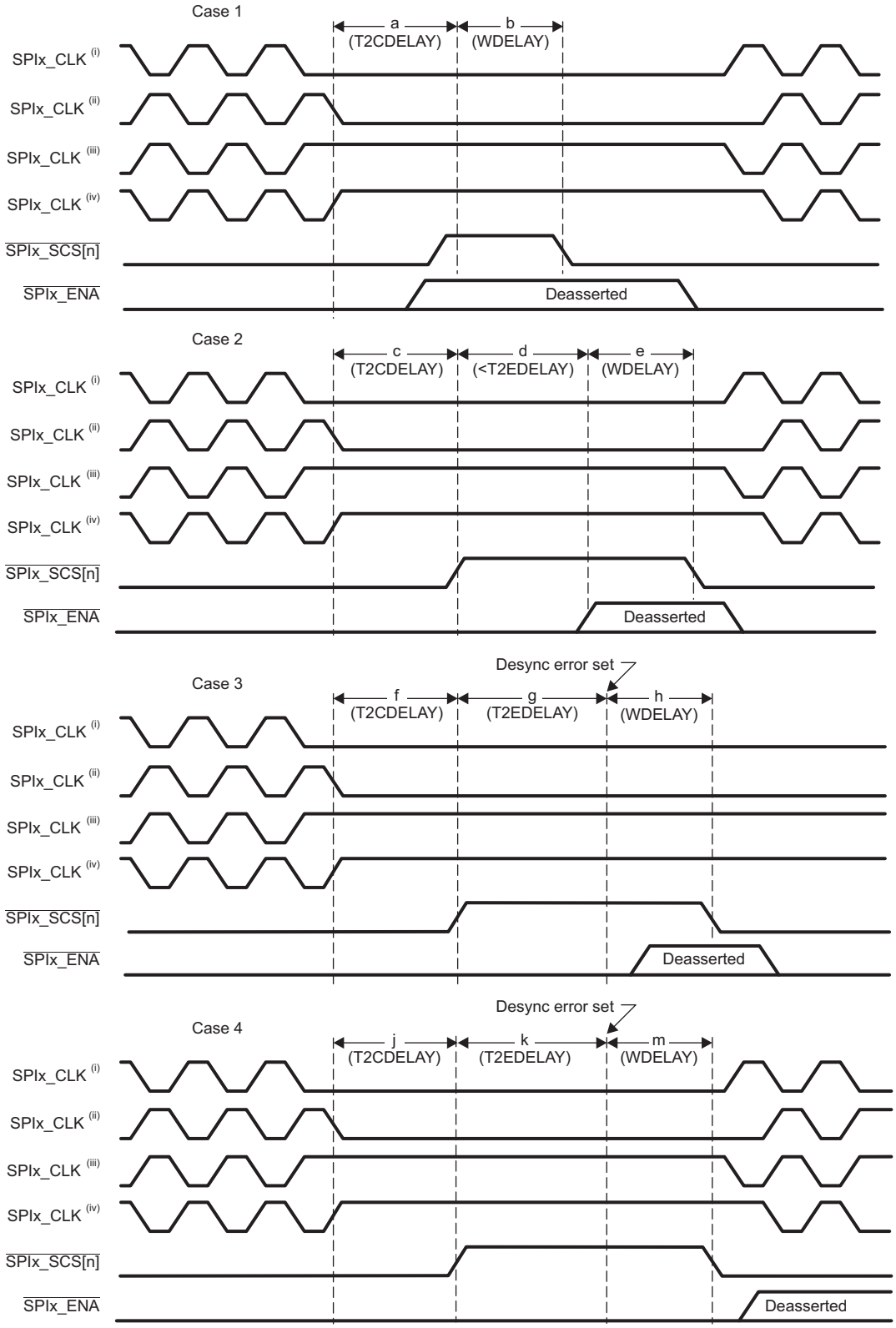
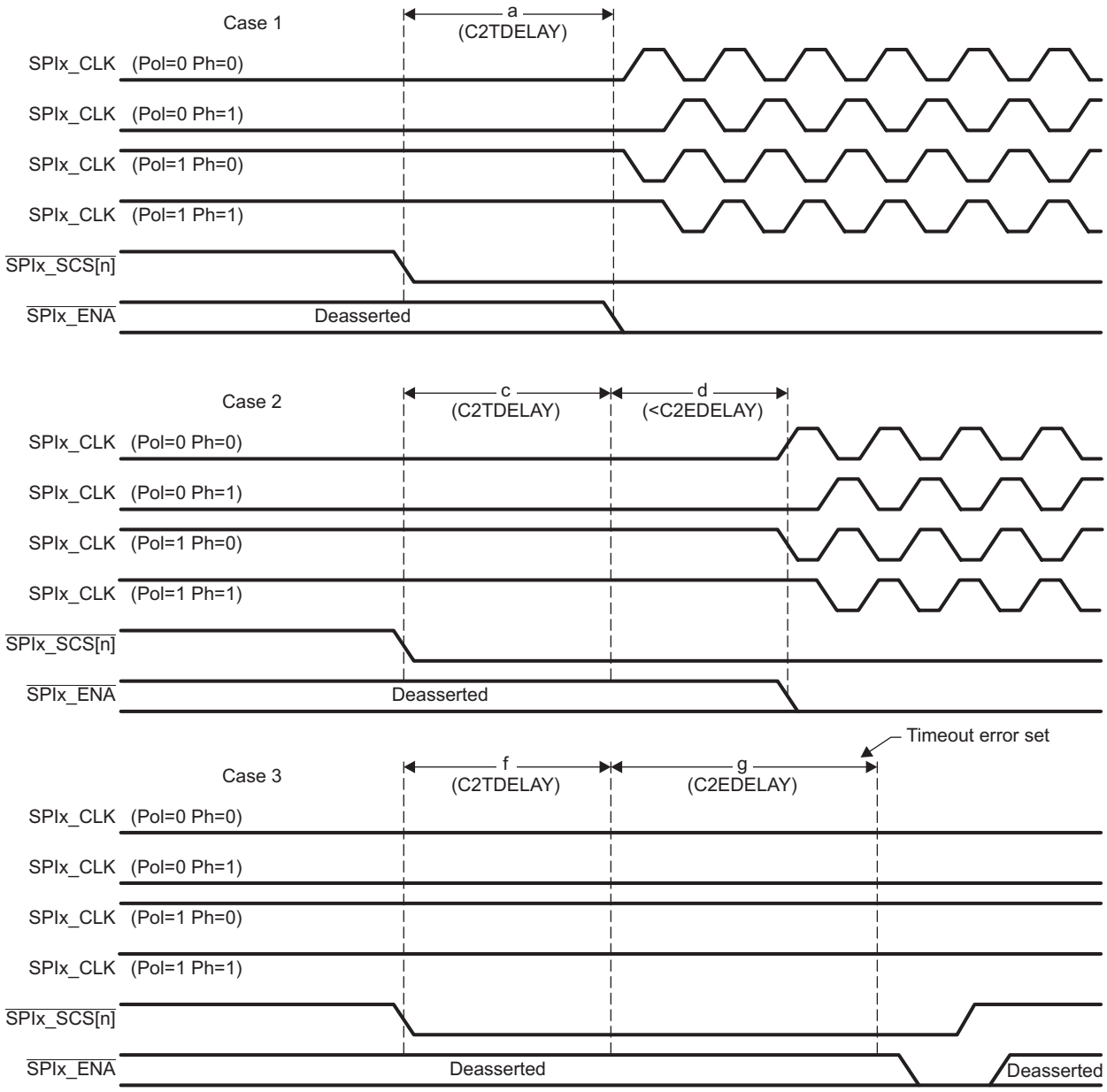


Figure 29-17. SPI 5-Pin Mode Demonstrating C2TDELAY and C2EDELAY



29.3 Registers

This section describes the SPI control, data, and pin registers. The offset is relative to the associated base address of the module. See your device-specific data manual for the memory address of these registers.

Table 29-8. SPI Registers

Offset Address	Acronym	Register Description	Section
0h	SPIGCR0	SPI Global Control Register 0	Section 29.3.1
4h	SPIGCR1	SPI Global Control Register 1	Section 29.3.2
8h	SPIINT0	SPI Interrupt Register	Section 29.3.3
Ch	SPILVL	SPI Interrupt Level Register	Section 29.3.4
10h	SPIFLG	SPI Flag Register	Section 29.3.5
14h	SPIPC0	SPI Pin Control Register 0 (Function)	Section 29.3.6
18h	SPIPC1	SPI Pin Control Register 1 (Direction)	Section 29.3.7
1Ch	SPIPC2	SPI Pin Control Register 2 (Input)	Section 29.3.8
20h	SPIPC3	SPI Pin Control Register 3 (Output)	Section 29.3.9
24h	SPIPC4	SPI Pin Control Register 4 (Set SPIPC3)	Section 29.3.10
28h	SPIPC5	SPI Pin Control Register 5 (Clear SPIPC3)	Section 29.3.11
38h	SPIDAT0	SPI Data Transmit Register 0	Section 29.3.12
3Ch	SPIDAT1	SPI Data Transmit Register 1 (Data Transmit and Format Select)	Section 29.3.13
40h	SPIBUF	SPI Receive Buffer Register	Section 29.3.14
44h	SPIEMU	SPI Receive Emulation Register	Section 29.3.15
48h	SPIDELAY	SPI Delay Register	Section 29.3.16
4Ch	SPIDEF	SPI Default Chip Select Register	Section 29.3.17
50h	SPIFMT0	SPI Data Format Register 0	Section 29.3.18
54h	SPIFMT1	SPI Data Format Register 1	Section 29.3.18
58h	SPIFMT2	SPI Data Format Register 2	Section 29.3.18
5Ch	SPIFMT3	SPI Data Format Register 3	Section 29.3.18
64h	INTVEC1	SPI Interrupt Vector Register 1	Section 29.3.19

29.3.1 SPI Global Control Register 0 (SPIGCR0)

The SPI global control register 0 (SPIGCR0) is shown in Figure 29-18 and described in Table 29-9.

Figure 29-18. SPI Global Control Register 0 (SPIGCR0)

31	16
Reserved	
R-0	

15	1	0
Reserved		RESET
R-0		R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 29-9. SPI Global Control Register 0 (SPIGCR0) Field Descriptions

Bit	Field	Value	Description
31-1	Reserved	0	Reads return zero and writes have no effect.
0	RESET		Reset bit for the module. This bit needs to be set to 1 before any operation on SPI can be done.
		0	SPI is in reset state.
		1	SPI is out of reset state.

29.3.2 SPI Global Control Register 1 (SPIGCR1)

The SPI global control register 1 (SPIGCR1) is shown in Figure 29-19 and described in Table 29-10.

Figure 29-19. SPI Global Control Register 1 (SPIGCR1)

31	25	24
Reserved		ENABLE
R-0		R/W-0
23	**17**	**16**
Reserved		LOOPBACK
R-0		R/W-0
15	**9**	**8**
Reserved		POWERDOWN
R-0		R/W-0

7	2	1	0
Reserved		CLKMOD	MASTER
R-0		R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 29-10. SPI Global Control Register 1 (SPIGCR1) Field Descriptions

Bit	Field	Value	Description
31-25	Reserved	0	Reads return zero and writes have no effect.
24	ENABLE		SPI enable. This bit enables the SPI transfers. The other SPI configuration registers except SPIINT0.DMAREQEN should be configured before writing a 1 to this bit. This will prevent the SPI from responding to bus operations erroneously while it is in the process of being configured. The SPIINT0.DMAREQEN should be enabled after setting ENABLE. If SPIINT0.DMAREQEN is enabled before setting ENABLE then the first DMA request that occurs before the SPI is ready for data transfer may get dropped. When ENABLE bit is cleared to 0, the following SPI registers get forced to their default states (to 0s except for RXEMPTY bit in SPIBUF): • Both TX and RX shift registers • The TXDATA fields of SPIDAT0 and SPIDAT1 registers • All the fields of the SPIFLG register • Contents of SPIBUF and the internal RXBUF registers
		0	SPI is not activated for transfers.
		1	Activates SPI.
23-17	Reserved	0	Reads return zero and writes have no effect.
16	LOOPBACK		Internal loop-back test mode. The internal self-test option can be enabled by setting this bit. If the SPIx_SIMO and SPIx_SOMI pins are configured with SPI functionality, then the SPIx_SIMO pin is internally connected to the SPIx_SOMI pin. The transmit data is looped back as receive data and is stored in the receive field of the concerned buffer. Externally, during loop-back operation, the SPIx_CLK pin outputs an inactive value, SPIx_SIMO and SPIx_SOMI pins remain in high-impedance state. The SPI has to be initialized in master mode before the loop-back can be selected. If the SPI is initialized in slave mode or a data transfer is ongoing, errors may result.
		0	Internal loop-back test mode disabled.
		1	Internal loop-back test mode enabled.
15-9	Reserved	0	Reads return zero and writes have no effect.
8	POWERDOWN		When active, the SPI state machine enters a power-down state.
		0	The SPI is in active mode.
		1	The SPI is in power-down mode.
7-2	Reserved	0	Reads return zero and writes have no effect.

Table 29-10. SPI Global Control Register 1 (SPIGCR1) Field Descriptions (continued)

Bit	Field	Value	Description
1-0	CLKMOD,MASTER	0-3h	These two bits (CLKMOD,MASTER) determine whether the SPI operates in master or slave mode.
		0	SLAVE MODE. SPIx_CLK is an input from the master who initiates the transfers. Data is transmitted on the SPIx_SOMI pin and received on the SPIx_SIMO pin. The $\overline{\text{SPIx\_SCS[n]}}$ pin is an input pin if configured as SPI slave chip select. The $\overline{\text{SPIx\_ENA}}$ pin is an output pin if configured as the SPI enable pin.
		1h-2h	Reserved
		3h	MASTER MODE. SPIx_CLK is an output and the SPI initiates transfers. Data is transmitted on the SPIx_SIMO pin and received on the SPIx_SOMI pin. The $\overline{\text{SPIx\_SCS[n]}}$ pin is an output pin if configured as SPI slave chip select. The $\overline{\text{SPIx\_ENA}}$ pin is an input pin if configured as the SPI enable pin.

29.3.3 SPI Interrupt Register (SPIINT0)

The SPI interrupt register (SPIINT0) is shown in Figure 29-20 and described in Table 29-11.

Figure 29-20. SPI Interrupt Register (SPIINT0)

31	25	24
Reserved		ENABLEHIGHZ
R-0		R/W-0

23	17	16
Reserved		DMAREQEN
R-0		R/W-0

15	10	9	8
Reserved		TXINTENA	RXINTENA
R-0		R/W-0	R/W-0

7	6	5	4	3	2	1	0
Reserved	OVRNINTENA	Reserved	BITERRENA	DESYNCENA	PARERRENA	TIMEOUTENA	DLENERRENA
R-0	R/W-0	R-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 29-11. SPI Interrupt Register (SPIINT0) Field Descriptions

Bit	Field	Value	Description
31-25	Reserved	0	Reads return zero and writes have no effect.
24	ENABLEHIGHZ		$\overline{\text{SPIx\_ENA}}$ pin high-impedance enable. If ENABLEHIGHZ is enabled, the $\overline{\text{SPIx\_ENA}}$ pin (when it is configured as a WAIT functional output signal in a slave SPI) is forced to place it is output in high-impedance when not driving a low signal. If ENABLEHIGHZ is disabled, then the pin will output both a high and a low signal.
		0	$\overline{\text{SPIx\_ENA}}$ pin is pulled high when not active.
		1	$\overline{\text{SPIx\_ENA}}$ pin remains in high-impedance when not active.
23-17	Reserved	0	Reads return zero and writes have no effect.
16	DMAREQEN		DMA request enable. Enables the DMA request signal to be generated for both receive and transmit channels. Set DMAREQEN only after setting the SPIGCR1.ENABLE bit to 1.
		0	DMA is not used.
		1	DMA requests will be generated.
			Note: A transmit DMA request will be generated each time a transmit data is copied to the shift register either from TXBUF or directly from SPIDAT0/SPIDAT1.
			Note: A receive DMA request will be generated each time a received data is copied to SPIBUF register either from RXBUF or directly from the shift register.
15-10	Reserved	0	Reads return zero and writes have no effect.
9	TXINTENA		An interrupt is to be generated every time data is written to the shift register, so that a new data can be written to TXBUF. Setting this bit will generate an interrupt if the SPIFLG.TXINTFLG bit is set to 1.
		0	No interrupt will be generated upon SPIFLG.TXINTFLG being set to 1.
		1	Interrupt will be generated upon SPIFLG.TXINTFLG being set to 1.
8	RXINTENA		Receive interrupt enable. An interrupt is to be generated when the SPIFLG.RXINTFLAG bit is set.
		0	Interrupt will not be generated.
		1	Interrupt will be generated.
7	Reserved	0	Reads return zero and writes have no effect.
6	OVRNINTENA		Overrun interrupt enable. An interrupt is to be generated when the SPIFLG.OVRNINTFLG bit is set. The overrun interrupt is not useful if receive data is serviced with CPU interrupts because the overrun and receive events share a common level interrupt signal.
		0	Overrun interrupt will not be generated.
		1	Overrun interrupt will be generated.
5	Reserved	0	Reads return zero and writes have no effect.

Table 29-11. SPI Interrupt Register (SPIINT0) Field Descriptions (continued)

Bit	Field	Value	Description
4	BITERRENA		Enables interrupt on bit error. An interrupt is to be generated when the SPIFLG.BITERRFLG is set.
		0	No interrupt asserted upon bit error.
		1	Enables an interrupt on a bit error.
3	DESYNCENA		Enables interrupt on desynchronized slave. DESYNCENA is used in master mode only. The desynchronization monitor is active in master mode for the 4-pin with enable and 5-pin options. An interrupt is to be generated when the SPIFLG.DESYNCFLG is set.
		0	No interrupt asserted upon desynchronization error.
		1	Enables an interrupt on desynchronization of the slave.
2	PARERRENA		Enables interrupt on parity error. An interrupt is to be generated when the SPIFLG.PARERRFLG is set.
		0	No interrupt asserted upon parity error.
		1	Enables an interrupt on a parity error.
1	TIMEOUTENA		Enables interrupt on $\overline{\text{SPIx\_ENA}}$ signal time-out. An interrupt is to be generated when SPIFLG.TIMEOUTFLG is set.
		0	No interrupt asserted upon $\overline{\text{SPIx\_ENA}}$ signal time-out.
		1	Enables an interrupt on a time-out of the $\overline{\text{SPIx\_ENA}}$ signal.
0	DLENERRENA		Data length error interrupt enable. A data length error occurs under the following conditions. Master: In a 4-pin with $\overline{\text{SPIx\_ENA}}$ mode or 5-pin mode, if the $\overline{\text{SPIx\_ENA}}$ pin from the slave is deasserted before the master has completed its transfer, the data length error is set. That is, if the character length counter has not overflowed while $\overline{\text{SPIx\_ENA}}$ deassertion is detected, then it means that the slave has neither received full data from the master nor has it transmitted complete data. Slave: In a 4-pin with chip select mode or 5-pin mode, if the incoming valid $\overline{\text{SPIx\_SCS}}$[n] pin is deactivated before the character length counter overflows, then data length error is set.
		0	No interrupt is generated upon data length error.
		1	Enables an interrupt when data length error occurs.

29.3.4 SPI Interrupt Level Register (SPILVL)

The SPI interrupt level register (SPILVL) is shown in Figure 29-21 and described in Table 29-12.

Figure 29-21. SPI Interrupt Level Register (SPILVL)

31	16
Reserved	
R-0	

15	10	9	8
Reserved		TXINTLVL	RXINTLVL
R-0		R/W-0	R/W-0

7	6	5	4	3	2	1	0
Reserved	OVRNINTLVL	Reserved	BITERRLVL	DESYNCLVL	PARERRLVL	TIMEOUTLVL	DLENERRLVL
R-0	R/W-0	R-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 29-12. SPI Interrupt Level Register (SPILVL) Field Descriptions

Bit	Field	Value	Description
31-10	Reserved	0	Reads return zero and writes have no effect.
9	TXINTLVL		Transmit interrupt level.
		0	Reserved
		1	Transmit interrupt is mapped to interrupt line INT1.
8	RXINTLVL		Receive interrupt level.
		0	Reserved
		1	Receive interrupt is mapped to interrupt line INT1.
7	Reserved	0	Reads return zero and writes have no effect.
6	OVRNINTLVL		Receive overrun interrupt level. The overrun interrupt is not useful if receive data is serviced with CPU interrupts because the overrun and receive events share a common level interrupt signal.
		0	Reserved
		1	Receive overrun interrupt is mapped to interrupt line INT1.
5	Reserved	0	Reads return zero and writes have no effect.
4	BITERRLVL		Bit error interrupt level.
		0	Reserved
		1	Bit error interrupt is mapped to interrupt line INT1.
3	DESYNCLVL		Desynchronized slave interrupt level. DESYNCLVL is used in master mode only.
		0	Reserved
		1	An interrupt due to desynchronization of the slave is mapped to interrupt line INT1.
2	PARERRLVL		Parity error interrupt level.
		0	Reserved
		1	A parity error interrupt is mapped to interrupt line INT1.
1	TIMEOUTLVL		$\overline{\text{SPIx\_ENA}}$ signal time-out interrupt level.
		0	Reserved
		1	An interrupt on a time-out of the $\overline{\text{SPIx\_ENA}}$ signal is mapped to interrupt line INT1.
0	DLENERRLVL		Data length error interrupt enable level.
		0	Reserved
		1	An interrupt on data length error is mapped to interrupt line INT1.

29.3.5 SPI Flag Register (SPIFLG)

The SPI flag register (SPIFLG) is shown in Figure 29-22 and described in Table 29-13.

Figure 29-22. SPI Flag Register (SPIFLG)

31	16
Reserved	
R-100h	

15	10	9	8
Reserved		TXINTFLG	RXINTFLG
R-0		R-0	R/WC-0

7	6	5	4	3	2	1	0
Reserved	OVRNINTFLG	Reserved	BITERRFLG	DESYNCFLG	PARERRFLG	TIMEOUTFLG	DLENERRFLG
R-0	R/W1C-0	R-0	R/W1C-0	R/W1C-0	R/W1C-0	R/W1C-0	R/W1C-0

LEGEND: R/W = Read/Write; R = Read only; W1C = Write 1 to clear bit; -*n* = value after reset

Table 29-13. SPI Flag Register (SPIFLG) Field Descriptions

Bit	Field	Value	Description
31-10	Reserved	4000h	Reads return default value and writes have no effect.
9	TXINTFLG		Transmitter empty interrupt flag. Serves as an interrupt flag indicating that the transmit buffer (TXBUF) is empty and a new data can be written to it. This flag is set when a data is copied to the shift register either directly or from the TXBUF register. This bit is cleared by one of following ways: • Writing a new data to either SPIDAT0 or SPIDAT1 • Writing a 0 to SPIGCR1.ENABLE
		0	Transmit buffer is now full. No interrupt pending for transmitter empty.
		1	Transmit buffer is empty. An interrupt is pending to fill the transmitter.
8	RXINTFLG		Receiver full interrupt flag. This flag is set when a word is received and copied into the buffer register (SPIBUF). This bit is cleared under the following ways: • Reading the SPIBUF register. During emulation mode, however, a read to the emulation register (SPIEMU) does not clear this flag bit. • Reading INTVEC1 register when there is a receive buffer full interrupt • Writing a 1 to this bit • Writing a 0 to SPIGCR1.ENABLE • System reset
		0	No new received data pending. Receive buffer is empty.
		1	A newly received data is ready to be read. Receive buffer is full. **Note:** Clearing RXINTFLG bit by writing a 1 before reading the SPIBUF sets the RXEMPTY bit of the SPIBUF register too. This way, one can ignore a received data. However, if the internal RXBUF is already full, the data from RXBUF will be copied to SPIBUF and the RXEMPTY bit will be cleared again. The SPIBUF contents should be read first if this situation needs to be avoided.
7	Reserved	0	Reads return zero and writes have no effect.
6	OVRNINTFLG		Receiver overrun flag. The bit is set when a receive operation completes before the previous character has been read from the receive buffer. The bit indicates that the last received character has been overwritten and therefore lost. This bit is cleared under the following conditions: • Reading INTVEC1 register when there is a receive buffer overrun interrupt • Writing a 1 to this bit
		0	Overrun condition did not occur.
		1	Overrun condition has occurred. **Note:** Reading SPIBUF register does not clear the OVRNINTFLG bit. If an overrun interrupt is detected, then the SPIBUF may need to be read twice to get to the overrun buffer. This is due to the fact that the overrun will always occur to the internal RXBUF. Each read to the SPIBUF will result in RXBUF contents (if it is full) getting copied to SPIBUF. **Note:** A special condition under which OVRNINTFLG flag gets set. If both SPIBUF and RXBUF are already full and while another buffer receive is underway, if any errors like TIMEOUT, BITERR and DLENERR occur, then OVRNINTFLG will be set to indicate that the status flags are getting overwritten by the new transfer. This overrun should be treated like a normal receiver overrun.

Table 29-13. SPI Flag Register (SPIFLG) Field Descriptions (continued)

Bit	Field	Value	Description
5	Reserved	0	Reads return zero and writes have no effect.
4	BITERRFLG		This bit is set when a mismatch of internal transmit data and transmitted data is detected. The SPI samples the signal of the transmit pin (master: SPIx_SIMO, slave: SPIx_SOMI) at the receive point (half clock cycle after transmit point). If the sampled value differs from the transmitted value a bit error is detected and the flag is set. A possible reason for a bit error can be a too high bit rate/capacitive load or another master/slave trying to transmit at the same time. This flag can be cleared by one of the following ways: • Write a 1 to this bit. • Set SPIGCR1.ENABLE bit to 0.
		0	No bit error occurred.
		1	A bit error occurred.
3	DESYNCFLG		Desynchronization of slave device. Desynchronization monitor is active in master mode only. The master monitors the $\overline{\text{SPIx\_ENA}}$ signal coming from the slave device and sets the DESYNCFLG bit if the $\overline{\text{SPIx\_ENA}}$ signal is not deasserted after the last bit is transmitted plus $t_{T2EDELAY}$. Desynchronization can occur if a slave device misses a clock edge coming from the master. This flag can be cleared by one of the following ways: • Write a 1 to this bit. • Set SPIGCR1.ENABLE bit to 0.
		0	No slave desynchronization detected.
		1	Slave is desynchronized
			Note: Inconsistency of DESYNCFLG in SPI. Due to the nature of this error, under some circumstances it is possible for a desynchronized error detected for the previous buffer to be visible in the current buffer. This is due to the fact that receive completion flag/interrupt will be generated when the buffer transfer is completed. But decence will be detected after the buffer transfer is completed. So, if CPU/DMA reads the received data quickly when an receive interrupt is detected, then the status flag may not reflect the correct decence condition.
2	PARERRFLG		Calculated parity differs from received parity bit. If the parity generator is enabled an even or odd parity bit is added at the end of a data word . During reception of the data word the parity generator calculates the reference parity and compares it to the received parity bit. In the event of a mismatch the PARERRFLG flag is set. This flag can be cleared by one of the following ways: • Write a 1 to this bit. • Set SPIGCR1.ENABLE bit to 0.
		0	No parity error detected.
		1	A parity error occurred.
1	TIMEOUTFLG		Time-out due to non-activation of $\overline{\text{SPIx\_ENA}}$ signal. This flag is applicable only for the master mode. The SPI generates a time-out because the slave hasn't responded in time by activating the $\overline{\text{SPIx\_ENA}}$ signal after the chip select signal has been activated. If a time-out condition is detected the corresponding chip select is deactivated immediately and the TIMEOUTFLG flag is set. This flag can be cleared by one of the following ways: • Write a 1 to this bit. • Set SPIGCR1.ENABLE bit to 0.
		0	No $\overline{\text{SPIx\_ENA}}$ signal time-out occurred.
		1	An $\overline{\text{SPIx\_ENA}}$ signal time-out occurred.
0	DLENERRFLG		Data length error flag. This flag can be cleared by one of the following ways: • Write a 1 to this bit. • Set SPIGCR1.ENABLE bit to 0.
		0	No data length error has occurred.
		1	A data length error has occurred.

29.3.6 SPI Pin Control Register 0 (SPIPC0)

The SPI pin control register 0 (SPIPC0) is shown in Figure 29-23 and described in Table 29-14.

Figure 29-23. SPI Pin Control Register 0 (SPIPC0)

31	16
Reserved	
R-0	

15	12	11	10	9	8
Reserved		SOMIFUN	SIMOFUN	CLKFUN	ENAFUN
R-0		R/W-0	R/W-0	R/W-0	R/W-0

7	1	0
Reserved		SCS0FUN
R-0		R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 29-14. SPI Pin Control Register 0 (SPIPC0) Field Descriptions

Bit	Field	Value	Description
31-12	Reserved	0	Reads return zero and writes have no effect.
11	SOMIFUN		Slave out, master in pin function. This bit determines whether the SPIx_SOMI pin is to be used as a general-purpose I/O pin or as a SPI functional pin.
		0	SPIx_SOMI pin is a GPIO pin.
		1	SPIx_SOMI pin is a SPI functional pin.
10	SIMOFUN		Slave in, master out pin function. This bit determines whether the SPIx_SIMO pin is to be used as a general-purpose I/O pin or as a SPI functional pin.
		0	SPIx_SIMO pin is a GPIO pin.
		1	SPIx_SIMO pin is a SPI functional pin.
9	CLKFUN		SPI clock pin function. This bit determines whether the SPIx_CLK pin is to be used as a general-purpose I/O pin, or as a SPI functional pin.
		0	SPIx_CLK pin is a GPIO pin.
		1	SPIx_CLK pin is a SPI functional pin.
8	ENAFUN		SPI enable pin function. This bit determines whether the $\overline{\text{SPIx\_ENA}}$ pin is to be used as a general-purpose I/O pin, or as a SPI functional pin.
		0	$\overline{\text{SPIx\_ENA}}$ pin is a GPIO pin.
		1	$\overline{\text{SPIx\_ENA}}$ pin is a SPI functional pin.
7-1	Reserved	0	Reserved
0	SCS0FUN		SPI chip select pin *n* function. This bit determines whether the $\overline{\text{SPIx\_SCS[0]}}$ pin is to be used as a general-purpose I/O pin, or as a SPI functional pin.
		0	$\overline{\text{SPIx\_SCS[0]}}$ pin is a GPIO pin.
		1	$\overline{\text{SPIx\_SCS[0]}}$ pin is a SPI functional pin.

29.3.7 SPI Pin Control Register 1 (SPIPC1)

The SPI pin control register 1 (SPIPC1) is shown in Figure 29-24 and described in Table 29-15.

Figure 29-24. SPI Pin Control Register 1 (SPIPC1)

31	16
Reserved	
R-0	

15	12	11	10	9	8
Reserved		SOMIDIR	SIMODIR	CLKDIR	ENADIR
R-0		R/W-0	R/W-0	R/W-0	R/W-0

7	1	0
Reserved		SCS0DIR
R-0		R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 29-15. SPI Pin Control Register 1 (SPIPC1) Field Descriptions

Bit	Field	Value	Description
31-12	Reserved	0	Reads return zero and writes have no effect.
11	SOMIDIR		SPIx_SOMI pin direction. Controls the direction of the SPIx_SOMI pin when it is used as a general-purpose I/O pin. If the SPIx_SOMI pin is used as a SPI functional pin, the I/O direction is determined by whether the SPI is configured as master or slave.
		0	SPIx_SOMI pin is an input.
		1	SPIx_SOMI pin is an output.
10	SIMODIR		SPIx_SIMO pin direction. Controls the direction of the SPIx_SIMO pin when it is used as a general-purpose I/O pin. If the SPIx_SIMO pin is used as a SPI functional pin, the I/O direction is determined by whether the SPI is configured as master or slave.
		0	SPIx_SIMO pin is an input.
		1	SPIx_SIMO pin is an output.
9	CLKDIR		SPIx_CLK pin direction. Controls the direction of the SPIx_CLK pin when it is used as a general-purpose I/O pin. If the SPIx_CLK pin is used as a SPI functional pin, the I/O direction is determined by whether the SPI is configured as master or slave.
		0	SPIx_CLK pin is an input.
		1	SPIx_CLK pin is an output.
8	ENADIR		$\overline{\text{SPIx\_ENA}}$ pin direction. Controls the direction of the $\overline{\text{SPIx\_ENA}}$ pin when it is used as a general-purpose I/O pin. If the $\overline{\text{SPIx\_ENA}}$ pin is used as a SPI functional pin, then the I/O direction is determined by whether the SPI is configured as master or slave.
		0	$\overline{\text{SPIx\_ENA}}$ pin is an input.
		1	$\overline{\text{SPIx\_ENA}}$ pin is an output.
7-1	Reserved	0	Reserved
0	SCS0DIR		$\overline{\text{SPIx\_SCS[0]}}$ pin direction. Controls the direction of the $\overline{\text{SPIx\_SCS[0]}}$ pin when it is used as a general-purpose I/O pin. If the $\overline{\text{SPIx\_SCS[0]}}$ pin is used as a SPI functional pin, then the I/O direction is determined by whether the SPI is configured as master or slave.
		0	$\overline{\text{SPIx\_SCS[0]}}$ pin is an input.
		1	$\overline{\text{SPIx\_SCS[0]}}$ pin is an output.

29.3.8 SPI Pin Control Register 2 (SPIPC2)

The SPI pin control register 2 (SPIPC2) is shown in Figure 29-25 and described in Table 29-16.

Figure 29-25. SPI Pin Control Register 2 (SPIPC2)

31	16
Reserved	
R-0	

15	12	11	10	9	8
Reserved		SOMIDIN	SIMODIN	CLKDIN	ENADIN
R-0		R-U	R-U	R-U	R-U

7	1	0
Reserved		SCS0DIN
R-0		R-U

LEGEND: R = Read only; U = Undefined; -*n* = value after reset

Table 29-16. SPI Pin Control Register 2 (SPIPC2) Field Descriptions

Bit	Field	Value	Description
31-12	Reserved	0	Reads return zero and writes have no effect.
11	SOMIDIN		SPIx_SOMI data in. This bit reflects the value of the SPIx_SOMI pin.
		0	Current value of SPIx_SOMI pin is logic 0.
		1	Current value of SPIx_SOMI pin is logic 1.
10	SIMODIN		SPIx_SIMO data in. This bit reflects the value of the SPIx_SIMO pin.
		0	Current value of SPIx_SIMO pin is logic 0.
		1	Current value of SPIx_SIMO pin is logic 1.
9	CLKDIN		Clock data in. This bit reflects the value of the SPIx_CLK pin.
		0	Current value of SPIx_CLK pin is logic 0.
		1	Current value of SPIx_CLK pin is logic 1.
8	ENADIN		$\overline{\text{SPIx\_ENA}}$ data in. This bit reflects the value of the $\overline{\text{SPIx\_ENA}}$ pin.
		0	Current value of $\overline{\text{SPIx\_ENA}}$ pin is logic 0.
		1	Current value of $\overline{\text{SPIx\_ENA}}$ pin is logic 1.
7-1	Reserved	0	Reserved
0	SCS0DIN		$\overline{\text{SPIx\_SCS[0]}}$ data in. This bit reflects the value of the $\overline{\text{SPIx\_SCS[0]}}$ pin.
		0	Current value of $\overline{\text{SPIx\_SCS[0]}}$ pin is logic 0.
		1	Current value of $\overline{\text{SPIx\_SCS[0]}}$ pin is logic 1.

29.3.9 SPI Pin Control Register 3 (SPIPC3)

The SPI pin control register 3 (SPIPC3) is shown in Figure 29-26 and described in Table 29-17.

Figure 29-26. SPI Pin Control Register 3 (SPIPC3)

31	16
Reserved	
R-0	

15	12	11	10	9	8
Reserved		SOMIDOUT	SIMODOUT	CLKDOUT	ENADOUT
R-0		R/W-0	R/W-0	R/W-0	R/W-0

7	1	0
Reserved		SCS0DOUT
R-0		R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 29-17. SPI Pin Control Register 3 (SPIPC3) Field Descriptions

Bit	Field	Value	Description
31-12	Reserved	0	Reads return zero and writes have no effect.
11	SOMIDOUT		SPIx_SOMI data out write. This bit is only active when the SPIx_SOMI pin is configured as a general-purpose I/O pin and configured as an output pin. The value of this bit indicates the value sent to the pin.
		0	Current value of SPIx_SOMI pin is logic 0.
		1	Current value of SPIx_SOMI pin is logic 1.
10	SIMODOUT		SPIx_SIMO data out write. This bit is only active when the SPIx_SIMO pin is configured as a general-purpose I/O pin and configured as an output pin. The value of this bit indicates the value sent to the pin.
		0	Current value of SPIx_SIMO pin is logic 0.
		1	Current value of SPIx_SIMO pin is logic 1.
9	CLKDOUT		SPIx_CLK data out write. This bit is only active when the SPIx_CLK pin is configured as a general-purpose I/O pin and configured as an output pin. The value of this bit indicates the value sent to the pin.
		0	Current value of SPIx_CLK pin is logic 0.
		1	Current value of SPIx_CLK pin is logic 1.
8	ENADOUT		$\overline{\text{SPIx\_ENA}}$ data out write. Only active when the $\overline{\text{SPIx\_ENA}}$ pin is configured as a general-purpose I/O pin and configured as an output pin. The value of this bit indicates the value sent to the pin.
		0	Current value of $\overline{\text{SPIx\_ENA}}$ pin is logic 0.
		1	Current value of $\overline{\text{SPIx\_ENA}}$ pin is logic 1.
7-1	Reserved	0	Reserved
0	SCS0DOUT		$\overline{\text{SPIx\_SCS[0]}}$ data out write. Only active when the $\overline{\text{SPIx\_SCS[0]}}$ pin is configured as a general-purpose I/O pin and configured as an output pin. The value of this bit indicates the value sent to the pin.
		0	Current value of $\overline{\text{SPIx\_SCS[0]}}$ pin is logic 0.
		1	Current value of $\overline{\text{SPIx\_SCS[0]}}$ pin is logic 1.

29.3.10 SPI Pin Control Register 4 (SPIPC4)

The SPI pin control register 4 (SPIPC4) is shown in Figure 29-27 and described in Table 29-18.

Figure 29-27. SPI Pin Control Register 4 (SPIPC4)

31	16
Reserved	
R-0	

15	12	11	10	9	8
Reserved		SOMISET	SIMOSET	CLKSET	ENASET
R-0		R/W-0	R/W-0	R/W-0	R/W-0

7	1	0
Reserved		SCS0SET
R-0		R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 29-18. SPI Pin Control Register 4 (SPIPC4) Field Descriptions

Bit	Field	Value	Description
31-12	Reserved	0	Reads return zero and writes have no effect.
11	SOMISET		SPIx_SOMI data out set. This bit is only active when the SPIx_SOMI pin is configured as a general-purpose output pin. Reads return the value of the SPIx_SOMI pin.
		Write 0	No effect
		Write 1	SPIPC3.SOMIDOUT is set to 1.
10	SIMOSET		SPIx_SIMO data out set. This bit is only active when the SPIx_SIMO pin is configured as a general-purpose output pin. Reads return the value of the SPIx_SIMO pin.
		Write 0	No effect
		Write 1	SPIPC3.SIMODOUT is set to 1.
9	CLKSET		SPIx_CLK data out set. This bit is only active when the SPIx_CLK pin is configured as a general-purpose output pin. Reads return the value of the SPIx_CLK pin.
		Write 0	No effect
		Write 1	SPIPC3.CLKDOUT is set to 1.
8	ENASET		$\overline{\text{SPIx\_ENA}}$ data out set. This bit is only active when the $\overline{\text{SPIx\_ENA}}$ pin is configured as a general-purpose output pin. Reads return the value of the $\overline{\text{SPIx\_ENA}}$ pin.
		Write 0	No effect.
		Write 1	SPIPC3.ENADOUT is set to 1.
7-1	Reserved	0	Reserved
0	SCS0SET		$\overline{\text{SPIx\_SCS[0]}}$ data out set. This bit is only active when the $\overline{\text{SPIx\_SCS[0]}}$ pin is configured as a general-purpose output pin. Reads return the value of the $\overline{\text{SPIx\_SCS[0]}}$ pin.
		Write 0	No effect
		Write 1	SPIPC3.SCS0DOUT is set to 1.

29.3.11 SPI Pin Control Register 5 (SPIPC5)

The SPI pin control register 5 (SPIPC5) is shown in Figure 29-28 and described in Table 29-19.

Figure 29-28. SPI Pin Control Register 5 (SPIPC5)

31	16
Reserved	
R-0	

15	12	11	10	9	8
Reserved		SOMICLR	SIMOCLR	CLKCLR	ENACLR
R-0		R/W-0	R/W-0	R/W-0	R/W-0

7	1	0
Reserved		SCS0CLR
R-0		R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

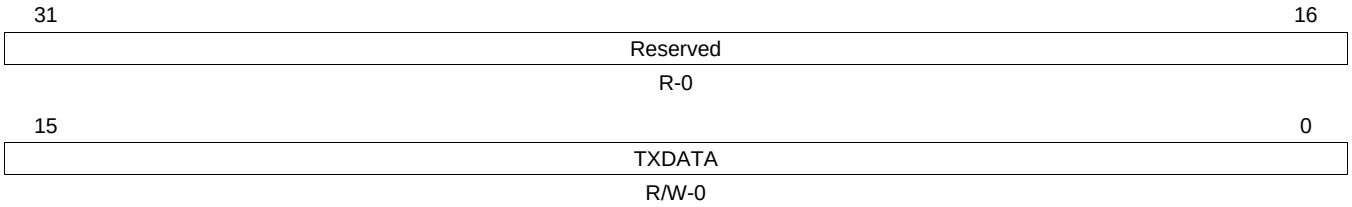
Table 29-19. SPI Pin Control Register 5 (SPIPC5) Field Descriptions

Bit	Field	Value	Description
31-12	Reserved	0	Reads return zero and writes have no effect.
11	SOMICLR		SPIx_SOMI data out clear. This bit is only active when the SPIx_SOMI pin is configured as a general-purpose output pin. Reads return the value of the SPIx_SOMI pin.
		Write 0	No effect.
		Write 1	SPIPC3.SOMIDOUT is cleared to 0.
10	SIMOCLR		SPIx_SIMO data out clear. This bit is only active when the SPIx_SIMO pin is configured as a general-purpose output pin. Reads return the value of the SPIx_SIMO pin.
		Write 0	No effect.
		Write 1	SPIPC3.SIMODOUT is cleared to 0.
9	CLKCLR		SPIx_CLK data out clear. This bit is only active when the SPIx_CLK pin is configured as a general-purpose output pin. Reads return the value of the SPIx_CLK pin.
		Write 0	No effect.
		Write 1	SPIPC3.CLKDOUT is cleared to 0.
8	ENACLR		$\overline{\text{SPIx\_ENA}}$ data out clear. This bit is only active when the $\overline{\text{SPIx\_ENA}}$ pin is configured as a general-purpose output pin. Reads return the value of the $\overline{\text{SPIx\_ENA}}$ pin.
		Write 0	No effect.
		Write 1	SPIPC3.ENADOUT is cleared to 0.
7-1	Reserved	0	Reserved
0	SCS0CLR		$\overline{\text{SPIx\_SCS[0]}}$ data out clear. This bit is only active when the $\overline{\text{SPIx\_SCS[0]}}$ pin is configured as a general-purpose output pin. Reads return the value of the $\overline{\text{SPIx\_SCS[0]}}$ pin.
		Write 0	No effect.
		Write 1	SPIPC3.SCS0DOUT is cleared to 0.

29.3.12 SPI Transmit Data Register 0 (SPIDAT0)

The SPI transmit data register 0 (SPIDAT0) is shown in Figure 29-29 and described in Table 29-20.

Figure 29-29. SPI Data Register 0 (SPIDAT0)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 29-20. SPI Data Register 0 (SPIDAT0) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	Reads return zero and writes have no effect.
15-0	TXDATA	0-FFFFh	SPI transmit data. When written, these bits will be copied to the shift register if it is empty. If the shift register is not empty, the TXBUF will hold the written values. SPIGCR1.ENABLE must be set to 1 before this register can be written to. Writing a 0 to the SPIGCR1.ENABLE forces the TXDATA field to 0. **Note:** Irrespective of the character length, the transmit data should be right-justified before writing to SPIDAT0 register. **Note:** The default data format control register for SPIDAT0 is SPIFMT0. However, it is possible to reprogram the DFSEL field of SPIDAT1 before using SPIDAT0, to select a different SPIFMT*n* register.

29.3.13 SPI Transmit Data Register 1 (SPIDAT1)

The SPI transmit data register (SPIDAT1) is shown in Figure 29-30 and described in Table 29-21.

Figure 29-30. SPI Data Register 1 (SPIDAT1)

31	29	28	27	26	25	24
Reserved		CSHOLD	Reserved	WDEL	DFSEL	
R-0		R/W-0	R-0	R/W-0	R/W-0	

23	17	16
Reserved		CSNR
R-0		R/W-0

15	0
TXDATA	
R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 29-21. SPI Data Register 1 (SPIDAT1) Field Descriptions

Bit	Field	Value	Description
31-29	Reserved	0	Reads return zero and writes have no effect.
28	CSHOLD		Chip select hold mode. The CSHOLD bit is supported in master mode only. In slave mode, this bit is ignored. CSHOLD defines the behavior of the chip select line at the end of a data transfer.
		0	The chip select signal is deactivated at the end of a transfer after the T2CDELAY time has passed.
		1	The chip select signal is held active at the end of a transfer until a control field with new data and control information is loaded into SPIDAT1. If the new chip select hold information equals the previous one, the active chip select signal is extended until the end of transfer with CSHOLD cleared.
27	Reserved	0	Reads return zero and writes have no effect.
26	WDEL		Enable the delay counter at the end of the current transaction. The WDEL bit is supported in master mode only. In slave mode, this bit is ignored.
		0	No delay will be inserted. However, $\overline{\text{SPIx\_SCS[n]}}$ pin will still be deactivated for at least 2 SPI module clock cycles if CSHOLD = 0.
		1	After a transaction, SPIFMT*n*.WDELAY of the selected data format will be loaded into the delay counter. No transaction will be performed until the SPIFMT*n*.WDELAY counter overflows. The $\overline{\text{SPIx\_SCS[n]}}$ pin will be deactivated for at least (WDELAY + 2) × SPI module clock period.
25-24	DFSEL	0-3h	Data word format select
		0	Data word format 0 is selected
		1h	Data word format 1 is selected
		2h	Data word format 2 is selected
		3h	Data word format 3 is selected
			Note: Preselecting a Format Register. Writing to just the control field (using byte writes) does not initiate any SPI transfer in master mode. This feature can be used to set up SPIx_CLK phase or polarity before actually starting the transfer by just updating the DFSEL fields in the control field to select the required phase/polarity combination.
23-17	Reserved	0	Reserved
16	CSNR		Chip select number. The CSNR defines the state of the $\overline{\text{SPIx\_SCS[0]}}$ pin during a master data transfer. The value of the CSNR bit is driven directly on the $\overline{\text{SPIx\_SCS[0]}}$ pin.
			The state of the chip select pin when no transmission is active is specified through the CSDEF bit in the SPI default chip select register (SPIDEF). The chip select pin remains in its active state by setting the CSHOLD bit to 1. When the SPI is configured in slave mode, this bit must be written as 0.
		0	$\overline{\text{SPIx\_SCS[0]}}$ pin is driven low.
		1	$\overline{\text{SPIx\_SCS[0]}}$ pin is driven high.

Table 29-21. SPI Data Register 1 (SPIDAT1) Field Descriptions (continued)

Bit	Field	Value	Description
15-0	TXDATA	0-FFFFh	Transfer data. When written, these bits will be copied to the shift register if it is empty. If the shift register is not empty, the TXBUF will hold the written values. SPIGCR1.ENABLE must be set to 1 before this register can be written to. Writing a 0 to the SPIGCR1.ENABLE forces the lower 16 bits of the SPIDAT1 to 0. **Note:** Irrespective of the character length, the transmit data should be right-justified before writing to SPIDAT1.

29.3.14 SPI Receive Buffer Register (SPIBUF)

The SPI receive buffer register (SPIBUF) is shown in Figure 29-31 and described in Table 29-22.

Figure 29-31. SPI Buffer Register (SPIBUF)

31	30	29	28	27	26	25	24
RXEMPTY	RXOVR	TXFULL	BITERR	DESYNC	PARERR	TIMEOUT	DLENERR
RS-1	RC-0	R-0	RC-0	RC-0	RC-0	RC-0	RC-0

23	16
Reserved	
R-0	

15	0
RXDATA	
R-0	

LEGEND: R/W = Read/Write; R = Read only; C = Clear; S = Set; -*n* = value after reset

Table 29-22. SPI Buffer Register (SPIBUF) Field Descriptions

Bit	Field	Value	Description
31	RXEMPTY		Receive data buffer empty. When host reads the RXDATA field or the entire SPIBUF register this automatically sets the RXEMPTY flag. When a data transfer is completed, the received data is copied into SPIBUF, the RXEMPTY flag is cleared. This flag gets set to 1 under following conditions: • Reading the RXDATA field of the SPIBUF register. • Writing 1 to clear the RXINTFLG bit in the SPIFLG register.
		0	New data has been received and copied into the SPIBUF register.
		1	No data received since last reading of the SPIBUF register.
			Write-Clearing the SPIFLG.RXINTFLG bit before reading the SPIBUF register indicates the received data is being ignored. Conversely, SPIFLG.RXINTFLG can be cleared by reading the RXDATA field of the SPIBUF register or the entire SPIBUF register.
30	RXOVR		Receive data buffer overrun. When a data transfer is completed and the received data is copied into the RXBUF while it is already full, RXOVR is set. An overrun always occurs to the RXBUF, and SPIBUF contents never get overwritten until after it is read by the CPU/DMA. Reading SPIBUF register does not clear the RXOVR bit. If an overrun interrupt is detected, then the SPIBUF may need to be read twice to get to the overrun buffer. This is due to the fact that the overrun will always occur to the internal RXBUF. Each read to the SPIBUF will result in RXBUF contents (if it is full) getting copied to SPIBUF. **Note:** A special condition under which RXOVR flag gets set. If both SPIBUF and RXBUF are already full and while another buffer receive is underway, if any errors like TIMEOUT, BITERR and DLENERR occur, then RXOVR will be set to indicate that the status flags are getting overwritten by the new transfer. This overrun should be treated like a normal receiver overrun.
		0	No receive data overrun condition occurred since last time reading the data field.
		1	A receive data overrun condition occurred since last time reading the data field.

Table 29-22. SPI Buffer Register (SPIBUF) Field Descriptions (continued)

Bit	Field	Value	Description
29	TXFULL		Transmit data buffer full. This flag is a read-only flag. Writing into SPIDAT0 or SPIDAT1 field while the TX shift register is full will automatically set the TXFULL flag. Once the data is copied to the shift register, the TXFULL flag will be cleared. Writing to the SPIDAT0/SPIDAT1 register when both TXBUF and the TX shift register are empty does not set the TXFULL flag.
		0	The transmit buffer is empty; SPIDAT0/SPIDAT1 is ready to accept a new data.
		1	The transmit buffer is full; SPIDAT0/SPIDAT1 is not ready to accept new data.
28	BITERR		Bit error. There was a mismatch of internal transmit data and transmitted data. The SPI samples the signal of the transmit pin (master: SIMO, slave: SOMI) at the receive point (half clock cycle after transmit point). If the sampled value differs from the transmitted value, a bit error is detected and the flag BITERR is set. A possible reason for a bit error can be noise, a too-high bit rate/capacitive load, or another master/slave trying to transmit at the same time.
			Note: This flag is cleared to 0 when RXDATA portion of the SPIBUF register is read.
		0	No bit error occurred.
		1	A bit error occurred.
27	DESYNC		Desynchronization of slave device. This bit is active in master mode only. The master monitors the $\overline{\text{SPIx\_ENA}}$ signal coming from the slave device and sets the DESYNC flag if $\overline{\text{SPIx\_ENA}}$ is deactivated before the last reception point or after the last bit is transmitted plus $t_{T2EDELAY}$. If DESYNCENA is set, an interrupt is asserted. Desynchronization can occur if a slave device misses a clock edge coming from the master.
			Note: Possible inconsistency of DESYNC flag in SPI. Because of the nature of this error, under some circumstances it is possible for a desync error detected for the previous buffer to be visible in the current buffer. This is because the receive completion flag/interrupt will be generated when the buffer transfer is completed. But desync will be detected after the buffer transfer is completed. So, if CPU/DMA reads the received data quickly when an RXINT is detected, then the status flag may not reflect the correct desync condition.
			Note: This flag is cleared to 0 when the RXDATA portion of the SPIBUF register is read.
		0	No slave de-synchronization detected.
		1	A slave device is desynchronized.
26	PARERR		Parity error. The calculated parity differs from received parity bit. If the parity generator is enabled an even or odd parity bit is added at the end of a data word. During reception of the data word ,the parity generator calculates the reference parity and compares it to the received parity bit. If a mismatch is detected, the PARERR flag is set.
			Note: This flag is cleared to 0 when the RXDATA portion of the SPIBUF register is read.
		0	No parity error detected.
		1	A parity error occurred.
25	TIMEOUT		Time-out because of non-activation of $\overline{\text{SPIx\_ENA}}$ pin. This bit is valid in master mode only. The SPI generates a time-out because the slave hasn't responded in time by activating the $\overline{\text{SPIx\_ENA}}$ signal after the chip select signal has been activated. If a time-out condition is detected, the corresponding chip select is deactivated immediately and the TIMEOUT flag is set.
			Note: This flag is cleared to 0 when RXDATA portion of the SPIBUF register is read.
		0	No $\overline{\text{SPIx\_ENA}}$ pin time-out occurred.
		1	An $\overline{\text{SPIx\_ENA}}$ signal time-out occurred.
24	DLENERR		Data length error flag.
			Note: This flag is cleared to 0 when the RXDATA portion of the SPIBUF register is read.
		0	No data length error has occurred.
		1	A data length error has occurred.
23-16	Reserved	0	Reads return zero and writes have no effect.
15-0	RXDATA	0-FFFFh	SPI receive data. This is the received data, transferred from the receive shift-register at the end of a transfer completion. Irrespective of the programmed character length and the direction of shifting, the received data is stored right-justified in the register.

29.3.15 SPI Emulation Register (SPIEMU)

The SPI emulation register (SPIEMU) is shown in Figure 29-32 and described in Table 29-23.

Figure 29-32. SPI Emulation Register (SPIEMU)

31	16
Reserved	
R-0	

15	0
RXDATA	
R-0	

LEGEND: R = Read only; -*n* = value after reset

Table 29-23. SPI Emulation Register (SPIEMU) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	Reads return zero and writes have no effect.
15-0	RXDATA	0-FFFFh	SPI receive data. SPI emulation is a mirror of the SPIBUF register. The only difference between SPIEMU and SPIBUF is that a read from SPIEMU does not clear any of the status flags.

29.3.16 SPI Delay Register (SPIDELAY)

The SPI delay register (SPIDELAY) is shown in Figure 29-33 and described in Table 29-24.

Figure 29-33. SPI Delay Register (SPIDELAY)

31	24	23	16
C2TDELAY		T2CDELAY	
R/W-0		R/W-0	

15	8	7	0
T2EDELAY		C2EDELAY	
R/W-0		R/W-0	

LEGEND: R/W = Read/Write; -*n* = value after reset

Table 29-24. SPI Delay Register (SPIDELAY) Field Descriptions

Bit	Field	Value	Description
31-24	C2TDELAY	0-FFh	Chip-select-active-to-transmit-start-delay. C2TDELAY is used in master mode only. It defines a setup time for the slave device that delays the data transmission from the chip select active edge by a multiple of SPI module clock cycles. C2TDELAY can be configured between 3 and 257 SPI module clock cycles. See Figure 29-34. The setup time value is calculated as follows: $t_{C2TDELAY}$ = (C2TDELAY + 2) × SPI module clock period **Note:** If C2TDELAY = 0, then $t_{C2TDELAY}$ = 0. Example: SPI module clock = 25 MHz -> SPI module clock period = 40 ns; C2TDELAY = 06h; > $t_{C2TDELAY}$ = 320 ns; When the chip select signal becomes active, the slave has to prepare for data transfer within 320 ns. **Note:** If phase = 1, the delay between $\overline{\text{SPIx\_SCS[n]}}$ falling edge to the first edge of SPIx_CLK will have an additional 0.5 SPIx_CLK period delay. This delay is as per the SPI protocol.
23-16	T2CDELAY	0-FFh	Transmit-end-to-chip-select-inactive-delay. T2CDELAY is used in master mode only. It defines a hold time for the slave device that delays the chip select deactivation by a multiple of SPI module clock cycles after the last bit is transferred. T2CDELAY can be configured between 2 and 256 SPI module clock cycles. See Figure 29-35. The hold time value is calculated as follows: $t_{T2CDELAY}$ = (T2CDELAY + 1) × SPI module clock period **Note:** If T2CDELAY = 0, then $t_{T2CDELAY}$ = 0 Example: VBUSPCLK = 25 MHz -> VBUSPCLK period = 40 ns; T2CDELAY = 03h; > $t_{T2CDELAY}$ = 160 ns; After the last data bit (or parity bit) is being transferred the chip select signal is held active for 160 ns. **Note:** If phase = 0, then between the last edge of SPIx_CLK and rise-edge of $\overline{\text{SPIx\_SCS[n]}}$ there will be an additional delay of 0.5 SPIx_CLK period. This is as per the SPI protocol. Both C2TDELAY and T2CDELAY counters will not have any dependancy on the $\overline{\text{SPIx\_ENA}}$ pin value. Even if the $\overline{\text{SPIx\_ENA}}$ pin is asserted by the slave, the master will continue to delay the start of SPIx_CLK until the C2TDELAY counter overflows. Similarly, even if the $\overline{\text{SPIx\_ENA}}$ pin is deasserted by the slave, the master will continue to hold the $\overline{\text{SPIx\_SCS[n]}}$ pins active until the T2CDELAY counter overflows. This way, it is assured that the setup/hold times of the $\overline{\text{SPIx\_SCS[n]}}$ pins are determined by the delay timers alone. To achieve better throughput, it should be ensured that these two timers are kept at the minimum possible values.

Table 29-24. SPI Delay Register (SPIDELAY) Field Descriptions (continued)

Bit	Field	Value	Description
15-8	T2EDELAY	0-FFh	Transmit-data-finished-to-$\overline{\text{SPIx\_ENA}}$-pin-inactive-time-out. T2EDELAY is used in master mode only. It defines a time-out value as a multiple of SPI clock before the $\overline{\text{SPIx\_ENA}}$ signal has to become inactive and after the CS becomes inactive. The SPI clock depends on which data format is selected. If the slave device is missing one or more clock edges, it is becoming desynchronized. Although the master has finished the data transfer the slave is still waiting for the missed clock pulses and the $\overline{\text{SPIx\_ENA}}$ signal is not disabled. The T2EDELAY defines a time-out value that triggers the DESYNC flag, if the $\overline{\text{SPIx\_ENA}}$ signal is not deactivated in time. The DESYNC flag is set to indicate that the slave device did not deassert its $\overline{\text{SPIx\_ENA}}$ pin in time to acknowledge that it has received all the bits of the sent character. The DESYNC flag is also set if the SPI detects a deassertion of the $\overline{\text{SPIx\_ENA}}$ pin even before the end of the transmission. See Figure 29-36. The time-out value is calculated as follows: $t_{T2EDELAY}$ = T2EDELAY/SPIclock Example: SPIclock = 8 Mbit/s; T2EDELAY = 10h; > $t_{T2EDELAY}$ = 2 µs; The slave device has to disable the $\overline{\text{SPIx\_ENA}}$ signal within 2 µs; otherwise, the DESYNC flag in SPIFLG is set and an interrupt is asserted if enabled.
7-0	C2EDELAY	0-FFh	Chip-select-active-to-$\overline{\text{SPIx\_ENA}}$-signal-active-time-out. C2EDELAY is used only in master mode and it applies only if the addressed slave generates an $\overline{\text{SPIx\_ENA}}$ signal as a hardware handshake response. C2EDELAY defines the maximum time between the SPI activates the chip select signal and the addressed slave has to respond by activating the $\overline{\text{SPIx\_ENA}}$ signal. C2EDELAY defines a time-out value as a multiple of SPI clocks. See Figure 29-37. **Note:** If the slave device is not responding with the $\overline{\text{SPIx\_ENA}}$ signal before the time-out value is reached, the TIMEOUT flag in SPIFLG is set and an interrupt is asserted if enabled. The timeout value is calculated as follows: $t_{C2EDELAY}$ = C2EDELAY/SPIclock Example: SPIclock = 8 Mbit/s; C2EDELAY = 30h; > $t_{C2EDELAY}$ = 6 µs; The slave device has to activate the $\overline{\text{SPIx\_ENA}}$ signal within 6 µs after the SPI has activated the chip select signal ($\overline{\text{SPIx\_SCS[n]}}$); otherwise, the TIMEOUT flag in SPIFLG is set and an interrupt is asserted if enabled.

Figure 29-34. Example: $t_{C2TDELAY}$ = 8 SPI Module Clock Cycles

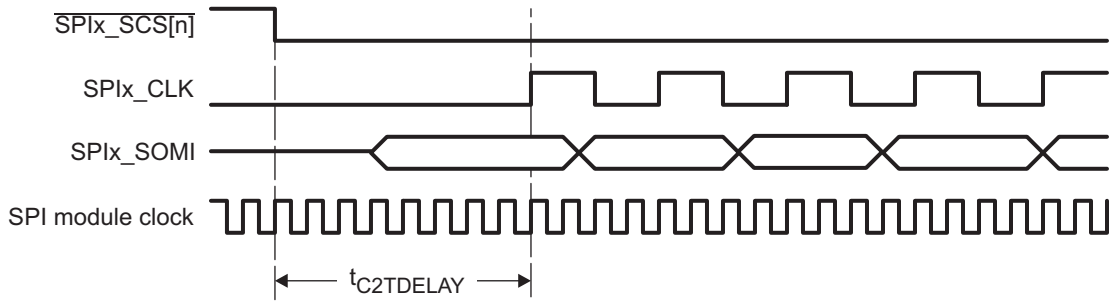


Figure 29-35. Example: $t_{T2CDELAY}$ = 4 SPI Module Clock Cycles

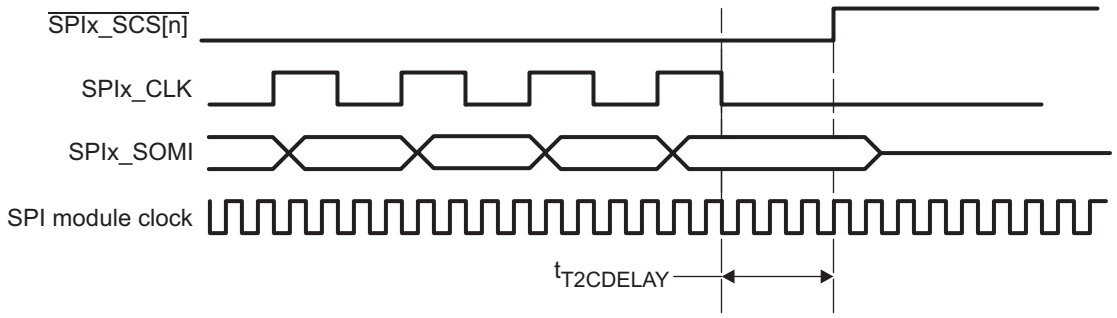


Figure 29-36. Transmit-Data-Finished-to-SPIx_ENA-Inactive-Timeout

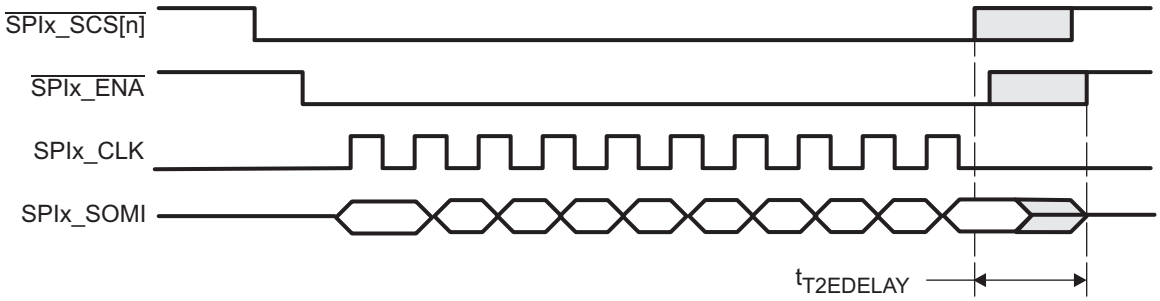
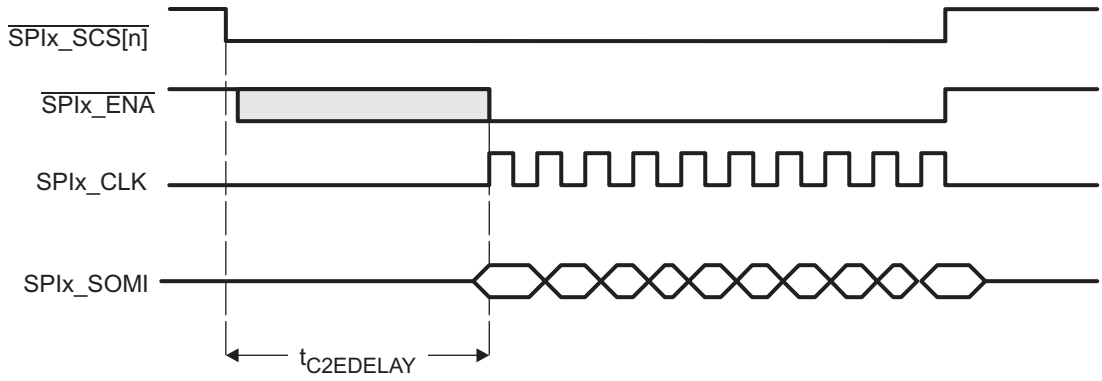


Figure 29-37. Chip-Select-Active-to-SPIx_ENA-Signal-Active-Timeout



29.3.17 SPI Default Chip Select Register (SPIDEF)

The SPI default chip select register (SPIDEF) is shown in Figure 29-38 and described in Table 29-25.

Figure 29-38. SPI Default Chip Select Register (SPIDEF)

31	16
Reserved	
R-0	

15	1	0
Reserved		CSDEF
R/W-7Fh		R/W-1

LEGEND: R/W = Read/Write; R = Read only; *-n* = value after reset

Table 29-25. SPI Default Chip Select Register (SPIDEF) Field Descriptions

Bit	Field	Value	Description
31-1	Reserved	7Fh	Reserved
0	CSDEF		Chip select default pattern. The CSDEF bit defines the state of the the $\overline{\text{SPIx\_SCS[0]}}$ pin when no transmissions are performed. The value of the CSDEF bit is driven directly on the $\overline{\text{SPIx\_SCS[0]}}$ pin. The state of the chip select pin during a transmission is specified through the CSNR bit in the SPI transmit data register (SPIDAT1). The chip select pin remains in its active state by setting the CSHOLD bit in SPIDAT1 to 1. In slave mode, the CSDEF bit should be set to 1.
		0	$\overline{\text{SPIx\_SCS[0]}}$ pin is driven low.
		1	$\overline{\text{SPIx\_SCS[0]}}$ pin is driven high.

29.3.18 SPI Data Format Registers (SPIFMT*n*)

The SPI data format registers (SPIFMT0, SPIFMT1, SPIFMT2, and SPIFMT3) are shown in Figure 29-39 and described in Table 29-26.

Figure 29-39. SPI Data Format Register (SPIFMT*n*)

31	30	29					24
Reserved		WDELAY					
R-0		R/W-0					
23	22	21	20	19	18	17	16
PARPOL	PARENA	WAITENA	SHIFTDIR	Reserved	DISCSTIMERS	POLARITY	PHASE
R/W-0	R/W-0	R/W-0	R/W-0	R-0	R/W-0	R/W-0	R/W-0
15							8
PRESCALE							
R/W-0							
7		5	4				0
Reserved			CHARLEN				
R-0			R/W-0				

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 29-26. SPI Data Format Register (SPIFMT*n*) Field Descriptions

Bit	Field	Value	Description
31-30	Reserved	0	Reads return zero and writes have no effect.
29-24	WDELAY	0-3Fh	Delay in between transmissions. Idle time that will be applied at the end of the current transmission if the bit WDEL is set in the current buffer. The delay to be applied is equal to: WDELAY × $P_{SPI\ module\ clock}$ + 2 × $P_{SPI\ module\ clock}$ $P_{SPI\ module\ clock}$ -> Period of SPI module clock
23	PARPOL		Parity polarity: even or odd. PARPOL can be modified in privilege mode only.
		0	An even parity flag is added at the end of the transmit data stream.
		1	An odd parity flag is added at the end of the transmit data stream.
22	PARENA		Parity enable.
		0	No parity generation/ verification is performed.
		1	A parity is transmitted at the end of each transmit data stream. At the end of a transfer the parity generator compares the received parity bit with the locally calculated parity flag. If the parity bits do not match the PARERR flag is set in the corresponding control field. The parity type (even or odd) can be selected via the PARPOL bit.
21	WAITENA		The master waits for $\overline{\text{SPIx\_ENA}}$ signal from slave. WAITENA is considered in master mode only. In slave mode this bit has no meaning. WAITENA enables a flexible SPI network where slaves with $\overline{\text{SPIx\_ENA}}$ signal and slaves without $\overline{\text{SPIx\_ENA}}$ signal can be mixed.
		0	The SPI does not wait for the $\overline{\text{SPIx\_ENA}}$ signal from the slave and directly starts the transfer.
		1	Before the SPI starts the data transfer it waits for the $\overline{\text{SPIx\_ENA}}$ signal to become low. If the $\overline{\text{SPIx\_ENA}}$ signal is not pulled down by the addressed slave before the internal time-out counter (C2EDELAY) overflows, then the master aborts the transfer and sets the TIMEOUT error flag.
20	SHIFTDIR		Shift direction.
		0	Most significant bit is shifted out first.
		1	Least significant bit is shifted out first.
19	Reserved	0	Reads return zero and writes have no effect.
18	DISCSTIMERS		Disable chip select timers for this format register. The C2TDELAY and T2CDELAY timers are by default enabled for all the data format registers. Using this bit, these timers can be disabled for a particular data format if not required. When a master is handling multiple slaves, with varied set-up hold requirement, the application can selectively choose to include or not include the chip select delay timers for any slaves.
		0	Both C2TDELAY and T2CDELAY counts are inserted for the chip selects.
		1	No C2TDELAY or T2CDELAY is inserted in the chip select timings.

Table 29-26. SPI Data Format Register (SPIFMT*n*) Field Descriptions (continued)

Bit	Field	Value	Description
17	POLARITY		SPI clock polarity.
		0	SPI clock signal is low-inactive (before and after data transfer the clock signal is low).
		1	SPI clock signal is high-inactive (before and after data transfer the clock signal is high).
16	PHASE		SPI clock delay.
		0	SPI clock signal is not delayed versus the transmit/receive data stream. The first data bit is transmitted with the first clock edge and the first bit is received with the second (inverse) clock edge.
		1	SPI clock signal is delayed by a half SPI clock cycle versus the transmit/receive data stream. The first transmit bit has to output prior to the first clock edge. The master and slave receive the first bit with the first edge.
15-8	PRESCALE	2h-FFh	SPI prescaler. It determines the bit transfer rate if the SPI is the network master and is directly derived from the SPI module clock. If the SPI is configured as slave, PRESCALE needs to be configured to a valid value, but PRESCALE is ignored. The clock rate can be calculated as: SPI clock frequency = SPI module clock/(PRESCALE + 1) **Note:** PRESCALE values less than 2h are not supported.
7-5	Reserved	0	Reads return zero and writes have no effect.
4-0	CHARLEN	0-1Fh	SPI data word length. Legal values are 2h (data word length = 2 bit) to 10h (data word length = 16). Illegal values, such as 0 or 1Fh are not detected and their effect is indeterminate.

29.3.19 SPI Interrupt Vector Register 1 (INTVEC1)

The SPI interrupt vector register 1 (INTVEC1) is shown in Figure 29-40 and described in Table 29-27.

Figure 29-40. SPI Interrupt Vector Register 1 (INTVEC1)

31	16
Reserved	
R-0	

15	6	5	1	0
Reserved		INTVECT1		Rsvd
R-0		R-0		R-0

LEGEND: R = Read only; -*n* = value after reset

Table 29-27. SPI Interrupt Vector Register 1 (INTVEC1) Field Descriptions

Bit	Field	Value	Description
31-6	Reserved	0	Reads return zero and writes have no effect.
5-1	INTVECT1	0-1Fh	Interrupt vector for interrupt line INT1. INTVECT1 returns the vector of the pending interrupt at interrupt line INT1. If more than one interrupt is pending, INTVECT1 always references the highest priority interrupt source first. The interrupts available for SPI in the descending order of their priorities are as given below. • Transmission error Interrupt • Receive buffer overrun interrupt • Receive buffer full interrupt • Transmit buffer empty interrupt The INTVECT1 field just reflects the status of SPIFLG in a vectorized format. So, any updates to SPIFLG will automatically reflect in the vector value in this register. Vectors for each of these interrupts will be reflected on the INTVECT1 bits, when they occur. Reading the vectors for the receive buffer overrun and receive buffer full interrupts will automatically clear the respective flags in the SPIFLG. Reading the vector register when transmitter empty is indicated does not clear the TXINTFLG in SPIFLG. Writing a new data to SPIDAT0/SPIDAT1 clears the transmitter empty interrupt. On reading the INTVECT1 bits, the vector of the next highest priority interrupt (if any) will be then reflected on the INTVECT1 bits. If two or more interrupts occur simultaneously, the vector for the highest priority interrupt will be reflected on the INTVECT1 bits. The following are the SPI interrupt vectors for line INT1:
		0	No interrupt pending
		1h-10h	Reserved
		11h	Error interrupt pending. Refer to lower halfword of SPIINT0 to determine more details about the type of error.
		12h	The pending interrupt is receive buffer full interrupt.
		13h	The pending interrupt is receive buffer overrun interrupt.
		14h	The pending interrupt is transmit buffer empty interrupt.
		15h-1Fh	Reserved
0	Reserved	0	Reads return zero and writes have no effect.

64-Bit Timer Plus

This chapter describes the operation of the software-programmable 64-bit Timer Plus. See your device-specific data manual to determine how many Timer modules are available on your device.

Topic **Page**

30.1 Introduction

The 64-bit Timer Plus can be programmed in 64-bit mode, dual 32-bit unchained mode, or dual 32-bit chained mode. Some Timer Plus implementations have signal connections to internal device reset that can be used in watchdog timer mode. New features over previous timers include: external clock/event input, period reload, external event capture, and timer counter register read reset.

30.1.1 Purpose of the Peripheral

The timer can support four basic modes of operation: a 64-bit general-purpose (GP) timer, dual unchained 32-bit GP timers, dual chained 32-bit timers, or a watchdog timer. The GP timer modes can be used to generate periodic interrupts and DMA synchronization events. The watchdog timer mode is used to provide a recovery mechanism for the device in the event of a fault condition (such as a non-exiting code loop).

30.1.2 Features

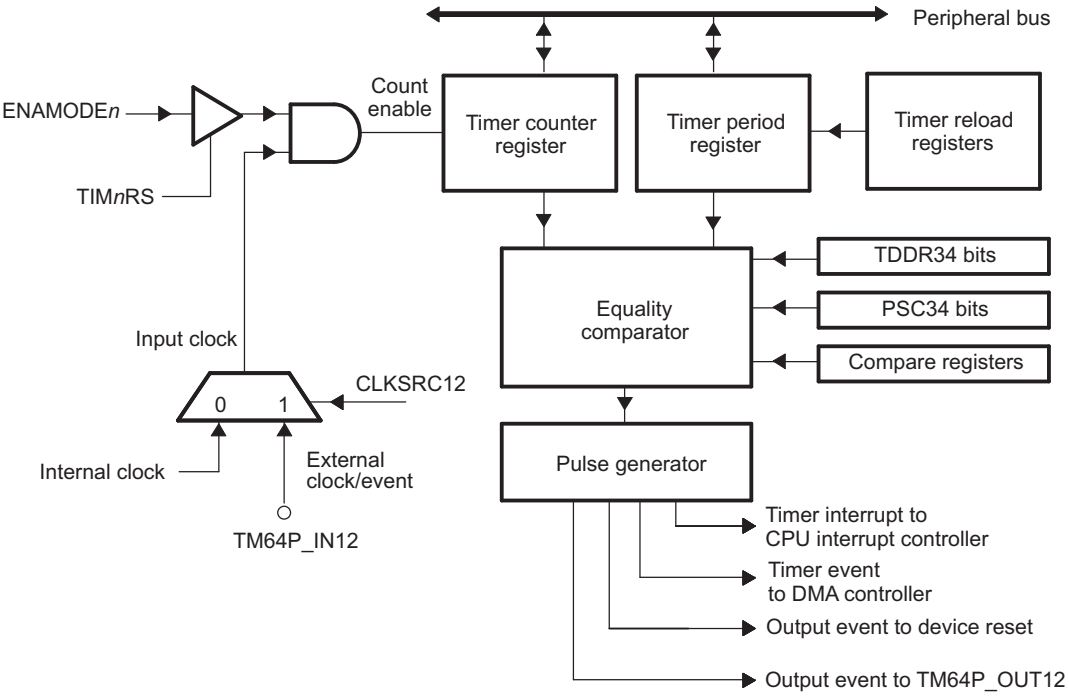
The 64-bit timer consists of the following features -- some features may not be supported on all timer instantiations (see your device-specific data manual for supported features):

- 64-bit count-up counter
- Timer modes:
  - 64-bit general-purpose timer mode
  - Dual 32-bit unchained general-purpose timer mode
  - Dual 32-bit chained timer mode
  - Watchdog timer mode
- 2 possible clock sources:
  - Internal clock
  - External clock/event input via timer input pins
- 3 possible operation modes:
  - One-time operation (timer runs for one period then stops)
  - Continuous operation (timer automatically resets to zero after each period and continues to operate)
  - Continuous operation with period reload (timer automatically assumes the value of the reload registers after each period and continues to operate)
- Generates interrupts to CPU
- Generates sync events to DMA
- Generates output event to device reset (watchdog only)
- Generates output event to timer output pins (if pins are available)
- External event capture via timer input pins (if pins are available)

30.1.3 Block Diagram

A block diagram of the timer is shown in Figure 30-1. Detailed information about the architecture and operation of the timers is in Section 30.2.1 and Section 30.2.2.

Figure 30-1. Timer Block Diagram



30.1.4 Industry Standard Compatibility Statement

This peripheral is not intended to conform to any specific industry standard.

30.2 Architecture

30.2.1 Architecture – General-Purpose Timer Mode

This section describes the timer in the general-purpose (GP) timer mode.

30.2.1.1 Backward Compatible Mode

The Timer Plus supports the following additional features over the other timers:

- External clock/event input
- Period reload
- External event capture mode
- Timer counter register read reset mode
- Timer counter capture registers
- Register for interrupt/DMA generation control and status

By default, period reload, external event capture mode, timer counter register read reset mode, timer counter capture registers, and interrupt/DMA/TM64P_OUT generation control and status are not available. To enable these features, you must set the PLUSEN bit in the timer global control register (TGCR). These features are described throughout the following sections. External clock/event input is always available, regardless of the state of the backward compatible bit.

30.2.1.2 Clock Control

The timer can use an internal or external clock source for the counter period. The following sections explain how to select the clock source.

As shown in Table 30-1 and Figure 30-2, the timer clock source is selected using the clock source (CLKSRC12) bit in the timer control register (TCR). Two clock sources are available to drive the timer clock:

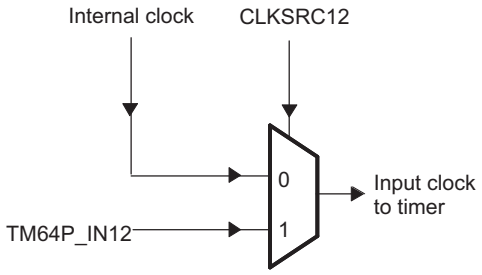
- internal clock by setting CLKSRC12 = 0.
- external clock on input pin TM64P_IN12 by setting CLKSRC12 = 1.

At reset, the clock source is the internal clock. Details on each of the clock source configuration options are included in the following sections.

Table 30-1. Timer Clock Source Selection

CLKSRC12	Input Clock
0	Internal clock (default)
1	External clock on timer input

Figure 30-2. Timer Clock Source Block Diagram



30.2.1.2.1 Using the Internal Clock Source to the Timer

The internal clock source to the timer is generated by the PLL controller. This clock source determines the speed of the timer since the timer counts up in units of source clock cycles. When determining the period and prescaler settings for the timer, choose the desired period in units of source clock cycles. For details on the generation of the on-chip clocks, see the *Phase-Locked Loop Controller (PLLC)* chapter.

The CLKSRC12 parameter in the timer control register (TCR) determines whether an internal or external clock is used as the clock source for the timer. If the timer is configured in 64-bit mode or 32-bit chained mode, CLKSRC12 controls the clock source for the entire timer. If the timer is configured in dual 32-bit unchained mode (TIMMODE = 01 in TGCR), CLKSRC12 controls the timer 1:2 side of the timer only.

To select the internal clock as the clock source for the timer, CLKSRC12 in TCR must be cleared to 0.

30.2.1.2.2 Using the External Clock Source to the Timer

An external clock source can be provided to clock the timer through the timer input pin TM64P_IN12. The CLKSRC12 parameter in the timer control register (TCR) determines whether an internal or external clock is used as the clock source for the timer. If the timer is configured in 64-bit mode or 32-bit chained mode, CLKSRC12 controls the clock source for the entire timer. If the timer is configured in dual 32-bit unchained mode (TIMMODE = 01 in TGCR), CLKSRC12 controls the timer 1:2 side of the timer only.

At reset, the clock source defaults to the internal clock. Details on each of the clock source configuration options are included in the following sections. To select the external clock as the clock source for the timer, CLKSRC12 in TCR must be set to 1. The external clock source frequency must be no greater than the timer peripheral reference clock (see your device-specific data manual).

30.2.1.3 Signal Descriptions

As shown in Figure 30-2, the TM64P_IN12 pin may be used as input to the timer. This signal can be used to drive the clock/event count or be used as an external event input for event capture mode. Pin TM64P_OUT12 may be used as an output from the timer to generate a clock or pulse signal.

30.2.1.4 Timer Modes

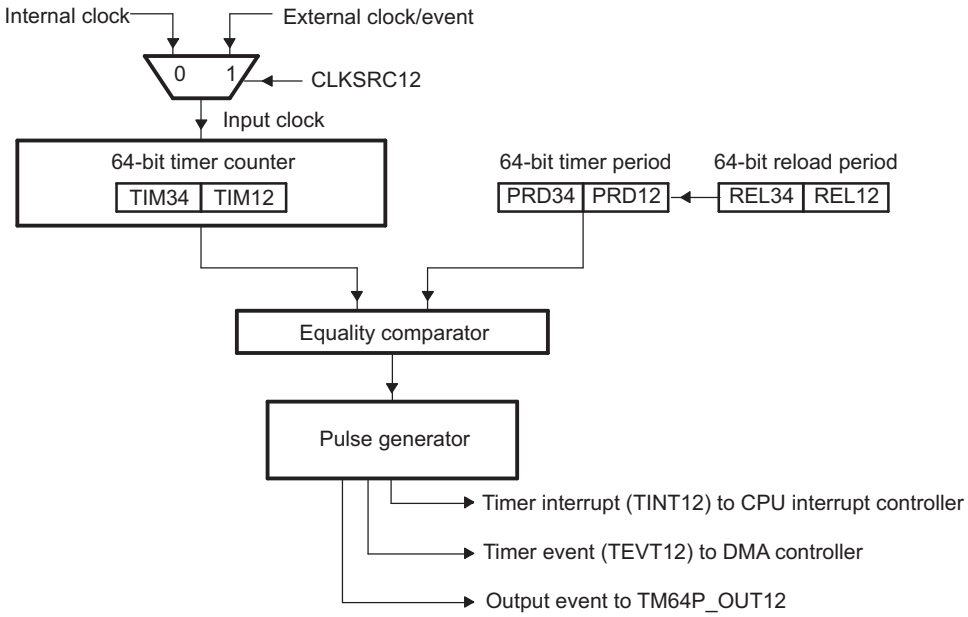
The following section describes the general-purpose (GP) timer modes.

30.2.1.4.1 64-Bit Timer Mode

The timer can be configured as a 64-bit timer by clearing the TIMMODE bit in the timer global control register (TGCR) to 0. At reset, 0 is the default setting for the TIMMODE bit.

In this mode, the timer operates as a single 64-bit up-counter (Figure 30-3). The counter registers (TIM12 and TIM34) form a 64-bit timer counter register and the period registers (PRD12 and PRD34) form a 64-bit timer period register. When the timer is enabled, the timer counter starts incrementing by 1 at every timer input clock cycle. When the timer counter matches the timer period, a maskable timer interrupt (TINT12) and a timer EDMA (TEVT12) are generated. When the timer is configured in continuous mode, the timer counter is reset to 0 on the cycle after the timer counter reaches the timer period. The timer can be stopped, restarted, reset, or disabled using control bits in TGCR.

Figure 30-3. 64-Bit Timer Mode Block Diagram



30.2.1.4.1.1 Enabling the 64-Bit Timer

The TIM12RS and TIM34RS bits in TGCR control whether the timer is in reset or capable of operating. For the timer to operate in 64-bit timer mode, the TIM12RS and TIM34RS bits must be set to 1.

The ENAMODE12 bit in the timer control register (TCR) controls whether the timer is disabled, enabled to run once, enabled to run continuously, or enabled to run continuously with period reload; the ENAMODE34 bit has no effect in 64-bit timer mode. When the timer is disabled (ENAMODE12 = 0), the timer does not run and maintains its current count value. When the timer is enabled for one time operation (ENAMODE12 = 1), it counts up until the counter value equals the period value and then stops. When the timer is enabled for continuous operation (ENAMODE12 = 2h), the counter counts up until it reaches the period value, then resets itself to zero and begins counting again. When the timer is enabled for continuous operation with period reload (ENAMODE12 = 3h), the counter counts up until it reaches the period value, then resets itself to zero, reloads the period registers (PRD12 and PRD34) with the value in the period reload registers (REL12 and REL34), and begins counting again.

Table 30-2 shows the bit values in TGCR to configure the 64-bit timer.

Table 30-2. 64-Bit Timer Configurations

	TGCR Bit		TCR Bit
64-Bit Timer Configuration	**TIM12RS**	**TIM34RS**	**ENAMODE12**
To place the 64-bit timer in reset	0	0	0
To disable the 64-bit timer (out of reset)	1h	1h	0
To enable the 64-bit timer for one-time operation	1h	1h	1h
To enable the 64-bit timer for continuous operation	1h	1h	2h
To enable the 64-bit timer for continuous operation with period reload	1h	1h	3h

Once the timer stops, if an external clock is used as the timer clock, the timer must remain disabled for at least one external clock period or the timer will not start counting again. When using the external clock, the count value is synchronized to the internal clock.

Note that when both the timer counter and timer period are cleared to 0, the timer can be enabled but the timer counter does not increment because the timer period is 0.

30.2.1.4.1.2 Reading the Counter Registers

When reading the timer count in 64-bit timer mode, the CPU must first read TIM12 followed by TIM34. When TIM12 is read, the timer copies TIM34 into a shadow register. When reading TIM34, the hardware logic returns the shadow register value. This ensures that the values read from the registers are not affected by the fact that the timer may continue to run as the registers are read. When reading the timers in 32-bit mode, TIM12 and TIM34 may be read in any order.

30.2.1.4.1.3 64-Bit Timer Configuration Procedure

To configure the GP timer to operate as a 64-bit timer, follow the steps below:

1. Select 64-bit mode (TIMMODE in TGCR).
2. Remove the timer from reset (TIM12RS and TIM34RS in TGCR).
3. Select the desired timer period (PRD12 and PRD34). Program with the desired timer period value - 1.
4. Enable the timer (ENAMODE12 in TCR).
5. If ENAMODE12 = 3h, write the desired timer period for the next timer cycle in the period reload registers (REL12 and REL34). Program with the desired timer period value - 1. This step can be done at any time before the current timer cycle ends.

30.2.1.4.2 Dual 32-Bit Timer Modes

Each of the general-purpose timers can be configured as dual 32-bit timers by configuring the TIMMODE bit in the timer global control register (TGCR). In dual 32-bit timer mode, the two 32-bit timers can be operated independently (unchained mode) or in conjunction with each other (chained mode).

30.2.1.4.2.1 Chained Mode

The general-purpose timers can each be configured as a dual 32-bit chained timer by setting the TIMMODE bit to 3h in TGCR.

In the chained mode (Figure 30-4), one 32-bit timer (timer 3:4) is used as a 32-bit prescaler and the other 32-bit timer (timer 1:2) is used as a 32-bit timer. The 32-bit prescaler is used to clock the 32-bit timer. The 32-bit prescaler uses one counter register (TIM34) to form a 32-bit prescale counter register and one period register (PRD34) to form a 32-bit prescale period register.

When the timer is enabled, the prescale counter starts incrementing by 1 at every timer input clock cycle. One cycle after the prescale counter matches the prescale period, a clock signal is generated and the prescale counter register is reset to 0 (see the example in Figure 30-5).

The other 32-bit timer (timer 1:2) uses one counter register (TIM12) to form a 32-bit timer counter register and one period register (PRD12) to form a 32-bit timer period register. This timer is clocked by the output clock from the prescaler. The timer counter increments by 1 at every prescaler output clock cycle. When the timer counter matches the timer period, a maskable timer interrupt (TINT12) and a timer EDMA event (TEVT12) are generated. When the timer is configured in continuous mode, the timer counter is reset to 0 on the cycle after the timer counter reaches the timer period. The timer can be stopped, restarted, reset, or disabled using the TIM12RS and TIM34RS bits in TGCR. In the chained mode, the upper 16-bits of the timer control register (TCR) are not used.

Figure 30-4. Dual 32-Bit Timers Chained Mode Block Diagram

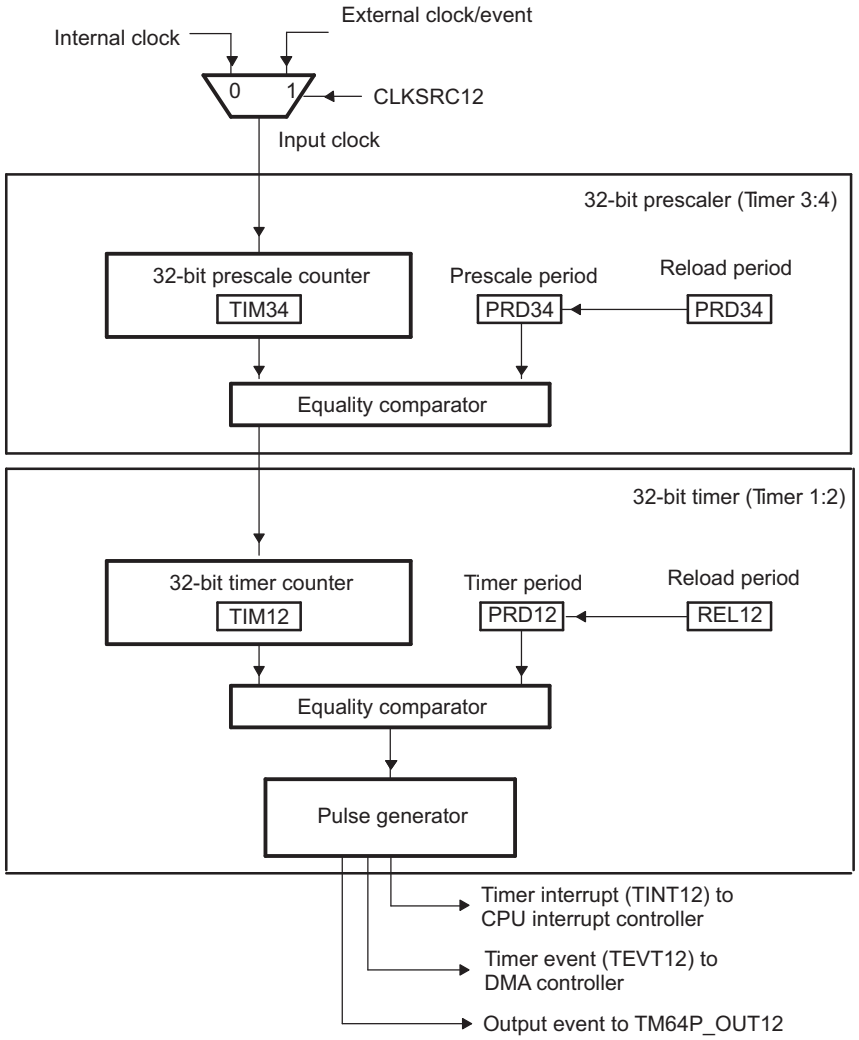
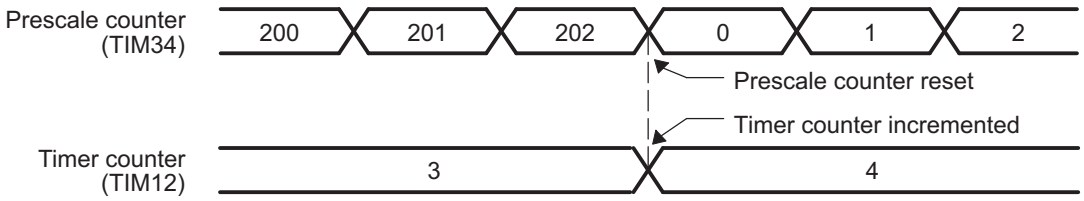


Figure 30-5. Dual 32-Bit Timers Chained Mode Example

32-bit prescaler settings: count = TIM34 = 200; period = PRD34 = 202
32-bit timer settings: count = TIM12 = 3; period = PRD12= 4



30.2.1.4.2.1.1 Enabling the 32-Bit Timer Chained Mode

The TIM12RS and TIM34RS bits in TGCR determine whether the timer is in reset, or if it is capable of operating. The TIM12RS bit controls the reset of the timer 1:2 side of the timer and the TIM34RS bits control the reset of the timer 3:4 side of the timer. For the timer to operate, the TIM12RS and TIM34RS bits must be set to 1.

The ENAMODE12 bit in the timer control register (TCR) controls whether the timer is disabled, enabled to run once, enabled to run continuously, or enabled to run continuously with period reload; the ENAMODE34 bit has no effect in 32-bit timer chained mode. When the timer is disabled (ENAMODE12 = 0), the timer does not run and maintains its current count value. When the timer is enabled for one time operation (ENAMODE12 = 1), it counts up until the counter value equals the period value and then stops. When the timer is enabled for continuous operation (ENAMODE12 = 2h), the counter counts up until it reaches the period value, then resets itself to zero and begins counting again. When the timer is enabled for continuous operation with period reload (ENAMODE12 = 3h), the counter counts up until it reaches the period value, then resets itself to zero, reloads the period registers (PRD12 and PRD34) with the value in the period reload registers (REL12 and REL34), and begins counting again.

Table 30-3 shows the bit values in TGCR to configure the 32-bit timer in chained mode.

Table 30-3. 32-Bit Timer Chained Mode Configurations

	TGCR Bit		TCR Bit
32-Bit Timer Configuration	**TIM12RS**	**TIM34RS**	**ENAMODE12**
To place the 32-bit timer chained mode in reset	0	0	0
To disable the 32-bit timer chained mode (out of reset)	1h	1h	0
To enable the 32-bit timer chained mode for one-time operation	1h	1h	1h
To enable the 32-bit timer chained mode for continuous operation	1h	1h	2h
To enable the 32-bit timer chained mode for continuous operation with period reload (Timer 3 only)	1h	1h	3h

Once the timer stops, if an external clock is used as the timer clock, the timer must remain disabled for at least one external clock period or the timer will not start counting again. When using the external clock, the count value is synchronized to the internal clock.

Note that when both the timer counter and timer period are cleared to 0, the timer can be enabled but the timer counter does not increment because the timer period is 0.

30.2.1.4.2.1.2 32-Bit Timer Chained Mode Configuration Procedure

To configure the GP timer to operate as a dual 32-bit chained mode timer, follow the steps below:

1. Select 32-bit chained mode (TIMMODE in TGCR).
2. Remove the timer from reset (TIM12RS and TIM34RS in TGCR).
3. Select the desired timer period (PRD12). Program with the desired timer period value - 1.
4. Select the desired timer prescaler value (PRD34).
5. Enable the timer (ENAMODE12 in TCR).
6. If ENAMODE12 = 3h, write the desired timer period for the next timer cycle in the period reload registers (REL12 and REL34). Program with the desired timer period value - 1. This step can be done at any time before the current timer cycle ends.

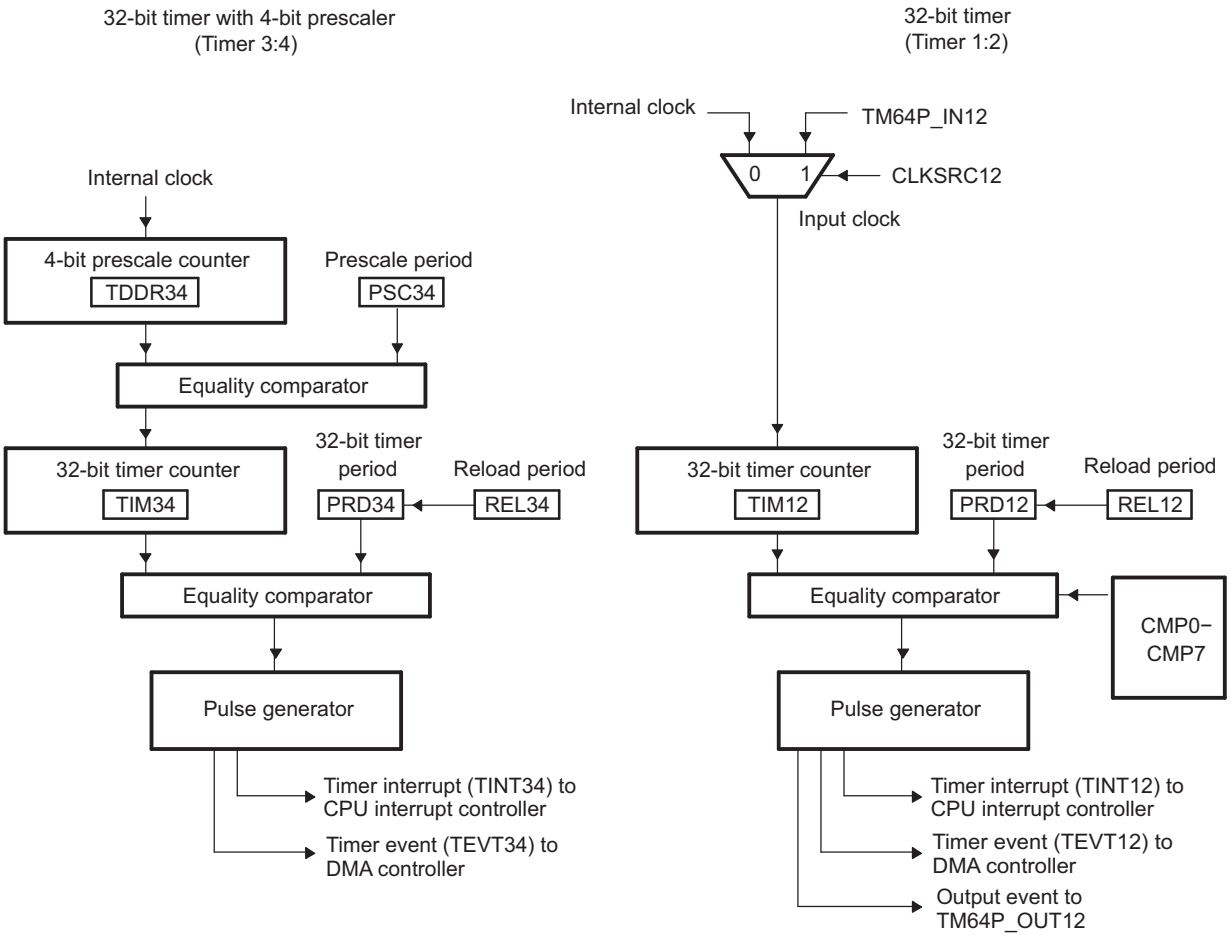
30.2.1.4.2.2 Unchained Mode

The general-purpose timers can be configured as a dual 32-bit unchained timers by setting the TIMMODE bit to 1 in TGCR.

In the unchained mode (Figure 30-6), the timer operates as two independent 32-bit timers. One 32-bit timer (timer 3:4) operates as a 32-bit timer being clocked by a 4-bit prescaler. The other 32-bit timer (timer 1:2) operates as a 32-bit timer with no prescaler.

Independent of the normal timer behavior, eight compare registers (CMP*n*) are compared against the value of the TIM12 register when the PLUSEN bit in TGCR is set. Upon a successful non-zero match, an interrupt and a DMA event are generated without affecting the TIM12 value, behavior, or associated counter registers. Note that some timer instantiations may not map the CMP interrupt and DMA events to the CPU and DMA engines (see your device-specific data manual for information).

Figure 30-6. Dual 32-Bit Timers Unchained Mode Block Diagram

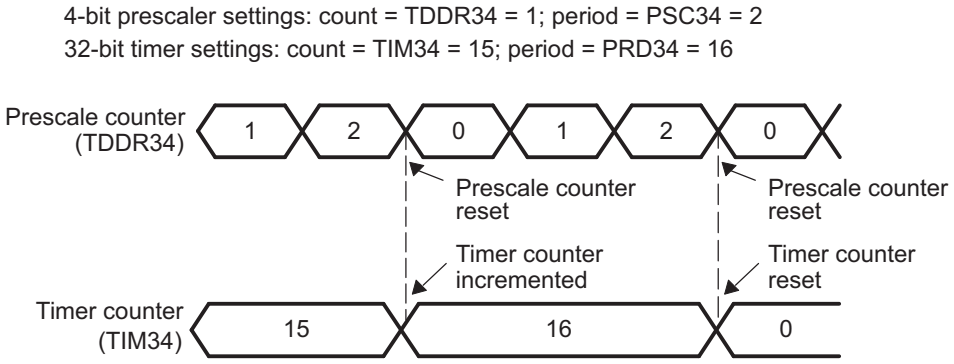


30.2.1.4.2.2.1 32-Bit Timer With a 4-Bit Prescaler

In the unchained mode, the 4-bit prescale is clocked by the internal clock. The 4-bit prescaler uses the timer divide-down ratio (TDDR34) bit in TGCR to form a 4-bit prescale counter register and the prescale counter bits (PSC34) to form a 4-bit prescale period register (see Figure 30-6). When the timer is enabled, the prescale counter starts incrementing by 1 at every timer input clock cycle. One cycle after the prescale counter matches the prescale period, a clock signal is generated for the 32-bit timer.

The 32-bit timer uses TIM34 as a 32-bit timer counter register and PRD34 as a 32-bit timer period register. The 32-bit timer is clocked by the output clock from the 4-bit prescaler (see the example in Figure 30-7). The timer counter increments by 1 at every prescaler output clock cycle. When the timer counter matches the period, a maskable timer interrupt (TINT34) and a timer DMA event (TEVT34) are generated. When the timer is configured in continuous mode, the timer counter is reset to 0 on the cycle after the timer counter reaches the timer period. The timer can be stopped, restarted, reset, or disabled using the TIM34RS bit in TGCR. For timer 3:4, the lower 16 bits of the timer control register (TCR) have no control.

Figure 30-7. Dual 32-Bit Timers Unchained Mode Example



30.2.1.4.2.2.2 32-Bit Timer with No Prescaler

The other 32-bit timer (timer 1:2) uses TIM12 as the 32-bit counter register and PRD12 as a 32-bit timer period register (see Figure 30-6). When the timer is enabled, the timer counter increments by 1 at every timer input clock cycle. When the timer counter matches the timer period, a maskable timer interrupt (TINT12), a timer DMA event (TEVT12), and a timer output event on TM64P_OUT12 are generated. When the timer is configured in continuous mode, the timer counter is reset to 0 on the cycle after the timer counter reaches the timer period. The timer can be stopped, restarted, reset, or disabled using the TIM12RS bit in TGCR. For timer 1:2, the upper 16 bit of the timer control register (TCR) have no control.

30.2.1.4.2.2.3 Enabling the 32-Bit Unchained Mode Timer

The TIM12RS and TIM34RS bits in TGCR determine whether the timer is in reset, or if it is capable of operating. The TIM12RS bit controls the reset of the timer 1:2 side of the timer and the TIM34RS bit controls the reset of the timer 3:4 side of the timer. For the timer to operate, the TIM12RS and/or TIM34RS bits must be set to 1.

The ENAMODE*n* bit in the timer control register (TCR) controls whether the timer is disabled, enabled to run once, or enabled to run continuously.

- When the timer is disabled (ENAMODE*n* = 0), the timer does not run and maintains its current count value.
- When the timer is enabled for one time operation (ENAMODE*n* = 1), it counts up until the counter value equals the period value and then stops.
- When the timer is enabled for continuous operation (ENAMODE*n* = 2h), the counter counts up until it reaches the period value, then resets itself to zero and begins counting again.
- When the timer is enabled for continuous operation with period reload (ENAMODE*n* = 3h), the counter counts up until it reaches the period value, then resets itself to zero, reloads the period registers (PRD12 and/or PRD34) with the value in the period reload registers (REL12 and/or REL34), and begins counting again.

Table 30-4 shows the bit values in TGCR to configure the 32-bit timer in unchained mode.

Once the timer stops, if an external clock is used as the timer clock, the timer must remain disabled for at least one external clock period or the timer will not start counting again. When using the external clock, the count value is synchronized to the internal clock.

Note that when both the timer counter and timer period are cleared to 0, the timer can be enabled but the timer counter does not increment because the timer period is 0.

Table 30-4. 32-Bit Timer Unchained Mode Configurations

	TGCR Bit		TCR Bit	
32-Bit Timer Configuration	**TIM12RS**	**TIM34RS**	**ENAMODE12**	**ENAMODE34**
To place the 32-bit timer unchained mode with 4-bit prescaler in reset	x	0	x	0
To disable the 32-bit timer unchained mode with 4-bit prescaler (out of reset)	x	1h	x	0
To enable the 32-bit timer unchained mode with 4-bit prescaler for one-time operation	x	1h	x	1h
To enable the 32-bit timer unchained mode with 4-bit prescaler for continuous operation	x	1h	x	2h
To enable the 32-bit timer unchained mode with 4-bit prescaler for continuous operation with period reload	x	1h	x	3h
To place the 32-bit timer unchained mode with no prescaler in reset	0	x	0	x
To disable the 32-bit timer unchained mode with no prescaler (out of reset)	1h	x	0	x
To enable the 32-bit timer unchained mode with no prescaler for one-time operation	1h	x	1h	x
To enable the 32-bit timer unchained mode with no prescaler for continuous operation	1h	x	2h	x
To enable the 32-bit timer unchained mode with no prescaler for continuous operation with period reload	1h	x	3h	x

30.2.1.4.2.2.4 32-Bit Timer Unchained Mode Configuration Procedure

To configure timer 1:2, follow the steps below:

1. Select 32-bit unchained mode (TIMMODE in TGCR).
2. Remove the timer 1:2 from reset (TIM12RS in TGCR).
3. Select the desired timer period for timer 1:2 (PRD12). Program with the desired timer period value - 1.
4. Select the desired clock source for timer 1:2 (CLKSRC12 in TCR).
5. Enable timer 1:2 (ENAMODE12 in TCR).
6. If ENAMODE12 = 3h, write the desired timer period for the next timer cycle in the period reload register (REL12). Program with the desired timer period value - 1. This step can be done at any time before the current timer cycle ends.

To configure timer 3:4, follow the steps below:

1. Select 32-bit unchained mode (TIMMODE in TGCR).
2. Remove the timer 3:4 from reset (TIM34RS in TGCR).
3. Select the desired timer period for timer 3:4 (PRD34). Program with the desired timer period value - 1.
4. Select the desired prescaler value for timer 3:4 (PSC34 in TGCR).
5. Enable timer 3:4 (ENAMODE34 in TCR).
6. If ENAMODE34 = 3h, write the desired timer period for the next timer cycle in the period reload register (REL34). Program with the desired timer period value - 1. This step can be done at any time before the current timer cycle ends.

30.2.1.4.2.2.5 Event Capture Mode

When the PLUSEN bit in the timer global control register (TGCR) is set, Event Capture Mode is available for TIM12 when the timer is configured in 32-bit unchained mode. When Event Capture Mode is enabled, the timer cycle is restarted when an external input event occurs on pin TM64P_IN12. In particular, when an external input event occurs, the timer stops counting, generates output events (TINT12, TEVT12, and TM64P_OUT12), copies values from the timer counter register TIM12 to the timer capture register CAP12, reloads the timer period register PRD12 if in continuous mode with period reload (ENAMODE = 3h), and then restarts counting in continuous mode. Event Capture Mode is available only when the timer clock source is the internal timer (CLKSRC = 0) and the timer is in continuous mode (ENAMODE = 2h or 3h).

Capture mode is enabled using the Capture mode enable bit CAPMODE12 in the timer control register (TCR). The type of input event is selected by the capture event mode bit CAPEVTMODE12 in the timer control register (TCR). All of the following input event types are available:

- Rising edge of input signal
- Falling edge of input signal
- Rising or falling edge of input signal

30.2.1.4.2.2.6 Timer Counter Register Read Reset Mode

Read Reset Mode is available when the PLUSEN bit in the timer global control register (TGCR) is set and the timer is configured in 32-bit unchained mode. When Read Reset Mode is enabled, the timer cycle will restart when the timer counter registers are read (TIM12 and/or TIM34). In particular, when the timer registers are read, the timer stops counting, copies values from the timer counter registers (TIM12 and/or TIM34) to the timer capture registers (CAP12 and/or CAP34), reloads the timer period registers (PRD12 and/or PRD34) if in continuous mode with period reload (ENAMODE = 3h), and then restarts counting in continuous mode. Timer output events (TINT*n*, TEVT*n*, and TM64P_OUT*n*) are not generated during this process. Read Reset Mode is enabled using the read reset mode enable bit (READRSTMODE) in the timer control register (TCR).

30.2.1.4.3 Timer Capture Registers

When the timer has a timeout due to a normal expiration of timer, external input event in Event Capture Mode, or read of timer counter registers in Read Reset Mode, the values of the timer counter registers (TIM12 and TIM34) are copied onto the timer counter capture registers (CAP12 and CAP34). Note that the value in TDDR is not captured when a read of TIM34 happens.

30.2.1.4.4 Counter and Period Registers Used in GP Timer Modes

Table 30-5 summarizes how the counter registers (TIM*n*) and period registers (PRD*n*) are used in each GP timer mode.

Table 30-5. Counter and Period Registers Used in GP Timer Modes

Timer Mode	Counter Registers	Period Registers
64-bit general-purpose	TIM34:TIM12	PRD34:PRD12
Dual 32-bit chained:		
Prescaler (Timer 3:4)	TIM34	PRD34
Timer (Timer 1:2)	TIM12	PRD12
Dual 32-bit unchained:		
Timer (Timer 1:2)	TIM12	PRD12
Timer with prescaler (Timer 3:4)	TDDR34 bits and TIM34	PSC34 bits and PRD34

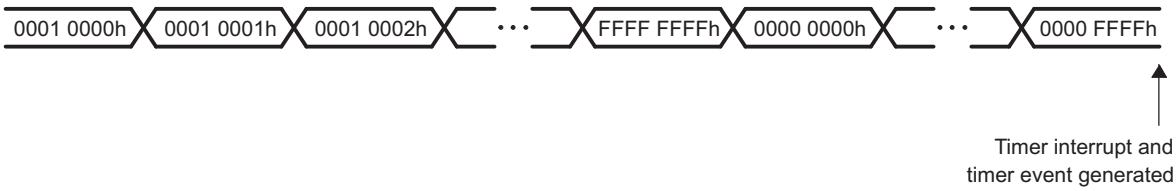
30.2.1.5 Timer Operation Boundary Conditions

The following boundary conditions affect the timer operation.

30.2.1.5.1 Timer Counter Overflow

Timer counter overflow can happen when the timer counter register is set to a value greater than the value in the timer period register. The counter reaches its maximum value (FFFF FFFFh or FFFF FFFF FFFF FFFFh), rolls over to 0, and continues counting until it reaches the timer period. An example is in Figure 30-8.

Figure 30-8. 32-Bit Timer Counter Overflow Example



30.2.1.5.2 Writing to Registers of an Active Timer

Writes to most timer registers are not allowed when the timer is active, except for setting the timer period reload registers (REL12 and REL34) and stopping and resetting the timers. In the 64-bit and dual 32-bit timer modes, registers that are protected by hardware are:

- TIM12
- TIM34
- PRD12
- PRD34
- TCR (except the ENAMODE bit)
- TGCR (except the TIM12RS and TIM34RS bits)

30.2.1.6 General-Purpose Timer Power Management

The timer can be placed in reduced power modes to conserve power during periods of low activity. The power management of the peripheral is controlled by the processor Power and Sleep Controller (PSC). The PSC acts as a master controller for power management for all of the peripherals on the device. For detailed information on power management procedures using the PSC, see the *Power and Sleep Controller (PSC)* chapter. The timer can be placed in an idle mode to conserve power when it is not being used.

30.2.2 Architecture – Watchdog Timer Mode

This section describes the use of the timer as a watchdog timer. In order to fully function in watchdog timer mode, the timer must be internally connected to the device hardware reset signal. For information on which timer instantiation can function as a watchdog timer, see your device-specific data manual.

30.2.2.1 Watchdog Timer

As a 64-bit watchdog timer, the peripheral can be used to prevent system lockup when the software becomes trapped in loops with no controlled exit.

After a hardware reset, the watchdog timer is disabled. The timer then can be configured as a watchdog timer using the timer mode (TIMMODE) bit in the timer global control register (TGCR) and the watchdog timer enable (WDEN) bit in the watchdog timer control register (WDTCR). In the watchdog timer mode, the timer requires a special service sequence to be executed periodically. Without this periodic servicing, the timer counter increments until it matches the timer period and causes a watchdog timeout event.

When the timeout event occurs, the watchdog timer resets the entire processor.

30.2.2.2 Watchdog Timer Mode Restrictions

The watchdog timer mode has the following restrictions:

- No external clock source
- No one-time enabling

30.2.2.3 Watchdog Timer Mode Operation

The watchdog timer mode is selected and enabled when:

- TIMMODE = 2h in TGCR
- WDEN = 1 in WDTCR

Figure 30-9 shows the timer when it is used in the watchdog timer mode. The counter registers (TIM12 and TIM34) form a 64-bit timer counter register and the period registers (PRD12 and PRD34) form a 64-bit period register. When the timer counter matches the timer period, the timer generates a watchdog timeout event which resets the entire processor.

To activate the watchdog timer, a certain sequence of events must be followed, as shown in the state diagram of Figure 30-10.

Once the watchdog timer is activated, it can be disabled only by a watchdog timeout event or by a hardware reset. A special key sequence is required to prevent the watchdog timer from being accidentally serviced while the software is trapped in a loop or by some other software failure.

To prevent a watchdog timeout event, the timer has to be serviced periodically by writing A5C6h followed by DA7Eh to the watchdog timer service key (WDKEY) bits in WDTCR before the timer finishes counting up. Both A5C6h and DA7Eh are allowed to be written to the WDKEY bits, but only the correct sequence of A5C6h followed by DA7Eh to the WDKEY bits services the watchdog timer. Any other writes to the WDKEY bits triggers the watchdog timeout event immediately.

When the watchdog timer is in the Timeout state, the watchdog timer is disabled, the WDEN bit is cleared to 0, and the timer is reset.

Figure 30-9. Watchdog Timer Mode Block Diagram

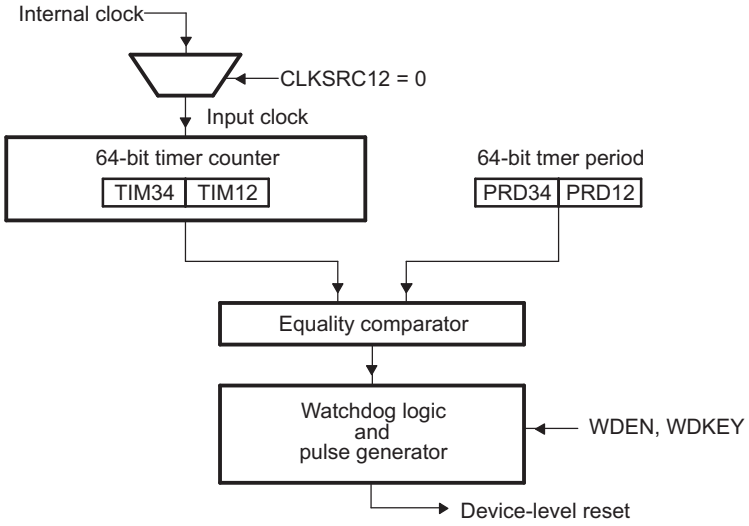
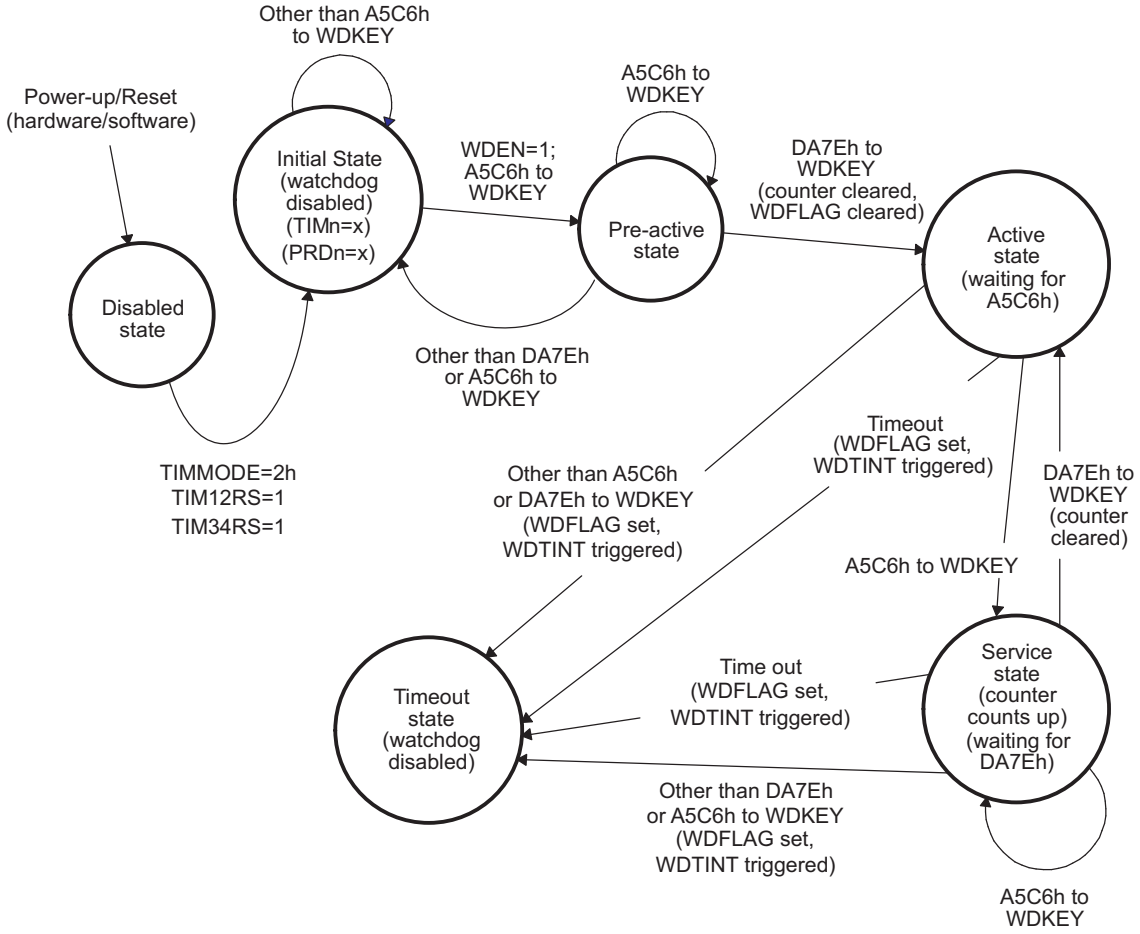


Figure 30-10. Watchdog Timer Operation State Diagram



After a hardware reset, the watchdog timer is disabled; however, reads or writes to the watchdog timer registers are allowed. Once the WDEN bit is set (enabling the watchdog timer) and A5C6h is written to the WDKEY bits, the watchdog timer enters the Pre-active state. In the Pre-active state:

- A write to WDTCR is allowed only when the write comes with the correct key (A5C6h or DA7Eh) to the WDKEY bits.
- A write of DA7Eh to the WDKEY bits when the WDEN bit is set to 1 resets the counters and activates the watchdog timer.

The watchdog timer must be configured before the watchdog timer enters the Active state. The WDEN bit must be set to 1 before writing DA7Eh to the WDKEY bits in the Pre-active state. Every time the watchdog timer is serviced by the correct WDKEY sequence, the watchdog timer counter is automatically reset.

30.2.2.4 Watchdog Timer Register Write Protection

Once the watchdog timer enters the Pre-active state (see Figure 30-10), writes to TIM12, TIM34, PRD12, PRD34, and WDTCR are write protected (except for the WDKEY field). While the watchdog timer is in the Timeout state, writing to the WDEN bit has no effect.

Once the watchdog timer enters its Initial state (see Figure 30-10), do not write to TGCR.

30.2.2.5 Watchdog Timer Power Management

The watchdog timer cannot be placed in power-down mode.

30.2.3 Reset Considerations

The timer has two reset sources: hardware reset and the timer reset (TIM12RS and TIM34RS) bits in the timer global control register (TGCR).

30.2.3.1 Software Reset Considerations

When the TIM12RS bit in TGCR is cleared to 0, the TIM12 register is held with the current value.

When the TIM34RS bit in TGCR is cleared to 0, the TIM34 register is held with the current value.

30.2.3.2 Hardware Reset Considerations

When a hardware reset is asserted, all timer registers are set to their default values.

30.2.4 Interrupt Support

Each of the timers can send either one of two separate interrupt events (TINT*n*) to the CPU, depending on the operating mode of the timer. The timer interrupts are generated when the count value in the counter register reaches the value specified in the period register.

When the PLUSEN bit in the timer global control register (TGCR) is set, matches between TIM12 and CMP*n* in dual 32-bit unchained mode will also generate interrupts. Setting the PLUSEN bit also enables additional features for control, status, and generation of interrupts. See Section 30.2.8 for more information.

30.2.5 DMA Event Support

Each of the timers can send either one of two separate timer events (TEVT*n*) to the DMA engine, depending on the operating mode of the timer. The timer events are generated when the count value in the counters register reaches the value specified in the period register.

When the PLUSEN bit in the timer global control register (TGCR) is set, matches between TIM12 and CMP*n* in dual 32-bit unchained mode will also generate DMA events. Setting the PLUSEN bit also enables additional features for control, status, and generation of dma events are enabled. See Section 30.2.8 for more information.

30.2.6 TM64P_OUT Event Support

The timer can generate an output pulse (Figure 30-11) or clock (Figure 30-12) signals on the TM64P_OUT12 pin. The output signal is generated when the count value in the counter registers reaches the value specified in the period registers (TSTAT12 drives the TM64P_OUT12 pin). Table 30-6 gives equations for various TSTAT12 timing parameters in pulse and clock modes.

The output mode is selected with the clock/pulse bit (CP*n*) in the timer control register (TCR). In pulse mode, the PWID12 bit in TCR sets the pulse width between 1 to 4 timer clock periods. The TM64P_OUT12 pin may be inverted using the INVOUTP12 bit in TCR.

Figure 30-11. Timer Operation in Pulse Mode (CP*n* = 0)

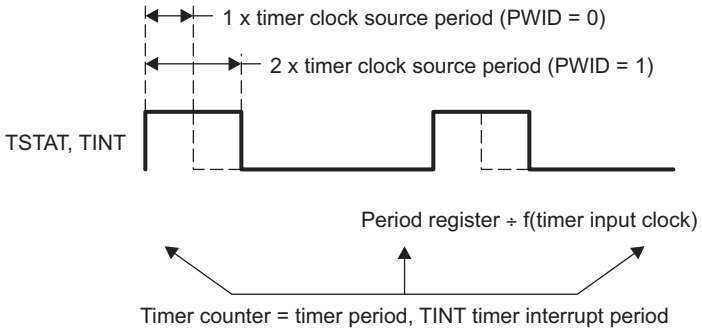


Figure 30-12. Timer Operation in Clock Mode (CP*n* = 1)

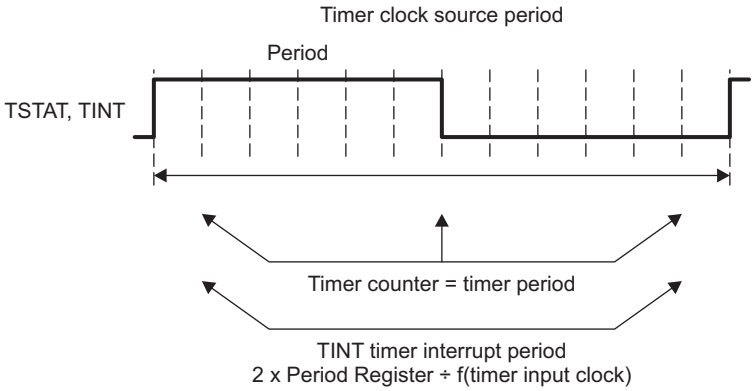


Table 30-6. TSTAT Parameters in Pulse and Clock Modes

Mode	Frequency	Period	Width High	Width Low
Pulse	$\frac{f\ (clock\ source)}{timer\ period\ register}$	$\frac{timer\ period\ register}{f\ (clock\ source)}$	$\frac{(PWID + 1)}{f\ (clock\ source)}$	$\frac{timer\ period\ register - (PWID + 1)}{f\ (clock\ source)}$
Clock	$\frac{f\ (clock\ source)}{2 \times timer\ period\ register}$	$\frac{2 \times timer\ period\ register}{f\ (clock\ source)}$	$\frac{timer\ period\ register}{f\ (clock\ source)}$	$\frac{timer\ period\ register}{f\ (clock\ source)}$

30.2.7 External Timer Pin GPIO Mode

The external timer pins (TM64P_IN12 and TM64P_OUT12) can be individually configured to function as general-purpose input/output (GPIO) pins. In GPIO mode, the pins are able to detect and drive arbitrary data. The pins are also able to source external interrupt events. Some timer instantiations may not have external pins, see your device-specific data manual for pin information.

The GPIO interrupt and GPIO enable register (GPINTGPEN) enables the GPIO mode and associated interrupts. The GPIO data and GPIO direction register (GPDATGPDIR) determines if GPIO-enabled pins are used as input or output pins; and it is the means by which data is read-from or written-to the GPIO pins.

Normal timer counting modes cannot be used when the GPIO mode is enabled -- TIM12RS in the timer global control register (TGCR) cannot be brought out of reset when either GPENO12 or GPENI12 in GPINTGPEN is asserted.

30.2.8 Interrupt/DMA Event Generation Control and Status

When the PLUSEN bit in the timer global control register (TGCR) is set, the timer supports additional features for control and status of interrupt and DMA event generation. Interrupt/DMA events are generated when the count value in the timer counter registers reaches the value specified in the timer period registers and interrupt/DMA events are also generated when the Event Capture Mode is enabled and an external event occurs.

To generate events in the case when the value in the timer counter registers equals the value specified in the timer period registers, set the period compare interrupt enable bit (PRDINTEN*n*) in the interrupt control and status register (INTCTLSTAT). The event status for this case is reflected in the period compare interrupt status bit (PRDINTSTAT*n*), which is also in INTCTLSTAT. The PRDINTSTAT*n* bit is cleared by writing a 1 to the bit.

Similarly, to generate events in Event Capture Mode, set the event interrupt enable bit (EVTINTEN*n*) in INTCTLSTAT. The event status for this case is reflected in the external interrupt status bit (EVTINTSTAT*n*) in INTCTLSTAT. The EVTINTSTAT*n* bit is cleared by writing a 1 to the bit.

30.2.9 Power Management

The general-purpose timers can be placed in reduced power modes to conserve power during periods of low activity. The power management of the peripheral is controlled by the processor Power and Sleep Controller (PSC). The PSC acts as a master controller for power management for all of the peripherals on the device. For detailed information on power management procedures using the PSC, see the *Power and Sleep Controller (PSC)* chapter.

30.2.10 Emulation Considerations

Each timer has an emulation management register (EMUMGT). As shown in Table 30-7, the FREE and SOFT bits of EMUMGT determine how the timer responds to an emulation suspend event. An emulation suspend event corresponds to any type of emulator access to the CPU, such as a hardware or software breakpoint or a probe point.

Note that during emulation, the timer count values will increment once every timer peripheral clock (not CPU clock). So when single-steeping though code, the timer values will not update on every CPU clock cycle.

The timer can respond to emulation events from the CPU based on the configuration of the Emulation Suspend Source Register (SUSPSRC) in the System Configuration Module. See the *System Configuration (SYSCFG) Module* chapter for information on SUSPSRC and how it is configured.

Table 30-7. Timer Emulation Modes Selection

FREE	SOFT	Emulation Mode
0	0	The timer stops immediately.
0	1	The timer stops when the timer counter value increments and reaches the value in the timer period register.
1	x	The timer runs free regardless of SOFT bit status.

30.3 Registers

Table 30-8 lists the memory-mapped registers for the 64-bit Timer Plus. See your device-specific data manual for the memory address of these registers. All other register offset addresses not listed in Table 30-8 should be considered as reserved locations and the register contents should not be modified.

Table 30-8. Timer Registers

Offset	Acronym	Register Description	Section
0h	REVID	Revision ID Register	Section 30.3.1
4h	EMUMGT	Emulation Management Register	Section 30.3.2
8h	GPINTGPEN	GPIO Interrupt and GPIO Enable Register	Section 30.3.3
Ch	GPDATGPDIR	GPIO Data and GPIO Direction Register	Section 30.3.4
10h	TIM12	Timer Counter Register 12	Section 30.3.5
14h	TIM34	Timer Counter Register 34	Section 30.3.5
18h	PRD12	Timer Period Register 12	Section 30.3.6
1Ch	PRD34	Timer Period Register 34	Section 30.3.6
20h	TCR	Timer Control Register	Section 30.3.7
24h	TGCR	Timer Global Control Register	Section 30.3.8
28h	WDTCR	Watchdog Timer Control Register	Section 30.3.9
34h	REL12	Timer Reload Register 12	Section 30.3.10
38h	REL34	Timer Reload Register 34	Section 30.3.11
3Ch	CAP12	Timer Capture Register 12	Section 30.3.12
40h	CAP34	Timer Capture Register 34	Section 30.3.13
44h	INTCTLSTAT	Timer Interrupt Control and Status Register	Section 30.3.14
60h	CMP0	Compare Register 0	Section 30.3.15
64h	CMP1	Compare Register 1	Section 30.3.15
68h	CMP2	Compare Register 2	Section 30.3.15
6Ch	CMP3	Compare Register 3	Section 30.3.15
70h	CMP4	Compare Register 4	Section 30.3.15
74h	CMP5	Compare Register 5	Section 30.3.15
78h	CMP6	Compare Register 6	Section 30.3.15
7Ch	CMP7	Compare Register 7	Section 30.3.15

30.3.1 Revision ID Register (REVID)

The revision ID register (REVID) contains the peripheral revision. The REVID is shown in Figure 30-13 and described in Table 30-9.

Figure 30-13. Revision ID Register (REVID)

31	0
REV	
R-4472 020Ch	

LEGEND: R = Read only; -*n* = value after reset

Table 30-9. Revision ID Register (REVID) Field Descriptions

Bit	Field	Value	Description
31-0	REV	4472 020Ch	Revision ID of the Timer.

30.3.2 Emulation Management Register (EMUMGT)

The emulation management register (EMUMGT) is shown in Figure 30-14 and described in Table 30-10.

Figure 30-14. Emulation Management Register (EMUMGT)

31	16
Reserved	
R-0	

15	2	1	0
Reserved		SOFT	FREE
R-0		R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 30-10. Emulation Management Register (EMUMGT) Field Descriptions

Bit	Field	Value	Description
31-2	Reserved	0	Reserved
1	SOFT		Determines emulation mode functionality of the timer. When the FREE bit is cleared to 0, the SOFT bit selects the timer mode.
		0	The timer stops immediately.
		1	The timer stops when the counter increments and reaches the value in the timer period register (PRD*n*).
0	FREE		Determines emulation mode functionality of the timer. When the FREE bit is cleared to 0, the SOFT bit selects the timer mode.
		0	The SOFT bit selects the timer mode.
		1	The timer runs free regardless of the SOFT bit.

30.3.3 GPIO Interrupt Control and Enable Register (GPINTGPEN)

The GPIO interrupt control and enable register (GPINTGPEN) is shown in Figure 30-15 and described in Table 30-11.

Figure 30-15. GPIO Interrupt Control and Enable Register (GPINTGPEN)

31	30	29	28	27	26	25	24
Reserved							
R/W-0							

23	22	21	20	19	18	17	16
Reserved						GPENO12	GPENI12
R/W-0						R/W-0	R/W-0

15	14	13	12	11	10	9	8
Reserved							
R/W-0							

7	6	5	4	3	2	1	0
Reserved		GPINT12INVO	GPINT12INVI	Reserved		GPINT12ENO	GPINT12ENI
R-0		R/W-0	R/W-0	R-0		R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; *-n* = value after reset

Table 30-11. GPIO Interrupt Control and Enable Register (GPINTGPEN) Field Descriptions

Bit	Field	Value	Description
31-18	Reserved	0	Reserved
17	GPENO12		Enable TM64P_OUT12 to function in GPIO mode.
		0	TM64P_OUT12 is used as a TIMER output pin.
		1	TM64P_OUT12 is used as a GPIO pin.
16	GPENI12		Enable TM64P_IN12 to function in GPIO mode
		0	TM64P_IN12 is used as a TIMER input pin.
		1	TM64P_IN12 is used as a GPIO pin.
15-6	Reserved	0	Reserved
5	GPINT12INVO		Invert interrupt/event signal from TM64P_OUT12 when GPINT12ENO = 1.
		0	Rising signal edge on TM64P_OUT12 generates the interrupt/event.
		1	Falling signal edge on TM64P_OUT12 generates the interrupt/event.
4	GPINT12INVI		Invert interrupt/event signal for TM64P_IN12 when GPINT12ENI = 1.
		0	Rising signal edge on TM64P_IN12 generates the interrupt/event.
		1	Falling signal edge on TM64P_IN12 generates the interrupt/event.
3-2	Reserved	0	Reserved
1	GPINT12ENO		Enable TM64P_OUT12 to source interrupts/events in GPIO mode.
		0	Timer interrupts/events are sourced in TIMER mode.
		1	Timer interrupts/events are sourced externally from TM64P_OUT12.
0	GPINT12ENI		Enable TM64P_IN12 to source interrupts/events in GPIO mode.
		0	Timer interrupts/events are sourced in TIMER mode.
		1	Timer interrupts/events are sourced externally from TM64P_IN12.

30.3.4 GPIO Data and Direction Register (GPDATGPDIR)

The GPIO data and direction register (GPDATGPDIR) is shown in Figure 30-16 and described in Table 30-12.

Figure 30-16. GPIO Data and Direction Register (GPDATGPDIR)

31	18	17	16
Reserved		GPDIRO12	GPDIRI12
R/W-0		R/W-0	R/W-0

15	2	1	0
Reserved		GPDATO12	GPDATI12
R/W-0		R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 30-12. GPIO Data and Direction Register (GPDATGPDIR) Field Descriptions

Bit	Field	Value	Description
31-18	Reserved	0	Reserved
17	GPDIRO12		Select direction of TM64P_OUT12 in GPIO mode.
		0	TM64P_OUT12 functions as an input pin in GPIO mode.
		1	TM64P_OUT12 functions as an output pin in GPIO mode (TM64P_OUT12 cannot capture GPIO interrupt events when configured as output).
16	GPDIRI12		Select direction of TM64P_IN12 in GPIO mode.
		0	TM64P_IN12 functions as an input pin in GPIO mode.
		1	TM64P_IN12 functions as an output pin in GPIO mode (TM64P_IN12 cannot capture GPIO interrupt events when configured as output).
15-2	Reserved	0	Reserved
1	GPDATO12		Data on TM64P_OUT12 in GPIO mode. Only valid when GPENO12 = 1.
			When GPDIRO12 = 0 (input):
		0	TM64P_OUT12 is detected logic low.
		1	TM64P_OUT12 is detected logic high.
			When GPDIRO12 = 1 (output):
		0	TM64P_OUT12 is driven logic low.
		1	TM64P_OUT12 is driven logic high.
0	GPDATI12		Data on TM64P_IN12 in GPIO mode. Only valid when GPENI12 = 1.
			When GPDIRI12 = 0 (input):
		0	TM64P_IN12 is detected logic low.
		1	TM64P_IN12 is detected logic high.
			When GPDIRI12 = 1 (output):
		0	TM64P_IN12 is driven logic low.
		1	TM64P_IN12 is driven logic high.

30.3.5 Timer Counter Registers (TIM12 and TIM34)

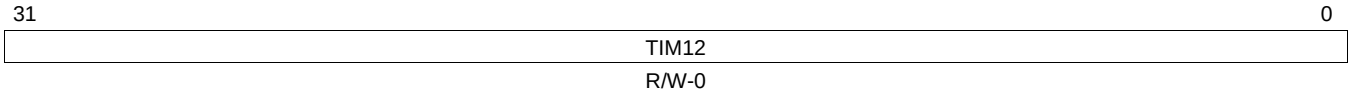
The timer counter register is a 64-bit wide register. This 64-bit register is divided into two 32-bit registers, TIM12 and TIM34.

In the dual 32-bit timer mode, the 64-bit register is divided with TIM12 acting as one 32-bit counter and TIM34 acting as another. These two registers can be configured as chained or unchained.

30.3.5.1 Timer Counter Register 12 (TIM12)

The timer counter register 12 (TIM12) is shown in Figure 30-17 and described in Table 30-13

Figure 30-17. Timer Counter Register 12 (TIM12)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

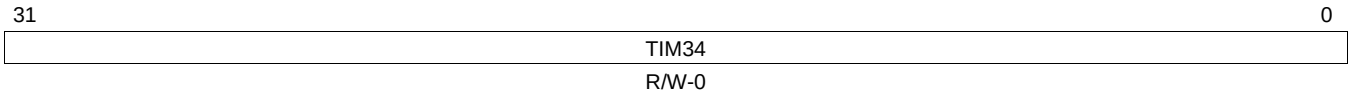
Table 30-13. Timer Counter Register 12 (TIM12) Field Descriptions

Bit	Field	Value	Description
31-0	TIM12	0-FFFF FFFFh	TIM12 count bits. This 32-bit value is the current count of the main counter.

30.3.5.2 Timer Counter Register 34 (TIM34)

The timer counter register 34 (TIM34) is shown in Figure 30-18 and described in Table 30-14.

Figure 30-18. Timer Counter Register 34 (TIM34)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 30-14. Timer Counter Register 34 (TIM34) Field Descriptions

Bit	Field	Value	Description
31-0	TIM34	0-FFFF FFFFh	TIM34 count bits. This 32-bit value is the current count of the main counter.

30.3.6 Timer Period Registers (PRD12 and PRD34)

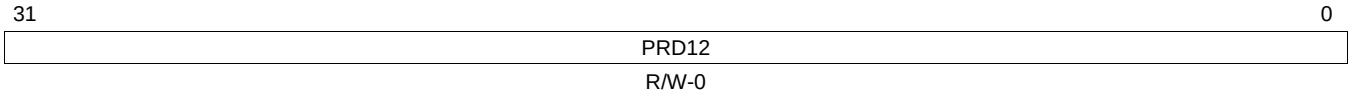
The timer period register is a 64-bit wide register. This 64-bit register is divided into two 32-bit registers, PRD12 and PRD34.

Similar to TIM*n* in the dual 32-bit timer mode, PRD*n* can be divided into 2 registers: for timer 1:2, PRD12 and for timer 3:4, PRD34. These two registers can be used in conjunction with the two timer counter registers TIM12 and TIM34.

30.3.6.1 Timer Period Register 12 (PRD12)

The timer period register 12 (PRD12) is shown in Figure 30-19 and described in Table 30-15.

Figure 30-19. Timer Period Register 12 (PRD12)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

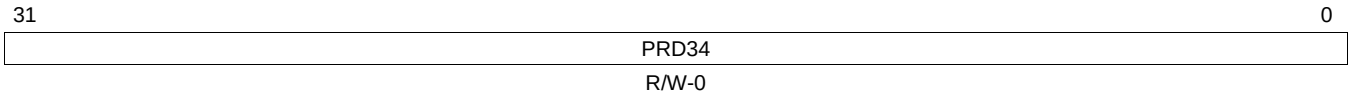
Table 30-15. Timer Period Register (PRD12) Field Descriptions

Bit	Field	Value	Description
31-0	PRD12	0-FFFF FFFFh	PRD12 period bits. This 32-bit value is the number of timer input clock cycles to count.

30.3.6.2 Timer Period Register 34 (PRD34)

The timer period register 34 (PRD34) is shown in Figure 30-20 and described in Table 30-16.

Figure 30-20. Timer Period Register 34 (PRD34)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 30-16. Timer Period Register (PRD34) Field Descriptions

Bit	Field	Value	Description
31-0	PRD34	0-FFFF FFFFh	PRD34 period bits. This 32-bit value is the number of timer input clock cycles to count.

30.3.7 Timer Control Register (TCR)

The timer control register (TCR) is shown in Figure 30-21 and described in Table 30-17.

Figure 30-21. Timer Control Register (TCR)

31	27	26	25	24
Reserved		READRSTMODE34	Reserved	
R/W-0		R/W-0	R/W-0	

23	22	21	16
ENAMODE34		Reserved	
R/W-0		R/W-0	

15	14	13	12	11	10	9	8
Reserved		CAPVTMODE12		CAPMODE12	READRSTMODE12	TIEN12	CLKSRC12
R-0		R/W-0		R/W-0	R/W-0	R/W-0	R/W-0

7	6	5	4	3	2	1	0
ENAMODE12		PWID12		CP12	INVINP12	INVOUTP12	TSTAT12
R/W-0		R/W-0		R/W-0	R/W-0	R/W-0	R-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 30-17. Timer Control Register (TCR) Field Descriptions

Bit	Field	Value	Description
31-27	Reserved	0	Reserved
26	READRSTMODE34		Read reset mode enable bit. Determines the effect of a timer counter read on TIM34. Read reset mode is only available in dual 32-bit unchained. Output events (interrupt/EDMA/other) are not generated when read reset occurs.
		0	There is no effect when timer counter register TIM34 is read.
		1	Timer counter is reset when timer counter register TIM34 is read.
25-24	Reserved	0	Reserved
23-22	ENAMODE34	0-3h	Enabling mode: determines the enabling modes fo the timer.
		0	The timer is disabled (not counting) and maintains current value.
		1h	The timer is enabled one time. The timer stops after the counter reaches the period.
		2h	The timer is enabled continuously, TIM34 increments until the timer counter matches the period, resets the timer counter to 0 on the cycle after matching and continues.
		3h	The timer is enabled continuously with period reload, TIM*n* increments until the timer counter matches the period, resets the timer counter to 0 on the cycle after matching, reloads the period register with the values in the reload registers (REL*n*), and continues counting.
21-14	Reserved	0	Reserved
13-12	CAPEVTMODE12	0-3h	Capture event mode. Uses these bits to specify the type of event for Capture mode.
		0	Event occurs on timer input rising edge.
		1h	Event occurs on time input falling edge.
		2h	Event occurs on both rising and falling edges.
		3h	Reserved
11	CAPMODE12		Capture mode enable bit. Determines if external event can reset timer. Capture mode is only available in dual 32-bit unchained mode and when CLKSRC = 0 and ENAMODE = 2h or 3h. Output events (interrupt/EDMA/other) are generated when capture mode event occurs.
		0	Timer is not in capture mode.
		1	Timer is in capture mode. External event can reset timer.
10	READRSTMODE12		Read reset mode enable bit. Determines the effect of a timer counter read on TIM12. Read reset mode is only available in dual 32-bit unchained. Output events (interrupt/EDMA/other) are not generated when read reset occurs.
		0	There is no effect when timer counter register TIM12 is read.
		1	Timer counter is reset when timer counter register TIM12 is read.

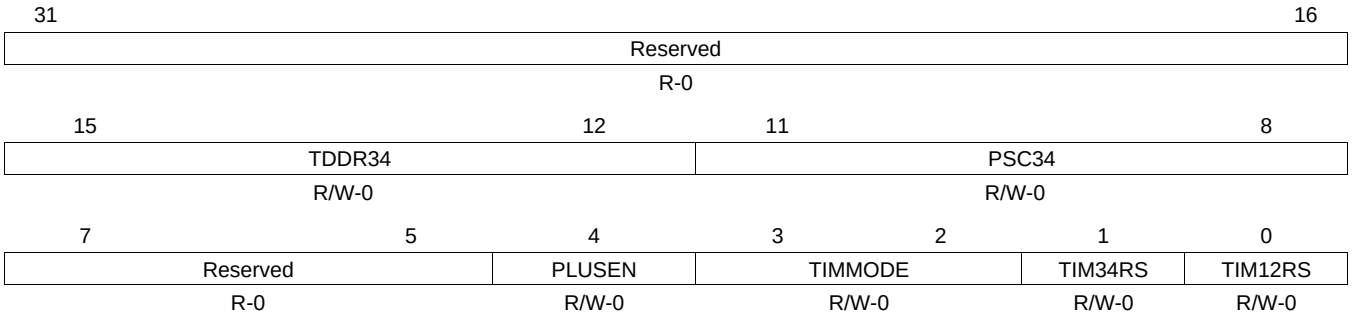
Table 30-17. Timer Control Register (TCR) Field Descriptions (continued)

Bit	Field	Value	Description
9	TIEN12		Timer input gate enable bit. Allows timer input pin TM64P_IN12 to gate the internal timer clock source (CLKSRC = 0). Timer starts counting when TM64P_IN12 transitions from low to high. Timer stops counting when TM64P_IN12 transitions from high to low.
		0	Timer clock is not gated by TM64P_IN12.
		1	Timer clock is gated by TM64P_IN12.
8	CLKSRC12		CLKSRC determines the selected clock source for the timer.
		0	Internal clock
		1	External clock on TM64P_IN12
7-6	ENAMODE12	0-3h	Enabling mode: determines the enabling modes fo the timer.
		0	The timer is disabled (not counting) and maintains current value.
		1h	The timer is enabled one time. The timer stops after the counter reaches the period.
		2h	The timer is enabled continuously, TIM*n* increments until the timer counter matches the period, resets the timer counter to 0 on the cycle after matching and continues.
		3h	The timer is enabled continuously with period reload, TIM*n* increments until the timer counter matches the period, resets the timer counter to 0 on the cycle after matching, reloads the period register with the values in the reload registers (REL*n*), and continues counting.
5-4	PWID12	0-3h	Pulse width - Determines the pulse width on the TSTAT12 bit (and the TM64P_OUT12 pin) when the clock/pulse mode is set to pulse.
		0	TSTAT12 stays active for one timer clock cycle when the timer counter reaches the period.
		1h	TSTAT12 stays active for two timer clock cycles when the timer counter reaches the period.
		2h	TSTAT12 stays active for three timer clock cycles when the timer counter reaches the period.
		3h	TSTAT12 stays active for four timer clock cycles when the timer counter reaches the period.
3	CP12		Clock/Pulse bit - Determines whether the TM64P_OUT12 output event should behave as a 50% duty-cycle clock or a signal pulse.
		0	Pulse Mode. TM64P_OUT12 goes active after the timer counter reaches the period. The pulse width is determined by PWID12.
		1	Clock Mode. TM64P_OUT12 will behave as a 50% duty cycle signal. It toggles high-to-low or low-to-high when the timer counter reaches zero.
2	INVINP12		Invert TM64P_IN12. Only affects operation if CLKSRC = 1.
		0	Uninverted TM64P_IN12 signal drives timer.
		1	Inverted TM64P_IN12 signal drives timer.
1	INVOUTP12		Invert TM64P_OUT12.
		0	TM64P_OUT12 signal is not inverted.
		1	TM64P_OUT12 signal is inverted.
0	TSTAT12		Timer status. Drives the value of timer output TM64P_OUT12 when it is configured to function as timer output.
		0	TM64P_OUT12 signal is not asserted.
		1	TM64P_OUT12 signal is asserted.

30.3.8 Timer Global Control Register (TGCR)

The timer global control register (TGCR) is shown in Figure 30-22 and described in Table 30-18.

Figure 30-22. Timer Global Control Register (TGCR)



LEGEND: R/W = Read/Write; R = Read only; *-n* = value after reset

Table 30-18. Timer Global Control Register (TGCR) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	Reserved
15-12	TDDR34	0-Fh	Timer linear divide-down ratio specifies the timer divide-down ratio for timer 3:4. When the timer is enabled, TDDR34 increments every timer clock. The TIM34 counter increments on the cycle after TDDR34 matches PSC34. TDDR34 resets to 0 and continues. When TIM34 matches PRD34, timer 3:4 stops, if timer 3:4 is enabled one time; TIM34 resets to 0 on the cycle after matching PRD34 and timer 3:4 continues, if timer 3:4 is enabled continuously.
11-8	PSC34	0-Fh	TIM34 pre-scalar counter specifies the count for timer 3:4.
7-5	Reserved	0	Reserved
4	PLUSEN		Enable new timer plus features.
		0	Enable backward compatibility. New timer features are unavailable.
		1	Disable backward compatibility. New timer features are available.
3-2	TIMMODE	0-3h	TIMMODE determines the timer mode.
		0	The timer is in 64-bit GP timer mode.
		1h	The timer is in dual 32-bit timer unchained mode.
		2h	The timer is in 64-bit watchdog timer mode.
		3h	The timer is in dual 32-bit timer, chained mode.
1	TIM34RS		Timer 3:4 reset.
		0	Timer 3:4 is in reset.
		1	Timer 3:4 is not in reset. Timer 3:4 can be used as a 32-bit timer. Note that for the timer to function properly in 64-bit timer mode, both TIM34RS and TIM12RS must be set to 1. Changing this bit does not affect the timer, if the timer is in the watchdog active state.
0	TIM12RS		Timer 1:2 reset.
		0	Timer 1:2 is in reset.
		1	Timer 1:2 is not in reset. Timer 1:2 can be used as a 32-bit timer. Note that for the timer to function properly in 64-bit timer mode, both TIM34RS and TIM12RS must be set to 1. Changing this bit does not affect the timer, if the timer is in the watchdog active state.

30.3.9 Watchdog Timer Control Register (WDTCR)

The watchdog timer control register (WDTCR) is shown in Figure 30-23 and described in Table 30-19.

Figure 30-23. Watchdog Timer Control Register (WDTCR)

31					16
WDKEY					
R/W-0					

15	14	13	12	11	0
WDFLAG	WDEN	Reserved		Reserved	
R/W-0	R/W-0	R/W-0		R-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

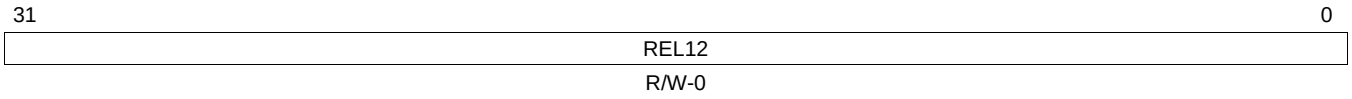
Table 30-19. Watchdog Timer Control Register (WDTCR) Field Descriptions

Bit	Field	Value	Description
31-16	WDKEY	0-FFFFh	16-bit watchdog timer service key. Only the sequence of an A5C6h followed by a DA7Eh services the watchdog. Not applicable in regular timer mode.
15	WDFLAG		Watchdog flag bit. WDFLAG can be cleared by enabling the watchdog timer, by device reset, or being written with 1. It is set by a watchdog time-out.
		0	No watchdog time-out occurred.
		1	Watchdog time-out occurred.
14	WDEN		Watchdog timer enable bit.
		0	Disable watchdog timer
		1	Enable watchdog timer
13-12	Reserved	0	Reserved. This bit field must be written as 00b.
11-0	Reserved	0	Reserved

30.3.10 Timer Reload Register 12 (REL12)

The timer reload register 12 (REL12) is shown in Figure 30-24 and described in Table 30-20.

Figure 30-24. Timer Reload Register 12 (REL12)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

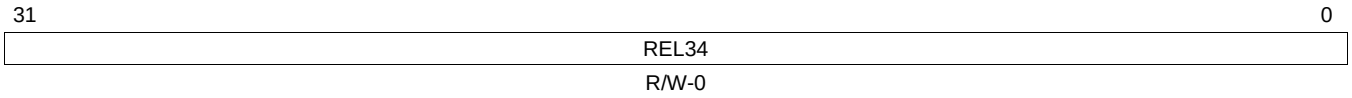
Table 30-20. Timer Reload Register 12 (REL12) Field Descriptions

Bit	Field	Value	Description
31- 0	REL12	0-FFFF FFFFh	Period reload bits.

30.3.11 Timer Reload Register 34 (REL34)

The timer reload register 34 (REL34) is shown in Figure 30-25 and described in Table 30-21.

Figure 30-25. Timer Reload Register 34 (REL34)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 30-21. Timer Reload Register 34 (REL34) Field Descriptions

Bit	Field	Value	Description
31- 0	REL34	0-FFFF FFFFh	Period reload bits.

30.3.12 Timer Capture Register 12 (CAP12)

The timer capture register 12 (CAP12) is shown in Figure 30-26 and described in Table 30-22.

Figure 30-26. Timer Capture Register 12 (CAP12)

31	0
CAP12	
R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 30-22. Timer Capture Register 12 (CAP12) Field Descriptions

Bit	Field	Value	Description
31- 0	CAP12	0-FFFF FFFFh	Captured timer counter bits.

30.3.13 Timer Capture Register 34 (CAP34)

The timer capture register 34 (CAP34) is shown in Figure 30-27 and described in Table 30-23.

Figure 30-27. Timer Capture Register 34 (CAP34)

31	0
CAP34	
R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 30-23. Timer Capture Register 34 (CAP34) Field Descriptions

Bit	Field	Value	Description
31- 0	CAP34	0-FFFF FFFFh	Captured timer counter bits.

30.3.14 Timer Interrupt Control and Status Register (INTCTLSTAT)

The timer interrupt control and status register (INTCTLSTAT) is shown in Figure 30-28 and described in Table 30-24.

Figure 30-28. Timer Interrupt Control and Status Register (INTCTLSTAT)

31					24
Reserved					
R-0					
23	**20**	**19**	**18**	**17**	**16**
Reserved		EVTINTSTAT34	EVTINTEN34	PRDINTSTAT34	PRDINTEN34
R-0		R/W1C-0	R/W-0	R/W1C-0	R/W-0
15					**8**
Reserved					
R-0					
7	**4**	**3**	**2**	**1**	**0**
Reserved		EVTINTSTAT12	EVTINTEN12	PRDINTSTAT12	PRDINTEN12
R-0		R/W1C-0	R/W-0	R/W1C-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; W1C = Write 1 to clear bit; -*n* = value after reset

Table 30-24. Timer Interrupt Control and Status Register (INTCTLSTAT) Field Descriptions

Bit	Field	Value	Description
31-20	Reserved	0	Reserved
19	EVTINTSTAT34		Interrupt status which reflects the condition that an external event caused a timeout when timer is in capture mode. Write a 1 to clear this bit.
		0	Interrupt has not occurred.
		1	Interrupt has occurred.
18	EVTINTEN34		Enables the interrupt generation when timer is in capture mode.
		0	Disable interrupt when in event capture mode.
		1	Enable interrupt when in event capture mode.
17	PRDINTSTAT34		Interrupt status which reflects the condition that timer counter matched the period register when timer is enabled. Write a 1 to clear this bit.
		0	Interrupt has not occurred.
		1	Interrupt has occurred.
16	PRDINTEN34		Enable interrupt generation when timer is enabled in 64-bit/32-bit chained/unchained/watchdog modes.
		0	Disable interrupt
		1	Enable interrupt
15-4	Reserved	0	Reserved
3	EVTINTSTAT12		Interrupt status which reflects the condition that an external event caused a timeout when timer is in capture mode. Write a 1 to clear this bit.
		0	Interrupt has not occurred.
		1	Interrupt has occurred.
2	EVTINTEN12		Enables the interrupt generation when timer is in capture mode.
		0	Disable interrupt when in event capture mode.
		1	Enable interrupt when in event capture mode.
1	PRDINTSTAT12		Interrupt status which reflects the condition that timer counter matched the period register when timer is enabled. Write a 1 to clear this bit.
		0	Interrupt has not occurred.
		1	Interrupt has occurred.

Table 30-24. Timer Interrupt Control and Status Register (INTCTLSTAT) Field Descriptions (continued)

Bit	Field	Value	Description
0	PRDINTEN12		Enable interrupt generation when timer is enabled in 64-bit/32-bit chained/unchained/watchdog modes.
		0	Disable interrupt
		1	Enable interrupt

30.3.15 Timer Compare Registers (CMP0-CMP7)

The timer compare register (CMP*n*) is shown in Figure 30-29 and described in Table 30-25.

Figure 30-29. Timer Compare Register (CMP*n*)

31	0
CMP*n*	
R/W-0	

LEGEND: R/W = Read/Write; -*n* = value after reset

Table 30-25. Timer Compare Register (CMP*n*) Field Descriptions

Bit	Field	Value	Description
31-0	CMP*n*	0-FFFF FFFFh	Timer compare register. When PLUSEN = 1 in the timer global control register (TGCR) and the timer is configured in 32-bit unchained mode, TIM12 is compared to all 8 compare registers (CMP0-CMP7). When CMP*n* matches TIM12, a timer CMP*n* interrupt and DMA event are generated. A CMP*n* match will not affect the TIM12 count or behavior.

Universal Asynchronous Receiver/Transmitter (UART)

This chapter describes the universal asynchronous receiver/transmitter (UART) peripheral. See your device-specific data manual to determine how many UARTs are available on your device.

Topic **Page**

31.1 Introduction

31.1.1 Purpose of the Peripheral

The UART peripheral is based on the industry standard TL16C550 asynchronous communications element, which in turn is a functional upgrade of the TL16C450. Functionally similar to the TL16C450 on power up (single character or TL16C450 mode), the UART can be placed in an alternate FIFO (TL16C550) mode. This relieves the CPU of excessive software overhead by buffering received and transmitted characters. The receiver and transmitter FIFOs store up to 16 bytes including three additional bits of error status per byte for the receiver FIFO.

The UART performs serial-to-parallel conversions on data received from a peripheral device and parallel-to-serial conversion on data received from the CPU. The CPU can read the UART status at any time. The UART includes control capability and a processor interrupt system that can be tailored to minimize software management of the communications link.

The UART includes a programmable baud generator capable of dividing the UART input clock by divisors from 1 to 65535 and producing a 16× reference clock or a 13× reference clock for the internal transmitter and receiver logic. For detailed timing and electrical specifications for the UART, see your device-specific data manual.

31.1.2 Features

Check your device-specific data manual to see the list of features that are supported and that are not supported by the UART.

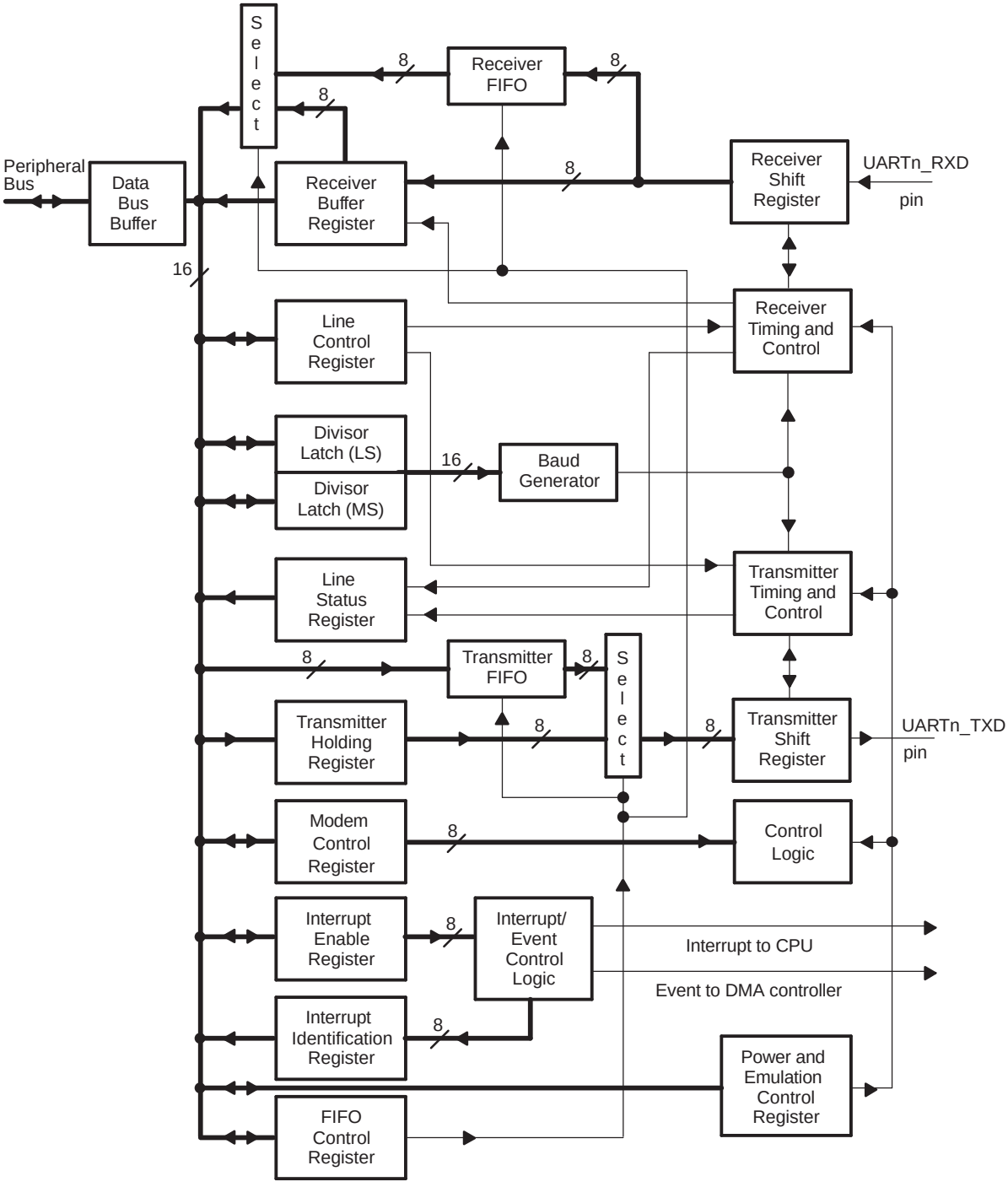
31.1.3 Functional Block Diagram

A functional block diagram of the UART is shown in Figure 31-1.

31.1.4 Industry Standard(s) Compliance Statement

The UART peripheral is based on the industry standard TL16C550 asynchronous communications element, which is a functional upgrade of the TL16C450. The information in this chapter assumes you are familiar with these standards.

Figure 31-1. UART Block Diagram



NOTE: The value *n* indicates the applicable UART; that is, UART0, UART1, and so on.

31.2 Peripheral Architecture

31.2.1 Clock Generation and Control

The UART bit clock is derived from an input clock to the UART. See your device-specific data manual to check the maximum data rate supported by the UART.

Figure 31-2 is a conceptual clock generation diagram for the UART. The processor clock generator receives a signal from an external clock source and produces a UART input clock with a programmed frequency. The UART contains a programmable baud generator that takes an input clock and divides it by a divisor in the range between 1 and (2^{16} - 1) to produce a baud clock (BCLK). The frequency of BCLK is sixteen times (16×) the baud rate (each received or transmitted bit lasts 16 BCLK cycles) or thirteen times (13×) the baud rate (each received or transmitted bit lasts 13 BCLK cycles). When the UART is receiving, the bit is sampled in the 8th BCLK cycle for 16× over sampling mode and on the 6th BCLK cycle for 13× over-sampling mode. The 16× or 13× reference clock is selected by configuring the OSM_SEL bit in the mode definition register (MDR). The formula to calculate the divisor is:

$$\text{Divisor} = \frac{\text{UART input clock frequency}}{\text{Desired baud rate} \times 16} \quad [\text{MDR.OSM\_SEL} = 0]$$

$$\text{Divisor} = \frac{\text{UART input clock frequency}}{\text{Desired baud rate} \times 13} \quad [\text{MDR.OSM\_SEL} = 1]$$

Two 8-bit register fields (DLH and DLL), called divisor latches, hold this 16-bit divisor. DLH holds the most significant bits of the divisor, and DLL holds the least significant bits of the divisor. For information about these register fields, see Section 31.3. These divisor latches must be loaded during initialization of the UART in order to ensure desired operation of the baud generator. Writing to the divisor latches results in two wait states being inserted during the write access while the baud generator is loaded with the new value.

Figure 31-3 summarizes the relationship between the transferred data bit, BCLK, and the UART input clock. Note that the timing relationship depicted in Figure 31-3 shows that each bit lasts for 16 BCLK cycles . This is in case of 16x over-sampling mode. For 13× over-sampling mode each bit lasts for 13 BCLK cycles .

Example baud rates and divisor values relative to a 150-MHz UART input clock and 16× over-sampling mode are shown in Table 31-1.

Figure 31-2. UART Clock Generation Diagram

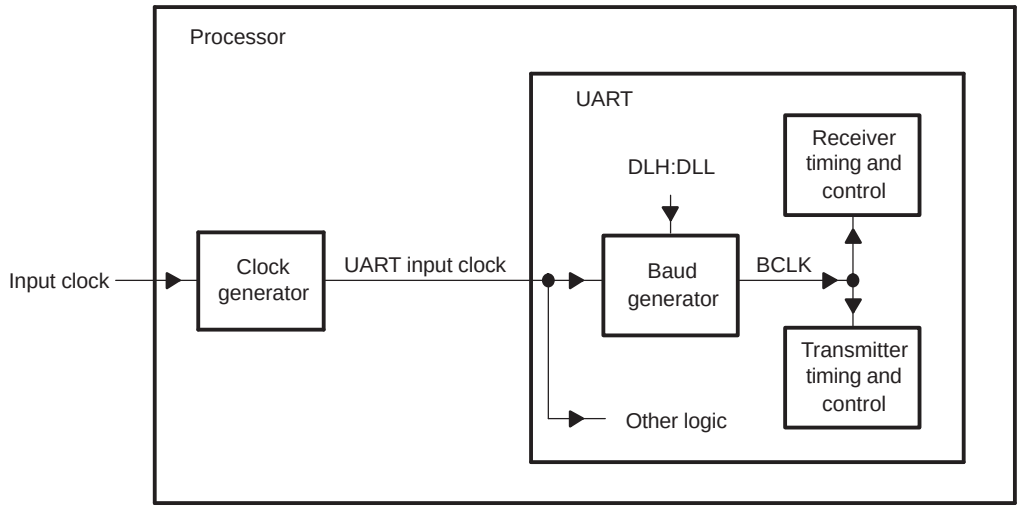


Figure 31-3. Relationships Between Data Bit, BCLK, and UART Input Clock

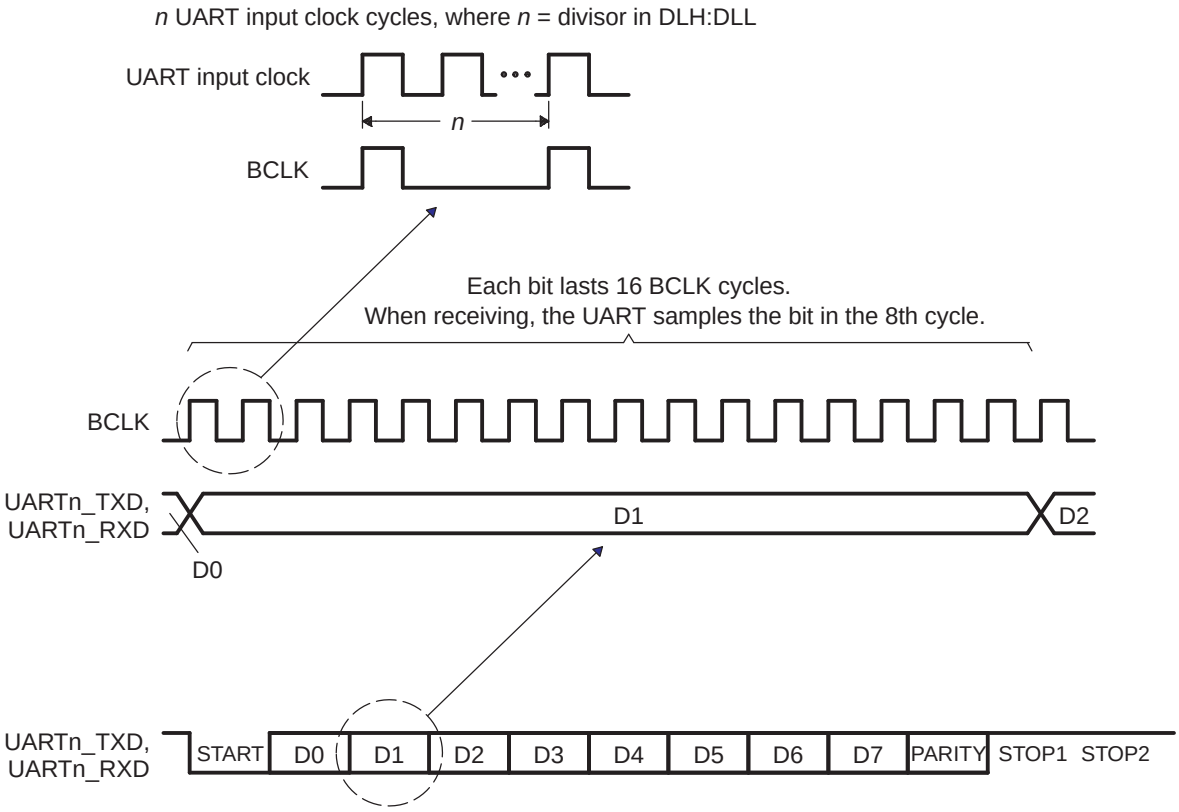


Table 31-1. Baud Rate Examples for 150-MHZ UART Input Clock and 16× Over-sampling Mode

Baud Rate	Divisor Value	Actual Baud Rate	Error (%)
2400	3906	2400.154	0.01
4800	1953	4800.372	0.01
9600	977	9595.701	-0.04
19200	488	19211.066	0.06
38400	244	38422.131	0.06
56000	167	56137.725	0.25
128000	73	129807.7	0.33
3000000	3	3125000	4.00

Table 31-2. Baud Rate Examples for 150-MHZ UART Input Clock and 13× Over-sampling Mode

Baud Rate	Divisor Value	Actual Baud Rate	Error (%)
2400	4808	2399	-0.01
4800	2404	4799.646	-0.01
9600	1202	9599.386	-0.01
19200	601	19198.771	-0.01
38400	300	38461.538	0.16
56000	206	56011.949	0.02
128000	90	128205.128	0.16
3000000	4	2884615.385	-4.00

31.2.2 Signal Descriptions

The UARTs utilize a minimal number of signal connections to interface with external devices. The UART signal descriptions are included in Table 31-3. Note that the number of UARTs and their supported features vary on each device, see your device-specific data manual for more details.

Table 31-3. UART Signal Descriptions

Signal Name [1]	Signal Type	Function
UARTn_TXD	Output	Serial data transmit
UARTn_RXD	Input	Serial data receive
$\overline{\text{UARTn\_CTS}}$ [2]	Input	Clear-to-Send handshaking signal
$\overline{\text{UARTn\_RTS}}$ [2]	Output	Request-to-Send handshaking signal

(1) The value *n* indicates the applicable UART; that is, UART0, UART1, etc.
(2) This signal is not supported in all UARTs. See your device-specific data manual to check if it is supported.

31.2.3 Pin Multiplexing

Extensive pin multiplexing is used to accommodate the largest number of peripheral functions in the smallest possible package. Pin multiplexing is controlled using a combination of hardware configuration at device reset and software programmable register settings. See your device-specific data manual to determine how pin multiplexing affects the UART.

31.2.4 Protocol Description

31.2.4.1 Transmission

The UART transmitter section includes a transmitter hold register (THR) and a transmitter shift register (TSR). When the UART is in the FIFO mode, THR is a 16-byte FIFO. Transmitter section control is a function of the UART line control register (LCR). Based on the settings chosen in LCR, the UART transmitter sends the following to the receiving device:

- 1 START bit
- 5, 6, 7, or 8 data bits
- 1 PARITY bit (optional)
- 1, 1.5, or 2 STOP bits

31.2.4.2 Reception

The UART receiver section includes a receiver shift register (RSR) and a receiver buffer register (RBR). When the UART is in the FIFO mode, RBR is a 16-byte FIFO. Receiver section control is a function of the UART line control register (LCR). Based on the settings chosen in LCR, the UART receiver accepts the following from the transmitting device:

- 1 START bit
- 5, 6, 7, or 8 data bits
- 1 PARITY bit (optional)
- 1 STOP bit (any other STOP bits transferred with the above data are not detected)

31.2.4.3 Data Format

The UART transmits in the following format:

1 START bit + data bits (5, 6, 7, 8) + 1 PARITY bit (optional) + STOP bit (1, 1.5, 2)

It transmits 1 START bit; 5, 6, 7, or 8 data bits, depending on the data width selection; 1 PARITY bit, if parity is selected; and 1, 1.5, or 2 STOP bits, depending on the STOP bit selection.

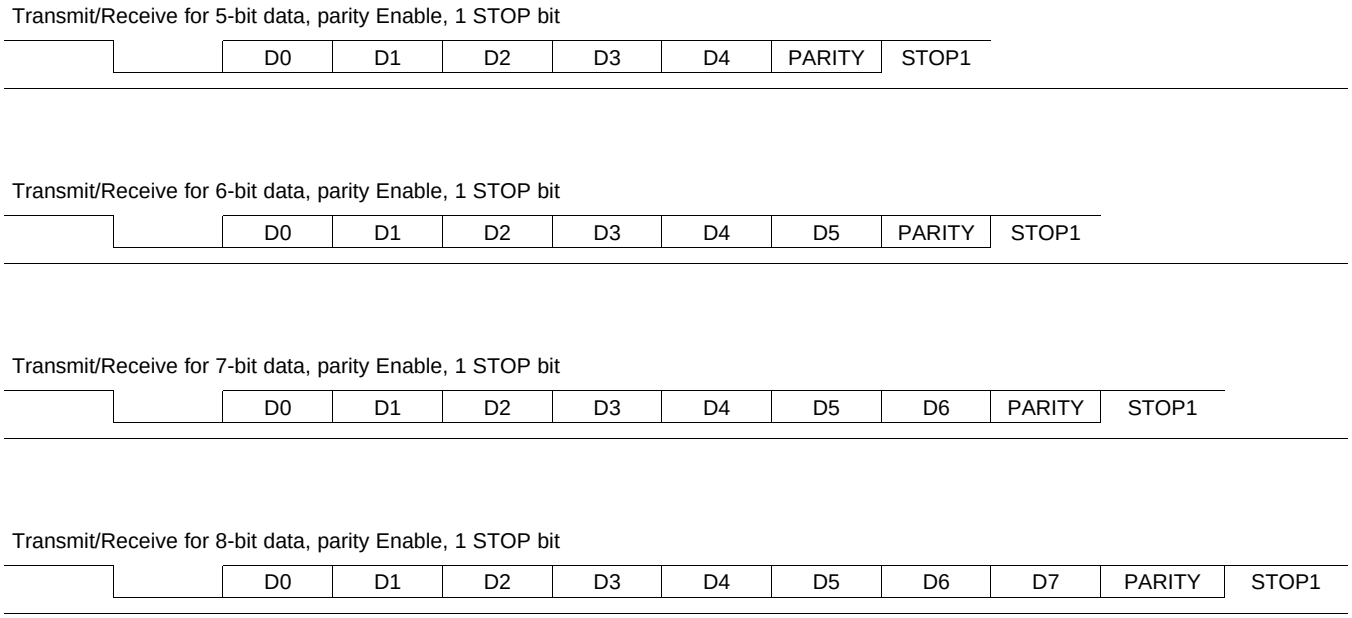
The UART receives in the following format:

1 START bit + data bits (5, 6, 7, 8) + 1 PARITY bit (optional) + 1 STOP bit

It receives 1 START bit; 5, 6, 7, or 8 data bits, depending on the data width selection; 1 PARITY bit, if parity is selected; and 1 STOP bit.

The protocol formats are shown in Figure 31-4.

Figure 31-4. UART Protocol Formats



31.2.5 Operation

31.2.5.1 Transmission

The UART transmitter section includes a transmitter hold register (THR) and a transmitter shift register (TSR). When the UART is in the FIFO mode, THR is a 16-byte FIFO. Transmitter section control is a function of the UART line control register (LCR). Based on the settings chosen in LCR, the UART transmitter sends the following to the receiving device:

- 1 START bit
- 5, 6, 7, or 8 data bits
- 1 PARITY bit (optional)
- 1, 1.5, or 2 STOP bits

THR receives data from the internal data bus, and when TSR is ready, the UART moves the data from THR to TSR. The UART serializes the data in TSR and transmits the data on the UARTn_TXD pin.

In the non-FIFO mode, if THR is empty and the THR empty (THRE) interrupt is enabled in the interrupt enable register (IER), an interrupt is generated. This interrupt is cleared when a character is loaded into THR or the interrupt identification register (IIR) is read. In the FIFO mode, the interrupt is generated when the transmitter FIFO is empty, and it is cleared when at least one byte is loaded into the FIFO or IIR is read.

31.2.5.2 Reception

The UART receiver section includes a receiver shift register (RSR) and a receiver buffer register (RBR). When the UART is in the FIFO mode, RBR is a 16-byte FIFO. Timing is supplied by the 16× receiver clock. Receiver section control is a function of the UART line control register (LCR). Based on the settings chosen in LCR, the UART receiver accepts the following from the transmitting device:

- 1 START bit
- 5, 6, 7, or 8 data bits
- 1 PARITY bit (optional)
- 1 STOP bit (any other STOP bits transferred with the above data are not detected)

RSR receives the data bits from the UARTn_RXD pin. Then RSR concatenates the data bits and moves the resulting value into RBR (or the receiver FIFO). The UART also stores three bits of error status information next to each received character, to record a parity error, framing error, or break.

In the non-FIFO mode, when a character is placed in RBR and the receiver data-ready interrupt is enabled in the interrupt enable register (IER), an interrupt is generated. This interrupt is cleared when the character is read from RBR. In the FIFO mode, the interrupt is generated when the FIFO is filled to the trigger level selected in the FIFO control register (FCR), and it is cleared when the FIFO contents drop below the trigger level.

31.2.5.3 FIFO Modes

The following two modes can be used for servicing the receiver and transmitter FIFOs:

- FIFO interrupt mode. The FIFO is enabled and the associated interrupts are enabled. Interrupts are sent to the CPU to indicate when specific events occur.
- FIFO poll mode. The FIFO is enabled but the associated interrupts are disabled. The CPU polls status bits to detect specific events.

Because the receiver FIFO and the transmitter FIFO are controlled separately, either one or both can be placed into the interrupt mode or the poll mode.

31.2.5.3.1 FIFO Interrupt Mode

When the receiver FIFO is enabled in the FIFO control register (FCR) and the receiver interrupts are enabled in the interrupt enable register (IER), the interrupt mode is selected for the receiver FIFO. The following are important points about the receiver interrupts:

- The receiver data-ready interrupt is issued to the CPU when the FIFO has reached the trigger level that is programmed in FCR. It is cleared when the CPU or the DMA controller reads enough characters from the FIFO such that the FIFO drops below its programmed trigger level.
- The receiver line status interrupt is generated in response to an overrun error, a parity error, a framing error, or a break. This interrupt has higher priority than the receiver data-ready interrupt. For details, see Section 31.2.8.
- The data-ready (DR) bit in the line status register (LSR) indicates the presence or absence of characters in the receiver FIFO. The DR bit is set when a character is transferred from the receiver shift register (RSR) to the empty receiver FIFO. The DR bit remains set until the FIFO is empty again.
- A receiver time-out interrupt occurs if all of the following conditions exist:
  - At least one character is in the FIFO,
  - The most recent character was received more than four continuous character times ago. A character time is the time allotted for 1 START bit, *n* data bits, 1 PARITY bit, and 1 STOP bit, where *n* depends on the word length selected with the WLS bits in the line control register (LCR). See Table 31-4.
  - The most recent read of the FIFO has occurred more than four continuous character times before.
- Character times are calculated by using the baud rate.
- When a receiver time-out interrupt has occurred, it is cleared and the time-out timer is cleared when the CPU or the EDMA controller reads one character from the receiver FIFO. The interrupt is also cleared if a new character is received in the FIFO or if the URRST bit is cleared in the power and emulation management register (PWREMU_MGMT).
- If a receiver time-out interrupt has not occurred, the time-out timer is cleared after a new character is received or after the CPU or EDMA reads the receiver FIFO.

When the transmitter FIFO is enabled in FCR and the transmitter holding register empty (THRE) interrupt is enabled in IER, the interrupt mode is selected for the transmitter FIFO. The THRE interrupt occurs when the transmitter FIFO is empty. It is cleared when the transmitter hold register (THR) is loaded (1 to 16 characters may be written to the transmitter FIFO while servicing this interrupt) or the interrupt identification register (IIR) is read.

Table 31-4. Character Time for Word Lengths

Word Length (*n*)	Character Time	Four Character Times
5	Time for 8 bits	Time for 32 bits
6	Time for 9 bits	Time for 36 bits
7	Time for 10 bits	Time for 40 bits
8	Time for 11 bits	Time for 44 bits

31.2.5.3.2 FIFO Poll Mode

When the receiver FIFO is enabled in the FIFO control register (FCR) and the receiver interrupts are disabled in the interrupt enable register (IER), the poll mode is selected for the receiver FIFO. Similarly, when the transmitter FIFO is enabled and the transmitter interrupts are disabled, the transmitted FIFO is in the poll mode. In the poll mode, the CPU detects events by checking bits in the line status register (LSR):

- The RXFIFOE bit indicates whether there are any errors in the receiver FIFO.
- The TEMT bit indicates that both the transmitter holding register (THR) and the transmitter shift register (TSR) are empty.
- The THRE bit indicates when THR is empty.
- The BI (break), FE (framing error), PE (parity error), and OE (overrun error) bits specify which error or errors have occurred.
- The DR (data-ready) bit is set as long as there is at least one byte in the receiver FIFO.

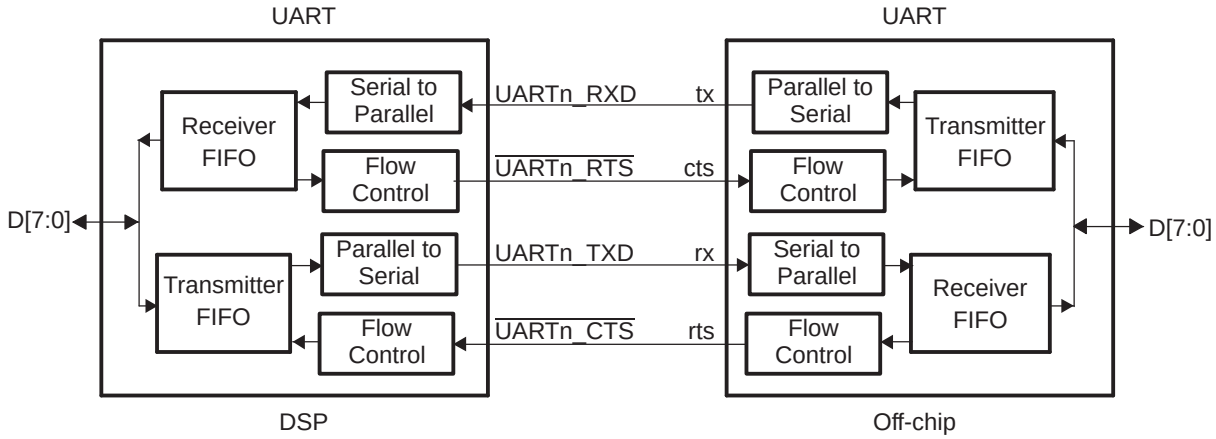
Also, in the FIFO poll mode:

- The interrupt identification register (IIR) is not affected by any events because the interrupts are disabled.
- The UART does not indicate when the receiver FIFO trigger level is reached or when a receiver time-out occurs.

31.2.5.4 Autoflow Control

The UART can employ autoflow control by connecting the $\overline{\text{UARTn\_CTS}}$ and $\overline{\text{UARTn\_RTS}}$ signals. Note that all UARTs do not support autoflow control, see your device-specific data manual for supported features. The $\overline{\text{UARTn\_CTS}}$ input must be active before the transmitter FIFO can transmit data. The $\overline{\text{UARTn\_RTS}}$ becomes active when the receiver needs more data and notifies the sending device. When $\overline{\text{UARTn\_RTS}}$ is connected to $\overline{\text{UARTn\_CTS}}$, data transmission does not occur unless the receiver FIFO has space for the data. Therefore, when two UARTs are connected as shown in Figure 31-5 with autoflow enabled, overrun errors are eliminated.

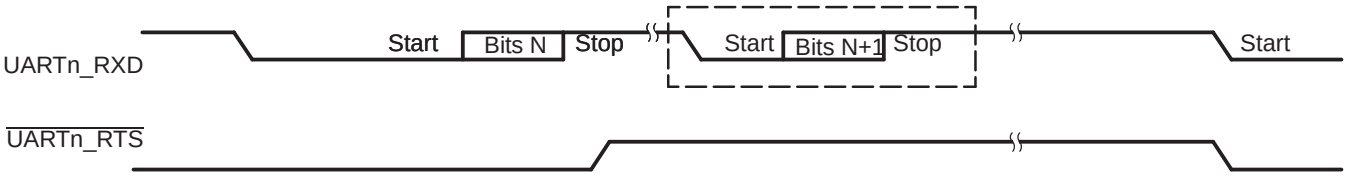
Figure 31-5. UART Interface Using Autoflow Diagram



31.2.5.4.1 UARTn_RTS Behavior

UARTn_RTS data flow control originates in the receiver block (see Figure 31-1). When the receiver FIFO level reaches a trigger level of 1, 4, 8, or 14 (see Figure 31-6), UARTn_RTS is deasserted. The sending UART may send an additional byte after the trigger level is reached (assuming the sending UART has another byte to send), because it may not recognize the deassertion of UARTn_RTS until after it has begun sending the additional byte. For trigger level 1, 4, and 8, UARTn_RTS is automatically reasserted once the receiver FIFO is emptied. For trigger level 14, UARTn_RTS is automatically reasserted once the receiver FIFO drops below the trigger level.

Figure 31-6. Autoflow Functional Timing Waveforms for UARTn_RTS



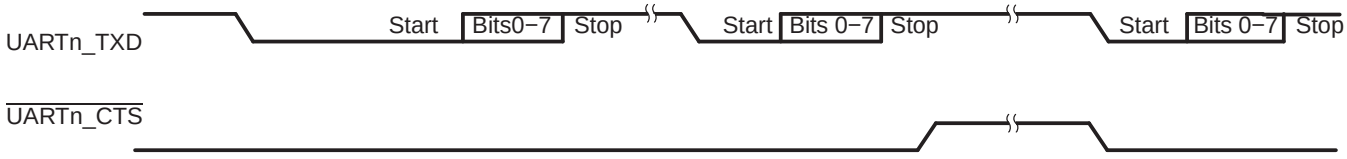
(1) N = Receiver FIFO trigger level.

(2) The two blocks in dashed lines cover the case where an additional byte is sent.

31.2.5.4.2 UARTn_CTS Behavior

The transmitter checks UARTn_CTS before sending the next data byte. If UARTn_CTS is active, the transmitter sends the next byte. To stop the transmitter from sending the following byte, UARTn_CTS must be released before the middle of the last STOP bit that is currently being sent (see Figure 31-7). When flow control is enabled, UARTn_CTS level changes do not trigger interrupts because the device automatically controls its own transmitter. Without autoflow control, the transmitter sends any data present in the transmitter FIFO and a receiver overrun error may result.

Figure 31-7. Autoflow Functional Timing Waveforms for UARTn_CTS



(1) When UARTn_CTS is active (low), the transmitter keeps sending serial data out.

(2) When UARTn_CTS goes high before the middle of the last STOP bit of the current byte, the transmitter finishes sending the current byte but it does not send the next byte.

(3) When UARTn_CTS goes from high to low, the transmitter begins sending data again.

31.2.5.5 Loopback Control

The UART can be placed in the diagnostic mode using the LOOP bit in the modem control register (MCR), which internally connects the UART output back to the UART input. In this mode, the transmit and receive data paths, the transmitter and receiver interrupts, and the modem control interrupts can be verified without connecting to another UART.

31.2.6 Reset Considerations

31.2.6.1 Software Reset Considerations

Two bits in the power and emulation management register (PWREMU_MGMT) control resetting the parts of the UART:

- The UTRST bit controls resetting the transmitter only. If UTRST = 1, the transmitter is active; if UTRST = 0, the transmitter is in reset.
- The URRST bit controls resetting the receiver only. If URRST = 1, the receiver is active; if URRST = 0, the receiver is in reset.

In each case, putting the receiver and/or transmitter in reset will reset the state machine of the affected portion but does not affect the UART registers.

31.2.6.2 Hardware Reset Considerations

When the processor RESET pin is asserted, the entire processor is reset and is held in the reset state until the RESET pin is released. As part of a device reset, the UART state machine is reset and the UART registers are forced to their default states. The default states of the registers are shown in Section 31.3.

31.2.7 Initialization

The following steps are required to initialize the UART:

1. Perform the necessary device pin multiplexing setup (see your device-specific data manual).
2. Set the desired baud rate by writing the appropriate clock divisor values to the divisor latch registers (DLL and DLH).
3. If the FIFOs will be used, select the desired trigger level and enable the FIFOs by writing the appropriate values to the FIFO control register (FCR). The FIFOEN bit in FCR must be set first, before the other bits in FCR are configured.
4. Choose the desired protocol settings by writing the appropriate values to the line control register (LCR).
5. If autoflow control is desired, write appropriate values to the modem control register (MCR). Note that all UARTs do not support autoflow control, see your device-specific data manual for supported features.
6. Choose the desired response to emulation suspend events by configuring the FREE bit and enable the UART by setting the UTRST and URRST bits in the power and emulation management register (PWREMU_MGMT).

31.2.8 Interrupt Support

31.2.8.1 Interrupt Events and Requests

The UART generates the interrupt requests described in Table 31-5. All requests are multiplexed through an arbiter to a single UART interrupt request to the CPU, as shown in Figure 31-8. Each of the interrupt requests has an enable bit in the interrupt enable register (IER) and is recorded in the interrupt identification register (IIR).

If an interrupt occurs and the corresponding enable bit is set to 1, the interrupt request is recorded in IIR and is forwarded to the CPU. If an interrupt occurs and the corresponding enable bit is cleared to 0, the interrupt request is blocked. The interrupt request is neither recorded in IIR nor forwarded to the CPU.

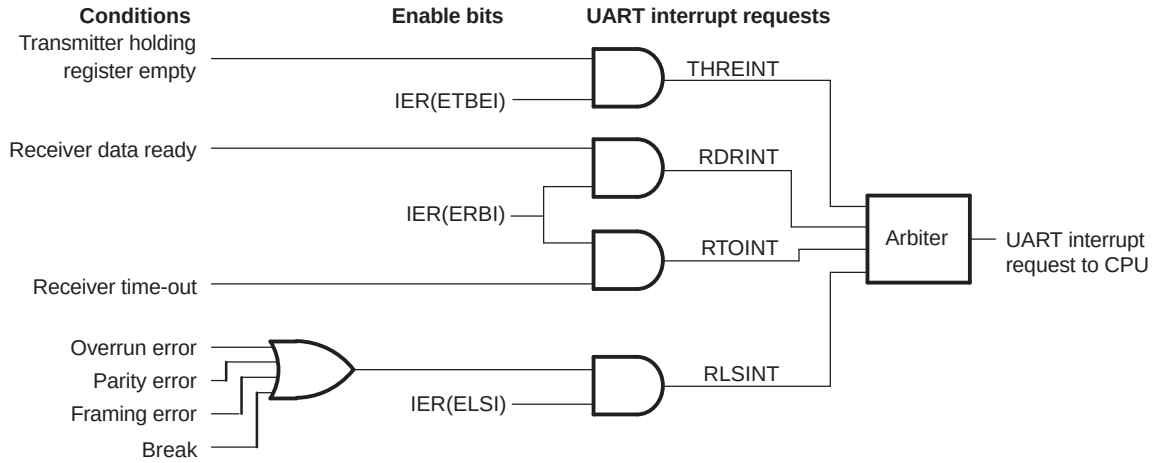
31.2.8.2 Interrupt Multiplexing

The UARTs have dedicated interrupt signals to the CPU and the interrupts are not multiplexed with any other interrupt source.

Table 31-5. UART Interrupt Requests Descriptions

UART Interrupt Request	Interrupt Source	Comment
THREINT	THR-empty condition: The transmitter holding register (THR) or the transmitter FIFO is empty. All of the data has been copied from THR to the transmitter shift register (TSR).	If THREINT is enabled in IER, by setting the ETBEI bit, it is recorded in IIR. As an alternative to using THREINT, the CPU can poll the THRE bit in the line status register (LSR).
RDAINT	Receive data available in non-FIFO mode or trigger level reached in the FIFO mode.	If RDAINT is enabled in IER, by setting the ERBI bit, it is recorded in IIR. As an alternative to using RDAINT, the CPU can poll the DR bit in the line status register (LSR). In the FIFO mode, this is not a functionally equivalent alternative because the DR bit does not respond to the FIFO trigger level. The DR bit only indicates the presence or absence of unread characters.
RTOINT	Receiver time-out condition (in the FIFO mode only): No characters have been removed from or input to the receiver FIFO during the last four character times (see Table 31-4), and there is at least one character in the receiver FIFO during this time.	The receiver time-out interrupt prevents the UART from waiting indefinitely, in the case when the receiver FIFO level is below the trigger level and thus does not generate a receiver data-ready interrupt. If RTOINT is enabled in IER, by setting the ERBI bit, it is recorded in IIR. There is no status bit to reflect the occurrence of a time-out condition.
RLSINT	Receiver line status condition: An overrun error, parity error, framing error, or break has occurred.	If RLSINT is enabled in IER, by setting the ELSI bit, it is recorded in IIR. As an alternative to using RLSINT, the CPU can poll the following bits in the line status register (LSR): overrun error indicator (OE), parity error indicator (PE), framing error indicator (FE), and break indicator (BI).

Figure 31-8. UART Interrupt Request Enable Paths



31.2.9 DMA Event Support

In the FIFO mode, the UART generates the following two DMA events:

- **Receive event (URXEVT):** The trigger level for the receiver FIFO (1, 4, 8, or 14 characters) is set with the RXFIFTL bit in the FIFO control register (FCR). Every time the trigger level is reached or a receiver time-out occurs, the UART sends a receive event to the EDMA controller. In response, the EDMA controller reads the data from the receiver FIFO by way of the receiver buffer register (RBR). Note that the receive event is not asserted if the data at the top of the receiver FIFO is erroneous even if the trigger level has been reached.
- **Transmit event (UTXEVT):** When the transmitter FIFO is empty (when the last byte in the transmitter FIFO has been copied to the transmitter shift register), the UART sends an UTXEVT signal to the EDMA controller. In response, the EDMA controller refills the transmitter FIFO by way of the transmitter holding register (THR). The UTXEVT signal is also sent to the DMA controller when the UART is taken out of reset using the UTRST bit in the power and emulation management register (PWREMU_MGMT).

Activity in DMA channels can be synchronized to these events. In the non-FIFO mode, the UART generates no DMA events. Any DMA channel synchronized to either of these events must be enabled at the time the UART event is generated. Otherwise, the DMA channel will miss the event and, unless the UART generates a new event, no data transfer will occur.

31.2.10 Power Management

The UART peripheral can be placed in reduced-power modes to conserve power during periods of low activity. The power management of the UART peripheral is controlled by the processor Power and Sleep Controller (PSC). The PSC acts as a master controller for power management for all of the peripherals on the device. For detailed information on power management procedures using the PSC, see the *Power and Sleep Controller (PSC)* chapter.

31.2.11 Emulation Considerations

The FREE bit in the power and emulation management register (PWREMU_MGMT) determines how the UART responds to an emulation suspend event such as an emulator halt or breakpoint. If FREE = 0 and a transmission is in progress, the UART halts after completing the one-word transmission; if FREE = 0 and a transmission is not in progress, the UART halts immediately. If FREE = 1, the UART does not halt and continues operating normally.

Note also that most emulator accesses are transparent to UART operation. Emulator read operations do not affect any register contents, status bits, or operating states, with the exception of the interrupt identification register (IIR). Emulator writes, however, may affect register contents and may affect UART operation, depending on what register is accessed and what value is written.

The UART registers can be read from or written to during emulation suspend events, even if the UART activity has stopped.

31.2.12 Exception Processing

31.2.12.1 Divisor Latch Not Programmed

Since the processor reset signal has no effect on the divisor latch, the divisor latch will have an unknown value after power up. If the divisor latch is not programmed after power up, the baud clock (BCLK) will not operate and will instead be set to a constant logic 1 state.

The divisor latch values should always be reinitialized following a processor reset.

31.2.12.2 Changing Operating Mode During Busy Serial Communication

Since the serial link characteristics are based on how the control registers are programmed, the UART will expect the control registers to be static while it is busy engaging in a serial communication. Therefore, changing the control registers while the module is still busy communicating with another serial device will most likely cause an error condition and should be avoided.

31.3 Registers

The system programmer has access to and control over any of the UART registers that are listed in Table 31-6. These registers, which control UART operations, receive data, and transmit data, are available at 32-bit addresses in the device memory map. See your device-specific data manual for the memory address of these registers.

- RBR, THR, and DLL share one address. When the DLAB bit in LCR is 0, reading from the address gives the content of RBR, and writing to the address modifies THR. When DLAB = 1, all accesses at the address read or modify DLL. DLL can also be accessed with address offset 20h.
- IER and DLH share one address. When DLAB = 0, all accesses read or modify IER. When DLAB = 1, all accesses read or modify DLH. DLH can also be accessed with address offset 24h.
- IIR and FCR share one address. Regardless of the value of the DLAB bit, reading from the address gives the content of IIR, and writing modifies FCR.

Table 31-6. UART Registers

Offset	Acronym	Register Description	Section
0h	RBR	Receiver Buffer Register (read only)	Section 31.3.1
0h	THR	Transmitter Holding Register (write only)	Section 31.3.2
4h	IER	Interrupt Enable Register	Section 31.3.3
8h	IIR	Interrupt Identification Register (read only)	Section 31.3.4
8h	FCR	FIFO Control Register (write only)	Section 31.3.5
Ch	LCR	Line Control Register	Section 31.3.6
10h	MCR	Modem Control Register	Section 31.3.7
14h	LSR	Line Status Register	Section 31.3.8
18h	MSR	Modem Status Register	Section 31.3.9
1Ch	SCR	Scratch Pad Register	Section 31.3.10
20h	DLL	Divisor LSB Latch	Section 31.3.11
24h	DLH	Divisor MSB Latch	Section 31.3.11
28h	REVID1	Revision Identification Register 1	Section 31.3.12
2Ch	REVID2	Revision Identification Register 2	Section 31.3.12
30h	PWREMU_MGMT	Power and Emulation Management Register	Section 31.3.13
34h	MDR	Mode Definition Register	Section 31.3.14

31.3.1 Receiver Buffer Register (RBR)

The receiver buffer register (RBR) is shown in Figure 31-9 and described in Table 31-7.

The UART receiver section consists of a receiver shift register (RSR) and a receiver buffer register (RBR). When the UART is in the FIFO mode, RBR is a 16-byte FIFO. Timing is supplied by the 16x receiver clock or 13x receiver clock by programming OSM_SEL bit field of MDR register. Receiver section control is a function of the line control register (LCR).

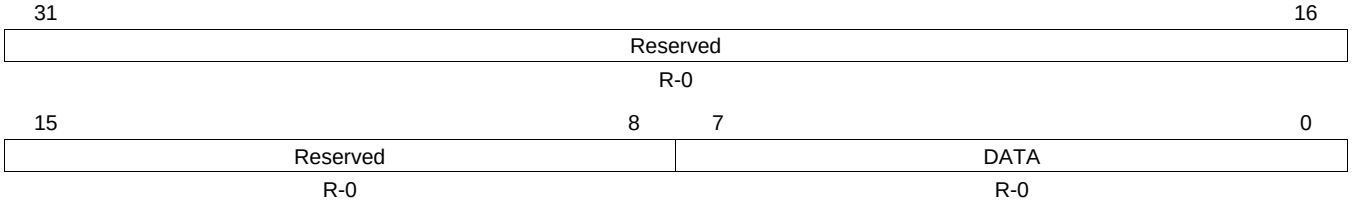
RSR receives serial data from the UARTn_RXD pin. Then RSR concatenates the data and moves it into RBR (or the receiver FIFO). In the non-FIFO mode, when a character is placed in RBR and the receiver data-ready interrupt is enabled (DR = 1 in IER), an interrupt is generated. This interrupt is cleared when the character is read from RBR. In the FIFO mode, the interrupt is generated when the FIFO is filled to the trigger level selected in the FIFO control register (FCR), and it is cleared when the FIFO contents drop below the trigger level.

Access considerations:

RBR, THR, and DLL share one address. To read RBR, write 0 to the DLAB bit in LCR, and read from the shared address. When DLAB = 0, writing to the shared address modifies THR. When DLAB = 1, all accesses at the shared address read or modify DLL.

DLL also has a dedicated address. If you use the dedicated address, you can keep DLAB = 0, so that RBR and THR are always selected at the shared address.

Figure 31-9. Receiver Buffer Register (RBR)



LEGEND: R = Read only; -*n* = value after reset

Table 31-7. Receiver Buffer Register (RBR) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved
7-0	DATA	0-FFh	Received data

31.3.2 Transmitter Holding Register (THR)

The transmitter holding register (THR) is shown in Figure 31-10 and described in Table 31-8.

The UART transmitter section consists of a transmitter hold register (THR) and a transmitter shift register (TSR). When the UART is in the FIFO mode, THR is a 16-byte FIFO. Transmitter section control is a function of the line control register (LCR).

THR receives data from the internal data bus and when TSR is idle, the UART moves the data from THR to TSR. The UART serializes the data in TSR and transmits the data on the TX pin. In the non-FIFO mode, if THR is empty and the THR empty (THRE) interrupt is enabled (ETBEI = 1 in IER), an interrupt is generated. This interrupt is cleared when a character is loaded into THR or the interrupt identification register (IIR) is read. In the FIFO mode, the interrupt is generated when the transmitter FIFO is empty, and it is cleared when at least one byte is loaded into the FIFO or IIR is read.

Access considerations:

RBR, THR, and DLL share one address. To load THR, write 0 to the DLAB bit of LCR, and write to the shared address. When DLAB = 0, reading from the shared address gives the content of RBR. When DLAB = 1, all accesses at the address read or modify DLL.

DLL also has a dedicated address. If you use the dedicated address, you can keep DLAB = 0, so that RBR and THR are always selected at the shared address.

Figure 31-10. Transmitter Holding Register (THR)

31	16
Reserved	
R-0	

15	8	7	0
Reserved		DATA	
R-0		W-0	

LEGEND: R = Read only; W = Write only; -*n* = value after reset

Table 31-8. Transmitter Holding Register (THR) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved
7-0	DATA	0-FFh	Data to transmit

31.3.3 Interrupt Enable Register (IER)

The interrupt enable register (IER) is used to individually enable or disable each type of interrupt request that can be generated by the UART. Each interrupt request that is enabled in IER is forwarded to the CPU. IER is shown in Figure 31-11 and described in Table 31-9.

Access considerations:

IER and DLH share one address. To read or modify IER, write 0 to the DLAB bit in LCR. When DLAB = 1, all accesses at the shared address read or modify DLH.

DLH also has a dedicated address. If you use the dedicated address, you can keep DLAB = 0, so that IER is always selected at the shared address.

Figure 31-11. Interrupt Enable Register (IER)

31															16
Reserved															
R-0															

15												4	3	2	1	0
Reserved													Rsvd	ELSI	ETBEI	ERBI
R-0													R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 31-9. Interrupt Enable Register (IER) Field Descriptions

Bit	Field	Value	Description
31-4	Reserved	0	Reserved
3	EDSSI	0	Enable Modem Status Interrupt
2	ELSI		Receiver line status interrupt enable.
		0	Receiver line status interrupt is disabled.
		1	Receiver line status interrupt is enabled.
1	ETBEI		Transmitter holding register empty interrupt enable.
		0	Transmitter holding register empty interrupt is disabled.
		1	Transmitter holding register empty interrupt is enabled.
0	ERBI		Receiver data available interrupt and character timeout indication interrupt enable.
		0	Receiver data available interrupt and character timeout indication interrupt is disabled.
		1	Receiver data available interrupt and character timeout indication interrupt is enabled.

31.3.4 Interrupt Identification Register (IIR)

The interrupt identification register (IIR) is a read-only register at the same address as the FIFO control register (FCR), which is a write-only register. When an interrupt is generated and enabled in the interrupt enable register (IER), IIR indicates that an interrupt is pending in the IPEND bit and encodes the type of interrupt in the INTID bits. Reading IIR clears any THR empty (THRE) interrupts that are pending.

IIR is shown in Figure 31-12 and described in Figure 31-12.

The UART has an on-chip interrupt generation and prioritization capability that permits flexible communication with the CPU. The UART provides three priority levels of interrupts:

- Priority 1 - Receiver line status (highest priority)
- Priority 2 - Receiver data ready or receiver timeout
- Priority 3 - Transmitter holding register empty

The FIFOEN bit in IIR can be checked to determine whether the UART is in the FIFO mode or the non-FIFO mode.

Access consideration:

IIR and FCR share one address. Regardless of the value of the DLAB bit in LCR, reading from the address gives the content of IIR, and writing to the address modifies FCR.

Figure 31-12. Interrupt Identification Register (IIR)

31	16
Reserved	
R-0	

15	8	7	6	5	4	3	1	0
Reserved		FIFOEN		Reserved		INTID		IPEND
R-0		R-0		R-0		R-0		R-1

LEGEND: R = Read only; -*n* = value after reset

Table 31-10. Interrupt Identification Register (IIR) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved
7-6	FIFOEN	0-3h	FIFOs enabled.
		0	Non-FIFO mode
		1h-2h	Reserved
		3h	FIFOs are enabled. FIFOEN bit in the FIFO control register (FCR) is set to 1.
5-4	Reserved	0	Reserved
3-1	INTID	0-7h	Interrupt type. See Table 31-11.
		0	Reserved
		1h	Transmitter holding register empty (priority 3)
		2h	Receiver data available (priority 2)
		3h	Receiver line status (priority 1, highest)
		4h-5h	Reserved
		6h	Character timeout indication (priority 2)
		7h	Reserved
0	IPEND		Interrupt pending. When any UART interrupt is generated and is enabled in IER, IPEND is forced to 0. IPEND remains 0 until all pending interrupts are cleared or until a hardware reset occurs. If no interrupts are enabled, IPEND is never forced to 0.
		0	Interrupts pending.
		1	No interrupts pending.

Table 31-11. Interrupt Identification and Interrupt Clearing Information

Priority Level	IIR Bits 3	2	1	0	Interrupt Type	Interrupt Source	Event That Clears Interrupt
None	0	0	0	1	None	None	None
1	0	1	1	0	Receiver line status	Overrun error, parity error, framing error, or break is detected.	For an overrun error, reading the line status register (LSR) clears the interrupt. For a parity error, framing error, or break, the interrupt is cleared only after all the erroneous data have been read.
2	0	1	0	0	Receiver data-ready	Non-FIFO mode: Receiver data is ready.	Non-FIFO mode: The receiver buffer register (RBR) is read.
						FIFO mode: Trigger level reached. If four character times (see Table 31-4) pass with no access of the FIFO, the interrupt is asserted again.	FIFO mode: The FIFO drops below the trigger level.(1)
2	1	1	0	0	Receiver time-out	FIFO mode only: No characters have been removed from or input to the receiver FIFO during the last four character times (see Table 31-4), and there is at least one character in the receiver FIFO during this time.	One of the following events: • A character is read from the receiver FIFO.(1) • A new character arrives in the receiver FIFO. • The URRST bit in the power and emulation management register (PWREMU_MGMT) is loaded with 0.
3	0	0	1	0	Transmitter holding register empty	Non-FIFO mode: Transmitter holding register (THR) is empty. FIFO mode: Transmitter FIFO is empty.	A character is written to the transmitter holding register (THR) or the interrupt identification register (IIR) is read.

(1) In the FIFO mode, the receiver data-ready interrupt or receiver time-out interrupt is cleared by the CPU or by the DMA controller, whichever reads from the receiver FIFO first.

31.3.5 FIFO Control Register (FCR)

The FIFO control register (FCR) is a write-only register at the same address as the interrupt identification register (IIR), which is a read-only register. Use FCR to enable and clear the FIFOs and to select the receiver FIFO trigger level FCR is shown in Figure 31-13 and described in Table 31-12. The FIFOEN bit must be set to 1 before other FCR bits are written to or the FCR bits are not programmed.

Access consideration:

IIR and FCR share one address. Regardless of the value of the DLAB bit, reading from the address gives the content of IIR, and writing to the address modifies FCR.

CAUTION

For proper communication between the UART and the EDMA controller, the DMAMODE1 bit must be set to 1. Always write a 1 to the DMAMODE1 bit, and after a hardware reset, change the DMAMODE1 bit from 0 to 1.

Figure 31-13. FIFO Control Register (FCR)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
R-0															

15	14	13	12	11	10	9	8
Reserved							
R-0							

7	6	5	4	3	2	1	0
RXFIFTL		Reserved		DMAMODE1[1]	TXCLR	RXCLR	FIFOEN
W-0		R-0		W-0	W1C-0	W1C-0	W-0

LEGEND: R = Read only; W = Write only; W1C = Write 1 to clear (writing 0 has no effect); -*n* = value after reset

(1) Always write 1 to the DMAMODE1 bit. After a hardware reset, change the DMAMODE1 bit from 0 to 1. DMAMODE = 1 is required for proper communication between the UART and the DMA controller.

Table 31-12. FIFO Control Register (FCR) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved
7-6	RXFIFTL	0-3h	Receiver FIFO trigger level. RXFIFTL sets the trigger level for the receiver FIFO. When the trigger level is reached, a receiver data-ready interrupt is generated (if the interrupt request is enabled). Once the FIFO drops below the trigger level, the interrupt is cleared.
		0	1 byte
		1h	4 bytes
		2h	8 bytes
		3h	14 bytes
5-4	Reserved	0	Reserved
3	DMAMODE1		DMA MODE1 enable if FIFOs are enabled. Always write 1 to DMAMODE1. After a hardware reset, change DMAMODE1 from 0 to 1. DMAMOD1 = 1 is a requirement for proper communication between the UART and the EDMA controller.
		0	DMA MODE1 is disabled.
		1	DMA MODE1 is enabled.
2	TXCLR		Transmitter FIFO clear. Write a 1 to TXCLR to clear the bit.
		0	No effect.
		1	Clears transmitter FIFO and resets the transmitter FIFO counter. The shift register is not cleared.
1	RXCLR		Receiver FIFO clear. Write a 1 to RXCLR to clear the bit.
		0	No effect.
		1	Clears receiver FIFO and resets the receiver FIFO counter. The shift register is not cleared.
0	FIFOEN		Transmitter and receiver FIFOs mode enable. FIFOEN must be set before other FCR bits are written to or the FCR bits are not programmed. Clearing this bit clears the FIFO counters.
		0	Non-FIFO mode. The transmitter and receiver FIFOs are disabled, and the FIFO pointers are cleared.
		1	FIFO mode. The transmitter and receiver FIFOs are enabled.

31.3.6 Line Control Register (LCR)

The line control register (LCR) is shown in Figure 31-14 and described in Table 31-13.

The system programmer controls the format of the asynchronous data communication exchange by using LCR. In addition, the programmer can retrieve, inspect, and modify the content of LCR; this eliminates the need for separate storage of the line characteristics in system memory.

Figure 31-14. Line Control Register (LCR)

31	16
Reserved	
R-0	

15	8	7	6	5	4	3	2	1	0
Reserved		DLAB	BC	SP	EPS	PEN	STB	WLS	
R-0		R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 31-13. Line Control Register (LCR) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved
7	DLAB		Divisor latch access bit. The divisor latch registers (DLL and DLH) can be accessed at dedicated addresses or at addresses shared by RBR, THR, and IER. Using the shared addresses requires toggling DLAB to change which registers are selected. If you use the dedicated addresses, you can keep DLAB = 0.
		0	Allows access to the receiver buffer register (RBR), the transmitter holding register (THR), and the interrupt enable register (IER) selected. At the address shared by RBR, THR, and DLL, the CPU can read from RBR and write to THR. At the address shared by IER and DLH, the CPU can read from and write to IER.
		1	Allows access to the divisor latches of the baud generator during a read or write operation (DLL and DLH). At the address shared by RBR, THR, and DLL, the CPU can read from and write to DLL. At the address shared by IER and DLH, the CPU can read from and write to DLH.
6	BC		Break control.
		0	Break condition is disabled.
		1	Break condition is transmitted to the receiving UART. A break condition is a condition where the UARTn_TXD signal is forced to the spacing (cleared) state.
5	SP		Stick parity. The SP bit works in conjunction with the EPS and PEN bits. The relationship between the SP, EPS, and PEN bits is summarized in Table 31-14.
		0	Stick parity is disabled.
		1	Stick parity is enabled. • When odd parity is selected (EPS = 0), the PARITY bit is transmitted and checked as set. • When even parity is selected (EPS = 1), the PARITY bit is transmitted and checked as cleared.
4	EPS		Even parity select. Selects the parity when parity is enabled (PEN = 1). The EPS bit works in conjunction with the SP and PEN bits. The relationship between the SP, EPS, and PEN bits is summarized in Table 31-14.
		0	Odd parity is selected (an odd number of logic 1s is transmitted or checked in the data and PARITY bits).
		1	Even parity is selected (an even number of logic 1s is transmitted or checked in the data and PARITY bits).
3	PEN		Parity enable. The PEN bit works in conjunction with the SP and EPS bits. The relationship between the SP, EPS, and PEN bits is summarized in Table 31-14.
		0	No PARITY bit is transmitted or checked.
		1	Parity bit is generated in transmitted data and is checked in received data between the last data word bit and the first STOP bit.

Table 31-13. Line Control Register (LCR) Field Descriptions (continued)

Bit	Field	Value	Description
2	STB		Number of STOP bits generated. STB specifies 1, 1.5, or 2 STOP bits in each transmitted character. When STB = 1, the WLS bit determines the number of STOP bits. The receiver clocks only the first STOP bit, regardless of the number of STOP bits selected. The number of STOP bits generated is summarized in Table 31-15.
		0	1 STOP bit is generated.
		1	WLS bit determines the number of STOP bits: • When WLS = 0, 1.5 STOP bits are generated. • When WLS = 1h, 2h, or 3h, 2 STOP bits are generated.
1-0	WLS	0-3h	Word length select. Number of bits in each transmitted or received serial character. When STB = 1, the WLS bit determines the number of STOP bits.
		0	5 bits
		1h	6 bits
		2h	7 bits
		3h	8 bits

Table 31-14. Relationship Between ST, EPS, and PEN Bits in LCR

ST Bit	EPS Bit	PEN Bit	Parity Option
x	x	0	Parity disabled: No PARITY bit is transmitted or checked
0	0	1	Odd parity selected: Odd number of logic 1s
0	1	1	Even parity selected: Even number of logic 1s
1	0	1	Stick parity selected with PARITY bit transmitted and checked as set
1	1	1	Stick parity selected with PARITY bit transmitted and checked as cleared

Table 31-15. Number of STOP Bits Generated

STB Bit	WLS Bits	Word Length Selected with WLS Bits	Number of STOP Bits Generated	Baud Clock (BCLK) Cycles
0	x	Any word length	1	16
1	0h	5 bits	1.5	24
1	1h	6 bits	2	32
1	2h	7 bits	2	32
1	3h	8 bits	2	32

31.3.7 Modem Control Register (MCR)

The modem control register (MCR) is shown in Figure 31-15 and described in Table 31-16. The modem control register provides the ability to enable/disable the autoflow functions, and enable/disable the loopback function for diagnostic purposes.

Figure 31-15. Modem Control Register (MCR)

31							16
Reserved							
R-0							
15		**6**	**5**	**4**	**3**	**2**	**1**	**0**
Reserved			AFE[1]	LOOP	OUT2	OUT1	RTS[1]	Rsvd
R-0			R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

(1) All UARTs do not support this feature, see your device-specific data manual for supported features. If this feature is not available, this bit is reserved and should be cleared to 0.

Table 31-16. Modem Control Register (MCR) Field Descriptions

Bit	Field	Value	Description
31-6	Reserved	0	Reserved
5	AFE		Autoflow control enable. Autoflow control allows the $\overline{\text{UARTn\_RTS}}$ and $\overline{\text{UARTn\_CTS}}$ signals to provide handshaking between UARTs during data transfer. When AFE = 1, the RTS bit determines the autoflow control enabled. Note that all UARTs do not support this feature, see your device-specific data manual for supported features. If this feature is not available, this bit is reserved and should be cleared to 0.
		0	Autoflow control is disabled.
		1	Autoflow control is enabled: • When RTS = 0, $\overline{\text{UARTn\_CTS}}$ is only enabled. • When RTS = 1, $\overline{\text{UARTn\_RTS}}$ and $\overline{\text{UARTn\_CTS}}$ are enabled.
4	LOOP		Loop back mode enable. LOOP is used for the diagnostic testing using the loop back feature.
		0	Loop back mode is disabled.
		1	Loop back mode is enabled. When LOOP is set, the following occur: • The UARTn_TXD signal is set high. • The UARTn_RXD pin is disconnected • The output of the transmitter shift register (TSR) is lopped back in to the receiver shift register (RSR) input.
3	OUT2	0	OUT2 Control Bit
2	OUT1	0	OUT1 Control Bit
1	RTS		RTS control. When AFE = 1, the RTS bit determines the autoflow control enabled. Note that all UARTs do not support this feature, see your device-specific data manual for supported features. If this feature is not available, this bit is reserved and should be cleared to 0.
		0	$\overline{\text{UARTn\_RTS}}$ is disabled, $\overline{\text{UARTn\_CTS}}$ is only enabled.
		1	$\overline{\text{UARTn\_RTS}}$ and $\overline{\text{UARTn\_CTS}}$ are enabled.
0	Reserved	0	Reserved

31.3.8 Line Status Register (LSR)

The line status register (LSR) is shown in Figure 31-16 and described in Table 31-17. LSR provides information to the CPU concerning the status of data transfers. LSR is intended for read operations only; do not write to this register. Bits 1 through 4 record the error conditions that produce a receiver line status interrupt.

Figure 31-16. Line Status Register (LSR)

31								16
Reserved								
R-0								
15	8	7	6	5	4	3	2	1	0
Reserved		RXFIFOE	TEMT	THRE	BI	FE	PE	OE	DR
R-0		R-0	R-1	R-1	R-0	R-0	R-0	R-0	R-0

LEGEND: R = Read only; -*n* = value after reset

Table 31-17. Line Status Register (LSR) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved
7	RXFIFOE		Receiver FIFO error.
			In non-FIFO mode:
		0	There has been no error, or RXFIFOE was cleared because the CPU read the erroneous character from the receiver buffer register (RBR).
		1	There is a parity error, framing error, or break indicator in the receiver buffer register (RBR).
			In FIFO mode:
		0	There has been no error, or RXFIFOE was cleared because the CPU read the erroneous character from the receiver FIFO and there are no more errors in the receiver FIFO.
		1	At least one parity error, framing error, or break indicator in the receiver FIFO.
6	TEMT		Transmitter empty (TEMT) indicator.
			In non-FIFO mode:
		0	Either the transmitter holding register (THR) or the transmitter shift register (TSR) contains a data character.
		1	Both the transmitter holding register (THR) and the transmitter shift register (TSR) are empty.
			In FIFO mode:
		0	Either the transmitter FIFO or the transmitter shift register (TSR) contains a data character.
		1	Both the transmitter FIFO and the transmitter shift register (TSR) are empty.
5	THRE		Transmitter holding register empty (THRE) indicator. If the THRE bit is set and the corresponding interrupt enable bit is set (ETBEI = 1 in IER), an interrupt request is generated.
			In non-FIFO mode:
		0	Transmitter holding register (THR) is not empty. THR has been loaded by the CPU.
		1	Transmitter holding register (THR) is empty (ready to accept a new character). The content of THR has been transferred to the transmitter shift register (TSR).
			In FIFO mode:
		0	Transmitter FIFO is not empty. At least one character has been written to the transmitter FIFO. You can write to the transmitter FIFO if it is not full.
		1	Transmitter FIFO is empty. The last character in the FIFO has been transferred to the transmitter shift register (TSR).

Table 31-17. Line Status Register (LSR) Field Descriptions (continued)

Bit	Field	Value	Description
4	BI		Break indicator. The BI bit is set whenever the receive data input (UARTn_RXD) was held low for longer than a full-word transmission time. A full-word transmission time is defined as the total time to transmit the START, data, PARITY, and STOP bits. If the BI bit is set and the corresponding interrupt enable bit is set (ELSI = 1 in IER), an interrupt request is generated.
			In non-FIFO mode:
		0	No break has been detected, or the BI bit was cleared because the CPU read the erroneous character from the receiver buffer register (RBR).
		1	A break has been detected with the character in the receiver buffer register (RBR).
			In FIFO mode:
		0	No break has been detected, or the BI bit was cleared because the CPU read the erroneous character from the receiver FIFO and the next character to be read from the FIFO has no break indicator.
		1	A break has been detected with the character at the top of the receiver FIFO.
3	FE		Framing error (FE) indicator. A framing error occurs when the received character does not have a valid STOP bit. In response to a framing error, the UART sets the FE bit and waits until the signal on the RX pin goes high. Once the RX signal goes high, the receiver is ready to detect a new START bit and receive new data. If the FE bit is set and the corresponding interrupt enable bit is set (ELSI = 1 in IER), an interrupt request is generated.
			In non-FIFO mode:
		0	No framing error has been detected, or the FE bit was cleared because the CPU read the erroneous data from the receiver buffer register (RBR).
		1	A framing error has been detected with the character in the receiver buffer register (RBR).
			In FIFO mode:
		0	No framing error has been detected, or the FE bit was cleared because the CPU read the erroneous data from the receiver FIFO and the next character to be read from the FIFO has no framing error.
		1	A framing error has been detected with the character at the top of the receiver FIFO.
2	PE		Parity error (PE) indicator. A parity error occurs when the parity of the received character does not match the parity selected with the EPS bit in the line control register (LCR). If the PE bit is set and the corresponding interrupt enable bit is set (ELSI = 1 in IER), an interrupt request is generated.
			In non-FIFO mode:
		0	No parity error has been detected, or the PE bit was cleared because the CPU read the erroneous data from the receiver buffer register (RBR).
		1	A parity error has been detected with the character in the receiver buffer register (RBR).
			In FIFO mode:
		0	No parity error has been detected, or the PE bit was cleared because the CPU read the erroneous data from the receiver FIFO and the next character to be read from the FIFO has no parity error.
		1	A parity error has been detected with the character at the top of the receiver FIFO.
1	OE		Overrun error (OE) indicator. An overrun error in the non-FIFO mode is different from an overrun error in the FIFO mode. If the OE bit is set and the corresponding interrupt enable bit is set (ELSI = 1 in IER), an interrupt request is generated.
			In non-FIFO mode:
		0	No overrun error has been detected, or the OE bit was cleared because the CPU read the content of the line status register (LSR).
		1	Overrun error has been detected. Before the character in the receiver buffer register (RBR) could be read, it was overwritten by the next character arriving in RBR.
			In FIFO mode:
		0	No overrun error has been detected, or the OE bit was cleared because the CPU read the content of the line status register (LSR).
		1	Overrun error has been detected. If data continues to fill the FIFO beyond the trigger level, an overrun error occurs only after the FIFO is full and the next character has been completely received in the shift register. An overrun error is indicated to the CPU as soon as it happens. The new character overwrites the character in the shift register, but it is not transferred to the FIFO.

Table 31-17. Line Status Register (LSR) Field Descriptions (continued)

Bit	Field	Value	Description
0	DR		Data-ready (DR) indicator for the receiver. If the DR bit is set and the corresponding interrupt enable bit is set (ERBI = 1 in IER), an interrupt request is generated.
			In non-FIFO mode:
		0	Data is not ready, or the DR bit was cleared because the character was read from the receiver buffer register (RBR).
		1	Data is ready. A complete incoming character has been received and transferred into the receiver buffer register (RBR).
			In FIFO mode:
		0	Data is not ready, or the DR bit was cleared because all of the characters in the receiver FIFO have been read.
		1	Data is ready. There is at least one unread character in the receiver FIFO. If the FIFO is empty, the DR bit is set as soon as a complete incoming character has been received and transferred into the FIFO. The DR bit remains set until the FIFO is empty again.

31.3.9 Modem Status Register (MSR)

The Modem status register (MSR) is shown in Figure 31-17 and described in Table 31-18. MSR provides information to the CPU concerning the status of modem control signals. MSR is intended for read operations only; do not write to this register.

Figure 31-17. Modem Status Register (MSR)

31	16
Reserved	
R-0	

15	8	7	6	5	4	3	2	1	0
Reserved		CD	RI	DSR	CTS	DCD	TERI	DDSR	DCTS
R-0		R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0

LEGEND: R = Read only; -*n* = value after reset

Table 31-18. Modem Status Register (MSR) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved
7	CD	0	Complement of the Carrier Detect input. When the UART is in the diagnostic test mode (loopback mode MCR[4] = 1), this bit is equal to the MCR bit 3 (OUT2).
6	RI	0	Complement of the Ring Indicator input. When the UART is in the diagnostic test mode (loopback mode MCR[4] = 1), this bit is equal to the MCR bit 2 (OUT1).
5	DSR	0	Complement of the Data Set Ready input. When the UART is in the diagnostic test mode (loopback mode MCR[4] = 1), this bit is equal to the MCR bit 0 (DTR).
4	CTS	0	Complement of the Clear To Send input. When the UART is in the diagnostic test mode (loopback mode MCR[4] = 1), this bit is equal to the MCR bit 1 (RTS).
3	DCD	0	Change in DCD indicator bit. DCD indicates that the DCD input has changed state since the last time it was read by the CPU. When DCD is set and the modem status interrupt is enabled, a modem status interrupt is generated.
2	TERI	0	Trailing edge of RI (TERI) indicator bit. TERI indicates that the RI input has changed from a low to a high. When TERI is set and the modem status interrupt is enabled, a modem status interrupt is generated.
1	DDSR	0	Change in DSR indicator bit. DDSR indicates that the DSR input has changed state since the last time it was read by the CPU. When DDSR is set and the modem status interrupt is enabled, a modem status interrupt is generated.
0	DCTS	0	Change in CTS indicator bit. DCTS indicates that the CTS input has changed state since the last time it was read by the CPU. When DCTS is set (autoflow control is not enabled and the modem status interrupt is enabled), a modem status interrupt is generated. When autoflow control is enabled, no interrupt is generated.

31.3.10 Scratch Pad Register (SCR)

The Scratch Pad register (SCR) is shown in Figure 31-18 and described in Table 31-19. SCR is intended for programmer's use as a scratch pad. It temporarily holds the programmer's data without affecting UART operation.

Figure 31-18. Scratch Pad Register (SCR)

31	16
Reserved	
R-0	

15	8	7	0
Reserved		SCR	
R-0		R-0	

LEGEND: R = Read only; -*n* = value after reset

Table 31-19. Scratch Pad Register (MSR) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved
7-0	SCR	0	These bits are intended for the programmer's use as a scratch pad in the sense that it temporarily holds the programmer's data without affecting any other UART operation.

31.3.11 Divisor Latches (DLL and DLH)

Two 8-bit register fields (DLL and DLH), called divisor latches, store the 16-bit divisor for generation of the baud clock in the baud generator. The latches are in DLH and DLL. DLH holds the most-significant bits of the divisor, and DLL holds the least-significant bits of the divisor. These divisor latches must be loaded during initialization of the UART in order to ensure desired operation of the baud generator. Writing to the divisor latches results in two wait states being inserted during the write access while the baud generator is loaded with the new value.

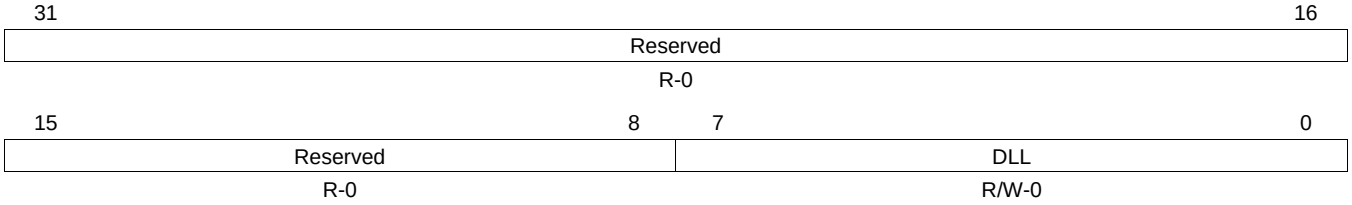
Access considerations:

- RBR, THR, and DLL share one address. When DLAB = 1 in LCR, all accesses at the shared address are accesses to DLL. When DLAB = 0, reading from the shared address gives the content of RBR, and writing to the shared address modifies THR.
- IER and DLH share one address. When DLAB = 1 in LCR, accesses to the shared address read or modify to DLH. When DLAB = 0, all accesses at the shared address read or modify IER.

DLL and DLH also have dedicated addresses. If you use the dedicated addresses, you can keep the DLAB bit cleared, so that RBR, THR, and IER are always selected at the shared addresses.

The divisor LSB latch (DLL) is shown in Figure 31-19 and described in Table 31-20. The divisor MSB latch (DLH) is shown in Figure 31-20 and described in Table 31-21.

Figure 31-19. Divisor LSB Latch (DLL)

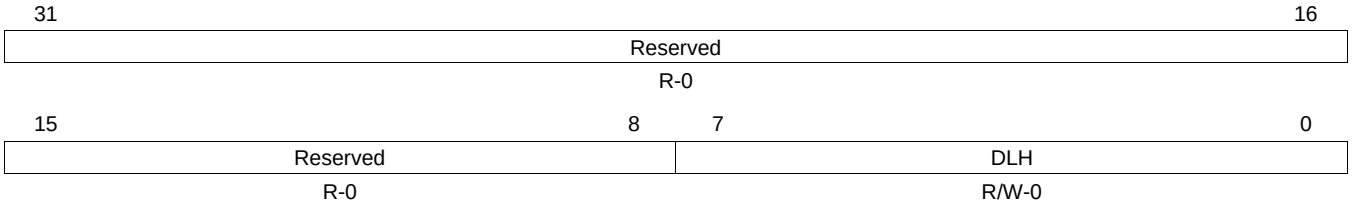


LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 31-20. Divisor LSB Latch (DLL) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved
7-0	DLL	0-FFh	The 8 least-significant bits (LSBs) of the 16-bit divisor for generation of the baud clock in the baud rate generator.

Figure 31-20. Divisor MSB Latch (DLH)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 31-21. Divisor MSB Latch (DLH) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved
7-0	DLH	0-FFh	The 8 most-significant bits (MSBs) of the 16-bit divisor for generation of the baud clock in the baud rate generator.

31.3.12 Revision Identification Registers (REVID1 and REVID2)

The revision identification registers (REVID1 and REVID2) contain peripheral identification data for the peripheral. REVID1 is shown in Figure 31-21 and described in Table 31-22. REVID2 is shown in Figure 31-22 and described in Table 31-23.

Figure 31-21. Revision Identification Register 1 (REVID1)

31	0
REVID1	
R-1102 0002h	

LEGEND: R = Read only; -*n* = value after reset

Table 31-22. Revision Identification Register 1 (REVID1) Field Descriptions

Bit	Field	Value	Description
31-0	REVID1	1102 0002h	Peripheral Identification Number

Figure 31-22. Revision Identification Register 2 (REVID2)

31	16
Reserved	
R-0	

15	8	7	0
Reserved		REVID2	
R-0		R-0	

LEGEND: R = Read only; -*n* = value after reset

Table 31-23. Revision Identification Register 2 (REVID2) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved
7-0	REVID2	0	Peripheral Identification Number

31.3.13 Power and Emulation Management Register (PWREMU_MGMT)

The power and emulation management register (PWREMU_MGMT) is shown in Figure 31-23 and described in Table 31-24.

Figure 31-23. Power and Emulation Management Register (PWREMU_MGMT)

31					16
Reserved					
R-0					

15	14	13	12	1	0
Rsvd	UTRST	URRST	Reserved		FREE
R/W-0	R/W-0	R/W-0	R-1		R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 31-24. Power and Emulation Management Register (PWREMU_MGMT) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	Reserved
15	Reserved	0	Reserved. This bit must always be written with a 0.
14	UTRST		UART transmitter reset. Resets and enables the transmitter.
		0	Transmitter is disabled and in reset state.
		1	Transmitter is enabled.
13	URRST		UART receiver reset. Resets and enables the receiver.
		0	Receiver is disabled and in reset state.
		1	Receiver is enabled.
12-1	Reserved	1	Reserved
0	FREE		Free-running enable mode bit. This bit determines the emulation mode functionality of the UART. When halted, the UART can handle register read/write requests, but does not generate any transmission/reception, interrupts or events.
		0	If a transmission is not in progress, the UART halts immediately. If a transmission is in progress, the UART halts after completion of the one-word transmission.
		1	Free-running mode is enabled; UART continues to run normally.

31.3.14 Mode Definition Register (MDR)

The Mode Definition register (MDR) determines the over-sampling mode for the UART. MDR is shown in Figure 31-24 and described in Table 31-25.

Figure 31-24. Mode Definition Register (MDR)

31	16
Reserved	
R-0	

15	1	0
Reserved		OSM_SEL
R-0		R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 31-25. Mode Definition Register (MDR) Field Descriptions

Bit	Field	Value	Description
31-1	Reserved	0	Reserved
0	OSM_SEL		Over-Sampling Mode Select.
		0	16× over-sampling.
		1	13× over-sampling.

Universal Serial Bus OHCI Host Controller

This chapter describes the universal serial bus OHCI host controller.

Topic **Page**

32.1 Introduction

32.1.1 Purpose of the Peripheral

The USB1.1 OHCI host controller (HC) is a single port controller that communicates with USB devices at the USB low-speed (1.5M bit-per-second maximum) and full-speed (12M bit-per-second maximum) data rates. It is compatible with the *Universal Serial Bus Specification Revision 2.0* and the *Open HCI—Open Host Controller Interface Specification for USB, Release 1.0a*, available through the Compaq Computer Corporation web site, and hereafter called the *OHCI Specification for USB*. It is assumed that users of the USB1.1 host controller are already familiar with the *USB Specification* and *OHCI Specification for USB*.

The USB1.1 host controller implements the register set and makes use of the memory data structures defined in the *OHCI Specification for USB*. These registers and data structures are the mechanisms by which a USB host controller driver software package can control the USB1.1 host controller. The *OHCI Specification for USB* also defines how the USB host controller implementation must interact with those registers and data structures in system memory.

To reduce processor software and interrupt overhead, the USB1.1 host controller generates USB traffic based on data structures and data buffers stored in system memory. The USB1.1 host controller accesses these data structures without direct intervention by the processor using its bus master port. These data structures and data buffers can be located in internal or external system RAM.

The USB1.1 host controller provides an interrupt to both the ARM and DSP.

32.2 Architecture

32.2.1 Clock and Reset

The USB1.1 module requires that several different clocks are present before it can be accessed:

1. Internal system bus clocks for accesses by the ARM or (Device SYSCLK2 and SYSCLK4)
2. Local bus clock to the USB1.1 host controller (derived from SYSCLK4)
3. USB bus side 48-MHz reference clock must be present. Several options are available to source this clock.

32.2.1.1 Internal System Bus Clocks Needed

The internal system bus clocks SYSCLK2 and SYSCLK4 are normally configured during the device reset process; as the device PLL controller is initialized. The USB1.1 host controller operates in the SYSCLK4 domain but most of the device level bus infrastructure operates on the SYSCLK2 domain. Normally one or both of the host CPU clock domains (SYSCLK6 for the ARM and SYSCLK1 for the DSP) are enabled as well.

32.2.1.2 Local Bus Clock and Local Reset

The USB1.1 host controller actually operates from a local (gated) version of SYSCLK4. This allows the module be put into a low power state when not in use. The module also has its own local reset that is asserted during a device level reset and remains asserted until released by software. Additionally software can at any time assert a hardware reset on the USB1.1 host controller individually, causing it to reinitialize without affecting any of the other peripherals on the device.

Both the local clock and local reset of the USB1.1 host controller are under the control of the device level power sleep controller 1 (PSC1) module. This module controls many local power sleep controller modules, and local power sleep controller 2 (LPSC2) of PSC1 controls the USB1.1 OHCI host controller.

32.2.1.3 48-MHz Reference Clock

This device includes an integrated USB 1.1 Phy for the OHCI Host Controller's Root Hub (Port 0). This Phy requires a 48-MHz reference clock for proper operation. Two options are available to provide this reference clock:

- Use the reference clock generated by the USB0 module integrated high-speed phy. The high-speed phy includes a phase locked loop (PLL) that is capable of generating a 48-MHz reference clock from multiple different input clock options. This method is probably the most convenient as it does not require an externally sourced clock, and the PLL in the USB0 module has flexibility in the frequency of its input clock. However when using this option, the USB0 phy must be operating in order to use the USB1.1 OHCI host controller. (This does not mean that the USB2.0 module must be running, only that its phy needs to be configured properly and enabled).
- Provide the 48 MHz clock externally, on the USB_REFCLKIN pin.

For details on device-level configuration of the 48-MHz reference clock, see the *Device Clocking* chapter.

The USB1.1 host controller completes its reset after the host controller clock is transitioned from disabled to enabled and the host controller reset is removed. After system software turns on the clock to the USB1.1 host controller and removes it from reset, it is necessary to wait until the USB1.1 host controller internal reset completes. To ensure that the USB1.1 host controller has completely reset, system software must wait until reads of both the HCREVISION register and the HCHCCA register return their correct reset default values.

32.2.2 Open Host Controller Interface Functionality

32.2.2.1 OHCI Controller Overview

The *Open HCI—Open Host Controller Interface Specification for USB, Release 1.0a* defines a set of registers and data structures stored in system memory that control how a USB host controller interfaces to system software. This specification, in conjunction with the *Universal Serial Bus Specification Version 2.0*, defines most of the USB functionality that the USB1.1 host controller provides.

The *OHCI Specification for USB* focuses on two main aspects of the USB host controller hardware implementation: its register set and the memory data structures that define the appearance of USB bus activity. Other topics include interrupt generation, USB host controller state, USB frame management, and the hardware methods used to process the lists of data structures in system memory.

This document does not duplicate the information presented in the *OHCI Specification for USB* or the *USB Specification*. USB1.1 host controller users can refer to the *USB Specification* and the *OHCI Specification for USB* for detailed discussions of USB requirements and OHCI controller operation.

32.2.3 Differences From OHCI Specification for USB

The USB1.1 module OHCI compatible host controller implementation does not implement every aspect of the functionality defined in the *OHCI Specification for USB*. The differences focus on power switching, overcurrent reporting, and the OHCI ownership change interrupt. Other restrictions are imposed by the effects of the pin multiplexing options.

32.2.3.1 Power Switching Output Pins Not Supported

The device does not provide pins that can be controlled directly by the USB1.1 host controller OHCI port power control features. The OHCI RHPORTSTATUS register port power control bits can be programmed by the USB1.1 host controller driver software, but this does not have any direct effect on any VBUS switching implemented on the board.

You can use software control of GPIO pins or other implementation-specific control mechanisms to control VBUS switching.

32.2.3.2 Overcurrent Protection Input Pins Not Supported

The device does not provide any pins that allow the USB1.1 host controller OHCI RHPORTSTATUS overcurrent protection status bits to be directly controlled by external hardware.

You can use software monitoring of GPIO pins or other implementation-specific control mechanisms to report port overcurrent information to the USB1.1 host controller driver.

32.2.3.3 No Ownership Change Interrupt

The USB1.1 host controller does not implement the OHCI ownership change interrupt.

32.2.4 Implementation of OHCI Specification for USB1.1

32.2.4.1 USB1.1 Host Controller Endpoint Descriptor (ED) List Head Pointers

The *OHCI Specification for USB* provides a specific sequence of operations for the host controller driver to perform when setting up the host controller. Failure to follow that sequence can result in malfunction. As a specific example, the HCCONTROLHEADED and HCBULKHEADED pointer registers and the 32 HCCAINTERRUPTTABLE pointers must all point to valid physical addresses of valid endpoint descriptors.

The USB1.1 host controller does not check HCCONTROLHEADED registers, HCBULKHEADED registers, or the values in the 32 HCCAINTERRUPTTABLE pointers before using them to access EDs. In particular if any of these pointers are NULL when the corresponding list enable bit is set, the USB1.1 host controller attempts to access using the physical address of 0, which is not a valid memory region for the USB1.1 host controller to access.

32.2.4.2 OHCI USB Suspend State

The USB1.1 host controller ignores upstream traffic from downstream devices for about 3 ms after the host controller state (HCCONTROL.HCFS) changes from USB resume state to USB operational state. If any TDs cause generation of downstream packets during that time, the downstream packets are sent, but downstream device responses are ignored. Any such TDs are aborted with completion codes marked as Device Not Responding. TDs on any of the lists (periodic, control, bulk, and isochronous) can cause such an occurrence.

The *USB Specification* requires that system software must provide a 10-ms resume recovery time (TRSMRCY) after a bus segment transitions from resume signaling to normal operational mode. During that time, only start of frame packets are to be sent on the bus segment. The system software should disable all list enable bits (HCCONTROL.PLE, HCCONTROL.IE, HCCONTROL.CLE, and HCCONTROL.BLE) and then wait for at least 1 ms before setting the host controller into USB suspend state (via HCCONTROL.HCFS). When restoring from suspend, system software must set the host controller into USB resume state, and wait for the host controller to transition into USB operational state. System software must then wait 10 ms before enabling the host controller list enable bits.

When the host controller has been placed into the USB suspend state under software control, but is brought out by a remote wake-up, system software must monitor the HCRHPORTSTATUS[x].PSS and HCRHPORTSTATUS[x].PSSC bits. The HCRHPORTSTATUS[x].PSS bit changes to 0 only after completion of resume signaling on the bus segment, and completion of the 3-ms period (packets from downstream devices are ignored).

When using port-specific suspend, it is not necessary to disable the host controller lists, as long as there are no active EDs and TDs directed toward devices that are downstream of the suspended port. For port-specific suspend operations, the host controller does not issue a root hub status change interrupt (HCRHPORTSTATUS[n].PSSC bit = 1 and HCRHPORTSTATUS[n].PSS = 0), until the end of the approximately 3-ms delay after the resume signaling completes.

When using port-specific suspend, system software must ensure that there are no active EDs for devices that are downstream of the suspended port before setting the port into suspend mode. While the port is in suspend or being resumed, system software must not enable any EDs for any devices downstream of the suspended port. Once the root hub status change interrupt occurs as a result of the suspended port PSS bit changing to 0, EDs can be enabled for devices downstream of the operational port.

32.2.5 OHCI Interrupts

The USB1.1 host controller is controlled by either the ARM or the DSP. It has the ability to interrupt either processor.

32.2.6 USB1.1 Host Controller Access to System Memory

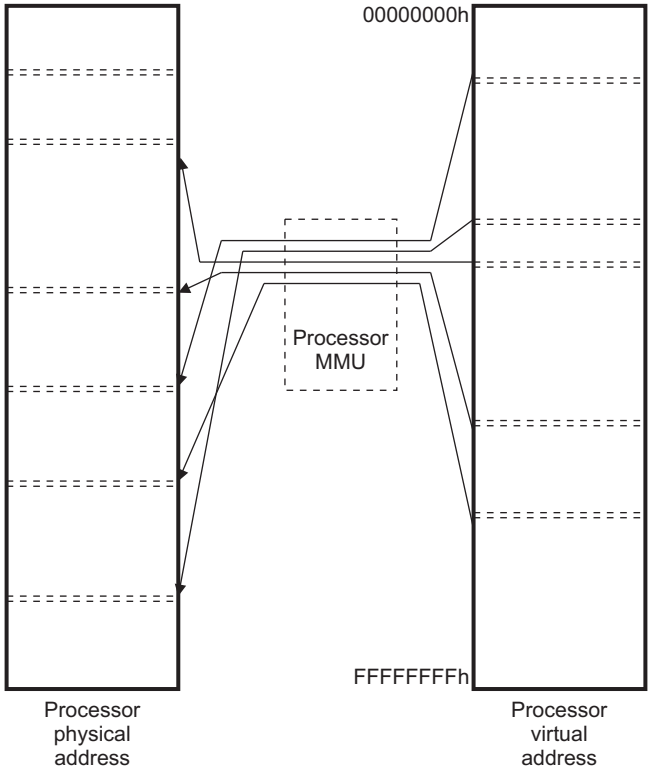
The USB1.1 module needs to access system memory to read and write the OHCI data structures and data buffers associated with USB traffic. The switch fabric allows the USB1.1 host controller to access system memory.

32.2.7 Physical Addressing

Transactions on the internal bus use physical addresses, so all system memory accesses initiated by the USB1.1 host controller must use physical addresses. The CPU can be configured to use virtual addressing. In this case, software manipulates virtual addresses that may or may not be identical to physical addresses. When virtual addressing is used, system software must perform the appropriate virtual address to physical address and physical address to virtual address conversions when manipulating the USB1.1 host controllers data structures and pointers to those data structures.

Figure 32-1 shows the virtual address to physical address conversion.

Figure 32-1. Relationships Between Virtual Address Physical Address



32.3 Registers

Most of the host controller (HC) registers are OHCI operational registers, defined by the *OHCI Specification for USB*. Four additional registers not specified by the *OHCI Specification for USB* provide additional information about the USB1.1 host controller state. The USB1.1 host controller registers can be accessed in user and supervisor modes.

To enhance code reusability with possible future versions of the USB1.1 host controller, reads and writes to reserved USB1.1 host controller register addresses are to be avoided. Unless otherwise specified, when writing registers that have reserved bits, read-modify-write operations must be used so that the reserved bits are written with their previous values.

The USB1.1 host controller registers are listed in Table 32-1.

Table 32-1. USB1.1 Host Controller Registers

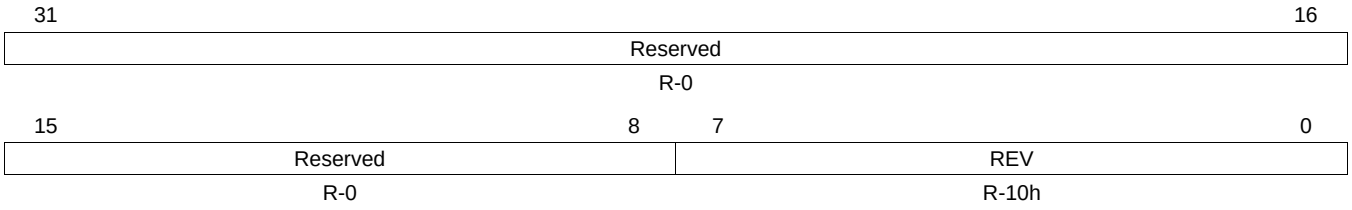
Address	Acronym	Register Description	Section
01E2 5000h	HCREVISION	OHCI Revision Number Register	Section 32.3.1
01E2 5004h	HCCONTROL	HC Operating Mode Register	Section 32.3.2
01E2 5008h	HCCOMMANDSTATUS	HC Command and Status Register	Section 32.3.3
01E2 500Ch	HCINTERRUPTSTATUS	HC Interrupt and Status Register	Section 32.3.4
01E2 5010h	HCINTERRUPTENABLE	HC Interrupt Enable Register	Section 32.3.5
01E2 5014h	HCINTERRUPTDISABLE	HC Interrupt Disable Register	Section 32.3.6
01E2 5018h	HCHCCA	HC HCAA Address Register(1)	Section 32.3.7
01E2 501Ch	HCPERIODCURRENTED	HC Current Periodic Register(1)	Section 32.3.8
01E2 5020h	HCCONTROLHEADED	HC Head Control Register(1)	Section 32.3.9
01E2 5024h	HCCONTROLCURRENTED	HC Current Control Register(1)	Section 32.3.10
01E2 5028h	HCBULKHEADED	HC Head Bulk Register(1)	Section 32.3.11
01E2 502Ch	HCBULKCURRENTED	HC Current Bulk Register(1)	Section 32.3.12
01E2 5030h	HCDONEHEAD	HC Head Done Register(1)	Section 32.3.13
01E2 5034h	HCFMINTERVAL	HC Frame Interval Register	Section 32.3.14
01E2 5038h	HCFMREMAINING	HC Frame Remaining Register	Section 32.3.15
01E2 503Ch	HCFMNUMBER	HC Frame Number Register	Section 32.3.16
01E2 5040h	HCPERIODICSTART	HC Periodic Start Register	Section 32.3.17
01E2 5044h	HCLSTHRESHOLD	HC Low-Speed Threshold Register	Section 32.3.18
01E2 5048h	HCRHDESCRIPTORA	HC Root Hub A Register	Section 32.3.19
01E2 504Ch	HCRHDESCRIPTORB	HC Root Hub B Register	Section 32.3.20
01E2 5050h	HCRHSTATUS	HC Root Hub Status Register	Section 32.3.21
01E2 5054h	HCRHPORTSTATUS1	HC Port 1 Status and Control Register(2)	Section 32.3.22
01E2 5058h	HCRHPORTSTATUS2	HC Port 2 Status and Control Register(3)	Section 32.3.23

(1) Restrictions apply to the physical addresses used in these registers (see Section 32.2.7).
(2) Connected to the integrated USB1.1 phy pins (DM, DP).
(3) Although the controller implements two ports, the second port cannot be used.

32.3.1 OHCI Revision Number Register (HCREVISION)

The OHCI revision number register (HCREVISION) is shown in Figure 32-2 and described in Table 32-2.

Figure 32-2. OHCI Revision Number Register (HCREVISION)



LEGEND: R = Read only; -*n* = value after reset

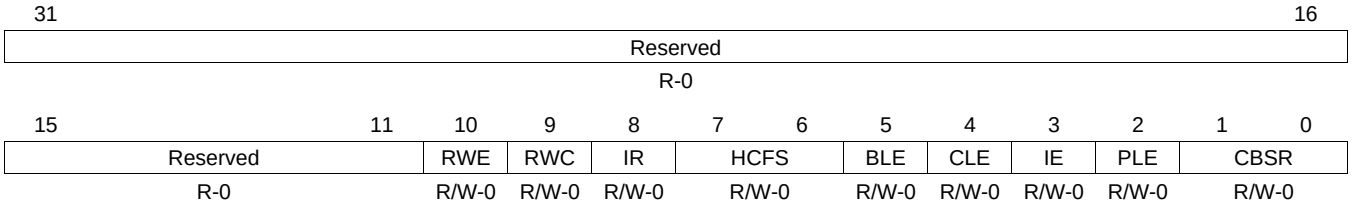
Table 32-2. OHCI Revision Number Register (HCREVISION) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved
7-0	REV	10h	OHCI revision number.

32.3.2 HC Operating Mode Register (HCCONTROL)

The HC operating mode register (HCCONTROL) controls the operating mode of the USB1.1 host controller. HCCONTROL is shown in Figure 32-3 and described in Table 32-3.

Figure 32-3. HC Operating Mode Register (HCCONTROL)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 32-3. HC Operating Mode Register (HCCONTROL) Field Descriptions

Bit	Field	Value	Description
31-11	Reserved	0	Reserved
10	RWE	0-1	Remote wake-up enable.
9	RWC	0-1	Remote wake-up connected.
8	IR	0	Interrupt routing. The USB1.1 host controller does not provide an SMI interrupt. This bit must be 0 to allow the USB1.1 host controller interrupt to propagate to the MPU level 2 interrupt controller.
7-6	HCFS	0-3h	Host controller functional state. A transition to USB operational causes SOF generation to begin in 1 ms. The USB1.1 host controller can automatically transition from USB suspend to USB resume, if a downstream resume is received. The USB1.1 host controller enters USB suspend after a software reset. The USB1.1 host controller enters USB reset after a hardware reset. The USB reset state resets the root hub and causes downstream signaling of USB reset.
		0	USB reset
		1h	USB resume
		2h	USB operational
		3h	USB suspend
5	BLE		Bulk list enable.
		0	The bulk ED list is not processed in the next 1 ms frame. The host controller driver can modify the bulk ED list. If the driver removes the ED pointed to by the HC current bulk register (HCBULKCURRENTED) from the ED list, it must update HCBULKCURRENTED to point to a current ED before it reenables the bulk list.
		1	Enables processing of the bulk ED list. The HC head bulk register (HCBULKHEADED) must be 0 or point to a valid ED before setting this bit. The HC current bulk register (HCBULKCURRENTED) must be 0 or point to a valid ED before setting this bit.
4	CLE		Control list enable.
		0	The control ED list is not processed in the next 1 ms frame. The host controller driver can modify the control ED list. If the driver removes the ED pointed to by the HC current control register (HCCONTROLCURRENTED) from the ED list, it must update HCCONTROLCURRENTED to point to a current ED before it reenables the control list.
		1	Enables processing of the control ED list. The HC head control register (HCCONTROLHEADED) must be 0 or point to a valid ED before setting this bit. The HC current control register (HCCONTROLCURRENTED) must be 0 or point to a valid ED before setting this bit.
3	IE		Isochronous enable.
		0	Isochronous EDs are not processed. The USB1.1 host controller checks this bit every time it finds an isochronous ED in the periodic list.
		1	Enables processing of isochronous EDs in the next frame, if not in the current frame.
2	PLE		Periodic list enable.
		0	Periodic ED lists are not processed. Periodic list processing is disabled beginning with the next frame.
		1	Enables processing of the periodic ED lists. Periodic list processing begins in the next frame.
1-0	CBSR	0-3h	Control/bulk service ratio. Specifies the ratio between control and bulk EDs processed in a frame.
		0	1 control ED per bulk ED.
		1h	2 control EDs per bulk ED.
		2h	3 control EDs per bulk ED.
		3h	4 control EDs per bulk ED.

32.3.3 HC Command and Status Register (HCCOMMANDSTATUS)

The HC command and status register (HCCOMMANDSTATUS) shows the current state of the host controller and accepts commands from the host controller driver. HCCOMMANDSTATUS is shown in Figure 32-4 and described in Table 32-4.

Figure 32-4. HC Command and Status Register (HCCOMMANDSTATUS)

31	18	17	16
Reserved		SOC	
R-0		R-0	

15	4	3	2	1	0
Reserved		OCR	BLF	CLF	HCR
R-0		R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 32-4. HC Command and Status Register (HCCOMMANDSTATUS) Field Descriptions

Bit	Field	Value	Description
31-18	Reserved	0	Reserved
17-16	SOC	0-3h	Scheduling overrun count. Counts the number of times a scheduling overrun occurs. This count is incremented even if the host controller driver has not acknowledged any previous pending scheduling overrun interrupt.
15-4	Reserved	0	Reserved
3	OCR	0-1	Ownership change request. The host controller driver sets this bit to gain ownership of the host controller. The processor does not support SMI interrupts, so no ownership change interrupt occurs.
2	BLF	0-1	Bulk list filled. The host controller driver must set this bit if it modifies the bulk list to include new TDs. If the HC current bulk register (HCBULKCURRENTED) is 0, the USB1.1 host controller does not begin processing bulk list EDs unless this bit is set. When the USB1.1 host controller sees this bit set and begins processing the bulk list, it clears this bit to 0.
1	CLF	0-1	Control list filled. The host controller driver must set this bit if it modifies the control list to include new TDs. If the HC head control register (HCCONTROLHEADED) is 0, the USB1.1 host controller does not begin processing control list EDs unless this bit is set. When the USB1.1 host controller sees this bit set and begins processing the control list, it clears this bit to 0.
0	HCR		Host controller reset.
		0	No effect.
		1	Initiates a software reset of the USB1.1 host controller. This transitions the USB1.1 host controller to the USB suspend state. This resets most USB1.1 host controller OHCI registers. OHCI register accesses must not be attempted until a read of this bit returns a 0. A write of 1 to this bit does not reset the root hub and does not signal USB reset to downstream USB functions.

32.3.4 HC Interrupt and Status Register (HCINTERRUPTSTATUS)

The HC interrupt and status register (HCINTERRUPTSTATUS) reports the status of the USB1.1 host controller internal interrupt sources. HCINTERRUPTSTATUS is shown in Figure 32-5 and described in Table 32-5.

Figure 32-5. HC Interrupt and Status Register (HCINTERRUPTSTATUS)

31	30	29	16
Rsvd	OC	Reserved	
R-0	R-0	R-0	

15	7	6	5	4	3	2	1	0
Reserved		RHSC	FNO	UE	RD	SF	WDH	SO
R-0		R/W1C-0	R/W1C-0	R/W1C-0	R/W1C-0	R/W1C-0	R/W1C-0	R/W1C-0

LEGEND: R/W = Read/Write; R = Read only; W1C = Write 1 to clear (writing 0 has no effect); -*n* = value after reset

Table 32-5. HC Interrupt and Status Register (HCINTERRUPTSTATUS) Field Descriptions

Bit	Field	Value	Description
31	Reserved	0	Reserved
30	OC	0-1	Ownership change.
29-7	Reserved	0	Reserved
6	RHSC		Root hub status change. A write of 1 clears this bit; a write of 0 has no effect.
		0	A root hub status change has not occurred.
		1	A root hub status change has occurred.
5	FNO		Frame number overflow. A write of 1 clears this bit; a write of 0 has no effect.
		0	A frame number overflow has not occurred.
		1	A frame number overflow has occurred.
4	UE		Unrecoverable error. A write of 1 clears this bit; a write of 0 has no effect.
		0	An unrecoverable error has not occurred.
		1	An unrecoverable error has occurred on the OCPI bus, or that an isochronous TD PSW field condition code was not set to Not Accessed when the USB1.1 host controller attempted to perform a transfer using that PSW/offset pair.
3	RD		Resume detected. A write of 1 clears this bit; a write of 0 has no effect.
		0	A downstream device has not issued a resume request.
		1	A downstream device has issued a resume request.
2	SF		Start of frame. A write of 1 clears this bit; a write of 0 has no effect.
		0	A SOF has not been issued.
		1	A SOF has been issued.
1	WDH		Write done head. The host controller driver must read the value from the HC head done register (HCDONEHEAD) before writing 1 to this bit. A write of 1 clears this bit; a write of 0 has no effect.
		0	USB1.1 host controller has not updated the HC head done register (HCDONEHEAD).
		1	USB1.1 host controller has updated the HC head done register (HCDONEHEAD).
0	SO		Scheduling overrun. A write of 1 clears this bit; a write of 0 has no effect.
		0	A scheduling overrun has not occurred.
		1	A scheduling overrun has occurred.

32.3.5 HC Interrupt Enable Register (HCINTERRUPTENABLE)

The HC interrupt enable register (HCINTERRUPTENABLE) enables various OHCI interrupt sources to generate interrupts to the level 2 interrupt controller. HCINTERRUPTENABLE is shown in Figure 32-6 and described in Table 32-6.

Figure 32-6. HC Interrupt Enable Register (HCINTERRUPTENABLE)

31	30	29	16
MIE	OC	Reserved	
R/W1S-0	R-0	R-0	

15	7	6	5	4	3	2	1	0
Reserved		RHSC	FNO	UE	RD	SF	WDH	SO
R-0		R/W1S-0	R/W1S-0	R/W1S-0	R/W1S-0	R/W1S-0	R/W1S-0	R/W1S-0

LEGEND: R/W = Read/Write; R = Read only; W1S = Write 1 to set (writing 0 has no effect); -*n* = value after reset

Table 32-6. HC Interrupt Enable Register (HCINTERRUPTENABLE) Field Descriptions

Bit	Field	Value	Description
31	MIE		Master interrupt enable. A write of 1 sets this bit; a write of 0 has no effect. A write of 1 to the corresponding bit in the HC interrupt disable register (HCINTERRUPTDISABLE) clears this bit.
		0	OHCI interrupt sources are ignored and USB1.1 host controller interrupts are not propagated to the level 2 interrupt controller.
		1	Allows other enabled OHCI interrupt sources to propagate to the level 2 interrupt controller.
30	OC	0-1	Ownership change.
29-7	Reserved	0	Reserved
6	RHSC		Root hub status change. A write of 1 sets this bit; a write of 0 has no effect. A write of 1 to the corresponding bit in the HC interrupt disable register (HCINTERRUPTDISABLE) clears this bit.
		0	Root hub status change interrupts do not propagate.
		1	When MIE is 1, allows root hub status change interrupts to propagate to the level 2 interrupt controller.
5	FNO		Frame number overflow. A write of 1 sets this bit; a write of 0 has no effect. A write of 1 to the corresponding bit in the HC interrupt disable register (HCINTERRUPTDISABLE) clears this bit.
		0	Frame number overflow interrupts do not propagate.
		1	When MIE is 1, allows frame number overflow interrupts to propagate to the level 2 interrupt controller.
4	UE		Unrecoverable error. A write of 1 sets this bit; a write of 0 has no effect. A write of 1 to the corresponding bit in the HC interrupt disable register (HCINTERRUPTDISABLE) clears this bit.
		0	Unrecoverable error interrupts do not propagate.
		1	When MIE is 1, allows unrecoverable error interrupts to propagate to the level 2 interrupt controller.
3	RD		Resume detected. A write of 1 sets this bit; a write of 0 has no effect. A write of 1 to the corresponding bit in the HC interrupt disable register (HCINTERRUPTDISABLE) clears this bit.
		0	Resume detected interrupts do not propagate.
		1	When MIE is 1, allows resume detected interrupts to propagate to the level 2 interrupt controller.
2	SF		Start of frame. A write of 1 sets this bit; a write of 0 has no effect. A write of 1 to the corresponding bit in the HC interrupt disable register (HCINTERRUPTDISABLE) clears this bit.
		0	Start of frame interrupts do not propagate.
		1	When MIE is 1, allows start of frame interrupts to propagate to the level 2 interrupt controller.
1	WDH		Write done head. A write of 1 sets this bit; a write of 0 has no effect. A write of 1 to the corresponding bit in the HC interrupt disable register (HCINTERRUPTDISABLE) clears this bit.
		0	Write done head interrupts do not propagate.
		1	When MIE is 1, allows write done head interrupts to propagate to the level 2 interrupt controller.
0	SO		Scheduling overrun. A write of 1 sets this bit; a write of 0 has no effect. A write of 1 to the corresponding bit in the HC interrupt disable register (HCINTERRUPTDISABLE) clears this bit.
		0	Scheduling overrun interrupts do not propagate.
		1	When MIE is 1, allows scheduling overrun interrupts to propagate to the level 2 interrupt controller.

32.3.6 HC Interrupt Disable Register (HCINTERRUPTDISABLE)

The HC interrupt disable register (HCINTERRUPTDISABLE) is used to clear bits in the HC interrupt enable register (HCINTERRUPTENABLE). HCINTERRUPTDISABLE is shown in Figure 32-7 and described in Table 32-7.

Figure 32-7. HC Interrupt Disable Register (HCINTERRUPTDISABLE)

31	30	29	16
MIE	OC	Reserved	
R/W-0	R-0	R-0	

15	7	6	5	4	3	2	1	0
Reserved		RHSC	FNO	UE	RD	SF	WDH	SO
R-0		R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

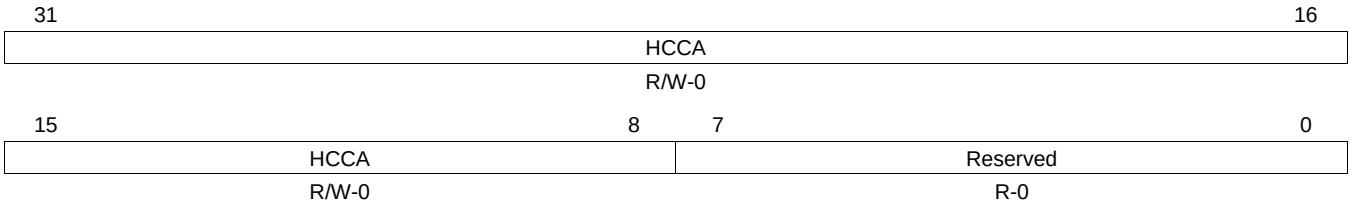
Table 32-7. HC Interrupt Disable Register (HCINTERRUPTDISABLE) Field Descriptions

Bit	Field	Value	Description
31	MIE		Master interrupt enable. Read always returns 0.
		0	No effect.
		1	Clears the MIE bit in the HC interrupt enable register (HCINTERRUPTENABLE).
30	OC	0-1	Ownership change.
29-7	Reserved	0	Reserved
6	RHSC		Root hub status change. Read always returns 0.
		0	No effect.
		1	Clears the RHSC bit in the HC interrupt enable register (HCINTERRUPTENABLE).
5	FNO		Frame number overflow. Read always returns 0.
		0	No effect.
		1	Clears the FNO bit in the HC interrupt enable register (HCINTERRUPTENABLE).
4	UE		Unrecoverable error. Read always returns 0.
		0	No effect.
		1	Clears the UE bit in the HC interrupt enable register (HCINTERRUPTENABLE).
3	RD		Resume detected. Read always returns 0.
		0	No effect.
		1	Clears the RD bit in the HC interrupt enable register (HCINTERRUPTENABLE).
2	SF		Start of frame. Read always returns 0.
		0	No effect.
		1	Clears the SF bit in the HC interrupt enable register (HCINTERRUPTENABLE).
1	WDH		Write done head. Read always returns 0.
		0	No effect.
		1	Clears the WDH bit in the HC interrupt enable register (HCINTERRUPTENABLE).
0	SO		Scheduling overrun. Read always returns 0.
		0	No effect.
		1	Clears the SO bit in the HC interrupt enable register (HCINTERRUPTENABLE).

32.3.7 HC HCAA Address Register (HCHCCA)

The HC HCAA address register (HCHCCA) defines the physical address of the beginning of the HCCA. HCHCCA is shown in Figure 32-8 and described in Table 32-8.

Figure 32-8. HC HCAA Address Register (HCHCCA)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

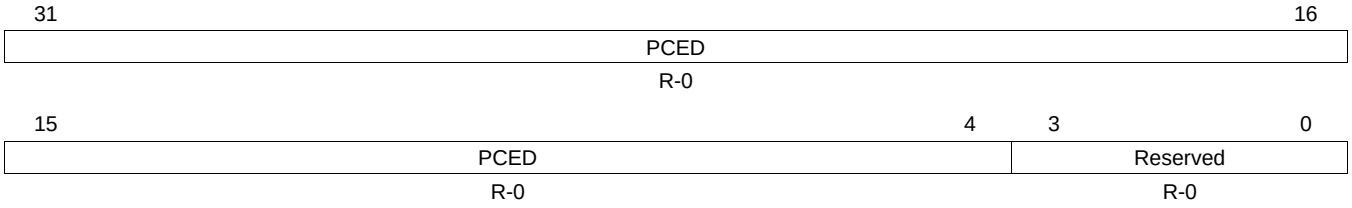
Table 32-8. HC HCAA Address Register (HCHCCA) Field Descriptions

Bit	Field	Value	Description
31-8	HCCA	0-FF FFFFh	Physical address of the beginning of the HCCA.
7-0	Reserved	0	Reserved

32.3.8 HC Current Periodic Register (HCPERIODCURRENTED)

The HC current periodic register (HCPERIODCURRENTED) defines the physical address of the next endpoint descriptor (ED) on the periodic ED list. HCPERIODCURRENTED is shown in Figure 32-9 and described in Table 32-9.

Figure 32-9. HC Current Periodic Register (HCPERIODCURRENTED)



LEGEND: R = Read only; -*n* = value after reset

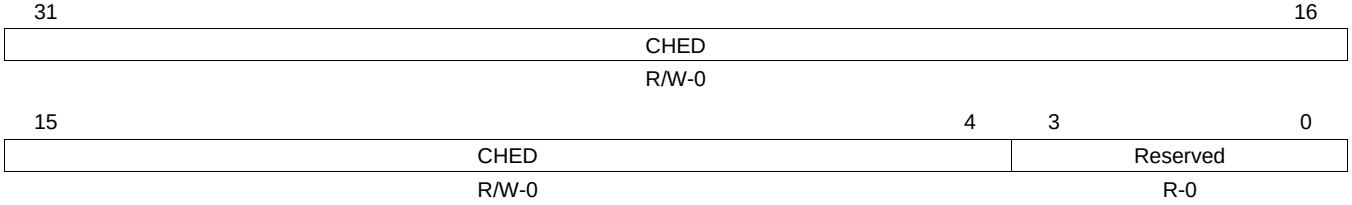
Table 32-9. HC Current Periodic Register (HCPERIODCURRENTED) Field Descriptions

Bit	Field	Value	Description
31-4	PCED	0-FFF FFFFh	Physical address of the current ED on the periodic ED list. This field represents bits 31-4 of the physical address of the next ED on the periodic ED list. EDs are assumed to begin on a 16-byte aligned address, so bits 3-0 of this pointer are assumed to be 0. For the restrictions on physical addresses, see Section 32.2.7.
3-0	Reserved	0	Reserved

32.3.9 HC Head Control Register (HCCONTROLHEADED)

The HC head control register (HCCONTROLHEADED) defines the physical address of the head endpoint descriptor (ED) on the control ED list. HCCONTROLHEADED is shown in Figure 32-10 and described in Table 32-10.

Figure 32-10. HC Head Control Register (HCCONTROLHEADED)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

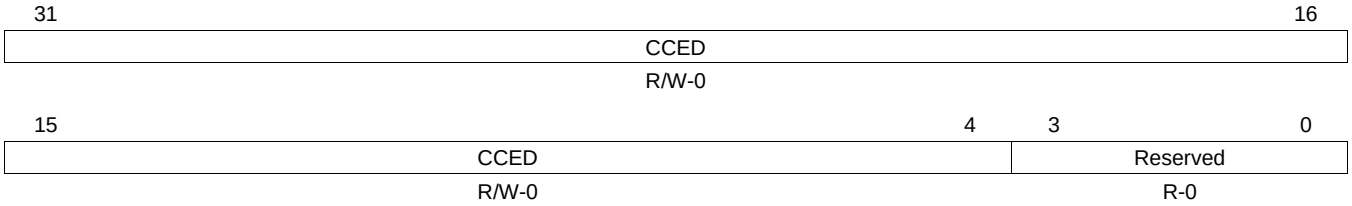
Table 32-10. HC Head Control Register (HCCONTROLHEADED) Field Descriptions

Bit	Field	Value	Description
31-4	CHED	0-FFF FFFFh	Physical address of the head ED on the control ED list. This field represents bits 31-4 of the physical address of the head ED on the control ED list. EDs are assumed to begin on a 16-byte aligned address, so bits 3-0 of this pointer are assumed to be 0. For the restrictions on physical addresses, see Section 32.2.7.
3-0	Reserved	0	Reserved

32.3.10 HC Current Control Register (HCCONTROLCURRENTED)

The HC current control register (HCCONTROLCURRENTED) defines the physical address of the next endpoint descriptor (ED) on the control ED list. HCCONTROLCURRENTED is shown in Figure 32-11 and described in Table 32-11.

Figure 32-11. HC Current Control Register (HCCONTROLCURRENTED)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 32-11. HC Current Control Register (HCCONTROLCURRENTED) Field Descriptions

Bit	Field	Value	Description
31-4	CCED	0-FFF FFFFh	Physical address of the current ED on the control ED list. This field represents bits 31-4 of the physical address of the next ED on the control ED list. EDs are assumed to begin on a 16-byte aligned address, so bits 3-0 of this pointer are assumed to be 0. For the restrictions on physical addresses, see Section 32.2.7. A value of 0 indicates that the USB1.1 host controller has reached the end of the control ED list without finding any transfers to process. This register is automatically updated by the USB1.1 host controller.
3-0	Reserved	0	Reserved

32.3.11 HC Head Bulk Register (HCBULKHEADED)

The HC head bulk register (HCBULKHEADED) defines the physical address of the head endpoint descriptor (ED) on the bulk ED list. HCBULKHEADED is shown in Figure 32-12 and described in Table 32-12.

Figure 32-12. HC Head Bulk Register (HCBULKHEADED)

31	16
BHED	
R/W-0	

15	4	3	0
BHED		Reserved	
R/W-0		R-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 32-12. HC Head Bulk Register (HCBULKHEADED) Field Descriptions

Bit	Field	Value	Description
31-4	BHED	0-FFF FFFFh	Physical address of the head ED on the bulk ED list. This field represents bits 31-4 of the physical address of the head ED on the bulk ED list. EDs are assumed to begin on a 16-byte aligned address, so bits 3-0 of this pointer are assumed to be 0. For the restrictions on physical addresses, see Section 32.2.7.
3-0	Reserved	0	Reserved

32.3.12 HC Current Bulk Register (HCBULKCURRENTED)

The HC current bulk register (HCBULKCURRENTED) defines the physical address of the next endpoint descriptor (ED) on the bulk ED list. HCBULKCURRENTED is shown in Figure 32-13 and described in Table 32-13.

Figure 32-13. HC Current Bulk Register (HCBULKCURRENTED)

31	16
BCED	
R/W-0	

15	4	3	0
BCED		Reserved	
R/W-0		R-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 32-13. HC Current Bulk Register (HCBULKCURRENTED) Field Descriptions

Bit	Field	Value	Description
31-4	BCED	0-FFF FFFFh	Physical address of the current ED on the bulk ED list. This field represents bits 31-4 of the physical address of the next ED on the bulk ED list. EDs are assumed to begin on a 16-byte aligned address, so bits 3-0 of this pointer are assumed to be 0. For the restrictions on physical addresses, see Section 32.2.7. A value of 0 indicates that the USB1.1 host controller has reached the end of the bulk ED list without finding any transfers to process. This register is automatically updated by the USB1.1 host controller.
3-0	Reserved	0	Reserved

32.3.13 HC Head Done Register (HCDONEHEAD)

The HC head done register (HCDONEHEAD) defines the physical address of the current head of the done TD queue. HCDONEHEAD is shown in Figure 32-14 and described in Table 32-14.

Figure 32-14. HC Head Done Register (HCDONEHEAD)

31	16
DH	
R-0	

15	4	3	0
DH		Reserved	
R-0		R-0	

LEGEND: R = Read only; -*n* = value after reset

Table 32-14. HC Head Done Register (HCDONEHEAD) Field Descriptions

Bit	Field	Value	Description
31-4	DH	0-FFF FFFFh	Physical address of the last TD that has added to the done queue. This field represents bits 31-4 of the physical address of the top TD on the done TD queue. TDs are assumed to begin on a 16-byte aligned address, so bits 3-0 of this pointer are assumed to be 0. A value of 0 indicates that there are no TDs on the done queue. This register is automatically updated by the USB1.1 host controller.
3-0	Reserved	0	Reserved

32.3.14 HC Frame Interval Register (HCFMINTERVAL)

The HC frame interval register (HCFMINTERVAL) defines the number of 12-MHz clock pulses in each USB frame. HCFMINTERVAL is shown in Figure 32-15 and described in Table 32-15.

Figure 32-15. HC Frame Interval Register (HCFMINTERVAL)

31	30	16
FIT	FSMPS	
R/W-0	R/W-0	

15	14	13	0
Reserved		FRAMEINTERVAL	
R-0		R/W-2EDFh	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 32-15. HC Frame Interval Register (HCFMINTERVAL) Field Descriptions

Bit	Field	Value	Description
31	FIT	0-1	Frame interval toggle. The host controller driver must toggle this bit any time it changes the frame interval field.
30-16	FSMPS	0-7FFFh	Largest data packet. Largest data packet size allowed for full-speed packets, in bit times.
15-14	Reserved	0	Reserved
13-0	FRAMEINTERVAL	0-3FFFh	Frame interval. Number of 12-MHz clocks in the USB frame. Nominally, this is set to 11,999 (2EDFh) to give a 1-ms frame. The host controller driver can make minor changes to this field to attempt to manually synchronize with another clock source.

32.3.15 HC Frame Remaining Register (HCFMREMAINING)

The HC frame remaining register (HCFMREMAINING) reports the number of full-speed bit times remaining in the current frame. HCFMREMAINING is shown in Figure 32-16 and described in Table 32-16.

Figure 32-16. HC Frame Remaining Register (HCFMREMAINING)

31	30	16
FRT	Reserved	
R-0	R-0	

15	14	13	0
Reserved		FR	
R-0		R-0	

LEGEND: R = Read only; -*n* = value after reset

Table 32-16. HC Frame Remaining Register (HCFMREMAINING) Field Descriptions

Bit	Field	Value	Description
31	FRT	0-1	Frame remaining toggle. This bit is loaded with the frame interval toggle bit every time the USB1.1 host controller loads the frame interval field into the frame remaining field.
30-14	Reserved	0	Reserved
13-0	FR	0-3FFFh	Frame remaining. The number of full-speed bit times remaining in the current frame. This field is automatically reloaded with the frame interval (FI) value in the HC frame interval register (HCFMINTERVAL) at the beginning of every frame.

32.3.16 HC Frame Number Register (HCFMNUMBER)

The HC frame number register (HCFMNUMBER) reports the current USB frame number. HCFMNUMBER is shown in Figure 32-17 and described in Table 32-17.

Figure 32-17. HC Frame Number Register (HCFMNUMBER)

31	16
Reserved	
R-0	

15	0
FN	
R-0	

LEGEND: R = Read only; -*n* = value after reset

Table 32-17. HC Frame Number Register (HCFMNUMBER) Field Descriptions

Bit	Field	Value	Description
31-16	Reserved	0	Reserved
15-0	FN	0-FFFFh	Frame number. This field reports the current USB frame number. It is incremented when the frame remaining field is reloaded with the frame interval (FI) value in the HC frame interval register (HCFMINTERVAL). Frame number automatically rolls over from FFFFh to 0. After frame number is incremented, its new value is written to the HCCA and the USB1.1 host controller sets the SOF interrupt status bit and begins processing the ED lists.

32.3.17 HC Periodic Start Register (HCPERIODICSTART)

The HC periodic start register (HCPERIODICSTART) defines the position within the USB frame where endpoint descriptors (EDs) on the periodic list have priority over EDs on the bulk and control lists. HCPERIODICSTART is shown in Figure 32-18 and described in Table 32-18.

Figure 32-18. HC Periodic Start Register (HCPERIODICSTART)

31	16
Reserved	
R-0	

15	14	13	0
Reserved		PS	
R-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 32-18. HC Periodic Start Register (HCPERIODICSTART) Field Descriptions

Bit	Field	Value	Description
31-14	Reserved	0	Reserved
13-0	PS	0-3FFFh	Periodic start. The host controller driver must program this value to be about 10% less than the frame interval (FI) value in the HC frame interval register (HCFMINTERVAL), so that control and bulk EDs have priority for the first 10% of the frame; then periodic EDs have priority for the remaining 90% of the frame.

32.3.18 HC Low-Speed Threshold Register (HCLSTHRESHOLD)

The HC low-speed threshold register (HCLSTHRESHOLD) defines the latest time in a frame that the USB1.1 host controller can begin a low-speed packet. HCLSTHRESHOLD is shown in Figure 32-19 and described in Table 32-19.

Figure 32-19. HC Low-Speed Threshold Register (HCLSTHRESHOLD)

31	16
Reserved	
R-0	

15	14	13	0
Reserved		LST	
R-0		R/W-628h	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 32-19. HC Low-Speed Threshold Register (HCLSTHRESHOLD) Field Descriptions

Bit	Field	Value	Description
31-14	Reserved	0	Reserved
13-0	LST	0-3FFFh	Low-speed threshold. This field defines the number of full-speed bit times in the frame after which the USB1.1 host controller cannot start an 8-byte low-speed packet. The USB1.1 host controller only begins a low-speed transaction if the frame remaining (FR) value in the HC frame remaining register (HCFMREMAINING) is greater than the low-speed threshold. The host controller driver must set this field to a value that ensures that an 8-byte low-speed TD completes before the end of the frame. When set, the host controller driver must not change the value.

32.3.19 HC Root Hub A Register (HCRHDESCRIPTORA)

The HC root hub A register (HCRHDESCRIPTORA) defines several aspects of the USB1.1 host controller root hub functionality. HCRHDESCRIPTORA is shown in Figure 32-20 and described in Table 32-20.

Figure 32-20. HC Root Hub A Register (HCRHDESCRIPTORA)

31	24	16
POTPG		Reserved
R/W-Ah		R-0

15 13	12	11	10	9	8	7 0
Reserved	NOCP	OCPM	DT	NPS	PSM	NDP
R-0	R/W-1	R/W-0	R-0	R/W-1	R/W-0	R-3h

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 32-20. HC Root Hub A Register (HCRHDESCRIPTORA) Field Descriptions

Bit	Field	Value	Description
31-24	POTPG	0-FFh	Power-on to power-good time. Defines the minimum amount of time (2 ms × POTPG) between the USB1.1 host controller turning on power to a downstream port and when the USB1.1 host can access the downstream device. This field has no effect on USB1.1 host controller operation. After turning on power to a port, the USB1.1 host controller driver must delay the amount of time implied by POTPG before attempting to reset an attached downstream device. The required amount of time is implementation-specific and must be calculated based on the amount of time the VBUS supply takes to provide valid VBUS to a worst-case downstream USB function controller. The implementation-specific value must be computed and then written to this register before the USB1.1 host controller driver is initialized. Because the device does not provide a direct control from the USB1.1 host controller to switch VBUS on and off, this value must take into account any delays caused by other methods of controlling VBUS externally. This field has no relationship to the OTG controller register bits that relate to VBUS. System software can update this register to simplify host controller driver and/or OTG driver coding.
23-13	Reserved	0	Reserved
12	NOCP	1	No overcurrent protection. Because the device does not provide signals to allow connection of external overcurrent indication signals to the USB1.1 host controller, this bit defaults to 1 that indicates that the USB1.1 host controller does not implement overcurrent protection inputs. This bit has no relationship to the OTG controller register bits that relate to VBUS.
11	OCPM	0	Overcurrent protection mode. Because the device does not provide host controller overcurrent protection input signals, this bit has no effect. This bit has no relationship to the OTG controller register bits that relate to VBUS.
10	DT	0	Device type. This bit is always 0, which indicates that the USB1.1 host controller implemented is not a compound device.
9	NPS	1	No power switching. Because the device does not provide connections from the USB1.1 host controller to control external VBUS switching, this bit defaults to 1 that indicates that VBUS power switching is not supported and that power is available to all downstream ports when the USB1.1 host controller is powered. This bit has no relationship to the OTG controller register bits that relate to VBUS. System software can update this register to simplify host controller driver and/or OTG driver coding.
8	PSM	0	Power switching mode. Because the device does not provide signals from the USB1.1 host controller to control external VBUS switching, this bit defaults to 0 that indicates that all ports are powered at the same time.
7-0	NDP	0-FFh	Number of downstream ports. The USB signal multiplexing mode and top-level pin multiplexing features can place the device in a mode where 0, 1, 2, or 3 of the USB1.1 host controller downstream ports are usable. This register reports three ports, regardless of USB signal multiplexing mode and top-level pin multiplexing mode.

32.3.20 HC Root Hub B Register (HCRHDESCRIPTORB)

The HC root hub B register (HCRHDESCRIPTORB) defines several aspects of the USB1.1 host controller root hub functionality. HCRHDESCRIPTORB is shown in Figure 32-21 and described in Table 32-21.

NOTE: The device does not provide connections from the USB1.1 host controller to pins to provide external port power switching. Systems that implement port power switching must use other mechanisms to control port power.

Figure 32-21. HC Root Hub B Register (HCRHDESCRIPTORB)

31	20	19	18	17	16
PPCM[15-4]		PPCM[3]	PPCM[2]	PPCM[1]	PPCM[0]
R/W-0		R/W-0	R/W-0	R/W-0	R/W-0
15	4	3	2	1	0
DR[15-4]		DR[3]	DR[2]	DR[1]	DR[0]
R/W-0		R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; -*n* = value after reset

Table 32-21. HC Root Hub B Register (HCRHDESCRIPTORB) Field Descriptions

Bit	Field	Value	Description
31-20	PPCM[15-4]	0	Port power control mask. PPCM[15] through PPCM[4] are reserved.
19	PPCM[3]		Port power control mask. PPCM[3] is the port power control mask for downstream port 3. Defines whether downstream port 3 has port power controlled by the global power control. System software can update these bits to simplify host controller driver and/or OTG driver coding.
		0	Global power control is implemented for downstream port 3.
		1	Per-port power control is implemented for downstream port 3.
18	PPCM[2]		Port power control mask. PPCM[2] is the port power control mask for downstream port 2. Defines whether downstream port 2 has port power controlled by the global power control. System software can update these bits to simplify host controller driver and/or OTG driver coding.
		0	Global power control is implemented for downstream port 2.
		1	Per-port power control is implemented for downstream port 2.
17	PPCM[1]		Port power control mask. PPCM[1] is the port power control mask for downstream port 1. Defines whether downstream port 1 has port power controlled by the global power control. System software can update these bits to simplify host controller driver and/or OTG driver coding.
		0	Global power control is implemented for downstream port 1.
		1	Per-port power control is implemented for downstream port 1.
16	PPCM[0]	0	Port power control mask. PPCM[0] is reserved.
15-4	DR[15-4]	0	Device removable. DR[15] through DR[4] are reserved.
3	DR[3]		Device removable. DR[3] is the device removable bit for downstream port 3. Defines whether downstream port 3 has a removable or nonremovable device.
		0	Downstream port 3 may have a removable device attached.
		1	Downstream port 3 has a nonremovable device attached.
2	DR[2]		Device removable. DR[2] is the device removable bit for downstream port 2. Defines whether downstream port 2 has a removable or nonremovable device.
		0	Downstream port 2 may have a removable device attached.
		1	Downstream port 2 has a nonremovable device attached.
1	DR[1]		Device removable. DR[1] is the device removable bit for downstream port 1. Defines whether downstream port 1 has a removable or nonremovable device.
		0	Downstream port 1 may have a removable device attached.
		1	Downstream port 1 has a nonremovable device attached.
0	DR[0]	0	Device removable. DR[0] is reserved.

32.3.21 HC Root Hub Status Register (HCRHSTATUS)

The HC root hub status register (HCRHSTATUS) reports the USB1.1 host controller root hub status. HCRHSTATUS is shown in Figure 32-22 and described in Table 32-22.

Figure 32-22. HC Root Hub Status Register (HCRHSTATUS)

31	30	18	17	16
CRWE	Reserved		OCIC	LPSC
R/W-0	R-0		R/W-0	R/W-0

15	14	2	1	0
DRWE	Reserved		OCI	LPS
R/W-0	R-0		R-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; *-n* = value after reset

Table 32-22. HC Root Hub Status Register (HCRHSTATUS) Field Descriptions

Bit	Field	Value	Description
31	CRWE		Clear remote wake-up enable.
		0	No effect..
		1	Clears the device remote wake-up enable bit.
30-18	Reserved	0	Reserved
17	OCIC		Overcurrent indication change. This bit is automatically set when the overcurrent indicator bit changes. This bit has no relationship to the OTG controller register bits that relate to VBUS. System software can update this register to simplify host controller driver and/or OTG driver coding.
		0	No effect.
		1	Clears this bit.
16	LPSC	0	Local power status change. Because the root hub does not support the local power status feature, this bit defaults to 0 and has no effect. This bit has no relationship to the OTG controller register bits that relate to VBUS. System software can update this register to simplify host controller driver and/or OTG driver coding.
15	DRWE		Device remote wake-up enable. When 1, this bit enables a connect status change event to be treated as a resume event, which causes a transition from USB suspend to USB resume state and sets the resume detected interrupt status bit. When 0, connect status change events do not cause a transition from USB suspend to USB resume state and the resume detected interrupt is not changed.
		0	A write of 0 has no effect.
		1	A write of 1 sets the device remote wake-up enable bit.
14-2	Reserved	0	Reserved
1	OCI	0	Overcurrent indicator. Because the device does not provide signals for external hardware to report overcurrent status to the USB1.1 host controller, this bit is always 0. This bit has no relationship to the OTG controller register bits that relate to VBUS.
0	LPS	0	Local power status. Because the root hub does not support the local power status feature, this bit defaults to 0 and has no effect. This bit has no relationship to the OTG controller register bits that relate to VBUS. System software can update this register to simplify host controller driver and/or OTG driver coding.

32.3.22 HC Port 1 Status and Control Register (HCRHPORTSTATUS1)

The HC port 1 status and control register (HCRHPORTSTATUS1) reports and controls the state of USB1.1 host port 1. HCRHPORTSTATUS1 is shown in Figure 32-23 and described in Table 32-23.

Figure 32-23. HC Port 1 Status and Control Register (HCRHPORTSTATUS1)

31	21	20	19	18	17	16
Reserved		PRSC	OCIC	PSSC	PESC	CSC
R-0		R/W1C-0	R/W-0	R/W1C-0	R/W1C-0	R/W1C-0

15	10	9	8
Reserved		LSDA/CPP	PPS/SPP
R-0		R/W-0	R/W-1

7	5	4	3	2	1	0
Reserved		PRS/SPR	POCI/CSS	PSS/SPS	PES/SPE	CCS/CPE
R-0		R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; W1C = Write 1 to clear (writing 0 has no effect); -*n* = value after reset

Table 32-23. HC Port 1 Status and Control Register (HCRHPORTSTATUS1) Field Descriptions

Bit	Field	Value	Description
31-21	Reserved	0	Reserved
20	PRSC		Port 1 reset status change. A write of 1 clears this bit; a write of 0 has no effect.
		0	Port 1 port reset status bit has not changed.
		1	Port 1 port reset status bit has changed.
19	OCIC	0	Port 1 overcurrent indicator change. Because the device does not provide inputs for signaling external overcurrent indication to the USB1.1 host controller, this bit is always 0. Overcurrent monitoring, if required, must be handled through some other mechanism. This bit has no relationship to the OTG controller register bits that relate to VBUS.
18	PSSC		Port 1 suspend status change. A write of 1 clears this bit; a write of 0 has no effect.
		0	Port 1 port suspend status has not changed.
		1	Port 1 port suspend status has changed. Suspend status is considered to have changed only after the resume pulse, low-speed EOP, and 3-ms synchronization delays have been completed.
17	PESC		Port 1 enable status change. A write of 1 clears this bit; a write of 0 has no effect.
		0	Port 1 port enable status has not changed.
		1	Port 1 port enable status has changed.
16	CSC		Port 1 connect status change. If the DR[1] bit in the HC root hub B register (HCRHDESCRIPTORB) is set to 1 to indicate a nonremovable USB device on port 1, this bit is set only after a root hub reset to inform the system that the device is attached. A write of 1 clears this bit; a write of 0 has no effect.
		0	Port 1 current connect status has not changed.
		1	Port 1 current connect status has changed due to a connect or disconnect event. If current connect status is 0 when a set port reset, set port enable, or set port suspend write occurs, then this bit is set.
15-10	Reserved	0	Reserved
9	LSDA/CPP		Port 1 low-speed device attached/clear port power. This bit is valid only when port 1 current connect status is 1. The host controller driver can write a 1 to this bit to clear the port 1 port power status bit; a write of 0 has no effect. The USB1.1 host controller does not control external port power using OHCI mechanisms, so, if required, USB1.1 host port power must be controlled through other means. This bit has no relationship to the OTG controller register bits that relate to VBUS. System software can update this register to simplify host controller driver and/or OTG driver coding.
		0	Full-speed device is attached to port 1.
		1	Low-speed device is attached to port 1.

Table 32-23. HC Port 1 Status and Control Register (HCRHPORTSTATUS1) Field Descriptions (continued)

Bit	Field	Value	Description
8	PPS/SPP		Port 1 port power status/set port power. The host controller driver can write a 1 to this bit to set the port 1 port power status bit; a write of 0 has no effect. The device does not provide signals from the USB1.1 host controller to control external port power, so if required, USB1.1 host port power control signals must be controlled through other means. Software can track the current power state using the port power status bit and other power control bits, but those bits have no direct effect on external port power control. This bit has no relationship to the OTG controller register bits that relate to VBUS. System software can update this register to simplify host controller driver and/or OTG driver coding.
		0	Port 1 power is disabled.
		1	Port 1 power is enabled.
7-5	Reserved	0	Reserved
4	PRS/SPR		Port 1 port reset status/set port reset. A write of 1 to this bit sets the port 1 port reset status bit and causes the USB1.1 host controller to begin signaling USB reset to port 1; a write of 0 has no effect.
		0	USB reset is not being sent to port 1.
		1	Port 1 is signaling the USB reset.
3	POCI/CSS		Port 1 port overcurrent indicator/clear suspend status. A write of 1 to this bit when port 1 port suspend status is 1 causes resume signaling on port 1; a write of 1 when port 1 port suspend status is 0 has no effect; a write of 0 has no effect. The device does not provide inputs for signaling external overcurrent indication to the USB1.1 host controller. Overcurrent monitoring, if required, must be handled through some other mechanism.
		0	Port 1 port overcurrent condition has not occurred.
		1	Port 1 port overcurrent condition has occurred.
2	PSS/SPS		Port 1 port suspend status/set port suspend. A write of 1 to this bit when port 1 current connect status is 1 sets the port 1 port suspend status bit and places port 1 in USB suspend state; a write of 1 when port 1 current connect status is 0 sets the connect status change to inform the USB1.1 host controller driver software of an attempt to suspend a disconnected device; a write of 0 has no effect. This bit is cleared automatically at the end of the USB resume sequence and also at the end of the USB reset sequence.
		0	Port 1 is not in the USB suspend state.
		1	Port 1 is in the USB suspend state or is in the resume sequence.
1	PES/SPE		Port 1 port enable status/set port enable. A write of 1 to this bit when port 1 current connect status is 1 sets the port 1 port enable status bit; a write of 1 when port 1 current connect status is 0 has no effect; a write of 0 has no effect. This bit is automatically set at completion of port 1 USB reset, if it was not already set before the USB reset completed; and this bit is automatically set at the end of a USB suspend, if the port was not enabled when the USB resume completed.
		0	Port 1 is disabled.
		1	Port 1 is enabled.
0	CCS/CPE		Port 1 current connection status/clear port enable. If the DR[1] bit in the HC root hub B register (HCRHDESCRIPTORB) is set to 1 to indicate a nonremovable USB device on port 1, this bit is set after a root hub reset to inform the system that the device is attached. A write of 1 clears this bit; a write of 0 has no effect.
		0	No USB device is attached to port 1.
		1	USB device is attached to port 1.

32.3.23 HC Port 2 Status and Control Register (HCRHPORTSTATUS2)

The HC port 2 status and control register (HCRHPORTSTATUS2) reports and controls the state of USB1.1 host port 2. HCRHPORTSTATUS2 is shown in Figure 32-24 and described in Table 32-24.

Figure 32-24. HC Port 2 Status and Control Register (HCRHPORTSTATUS2)

31	21	20	19	18	17	16
Reserved		PRSC	OCIC	PSSC	PESC	CSC
R-0		R/W1C-0	R/W-0	R/W1C-0	R/W1C-0	R/W-0

15	10	9	8
Reserved		LSDA/CPP	PPS/SPP
R-0		R/W-0	R/W-1

7	5	4	3	2	1	0
Reserved		PRS/SPR	POCI/CSS	PSS/SPS	PES/SPE	CCS/CPE
R-0		R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; W1C = Write 1 to clear (writing 0 has no effect); -*n* = value after reset

Table 32-24. HC Port 2 Status and Control Register (HCRHPORTSTATUS2) Field Descriptions

Bit	Field	Value	Description
31-21	Reserved	0	Reserved
20	PRSC		Port 2 reset status change. A write of 1 clears this bit; a write of 0 has no effect.
		0	Port 2 port reset status bit has not changed.
		1	Port 2 port reset status bit has changed.
19	OCIC	0	Port 2 overcurrent indicator change. Because the device does not provide inputs for signaling external overcurrent indication to the USB1.1 host controller, this bit is always 0. Overcurrent monitoring, if required, must be handled through some other mechanism. This bit has no relationship to the OTG controller register bits that relate to VBUS.
18	PSSC		Port 2 suspend status changed. A write of 1 clears this bit; a write of 0 has no effect.
		0	Port 2 port suspend status has not changed.
		1	Port 2 port suspend status has changed. Suspend status is considered to have changed only after the resume pulse, low-speed EOP, and 3-ms synchronization delays have been completed.
17	PESC		Port 2 enable status change. A write of 1 clears this bit; a write of 0 has no effect.
		0	Port 2 port enable status has not changed.
		1	Port 2 port enable status has changed.
16	CSC		Port 2 connect status change. If the DR[2] bit in the HC root hub B register (HCRHDESCRIPTORB) is set to 1 to indicate a nonremovable USB device on port 2, this bit is set only after a root hub reset to inform the system that the device is attached. A write of 1 clears this bit; a write of 0 has no effect.
		0	Port 2 current connect status has not changed.
		1	Port 2 current connect status has changed due to a connect or disconnect event. If current connect status is 0 when a set port reset, set port enable, or set port suspend write occurs, then this bit is set.
15-10	Reserved	0	Reserved
9	LSDA/CPP		Port 2 low-speed device attached/clear port power. This bit indicates, when read as 1, that a low-speed device is attached to port 2. A 0 in this bit indicates a full-speed device. This bit is valid only when port 2 current connect status is 1. The USB1.1 host controller does not control external port power using OHCI mechanisms, so, if required, USB1.1 host port power must be controlled through other means.
		0	A write of 0 to this bit has no effect.
		1	The host controller driver can write a 1 to this bit to clear the port 2 port power status.

Table 32-24. HC Port 2 Status and Control Register (HCRHPORTSTATUS2) Field Descriptions (continued)

Bit	Field	Value	Description
8	PPS/SPP		Port 2 port power status/set port power. This bit indicates, when read as 1, that the port 2 power is enabled. When read as 0, port 2 power is not enabled. The device does not provide signals from the USB1.1 host controller to control external port power, so, if required, USB1.1 host port power control signals must be controlled through other means. Software can track the current power state using the port power status bit and other power control bits, but those bits have no direct effect on external port power control. This bit has no relationship to the OTG controller register bits that relate to VBUS. System software can update this register to simplify host controller driver and/or OTG driver coding.
		0	A write of 0 has no effect.
		1	A write of 1 to this bit sets the port 2 port power status bit.
7-5	Reserved	0	Reserved
4	PRS/SPR		Port 2 port reset status/set port reset. When read as 1, indicates that port 2 is sending a USB reset. When read as 0, USB reset is not being sent to port 2.
		0	A write of 0 to this bit has no effect.
		1	A write of 1 to this bit sets the port 2 port reset status bit and causes the USB1.1 host controller to begin signaling USB reset to port 2.
3	POCI/CSS		Port 2 port overcurrent indicator/clear suspend status. When read as 1, indicates that a port 2 port overcurrent condition has occurred. When 0, no port 2 port overcurrent condition has occurred. The device does not provide inputs for signaling external overcurrent indication to the USB1.1 host controller. Overcurrent monitoring, if required, must be handled through some other mechanism. This bit has no relationship to the OTG controller register bits that relate to VBUS.
		0	A write of 0 has no effect.
		1	A write of 1 to this bit when port 2 port suspend status is 1 causes resume signaling on port 2. A write of 1 when port 2 port suspend status is 0 has no effect.
2	PSS/SPS		Port 2 port suspend status/set port suspend. When read as 1, indicates that port 2 is in the USB suspend state, or is in the resume sequence. When 0, indicates that port 2 is not in the USB suspend state. This bit is cleared automatically at the end of the USB resume sequence and also at the end of the USB reset sequence.
		0	A write of 0 to this bit has no effect.
		1	If port 2 current connect status is 1, a write of 1 to this bit sets the port 2 port suspend status bit and places port 2 in USB suspend state. If current connect status is 0, a write of 1 instead sets connect status change to inform the USB1.1 host controller driver software of an attempt to suspend a disconnected device.
1	PES/SPE		Port 2 port enable status/set port enable. When read as 1, indicates that port 2 is enabled. When read as 0, this bit indicates that port 2 is not enabled. This bit is automatically set at completion of port 2 USB reset if it was not already set before the USB reset completed and is automatically set at the end of a USB suspend if the port was not enabled when the USB resume completed.
		0	A write of 0 has no effect.
		1	A write of 1 to this bit when port 2 current connect status is 1 sets the port 2 port enable status bit. A write of 1 when port 2 current connect status is 0 has no effect.
0	CCS/CPE		Port 2 current connection status/clear port enable. When read as 1, indicates that port 2 currently has a USB device attached. When 0, indicates that no USB device is attached to port 2. This bit is set to 1 after root hub reset if the HCRHDESCRIPTORB.DR[2] bit is set to indicate a non-removable device on port 2.
		0	A write of 0 to this bit has no effect.
		1	A write of 1 to this bit clears the port 2 port enable bit.

Universal Serial Bus 2.0 (USB) Controller

This chapter describes the universal serial bus (USB) controller.

Topic **Page**

33.1 Introduction

The controller complies with the USB 2.0 standard high-speed and full-speed functions and low-speed, full-speed, and high-speed limited host mode operations. It also includes support for the Session Request and Host Negotiation Protocols used in point-to-point communications, details of which are given in the USB On-The-Go supplement to the USB 2.0 specification. In addition, the four test modes for high-speed operation described in the USB 2.0 specification are supported. It also allows options that allow the USB controller to be forced into full-speed mode, high-speed mode, or host mode that may be used for debug purposes.

33.1.1 Purpose of the Peripheral

The USB controller provides a low-cost connectivity solution for consumer portable devices by providing a mechanism for data transfer between USB devices up to 480 Mbps. Its support for a dual-role feature allows for additional versatility supporting operation capability as a host or peripheral.

33.1.2 Features

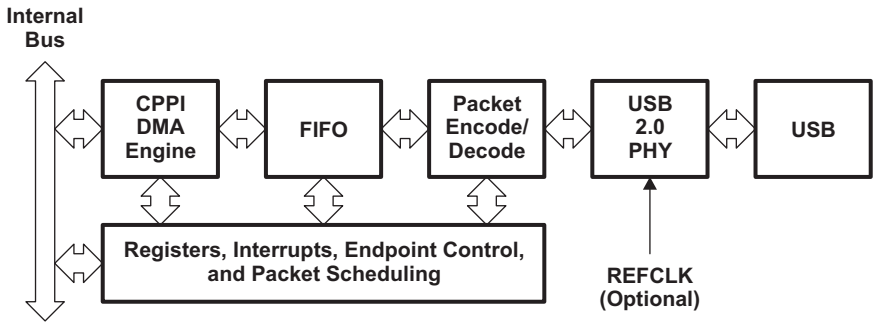
The USB has the following features:

- Operating as a host, it complies with the USB 2.0 standard for high-speed (480 Mbps), full-speed (12 Mbps), and low-speed (1.5 Mbps) operations with a peripheral
- Operating as a peripheral, it complies with the USB 2.0 standard for high-speed (480 Mbps) and full-speed (12 Mbps) operation with a host.
- Supports USB extensions for Session Request (SRP) and Host Negotiation (HNP) – OTG
- Supports 4 simultaneous RX and TX endpoints, in addition to control endpoint, more devices can be supported by dynamically switching endpoints states
- Each endpoint (other than endpoint 0) can support all transfer types (control, bulk, interrupt, and isochronous)
- Includes a 4K endpoint FIFO RAM, and supports programmable FIFO sizes
- External 5V power supply for VBUS, when operating as host, enabled directly by the USB controller through a dedicated signal
- Includes a DMA controller that supports 4 TX and 4 RX DMA channels
- Includes four types of Communications Port Programming Interface (CPPI) 4.1 DMA compliant transfer modes, Transparent, Generic RNDIS, RNDIS, and Linux CDC mode of DMA for accelerating RNDIS type protocols using short packet termination over USB.
- DMA supports single data transfer size up to 4Mbytes

33.1.3 Functional Block Diagram

The USB functional block diagram is shown in Figure 33-1.

Figure 33-1. Functional Block Diagram



33.1.4 Industry Standard(s) Compliance Statement

This device conforms to USB 2.0 Specification.

33.2 Architecture

33.2.1 Clock Control

Figure 33-2 shows the clock connections for the USB2.0 module. Note that there is no built-in oscillator. The USB2.0 subsystem requires a reference clock for its internal PLL. This reference clock can be sourced from either the USB_REFCLKIN pin or from the AUXCLK of the system PLL. The reference clock input to the USB2.0 subsystem is selected by programming the USB0PHYCLKMUX bit in the chip configuration 2 register (CFGCHIP2) of the System Configuration Module. The USB_REFCLKIN source should be selected when it is not possible (such as when specific audio rates are required) to operate the device at one of the allowed input frequencies to the USB2.0 subsystem. The USB2.0 subsystem peripheral bus clock is sourced from SYSCLK2. Table 33-1 determines the source origination as well as the source input frequency to the USB 2.0 PHY. Once the clock source origination (internal/external) and its frequency is determined, the firmware should program the PHY PLL with the correct input frequency via CFGCHIP2.USB0REF_FREQ (see Table 33-2).

NOTE: Prior to accessing any of the device configuration registers, including CFGCHIP2, in order to avoid inadvertent access, two Access Key Registers (KICK0R and KICK1R) should be written with key values. For more information on the device configuration registers, see your device-specific data manual.

Figure 33-2. USB Clocking Diagram

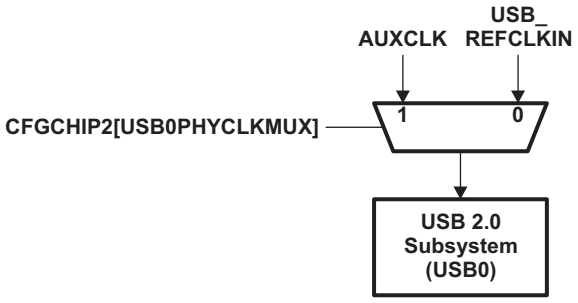


Table 33-1. USB Clock Multiplexing Options

CFGCHIP2. USB0PHYCLKMUX bit	CFGCHIP2. USB1PHYCLKMUX bit	USB2.0 Clock Source	USB1.1 Clock Source	Additional Conditions
0	0	USB_REFCLKIN	CLK48MHz output from USB2.0 PHY	USB_REFCLKIN must be 12, 24, 48, 19.2, 38.4, 13, 26, 20, or 40 MHz. The PLL inside the USB2.0 PHY can be configured to accept any of these input clock frequencies.
0	1	USB_REFCLKIN	USB_REFCLKIN	USB_REFCLKIN must be 48 MHz. The PLL inside the USB2.0 PHY can be configured to accept this input clock frequency.
1	0	PLL0_AUXCLK	CLK48MHz output from USB2.0 PHY	PLL0_AUXCLK must be 12, 24, 48, 19.2, 38.4, 13, 26, 20, or 40 MHz. The PLL inside the USB2.0 PHY can be configured to accept any of these input clock frequencies.
1	1	PLL0_AUXCLK	USB_REFCLKIN	PLL0_AUXCLK must be 12, 24, 48, 19.2, 38.4, 13, 26, 20, or 40 MHz. The PLL inside the USB2.0 PHY can be configured to accept any of these input clock frequencies. USB_REFCLKIN must be 48 MHz.

Table 33-2. PHY PLL Clock Frequencies Supported

CFGCHIP2.USB0REF_FREQ bit	Frequency
1h	12.0 MHz
2h	24.0 MHz
3h	48.0 MHz
4h	19.2 MHz
5h	38.4 MHz
6h	13.0 MHz
7h	26.0 MHz
8h	20.0 MHz
9h	40.0 MHz

33.2.2 Signal Descriptions

The USB controller provides the I/O signals listed in Table 33-3.

Table 33-3. USB Terminal Functions

Name	I/O [1]	Description
USB0_DP	A I/O/Z	USB0 D+ (differential signal pair)
USB0_DM	A I/O/Z	USB0 D- (differential signal pair)
USB0_ID	A I/O	USB0 operating mode identification pin. For OTG mode or device only mode of operation, do NOT connect the USB0_ID pin, that is, leave the pin floating. For host only mode of operation, connect the USB0_ID pin to ground via a 0 ohm resistor or connect the pin directly to ground.
USB0_VBUS	A I/O/Z	5 volt input that signifies that VBUS is connected. The OTG section of the PHY can also pull-up/pull-down on this signal for HNP and SRP. For device or host only mode of operation, pull-up this pin to 5V. For host mode of operation, also pull-up the USB power signal on the USB connector to 5V. For mixed host/device mode of operation, tie this to the charge pump.
USB0_DRVVBUS	I/O/Z	Digital output to control external 5-V supply
USB0_VDDA33	I/O/Z	USB0 PHY 3.3V supply
USB0_VDDA18	I/O/Z	USB0 PHY 1.8V supply input
USB_REFCLKIN	I/O/Z	External clock input for USB PHY
USB0_VDDA12	I/O/Z	USB PHY 1.2V LD0 output for bypass CAP

(1) A = Analog signal; I = Input; O = Output; Z = High impedance

33.2.3 Indexed and Non-Indexed Registers

The USB controller provides two mechanisms of accessing the endpoint control and status registers:

- Indexed Endpoint Control/Status Registers: These registers are memory-mapped at offset 410h to 41Fh. The endpoint is selected by programming the INDEX register of the controller.
- Non-indexed Endpoint Control/Status Registers: These registers are memory-mapped at offset 500h to 54Fh. Registers at offset 500h to 50Fh map to Endpoint 0; at offset 510h to 51Fh map to Endpoint 1, and so on.

For detailed information about the USB controller registers, see Section 33.4.

33.2.4 USB PHY Initialization

Two boot configuration registers, pin multiplexing control registers, and chip configuration 2 register (CFGCHIP2) are used to configure the multiplexed pins for USB 2.0 uses. See the *System Configuration (SYSCFG) Module* chapter for more information on the pin multiplexing control registers and CFGCHIP2.

The general procedure for USB PHY initialization starts by releasing the PHY from reset and programming the corresponding bits within the pin multiplexing control registers and CFGCHIP2, for achieving the multiplexed pins for the use of the USB2.0. Next, configuring PHY input clock related information and other PHY general configuration attributes.

When the USB2.0 controller assumes the role of a host, it is tasked to source the required 5V supply via USB0_VBUS (must be at least ≥ 4.75V) pin. The USB2.0 controller makes use of an external charge pump or logic by enabling and disabling the external power logic from the USB2.0 controller core level. It uses the USB0_DRVVBUS for controlling the enable/disable state of the external power logic. In order to achieve this task, the pin multiplexing control registers should be configured accordingly to map the USB0_DRVVBUS pin to be used for USB2.0 purposes. In addition, the source (internal or external) and frequency of the PHY clock should be identified and should be configured by the firmware. This is achieved using CFGCHIP2. Other PHY related fields within CFGCHIP2 should be programmed as: USB0PHYPWDN and USB0OTGPWRDN should be cleared to 0 and USB0DATPOL, USB0SESNDEN, and USB0VBDTCTEN should be set to 1. This will configure the PHY for normal operation as well as also turn on the PHYs VBUS comparator logic. The final task is to turn on the PHY PLL and wait until it locks. You should wait for the PHY clock good status to be set prior to ending the PHY initialization process.

33.2.5 VBUS Voltage Sourcing Control

When the USB controller assumes the role of a host, it is required to supply 5V power to an attached device through its VBUS line. In order to achieve this task, the USB controller requires the use of an external logic (or charge pump) capable of sourcing 5V power. A USB_DRVVBUS is used as a control signal to enable/disable the external logic to either source or disable power on the VBUS line. This control is automatic and is handled by the controller. The USB controller drives the USB_DRVVBUS signal high when it assumes the role of a host while the controller is in Session. When assuming the role of a device, the controller drives the USB_DRVVBUS signal low disabling the external charge pump; hence, no power is driven on the VBUS line.

33.2.6 Dynamic FIFO Sizing

The USB controller supports a total of 4K RAM to dynamically allocate FIFO to all endpoints. The allocation of FIFO space to the different endpoints requires the specification for each Tx and Rx endpoint of:

- The start address of the FIFO within the RAM block
- The maximum size of packet to be supported
- Whether double-buffering is required.

These details are specified through four registers, which are added to the indexed area of the memory map. That is, the registers for the desired endpoint are accessed after programming the INDEX register with the desired endpoint value. Section 33.4.55, Section 33.4.56, Section 33.4.57, and Section 33.4.58 provide details of these registers.

NOTE: The option of dynamically setting FIFO sizes only applies to Endpoints 1-4. The Endpoint 0 FIFO has a fixed size (64 bytes) and a fixed location (start address 0).

It is the responsibility of the firmware to ensure that all the Tx and Rx endpoints that are active in the current USB configuration have a block of RAM assigned exclusively to that endpoint. The RAM must be at least as large as the maximum packet size set for that endpoint.

33.2.7 USB Controller Host and Peripheral Modes Operation

The USB controller can be used in a range of different environments. It can be used as either a high-speed or a full-speed USB peripheral device attached to a conventional USB host (such as a PC). It can be used as either a host or a peripheral device in a point-to-point type of setup/arrangement or it can be used as a host connecting to a range of peripheral devices in a multi-point setup (that is, using a hub).

The USB2.0 controller role adaptation of a host or peripheral (device) is dependent upon the state of the USB0_ID pin on its mini-AB receptacle. If the USB0_ID pin state is not driven by the connector or is left floating, the USB2.0 controller would assume the role of a peripheral; if the USB0_ID pin state is driven low or is grounded, the USB2.0 controller would assume the role of a host. The state of the USB ID pin is controlled by the type of USB plug attached to the mini-AB connector. A mini/micro-B plug (peripheral) would leave the USB0_ID pin floating and a mini/micro-A plug (host) grounds the USB0_ID pin low. The procedure for the USB2.0 controller determining its operating modes (role of a host or a peripheral) starts when the USB 2.0 controller is in session. The USB 2.0 controller is in session when either it senses a voltage on the USB0_VBUS pin or when the firmware sets the DEVCTL[SESSION] bit.

Usually, the firmware sets the SESSION bit, when it assumes that it will be operating as a host. When the SESSION bit is set, the controller will start sensing the state of the USB0_ID pin. If the USB0_ID pin has been grounded low, then the USB2.0 controller will assume the role of a host; however, if the USB0_ID pin is left floating, then the USB2.0 controller will assume the role of a device. Upon determining its role as a host, it will drive the USB0_DRVVBUS pin high to enable the external power logic so that it start sourcing the required 5V power (must be ≥ 4.75V). The USB2.0 controller will then wait to for the voltage of the USB0_VBUS goes high. If it does not see the power on the USB0_VBUS pin greater than Vbus Valid (4.4V), it will generate an interrupt to the user indicating the existence of a problem. Assuming that the voltage level of the USB0_VBUS is found to be above Vbus Valid, then the USB 2.0 controller will wait for a device to connect, that is, for it to see one of its data lines USB0_DP/DM to be pulled high.

When assuming the role of a peripheral, assuming that the firmware has set the POWER[SOFTCONN] bit and has enabled the data lines and there is an external host sourcing power on the USB0_VBUS line, the USB2.0 controller will transition to session when it sees power (must be greater or equal to 4.01V) on the USB0_VBUS pin. The USB 2.0 controller will then set the SESSION bit upon detecting the power on the USB0_VBUS line. This will force the USB2.0 controller to sense the state of the USB0_ID pin. If the USB0_ID pin has been left floating, it will know that it has to assume the role of a device and will enable its 1.5 kohm pull-up resistor to signify to the attached external host that it is a Full-Speed device. Note that even when operating as a High-Speed; it has to first come up as Full-Speed. The USB2.0 controller will then await for a reset signal from the host.

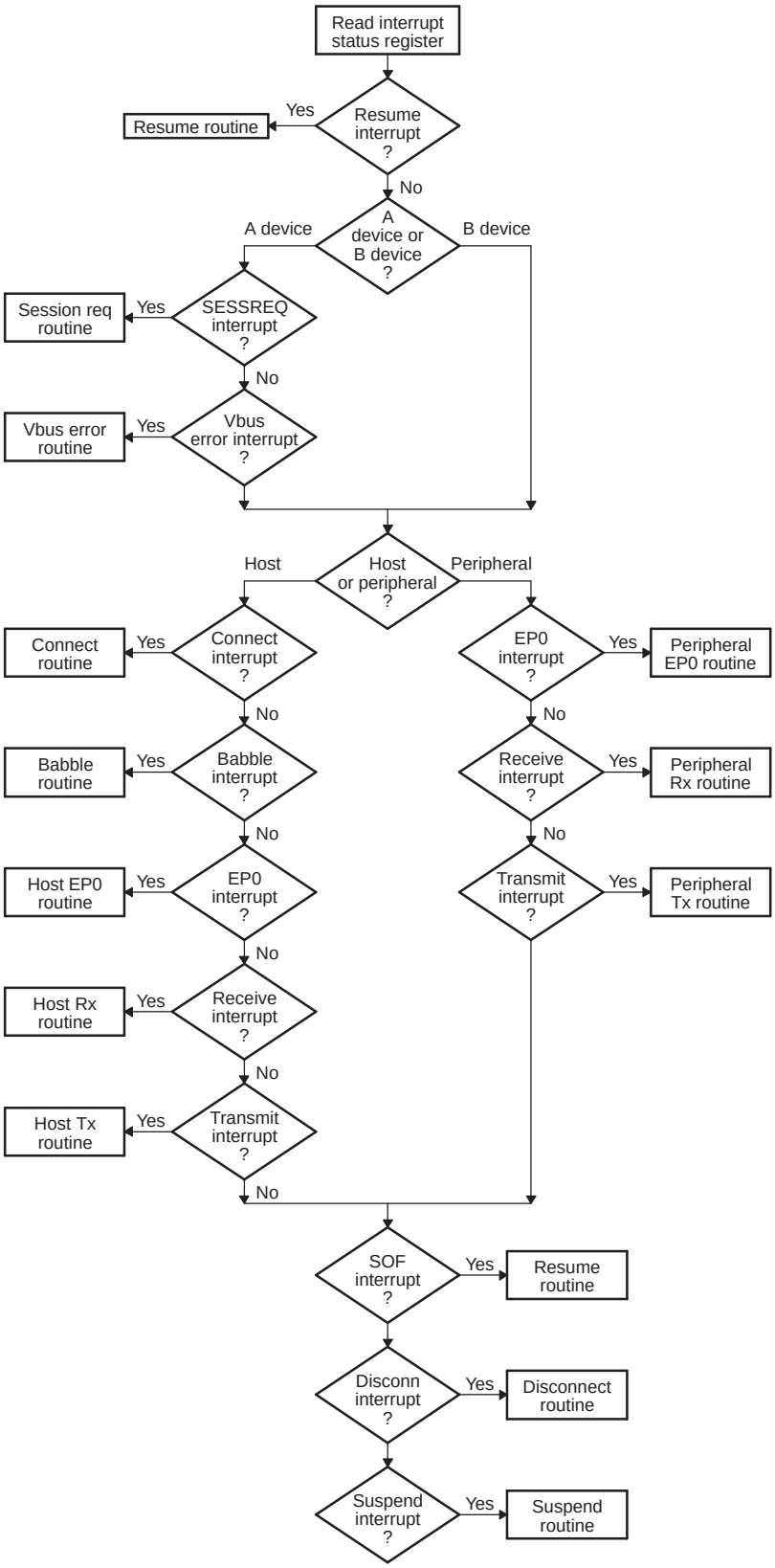
The USB controller interrupts the CPU on completion of the data transfer on any of the endpoints or on detecting reset, resume, suspend, connect, disconnect, or SOF on the bus.

When the CPU is interrupted with a USB interrupt, it needs to read the interrupt status register to determine the endpoints that have caused the interrupt and jump to the appropriate routine. If multiple endpoints have caused the interrupt, endpoint 0 should be serviced first, followed by the other endpoints. The suspend interrupt should be serviced last.

The flowchart in Figure 33-3 describes the interrupt service routine for the USB module.

The following sections describe the programming of USB controller in Peripheral mode and Host mode. DMA operations and interrupt handler mechanisms are common to both peripheral and host mode operations and are discussed after the programming in peripheral and Host mode.

Figure 33-3. Interrupt Service Routine Flow Chart



33.2.7.1 USB Controller Peripheral Mode Operation

- *Soft connect* - After a reset, the SOFTCONN bit of POWER register (bit 6) is cleared to 0. The controller will therefore appear disconnected until the software has set the SOFTCONN bit to 1. The application software can then choose when to set the PHY into its normal mode. Systems with a lengthy initialization procedure may use this to ensure that initialization is complete and the system is ready to perform enumeration before connecting to the USB.

  Once the SOFTCONN bit has been set, the software can also simulate a disconnect by clearing this bit to 0.
- *Entry into suspend mode* - When operating as a peripheral device, the controller monitors activity on the bus and when no activity has occurred for 3 ms, it goes into Suspend mode. If the Suspend interrupt has been enabled, an interrupt will be generated at this time.

  At this point, the controller can then be left active (and hence able to detect when Resume signaling occurs on the USB), or the application may arrange to disable the controller by stopping its clock. However, the controller will not then be able to detect Resume signaling on the USB. As a result, some external hardware will be needed to detect Resume signaling (by monitoring the DM and DP signals), so that the clock to the controller can be restarted.
- *Resume Signaling* - When resume signaling occurs on the bus, first the clock to the controller must be restarted if necessary. Then the controller will automatically exit Suspend mode. If the Resume interrupt is enabled, an interrupt will be generated.
- *Initiating a remote wakeup* - If the software wants to initiate a remote wakeup while the controller is in Suspend mode, it should write to the Power register to set the RESUME bit to 1. The software should leave then this bit set for approximately 10 ms (minimum of 2 ms, a maximum of 15 ms) before resetting it to 0.

  NOTE: No resume interrupt will be generated when the software initiates a remote wakeup.
- *Reset Signaling* - When reset signaling occurs on the bus, the controller performs the following actions:
  - Clears FADDR register to 0
  - Clears INDEX register to 0
  - Flushes all endpoint FIFOs
  - Clears all control/status registers
  - Generates a reset interrupt.

  If the HSENA bit in the POWER register (bit 5) was set, the controller also tries to negotiate for high-speed operation.

  Whether high-speed operation is selected is indicated by HSMODE bit of POWER register (bit 4).

  When the application software receives a reset interrupt, it should close any open pipes and wait for bus enumeration to begin.

33.2.7.1.1 Control Transactions

Endpoint 0 is the main control endpoint of the core. The software is required to handle all the standard device requests that may be sent or received via endpoint 0. These are described in Universal Serial Bus Specification, Revision 2.0, Chapter 9. The protocol for these device requests involves different numbers and types of transactions per transfer. To accommodate this, the software needs to take a state machine approach to command decoding and handling.

The Standard Device Requests received by a USB peripheral device can be divided into three categories: Zero Data Requests (in which all the information is included in the command), Write Requests (in which the command will be followed by additional data), and Read Requests (in which the device is required to send data back to the host).

This section looks at the sequence of actions that the software must perform to process these different types of device request.

NOTE: The Setup packet associated with any standard device request should include an 8-byte command. Any setup packet containing a command field of anything other than 8 bytes will be automatically rejected by the controller.

33.2.7.1.1.1 Zero Data Requests

Zero data requests have all their information included in the 8-byte command and require no additional data to be transferred. Examples of Zero Data standard device requests are:

- SET_FEATURE
- CLEAR_FEATURE
- SET_ADDRESS
- SET_CONFIGURATION
- SET_INTERFACE

The sequence of events will begin, as with all requests, when the software receives an endpoint 0 interrupt. The RXPKTRDY bit of PERI_CSR0 (bit 0) will also have been set. The 8-byte command should then be read from the endpoint 0 FIFO, decoded and the appropriate action taken.

For example, if the command is SET_ADDRESS, the 7-bit address value contained in the command should be written to the FADDR register. The PERI_CSR0 register should then be written to set the SERV_RXPKTRDY bit (bit 6) (indicating that the command has been read from the FIFO) and to set the DATAEND bit (bit 3) (indicating that no further data is expected for this request). The interval between setting SERV_RXPKTRDY bit and DATAEND bit should be very small to avoid getting a SetupEnd error condition.

When the host moves to the status stage of the request, a second endpoint 0 interrupt will be generated to indicate that the request has completed. No further action is required from the software. The second interrupt is just a confirmation that the request completed successfully. For SET_ADDRESS command, the address should be set in FADDR register only after the status stage interrupt is received.

If the command is an unrecognized command, or for some other reason cannot be executed, then when it has been decoded, the PERI_CSR0 register should be written to set the SERV_RXPKTRDY bit (bit 6) and to set the SENDSTALL bit (bit 5). When the host moves to the status stage of the request, the controller will send a STALL to tell the host that the request was not executed. A second endpoint 0 interrupt will be generated and the SENTSTALL bit (bit 2 of PERI_CSR0) will be set.

If the host sends more data after the DATAEND bit has been set, then the controller will send a STALL. An endpoint 0 interrupt will be generated and the SENTSTALL bit (bit 2 of PERI_CSR0) will be set.

NOTE: DMA is not supported for endpoint 0, so the command should be read by accessing the endpoint 0 FIFO register.

33.2.7.1.1.2 Write Requests

Write requests involve an additional packet (or packets) of data being sent from the host after the 8-byte command. An example of a Write standard device request is: SET_DESCRIPTOR.

The sequence of events will begin, as with all requests, when the software receives an endpoint 0 interrupt. The RXPKTRDY bit of PERI_CSR0 will also have been set. The 8-byte command should then be read from the Endpoint 0 FIFO and decoded.

As with a zero data request, the PERI_CSR0 register should then be written to set the SERV_RXPKTRDY bit (bit 6) (indicating that the command has been read from the FIFO) but in this case the DATAEND bit (bit 3) should not be set (indicating that more data is expected).

When a second endpoint 0 interrupt is received, the PERI_CSR0 register should be read to check the endpoint status. The RXPKTRDY bit of PERI_CSR0 should be set to indicate that a data packet has been received. The COUNT0 register should then be read to determine the size of this data packet. The data packet can then be read from the endpoint 0 FIFO.

If the length of the data associated with the request (indicated by the wLength field in the command) is greater than the maximum packet size for endpoint 0, further data packets will be sent. In this case, PERI_CSR0 should be written to set the SERV_RXPKTRDY bit, but the DATAEND bit should not be set.

When all the expected data packets have been received, the PERI_CSR0 register should be written to set the SERV_RXPKTRDY bit and to set the DATAEND bit (indicating that no more data is expected).

When the host moves to the status stage of the request, another endpoint 0 interrupt will be generated to indicate that the request has completed. No further action is required from the software, the interrupt is just a confirmation that the request completed successfully.

If the command is an unrecognized command, or for some other reason cannot be executed, then when it has been decoded, the PERI_CSR0 register should be written to set the SERV_RXPKTRDY bit (bit 6) and to set the SENDSTALL bit (bit 5). When the host sends more data, the controller will send a STALL to tell the host that the request was not executed. An endpoint 0 interrupt will be generated and the SENTSTALL bit of PERI_CSR0 (bit 2) will be set.

If the host sends more data after the DATAEND has been set, then the controller will send a STALL. An endpoint 0 interrupt will be generated and the SENTSTALL bit of PERI_CSR0 (bit 2) will be set.

33.2.7.1.1.3 Read Requests

Read requests have a packet (or packets) of data sent from the function to the host after the 8-byte command. Examples of Read Standard Device Requests are:

- GET_CONFIGURATION
- GET_INTERFACE
- GET_DESCRIPTOR
- GET_STATUS
- SYNCH_FRAME

The sequence of events will begin, as with all requests, when the software receives an endpoint 0 interrupt. The RXPKTRDY bit of PERI_CSR0 (bit 0) will also have been set. The 8-byte command should then be read from the endpoint 0 FIFO and decoded. The PERI_CSR0 register should then be written to set the SERV_RXPKTRDY bit (bit 6) (indicating that the command has read from the FIFO).

The data to be sent to the host should then be written to the endpoint 0 FIFO. If the data to be sent is greater than the maximum packet size for endpoint 0, only the maximum packet size should be written to the FIFO. The PERI_CSR0 register should then be written to set the TXPKTRDY bit (bit 1) (indicating that there is a packet in the FIFO to be sent). When the packet has been sent to the host, another endpoint 0 interrupt will be generated and the next data packet can be written to the FIFO.

When the last data packet has been written to the FIFO, the PERI_CSR0 register should be written to set the TXPKTRDY bit and to set the DATAEND bit (bit 3) (indicating that there is no more data after this packet).

When the host moves to the status stage of the request, another endpoint 0 interrupt will be generated to indicate that the request has completed. No further action is required from the software: the interrupt is just a confirmation that the request completed successfully.

If the command is an unrecognized command, or for some other reason cannot be executed, then when it has been decoded, the PERI_CSR0 register should be written to set the SERV_RXPKTRDY bit (bit 6) and to set the SENDSTALL bit (bit 5). When the host requests data, the controller will send a STALL to tell the host that the request was not executed. An endpoint 0 interrupt will be generated and the SENTSTALL bit of PERI_CSR0 (bit 2) will be set.

If the host requests more data after DATAEND (bit 3) has been set, then the controller will send a STALL. An endpoint 0 interrupt will be generated and the SENTSTALL bit of PERI_CSR0 (bit 2) will be set.

33.2.7.1.1.4 Endpoint 0 States

When the USB controller is operating as a peripheral device, the endpoint 0 control needs three modes – IDLE, TX and RX – corresponding to the different phases of the control transfer and the states endpoint 0 enters for the different phases of the transfer (described in later sections).

The default mode on power-up or reset should be IDLE. RXPKTRDY bit of PERI_CSR0 (bit 0) becoming set when endpoint 0 is in IDLE state indicates a new device request. Once the device request is unloaded from the FIFO, the controller decodes the descriptor to find whether there is a data phase and, if so, the direction of the data phase of the control transfer (in order to set the FIFO direction). See Figure 33-4.

Depending on the direction of the data phase, endpoint 0 goes into either TX state or RX state. If there is no Data phase, endpoint 0 remains in IDLE state to accept the next device request.

The actions that the CPU needs to take at the different phases of the possible transfers (for example, loading the FIFO, setting TXPKTRDY) are indicated in Figure 33-5 .

NOTE: The controller changes the FIFO direction, depending on the direction of the data phase independently of the CPU.

Figure 33-4. CPU Actions at Transfer Phases

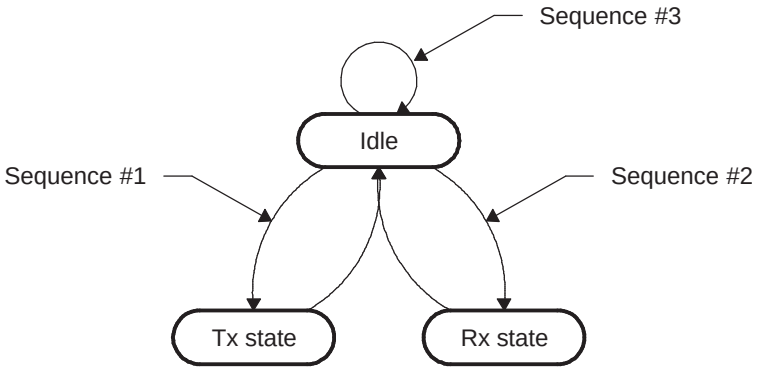
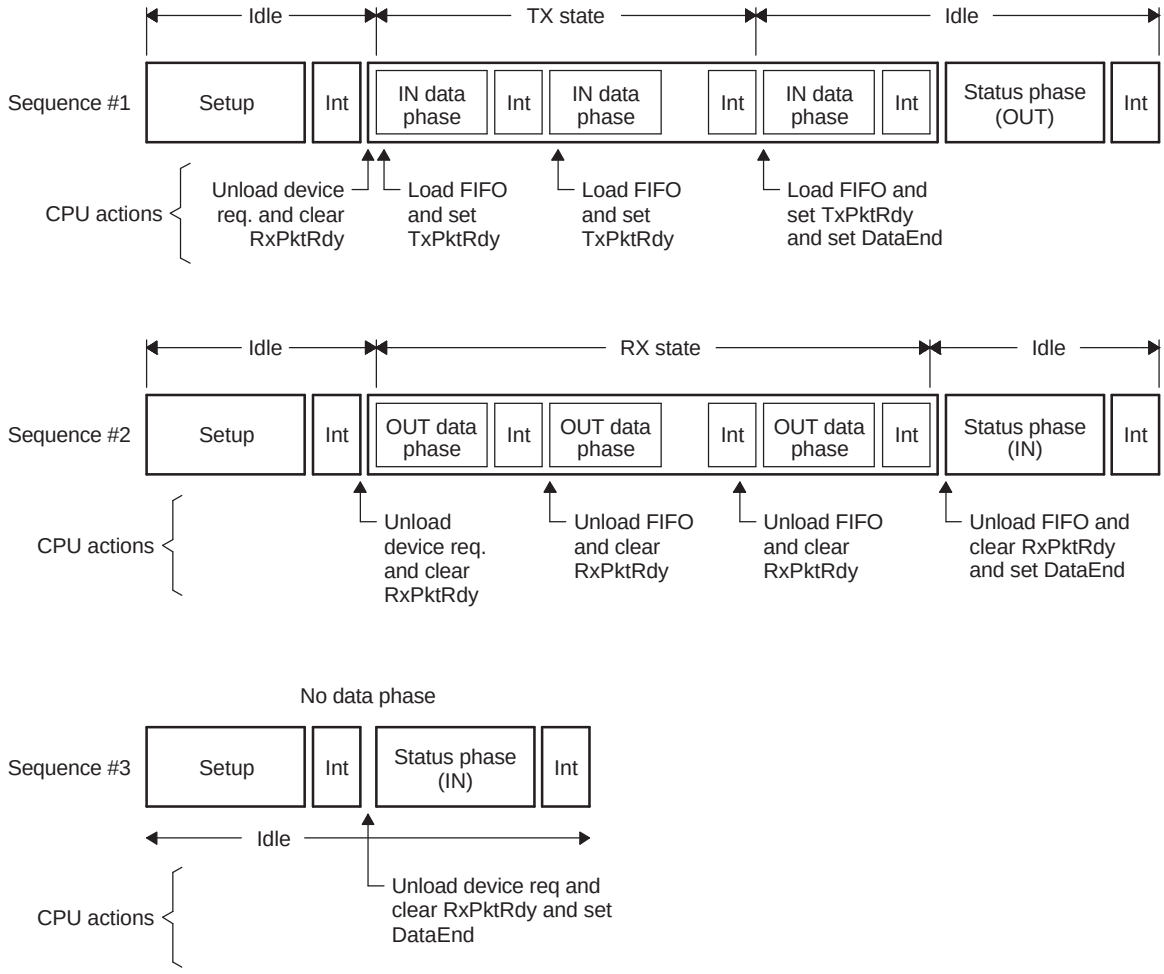


Figure 33-5. Sequence of Transfer



33.2.7.1.1.5 Endpoint 0 Service Routine

An Endpoint 0 interrupt is generated when:

- The controller sets the RXPKTRDY bit of PERI_CSR0 (bit 0) after a valid token has been received and data has been written to the FIFO.
- The controller clears the TXPKTRDY bit of PERI_CSR0 (bit 1) after the packet of data in the FIFO has been successfully transmitted to the host.
- The controller sets the SENTSTALL bit of PERI_CSR0 (bit 2) after a control transaction is ended due to a protocol violation.
- The controller sets the SETUPEND bit of PERI_CSR0 (bit 4) because a control transfer has ended before DATAEND (bit 3 of PERI_CSR0) is set.

Whenever the endpoint 0 service routine is entered, the software must first check to see if the current control transfer has been ended due to either a STALL condition or a premature end of control transfer. If the control transfer ends due to a STALL condition, the SENTSTALL bit would be set. If the control transfer ends due to a premature end of control transfer, the SETUPEND bit would be set. In either case, the software should abort processing the current control transfer and set the state to IDLE.

Once the software has determined that the interrupt was not generated by an illegal bus state, the next action taken depends on the endpoint state. Figure 33-6 shows the flow of this process.

If endpoint 0 is in IDLE state, the only valid reason an interrupt can be generated is as a result of the controller receiving data from the bus. The service routine must check for this by testing the RXPKTRDY bit of PERI_CSR0 (bit 0). If this bit is set, then the controller has received a SETUP packet. This must be unloaded from the FIFO and decoded to determine the action the controller must take. Depending on the command contained within the SETUP packet, endpoint 0 will enter one of three states:

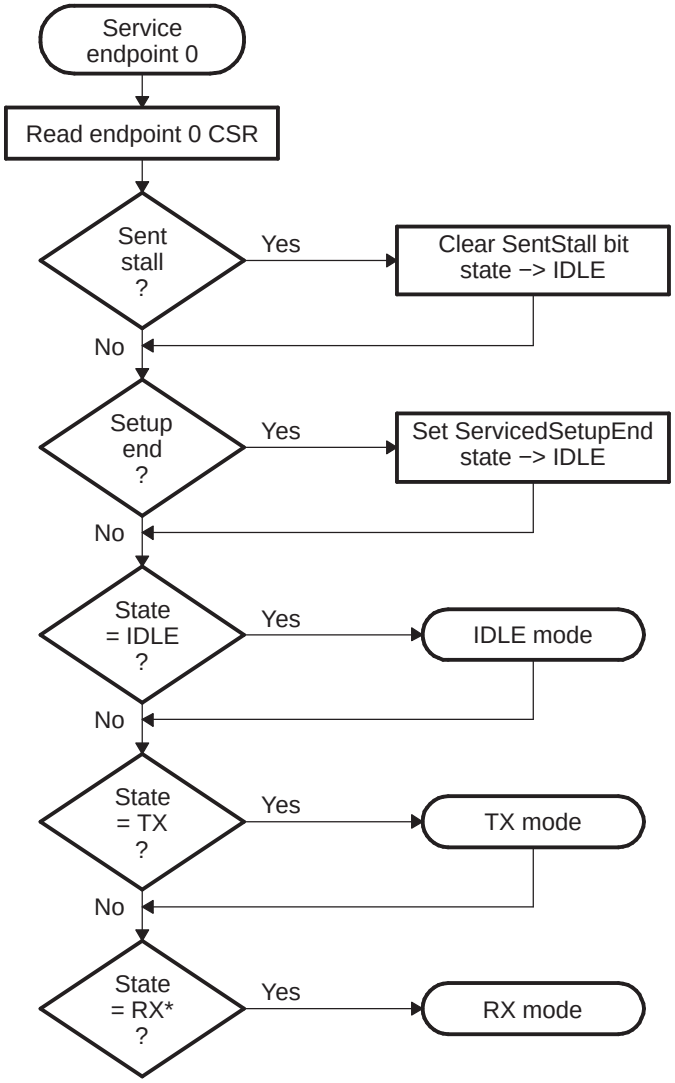
- If the command is a single packet transaction (SET_ADDRESS, SET_INTERFACE etc.) without any data phase, the endpoint will remain in IDLE state.
- If the command has an OUT data phase (SET_DESCRIPTOR etc.), the endpoint will enter RX state.
- If the command has an IN data phase (GET_DESCRIPTOR etc.), the endpoint will enter TX state.

If the endpoint 0 is in TX state, the interrupt indicates that the core has received an IN token and data from the FIFO has been sent. The software must respond to this either by placing more data in the FIFO if the host is still expecting more data or by setting the DATAEND bit to indicate that the data phase is complete. Once the data phase of the transaction has been completed, endpoint 0 should be returned to IDLE state to await the next control transaction.

NOTE: All command transactions include a field that indicates the amount of data the host expects to receive or is going to send.

If the endpoint is in RX state, the interrupt indicates that a data packet has been received. The software must respond by unloading the received data from the FIFO. The software must then determine whether it has received all of the expected data. If it has, the software should set the DATAEND bit and return endpoint 0 to IDLE state. If more data is expected, the firmware should set the SERV_RXPKTRDY bit of PERI_CSR0 (bit 6) to indicate that it has read the data in the FIFO and leave the endpoint in RX state.

Figure 33-6. Service Endpoint 0 Flow Chart

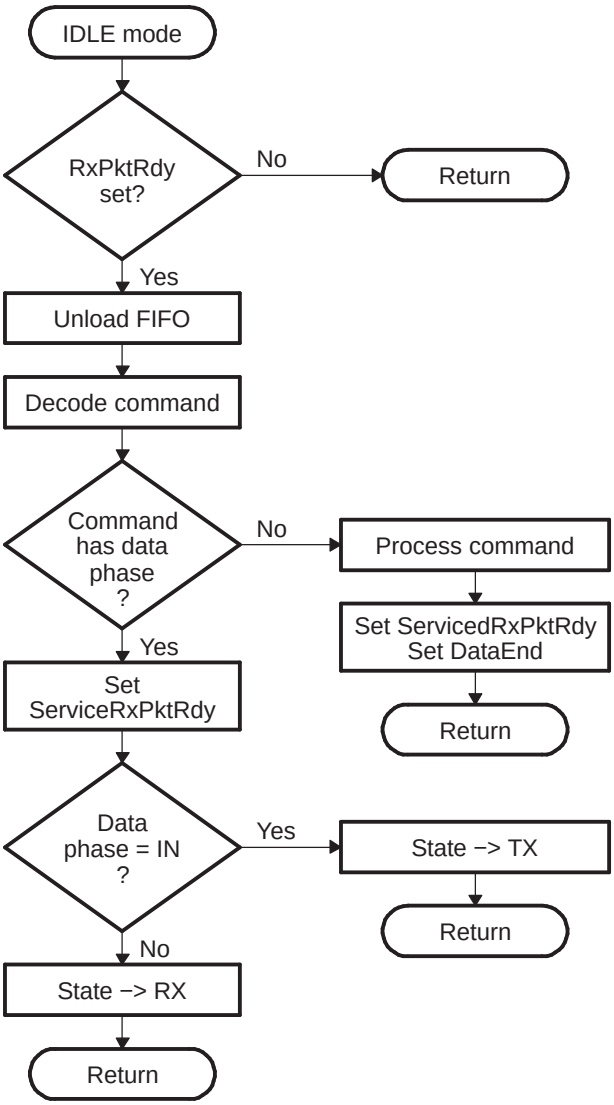


* By default

33.2.7.1.1.5.1 IDLE Mode

IDLE mode is the mode the endpoint 0 control must select at power-on or reset and is the mode to which the endpoint 0 control should return when the RX and TX modes are terminated. It is also the mode in which the SETUP phase of control transfer is handled (as outlined in Figure 33-7).

Figure 33-7. IDLE Mode Flow Chart



33.2.7.1.1.5.2 TX Mode

When the endpoint is in TX state all arriving IN tokens need to be treated as part of a data phase until the required amount of data has been sent to the host. If either a SETUP or an OUT token is received while the endpoint is in the TX state, this will cause a SetupEnd condition to occur as the core expects only IN tokens. See Figure 33-8.

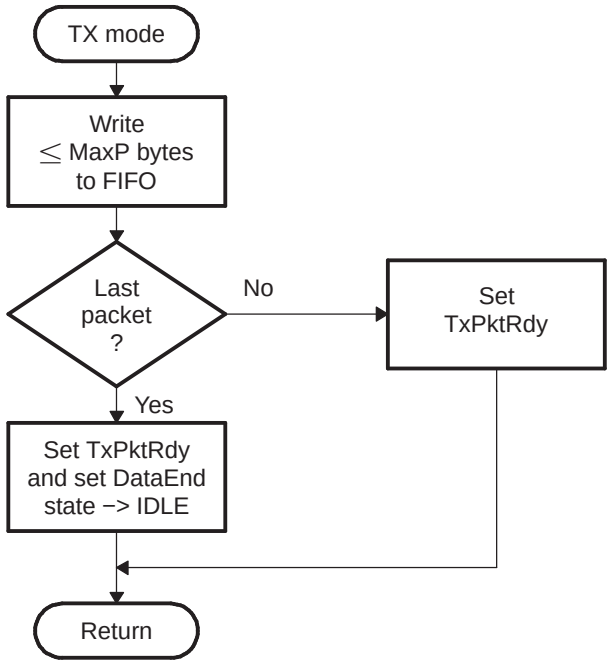
Three events can cause TX mode to be terminated before the expected amount of data has been sent:

1. The host sends an invalid token causing a SETUPEND condition (bit 4 of PERI_CSR0 set).
2. The software sends a packet containing less than the maximum packet size for endpoint 0.
3. The software sends an empty data packet.

Until the transaction is terminated, the software simply needs to load the FIFO when it receives an interrupt that indicates a packet has been sent from the FIFO. (An interrupt is generated when TXPKTRDY is cleared.)

When the software forces the termination of a transfer (by sending a short or empty data packet), it should set the DATAEND bit of PERI_CSR0 (bit 3) to indicate to the core that the data phase is complete and that the core should next receive an acknowledge packet.

Figure 33-8. TX Mode Flow Chart



33.2.7.1.1.5.3 RX Mode

In RX mode, all arriving data should be treated as part of a data phase until the expected amount of data has been received. If either a SETUP or an IN token is received while the endpoint is in RX state, a SetupEnd condition will occur as the controller expects only OUT tokens.

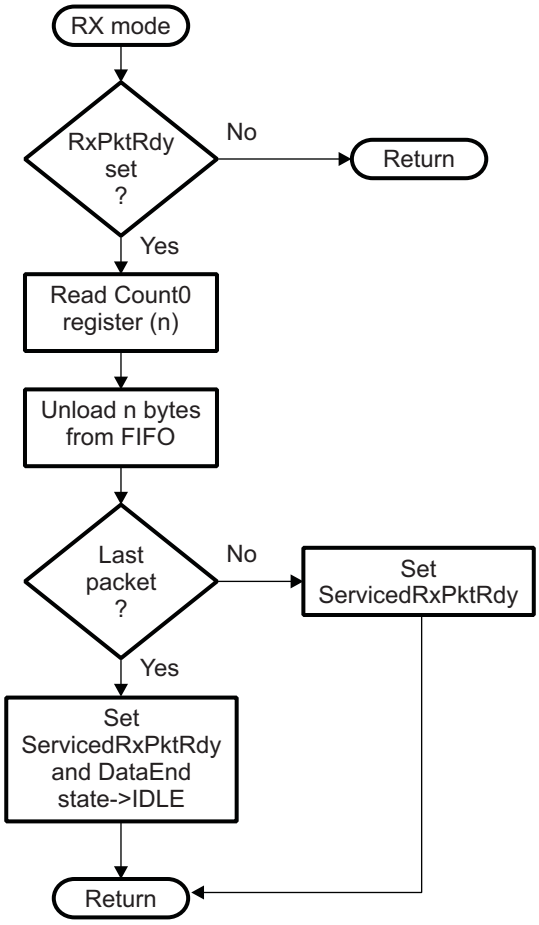
Three events can cause RX mode to be terminated before the expected amount of data has been received as shown in Figure 33-9:

1. The host sends an invalid token causing a SETUPEND condition (setting bit 4 of PERI_CSR0).
2. The host sends a packet which contains less than the maximum packet size for endpoint 0.
3. The host sends an empty data packet.

Until the transaction is terminated, the software unloads the FIFO when it receives an interrupt that indicates new data has arrived (setting RXPKTRDY bit of PERI_CSR0) and to clear RXPKTRDY by setting the SERV_RXPKTRDY bit of PERI_CSR0 (bit 6).

When the software detects the termination of a transfer (by receiving either the expected amount of data or an empty data packet), it should set the DATAEND bit (bit 3 of PERI_CSR0) to indicate to the controller that the data phase is complete and that the core should receive an acknowledge packet next.

Figure 33-9. RX Mode Flow Chart



33.2.7.1.1.5.4 Error Handling

A control transfer may be aborted due to a protocol error on the USB, the host prematurely ending the transfer, or if the software wishes to abort the transfer (for example, because it cannot process the command).

The controller automatically detects protocol errors and sends a STALL packet to the host under the following conditions:

- The host sends more data during the OUT Data phase of a write request than was specified in the command. This condition is detected when the host sends an OUT token after the DATAEND bit (bit 3 of PERI_CSR0) has been set.
- The host requests more data during the IN Data phase of a read request than was specified in the command. This condition is detected when the host sends an IN token after the DATAEND bit in the PERI_CSR0 register has been set.
- The host sends more than Max Packet Size data bytes in an OUT data packet.
- The host sends a non-zero length DATA1 packet during the STATUS phase of a read request.

When the controller has sent the STALL packet, it sets the SENTSTALL bit (bit 2 of PERI_CSR0) and generates an interrupt. When the software receives an endpoint 0 interrupt with the SENTSTALL bit set, it should abort the current transfer, clear the SENTSTALL bit, and return to the IDLE state.

If the host prematurely ends a transfer by entering the STATUS phase before all the data for the request has been transferred, or by sending a new SETUP packet before completing the current transfer, then the SETUPEND bit (bit 4 of PERI_CSR0) will be set and an endpoint 0 interrupt generated. When the software receives an endpoint 0 interrupt with the SETUPEND bit set, it should abort the current transfer, set the SERV_SETUPEND bit (bit 7 of PERI_CSR0), and return to the IDLE state. If the RXPKTRDY bit (bit 0 of PERI_CSR0) is set this indicates that the host has sent another SETUP packet and the software should then process this command.

If the software wants to abort the current transfer, because it cannot process the command or has some other internal error, then it should set the SENDSTALL bit (bit 5 of PERI_CSR0). The controller will then send a STALL packet to the host, set the SENTSTALL bit (bit 2 of PERI_CSR0) and generate an endpoint 0 interrupt.

33.2.7.1.1.5.5 Additional Conditions

When working as a peripheral device, the controller automatically responds to certain conditions on the USB bus or actions by the host. The details are:

- Stall Issued to Control Transfers
  - The host sends more data during an OUT Data phase of a Control transfer than was specified in the device request during the SETUP phase. This condition is detected by the controller when the host sends an OUT token (instead of an IN token) after the software has unloaded the last OUT packet and set DataEnd.
  - The host requests more data during an IN data phase of a Control transfer than was specified in the device request during the SETUP phase. This condition is detected by the controller when the host sends an IN token (instead of an OUT token) after the software has cleared TXPKTRDY and set DataEnd in response to the ACK issued by the host to what should have been the last packet.
  - The host sends more than MaxPktSize data with an OUT data token.
  - The host sends the wrong PID for the OUT Status phase of a Control transfer.
  - The host sends more than a zero length data packet for the OUT Status phase.
- Zero Length Out Data Packets In Control Transfer
  - A zero length OUT data packet is used to indicate the end of a Control transfer. In normal operation, such packets should only be received after the entire length of the device request has been transferred (i.e., after the software has set DataEnd). If, however, the host sends a zero length OUT data packet before the entire length of device request has been transferred, this signals the premature end of the transfer. In this case, the controller will automatically flush any IN token loaded by software ready for the Data phase from the FIFO and set SETUPEND bit (bit 4 of PERI_CSR0).

33.2.7.1.2 Bulk Transactions

33.2.7.1.2.1 Bulk In Transactions

A Bulk IN transaction is used to transfer non-periodic data from the USB peripheral device to the host.

The following optional features are available for use with a Tx endpoint used in peripheral mode for Bulk IN transactions:

- Double packet buffering: When enabled, up to two packets can be stored in the FIFO awaiting transmission to the host. Double packet buffering is enabled by setting the DPB bit of TXFIFOSZ register (bit 4).
- DMA: If DMA is enabled for the endpoint, a DMA request will be generated whenever the endpoint is able to accept another packet in its FIFO. This feature allows the DMA controller to load packets into the FIFO without processor intervention.

33.2.7.1.2.1.1 Setup

In configuring a TX endpoint for bulk transactions, the TXMAXP register must be written with the maximum packet size (in bytes) for the endpoint. This value should be the same as the wMaxPacketSize field of the Standard Endpoint Descriptor for the endpoint and the PERI_TXCSR register should be set as shown in Table 33-4 when using DMA:

Table 33-4. PERI_TXCSR Register Bit Configuration for Bulk IN Transactions

Bit Position	Bit Field Name	Configuration
Bit 14	ISO	Cleared to 0 for bulk mode operation.
Bit 13	MODE	Set to 1 to make sure the FIFO is enabled (only necessary if the FIFO is shared with an RX endpoint).
Bit 12	DMAEN	Set to 1 if DMA requests must be enabled.
Bit 11	FRCDATATOG	Cleared to 0 to allow normal data toggle operations.
Bit 10	DMAMODE	Set to 1 when DMA is enabled.

When the endpoint is first configured (following a SET_CONFIGURATION or SET_INTERFACE command on Endpoint 0), the lower byte of PERI_TXCSR should be written to set the CLRDATATOG bit (bit 6). This will ensure that the data toggle (which is handled automatically by the controller) starts in the correct state.

Also if there are any data packets in the FIFO, indicated by the FIFONOTEMPTY bit (bit 1 of PERI_TXCSR) being set, they should be flushed by setting the FLUSHFIFO bit (bit 3 of PERI_TXCSR).

NOTE: It may be necessary to set this bit twice in succession if double buffering is enabled.

33.2.7.1.2.1.2 Operation

When data is to be transferred over a Bulk IN pipe, a data packet needs to be loaded into the FIFO and the PERI_TXCSR register written to set the TXPKTRDY bit (bit 0). When the packet has been sent, the TXPKTRDY bit will be cleared by the USB controller and an interrupt generated so that the next packet can be loaded into the FIFO. If double packet buffering is enabled, then after the first packet has been loaded and the TXPKTRDY bit set, the TXPKTRDY bit will immediately be cleared by the USB controller and an interrupt generated so that a second packet can be loaded into the FIFO. The software should operate in the same way, loading a packet when it receives an interrupt, regardless of whether double packet buffering is enabled or not.

In the general case, the packet size must not exceed the size specified by the lower 11 bits of the TXMAXP register. This part of the register defines the payload (packet size) for transfers over the USB and is required by the USB Specification to be either 8, 16, 32, 64 (Full-Speed or High-Speed) or 512 bytes (High-Speed only).

The host may determine that all the data for a transfer has been sent by knowing the total amount of data that is expected. Alternatively it may infer that all the data has been sent when it receives a packet which is smaller than the stated payload (TXMAXP[10-0]). In the latter case, if the total size of the data block is a multiple of this payload, it will be necessary for the function to send a null packet after all the data has been sent. This is done by setting TXPKTRDY when the next interrupt is received, without loading any data into the FIFO.

If large blocks of data are being transferred, then the overhead of calling an interrupt service routine to load each packet can be avoided by using DMA.

33.2.7.1.2.1.3 Error Handling

If the software wants to shut down the Bulk IN pipe, it should set the SENDSTALL bit (bit 4 of PERI_TXCSR). When the controller receives the next IN token, it will send a STALL to the host, set the SENTSTALL bit (bit 5 of PERI_TXCSR) and generate an interrupt.

When the software receives an interrupt with the SENTSTALL bit (bit 5 of PERI_TXCSR) set, it should clear the SENTSTALL bit. It should however leave the SENDSTALL bit set until it is ready to re-enable the Bulk IN pipe.

NOTE: If the host failed to receive the STALL packet for some reason, it will send another IN token, so it is advisable to leave the SENDSTALL bit set until the software is ready to re-enable the Bulk IN pipe. When a pipe is re-enabled, the data toggle sequence should be restarted by setting the CLRDATATOG bit in the PERI_TXCSR register (bit 6).

33.2.7.1.2.2 Bulk OUT Transactions

A Bulk OUT transaction is used to transfer non-periodic data from the host to the function controller.

The following optional features are available for use with an Rx endpoint used in peripheral mode for Bulk OUT transactions:

- Double packet buffering: When enabled, up to two packets can be stored in the FIFO on reception from the host. Double packet buffering is enabled by setting the DPB bit of the RXFIFOSZ register (bit 4).
- DMA: If DMA is enabled for the endpoint, a DMA request will be generated whenever the endpoint has a packet in its FIFO. This feature can be used to allow the DMA controller to unload packets from the FIFO without processor intervention.

  When DMA is enabled, endpoint interrupt will not be generated for completion of packet reception. Endpoint interrupt will be generated only in the error conditions.

33.2.7.1.2.2.1 Setup

In configuring an Rx endpoint for Bulk OUT transactions, the RXMAXP register must be written with the maximum packet size (in bytes) for the endpoint. This value should be the same as the wMaxPacketSize field of the Standard Endpoint Descriptor for the endpoint. In addition, the relevant interrupt enable bit in the INTRRXE register should be set (if an interrupt is required for this endpoint) and the PERI_RXCSR register should be set as shown in Table 33-5.

Table 33-5. PERI_RXCSR Register Bit Configuration for Bulk OUT Transactions

Bit Position	Bit Field Name	Configuration
Bit 14	ISO	Cleared to 0 to enable Bulk protocol.
Bit 13	DMAEN	Set to 1 if a DMA request is required for this endpoint.
Bit 12	DISNYET	Cleared to 0 to allow normal PING flow control. This will affect only high speed transactions.
Bit 11	DMAMODE	Always clear this bit to 0.

When the endpoint is first configured (following a SET_CONFIGURATION or SET_INTERFACE command on Endpoint 0), the lower byte of PERI_RXCSR should be written to set the CLRDATATOG bit (bit 7). This will ensure that the data toggle (which is handled automatically by the USB controller) starts in the correct state.

Also if there are any data packets in the FIFO (indicated by the RXPKTRDY bit (bit 0 of PERI_RXCSR) being set), they should be flushed by setting the FLUSHFIFO bit (bit 4 of PERI_RXCSR).

NOTE: It may be necessary to set this bit twice in succession if double buffering is enabled.

33.2.7.1.2.2.2 Operation

When a data packet is received by a Bulk Rx endpoint, the RXPKTRDY bit (bit 0 of PERI_RXCSR) is set and an interrupt is generated. The software should read the RXCOUNT register for the endpoint to determine the size of the data packet. The data packet should be read from the FIFO, then the RXPKTRDY bit should be cleared.

The packets received should not exceed the size specified in the RXMAXP register (as this should be the value set in the wMaxPacketSize field of the endpoint descriptor sent to the host). When a block of data larger than wMaxPacketSize needs to be sent to the function, it will be sent as multiple packets. All the packets will be wMaxPacketSize in size, except the last packet which will contain the residue. The software may use an application specific method of determining the total size of the block and hence when the last packet has been received. Alternatively it may infer that the entire block has been received when it receives a packet which is less than wMaxPacketSize in size. (If the total size of the data block is a multiple of wMaxPacketSize, a null data packet will be sent after the data to signify that the transfer is complete.)

In the general case, the application software will need to read each packet from the FIFO individually. If large blocks of data are being transferred, the overhead of calling an interrupt service routine to unload each packet can be avoided by using DMA.

33.2.7.1.2.2.3 Error Handling

If the software wants to shut down the Bulk OUT pipe, it should set the SENDSTALL bit (bit 5 of PERI_RXCSR). When the controller receives the next packet it will send a STALL to the host, set the SENTSTALL bit (bit 6 of PERI_RXCSR) and generate an interrupt.

When the software receives an interrupt with the SENTSTALL bit (bit 6 of PERI_RXCSR) set, it should clear this bit. It should however leave the SENDSTALL bit set until it is ready to re-enable the Bulk OUT pipe.

NOTE: If the host failed to receive the STALL packet for some reason, it will send another packet, so it is advisable to leave the SENDSTALL bit set until the software is ready to re-enable the Bulk OUT pipe. When a Bulk OUT pipe is re-enabled, the data toggle sequence should be restarted by setting the CLRDATATOG bit (bit 7) in the PERI_RXCSR register.

33.2.7.1.3 Peripheral Mode: Interrupt Transactions

An Interrupt IN transaction uses the same protocol as a Bulk IN transaction and can be used the same way. Similarly, an Interrupt OUT transaction uses almost the same protocol as a Bulk OUT transaction and can be used the same way.

Tx endpoints in the USB controller have one feature for Interrupt IN transactions that they do not support in Bulk IN transactions. In Interrupt IN transactions, the endpoints support continuous toggle of the data toggle bit.

This feature is enabled by setting the FRCDATATOG bit in the PERI_TXCSR register (bit 11). When this bit is set, the controller will consider the packet as having been successfully sent and toggle the data bit for the endpoint, regardless of whether an ACK was received from the host.

Another difference is that interrupt endpoints do not support PING flow control. This means that the controller should never respond with a NYET handshake, only ACK/NAK/STALL. To ensure this, the DISNYET bit in the PERI_RXCSR register (bit 12) should be set to disable the transmission of NYET handshakes in high-speed mode.

Though DMA can be used with an interrupt OUT endpoint, it generally offers little benefit as interrupt endpoints are usually expected to transfer all their data in a single packet.

33.2.7.1.4 Isochronous Transactions

33.2.7.1.4.1 Peripheral Mode: Isochronous IN Transactions

An Isochronous IN transaction is used to transfer periodic data from the function controller to the host.

The following optional features are available for use with a Tx endpoint used in Peripheral mode for Isochronous IN transactions:

- Double packet buffering: When enabled, up to two packets can be stored in the FIFO awaiting transmission to the host. Double packet buffering is enabled by setting the DPB bit of TXFIFOSZ register (bit 4).

  NOTE: Double packet buffering is generally advisable for Isochronous transactions in order to avoid Underrun errors as described in later section.

- DMA: If DMA is enabled for the endpoint, a DMA request will be generated whenever the endpoint is able to accept another packet in its FIFO. This feature allows the DMA controller to load packets into the FIFO without processor intervention.

  However, this feature is not particularly useful with Isochronous endpoints because the packets transferred are often not maximum packet size and the PERI_TXCSR register needs to be accessed following every packet to check for Underrun errors.

  When DMA is enabled and DMAMODE bit of PERI_TXCSR is set, endpoint interrupt will not be generated for completion of packet transfer. Endpoint interrupt will be generated only in the error conditions.

33.2.7.1.4.1.1 Setup

In configuring a Tx endpoint for Isochronous IN transactions, the TXMAXP register must be written with the maximum packet size (in bytes) for the endpoint. This value should be the same as the wMaxPacketSize field of the Standard Endpoint Descriptor for the endpoint. In addition, the relevant interrupt enable bit in the INTRTXE register should be set (if an interrupt is required for this endpoint) and the PERI_TXCSR register should be set as shown in Table 33-6.

Table 33-6. PERI_TXCSR Register Bit Configuration for Isochronous IN Transactions

Bit Position	Bit Field Name	Configuration
Bit 14	ISO	Set to 1 to enable Isochronous transfer protocol.
Bit 13	MODE	Set to 1 to ensure the FIFO is enabled (only necessary if the FIFO is shared with an Rx endpoint).
Bit 12	DMAEN	Set to 1 if DMA Requests have to be enabled.
Bit 11	FRCDATATOG	Ignored in Isochronous mode.
Bit 10	DMAMODE	Set to 1 when DMA is enabled.

33.2.7.1.4.1.2 Operation

An Isochronous endpoint does not support data retries, so if data underrun is to be avoided, the data to be sent to the host must be loaded into the FIFO before the IN token is received. The host will send one IN token per frame (or microframe in High-speed mode), however the timing within the frame (or microframe) can vary. If an IN token is received near the end of one frame and then at the start of the next frame, there will be little time to reload the FIFO. For this reason, double buffering of the endpoint is usually necessary.

An interrupt is generated whenever a packet is sent to the host and the software may use this interrupt to load the next packet into the FIFO and set the TXPKTRDY bit in the PERI_TXCSR register (bit 0) in the same way as for a Bulk Tx endpoint. As the interrupt could occur almost any time within a frame(/microframe), depending on when the host has scheduled the transaction, this may result in irregular timing of FIFO load requests. If the data source for the endpoint is coming from some external hardware, it may be more convenient to wait until the end of each frame(/microframe) before loading the FIFO as this will minimize the requirement for additional buffering. This can be done by using either the SOF interrupt or the external SOF_PULSE signal from the controller to trigger the loading of the next data packet. The SOF_PULSE is generated once per frame(/microframe) when a SOF packet is received. (The controller also maintains an external frame(/microframe) counter so it can still generate a SOF_PULSE when the SOF packet has been lost.) The interrupts may still be used to set the TXPKTRDY bit in PERI_TXCSR (bit 0) and to check for data overruns/underruns.

Starting up a double-buffered Isochronous IN pipe can be a source of problems. Double buffering requires that a data packet is not transmitted until the frame(/microframe) after it is loaded. There is no problem if the function loads the first data packet at least a frame(/microframe) before the host sets up the pipe (and therefore starts sending IN tokens). But if the host has already started sending IN tokens by the time the first packet is loaded, the packet may be transmitted in the same frame(/microframe) as it is loaded, depending on whether it is loaded before, or after, the IN token is received. This potential problem can be avoided by setting the ISOUPDATE bit in the POWER register (bit 7). When this bit is set, any data packet loaded into an Isochronous Tx endpoint FIFO will not be transmitted until after the next SOF packet has been received, thereby ensuring that the data packet is not sent too early.

33.2.7.1.4.1.3 Error Handling

If the endpoint has no data in its FIFO when an IN token is received, it will send a null data packet to the host and set the UNDERRUN bit in the PERI_TXCSR register (bit 2). This is an indication that the software is not supplying data fast enough for the host. It is up to the application to determine how this error condition is handled.

If the software is loading one packet per frame(/microframe) and it finds that the TXPKTRDY bit in the PERI_TXCSR register (bit 0) is set when it wants to load the next packet, this indicates that a data packet has not been sent (perhaps because an IN token from the host was corrupted). It is up to the application how it handles this condition: it may choose to flush the unsent packet by setting the FLUSHFIFO bit in the PERI_TXCSR register (bit 3), or it may choose to skip the current packet.

33.2.7.1.4.2 Peripheral Mode: Isochronous OUT Transactions

An Isochronous OUT transaction is used to transfer periodic data from the host to the function controller.

Following optional features are available for use with an Rx endpoint used in Peripheral mode for Isochronous OUT transactions:

- Double packet buffering: When enabled, up to two packets can be stored in the FIFO on reception from the host. Double packet buffering is enabled by setting the DPB bit of RXFIFOSZ register (bit 4).

  NOTE: Double packet buffering is generally advisable for Isochronous transactions in order to avoid Overrun errors.

- DMA: If DMA is enabled for the endpoint, a DMA request will be generated whenever the endpoint has a packet in its FIFO. This feature can be used to allow the DMA controller to unload packets from the FIFO without processor intervention.

  However, this feature is not particularly useful with Isochronous endpoints because the packets transferred are often not maximum packet size and the PERI_RXCSR register needs to be accessed following every packet to check for Overrun or CRC errors.

  When DMA is enabled, endpoint interrupt will not be generated for completion of packet reception. Endpoint interrupt will be generated only in the error conditions.

33.2.7.1.4.2.1 Setup

In configuring an Rx endpoint for Isochronous OUT transactions, the RXMAXP register must be written with the maximum packet size (in bytes) for the endpoint. This value should be the same as the wMaxPacketSize field of the Standard Endpoint Descriptor for the endpoint. In addition, the relevant interrupt enable bit in the INTRRXE register should be set (if an interrupt is required for this endpoint) and the PERI_RXCSR register should be set as shown in Table 33-7.

Table 33-7. PERI_RXCSR Register Bit Configuration for Isochronous OUT Transactions

Bit Position	Bit Field Name	Configuration
Bit 14	ISO	Set to 1 to enable isochronous protocol.
Bit 13	DMAEN	Set to 1 if a DMA request is required for this endpoint.
Bit 12	DISNYET	Ignored in isochronous transfers.
Bit 11	DMAMODE	Always clear this bit to 0.

33.2.7.1.4.2.2 Operation

An Isochronous endpoint does not support data retries so, if a data overrun is to be avoided, there must be space in the FIFO to accept a packet when it is received. The host will send one packet per frame (or microframe in High-speed mode); however, the time within the frame can vary. If a packet is received near the end of one frame(/microframe) and another arrives at the start of the next frame, there will be little time to unload the FIFO. For this reason, double buffering of the endpoint is usually necessary.

An interrupt is generated whenever a packet is received from the host and the software may use this interrupt to unload the packet from the FIFO and clear the RXPKTRDY bit in the PERI_RXCSR register (bit 0) in the same way as for a Bulk Rx endpoint. As the interrupt could occur almost any time within a frame(/microframe), depending on when the host has scheduled the transaction, the timing of FIFO unload requests will probably be irregular. If the data sink for the endpoint is going to some external hardware, it may be better to minimize the requirement for additional buffering by waiting until the end of each frame(/microframe) before unloading the FIFO. This can be done by using either the SOF interrupt or the external SOF_PULSE signal from the controller to trigger the unloading of the data packet. The SOF_PULSE is generated once per frame(/microframe) when a SOF packet is received. (The controller also maintains an external frame(/microframe) counter so it can still generate a SOF_PULSE when the SOF packet has been lost.) The interrupts may still be used to clear the RXPKTRDY bit in PERI_RXCSR and to check for data overruns/underruns.

33.2.7.1.4.2.3 Error Handling

If there is no space in the FIFO to store a packet when it is received from the host, the OVERRUN bit in the PERI_RXCSR register (bit 2) will be set. This is an indication that the software is not unloading data fast enough for the host. It is up to the application to determine how this error condition is handled.

If the controller finds that a received packet has a CRC error, it will still store the packet in the FIFO and set the RXPKTRDY bit (bit 0 of PERI_RXCSR) and the DATAERROR bit (bit 3 of PERI_RXCSR). It is left up to the application how this error condition is handled.

33.2.7.2 USB Controller Host Mode Operation

- *Entry into Suspend mode*. When operating as a host, the controller can be prompted to enter Suspend mode by setting the SUSPENDM bit in the POWER register. When this bit is set, the controller will complete the current transaction then stop the transaction scheduler and frame counter. No further transactions will be started and no SOF packets will be generated. If the ENSUSPM bit (bit 0 of POWER register) is set, PHY will go into low-power mode when the controller enters Suspend mode.
- *Sending Resume Signaling.* When the application requires the controller to leave Suspend mode, it must clear the SUSPENDM bit in the POWER register (bit 1), set the RESUME bit (bit 2) and leave it set for 20ms. While the RESUME bit is high, the controller will generate Resume signaling on the bus. After 20 ms, the application should clear the Resume bit, at which point the frame counter and transaction scheduler will be started.
- *Responding to Remote Wake-up.* If Resume signaling is detected from the target while the controller is in Suspend mode, the PHY will be brought out of low-power mode. The controller will then exit Suspend mode and automatically set the RESUME bit in the POWER register (bit 2) to take over generating the Resume signaling from the target. If the Resume interrupt is enabled, an interrupt will be generated.
- *Reset Signaling.* If the RESET bit in the POWER register (bit 3) is set while the controller is in Host mode, it will generate Reset signaling on the bus. If the HSENAB bit in the POWER register (bit 5) was set, it will also try to negotiate for high-speed operation. The software should keep the RESET bit set for at least 20 ms to ensure correct resetting of the target device. After the software has cleared the bit, the controller will start its frame counter and transaction scheduler. Whether high-speed operation is selected will be indicated by HSMODE bit of POWER register (bit 4).

33.2.7.2.1 Control Transactions

Host Control Transactions are conducted through Endpoint 0 and the software is required to handle all the Standard Device Requests that may be sent or received via Endpoint 0 (as described in Universal Serial Bus Specification, Revision 2.0).

As for a USB peripheral device, there are three categories of Standard Device Requests to be handled: Zero Data Requests (in which all the information is included in the command), Write Requests (in which the command will be followed by additional data), and Read Requests (in which the device is required to send data back to the host).

1. Zero Data Requests consist of a SETUP command followed by an IN Status Phase
2. Write Requests consist of a SETUP command, followed by an OUT Data Phase which is in turn followed by an IN Status Phase
3. Read Requests consist of a SETUP command, followed by an IN Data Phase which is in turn followed by an OUT Status Phase

A timeout may be set to limit the length of time for which the controller will retry a transaction which is continually NAKed by the target. This limit can be between 2 and 215 frames/ microframes and is set through the HOST_NAKLIMIT0 register. The following sections describe the CPU actions required for these different types of requests by examining the steps to take in the different Control Transaction phases.

33.2.7.2.1.1 Setup Phase

For the SETUP Phase of a control transaction (Figure 33-10), the software driving the USB host device needs to:

1. Load the 8 bytes of the required Device request command into the Endpoint 0 FIFO.
2. Set SETUPPKT and TXPKTRDY (bits 3 and 1 of HOST_CSR0, respectively).

NOTE: These bits must be set together.

The controller then proceeds to send a SETUP token followed by the 8-byte command to Endpoint 0 of the addressed device, retrying as necessary. (On errors, controller retries the transaction three times.)

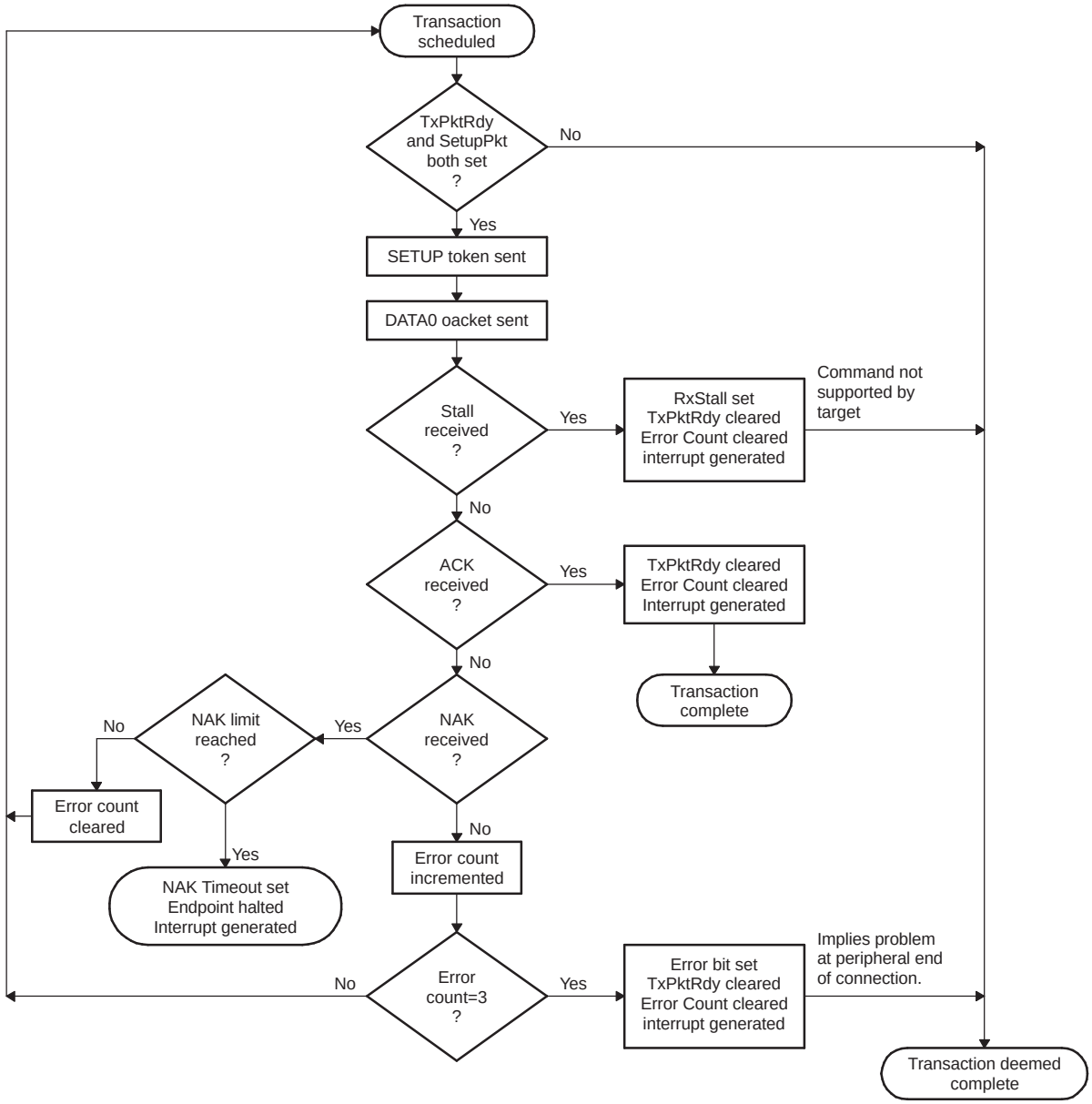
3. At the end of the attempt to send the data, the controller will generate an Endpoint 0 interrupt. The software should then read HOST_CSR0 to establish whether the RXSTALL bit (bit 2), the ERROR bit (bit 4) or the NAK_TIMEOUT bit (bit 7) has been set.

   If RXSTALL is set, it indicates that the target did not accept the command (for example, because it is not supported by the target device) and so has issued a STALL response.

   If ERROR is set, it means that the controller has tried to send the SETUP Packet and the following data packet three times without getting any response.

   If NAK_TIMEOUT is set, it means that the controller has received a NAK response to each attempt to send the SETUP packet, for longer than the time set in HOST_NAKLIMIT0. The controller can then be directed either to continue trying this transaction (until it times out again) by clearing the NAK_TIMEOUT bit or to abort the transaction by flushing the FIFO before clearing the NAK_TIMEOUT bit.
4. If none of RXSTALL, ERROR or NAK_TIMEOUT is set, the SETUP Phase has been correctly ACKed and the software should proceed to the following IN Data Phase, OUT Data Phase or IN Status Phase specified for the particular Standard Device Request.

Figure 33-10. Setup Phase of a Control Transaction Flow Chart



33.2.7.2.1.2 IN Data Phase

For the IN Data Phase of a control transaction (Figure 33-11), the software driving the USB host device needs to:

1. Set REQPKT bit of HOST_CSR0 (bit 5).
2. Wait while the controller sends the IN token and receives the required data back.
3. When the controller generates the Endpoint 0 interrupt, read HOST_CSR0 to establish whether the RXSTALL bit (bit 2), the ERROR bit (bit 4), the NAK_TIMEOUT bit (bit 7) or RXPKTRDY bit (bit 0) has been set.

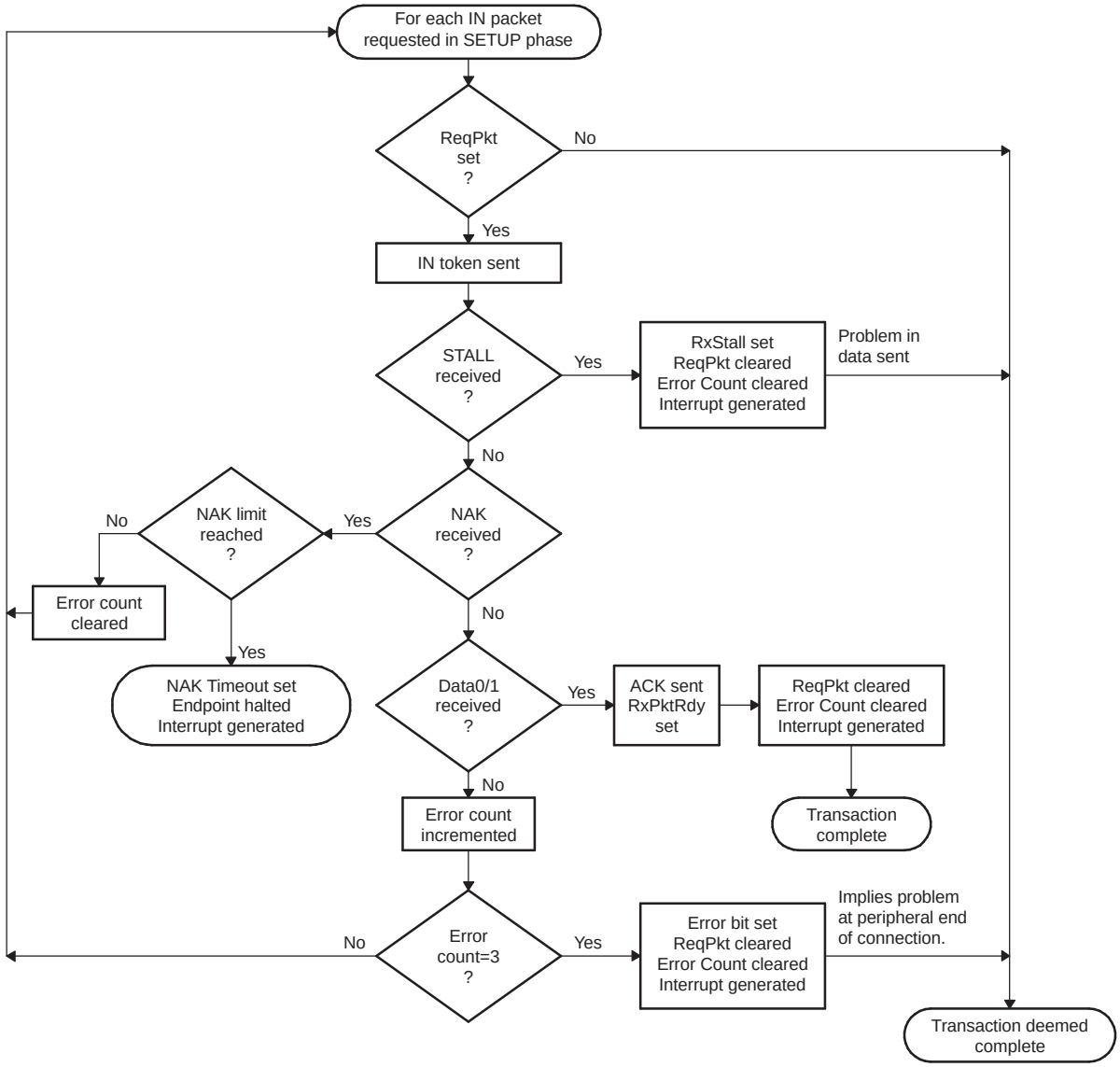
   If RXSTALL is set, it indicates that the target has issued a STALL response.

   If ERROR is set, it means that the controller has tried to send the required IN token three times without getting any response.

   If NAK_TIMEOUT bit is set, it means that the controller has received a NAK response to each attempt to send the IN token, for longer than the time set in HOST_NAKLIMIT0. The controller can then be directed either to continue trying this transaction (until it times out again) by clearing the NAK_TIMEOUT bit or to abort the transaction by clearing REQPKT before clearing the NAK_TIMEOUT bit.
4. If RXPKTRDY has been set, the software should read the data from the Endpoint 0 FIFO, then clear RXPKTRDY.
5. If further data is expected, the software should repeat Steps 1-4.

When all the data has been successfully received, the CPU should proceed to the OUT Status Phase of the Control Transaction.

Figure 33-11. IN Data Phase Flow Chart



33.2.7.2.1.3 OUT Data Phase

For the OUT Data Phase of a control transaction (Figure 33-12), the software driving the USB host device needs to:

1. Load the data to be sent into the endpoint 0 FIFO.
2. Set the TXPKTRDY bit of HOST_CSR0 (bit 1). The controller then proceeds to send an OUT token followed by the data from the FIFO to Endpoint 0 of the addressed device, retrying as necessary.
3. At the end of the attempt to send the data, the controller will generate an Endpoint 0 interrupt. The software should then read HOST_CSR0 to establish whether the RXSTALL bit (bit 2), the ERROR bit (bit 4) or the NAK_TIMEOUT bit (bit 7) has been set.

   If RXSTALL bit is set, it indicates that the target has issued a STALL response.

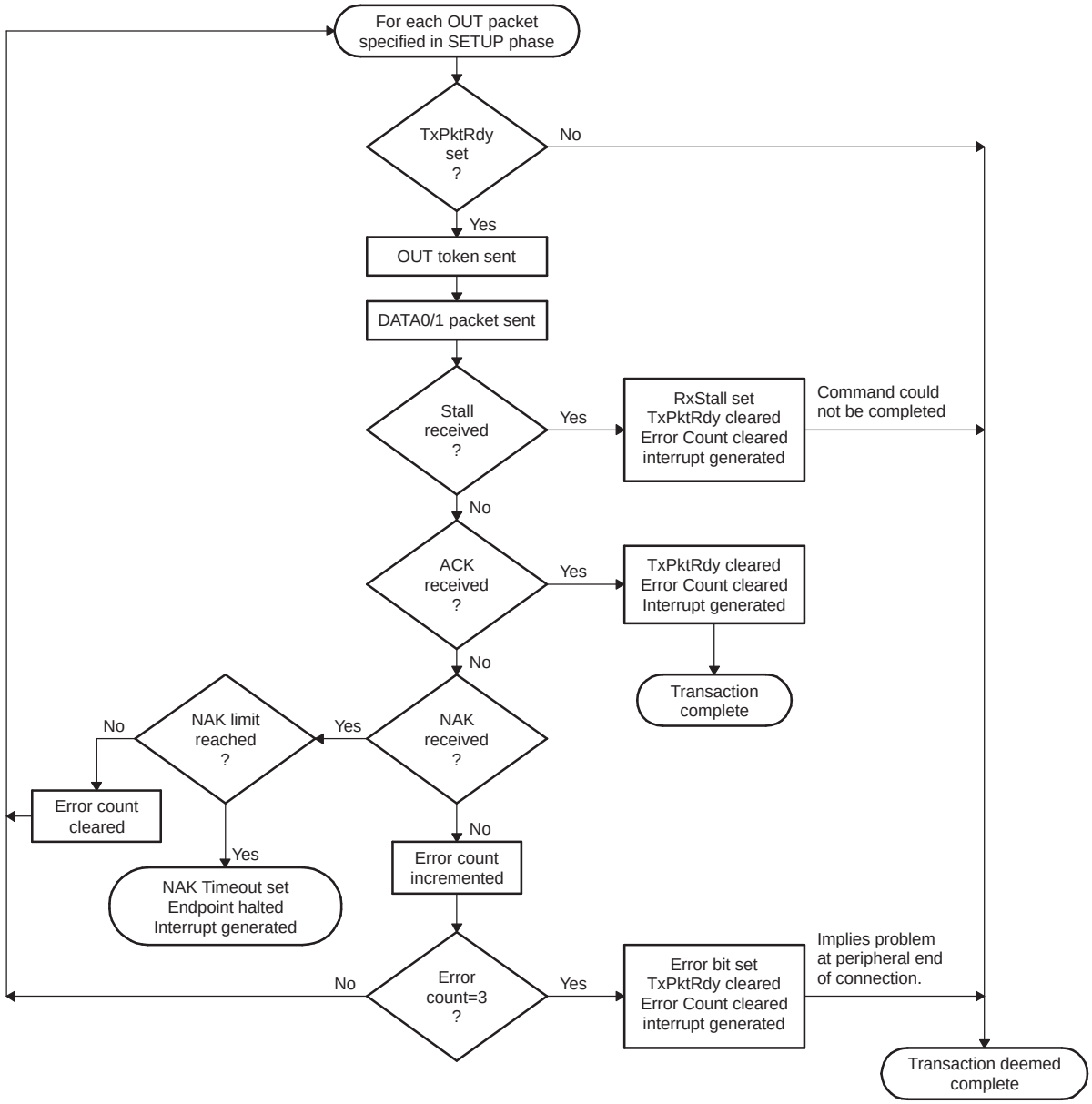
   If ERROR bit is set, it means that the controller has tried to send the OUT token and the following data packet three times without getting any response.

   If NAK_TIMEOUT is set, it means that the controller has received a NAK response to each attempt to send the OUT token, for longer than the time set in the HOST_NAKLIMIT0 register. The controller can then be directed either to continue trying this transaction (until it times out again) by clearing the NAK_TIMEOUT bit or to abort the transaction by flushing the FIFO before clearing the NAK_TIMEOUT bit.

   If none of RXSTALL, ERROR or NAKLIMIT is set, the OUT data has been correctly ACKed.
4. If further data needs to be sent, the software should repeat Steps 1-3.

   When all the data has been successfully sent, the software should proceed to the IN Status Phase of the Control Transaction.

Figure 33-12. OUT Data Phase Flow Chart



33.2.7.2.1.4 IN Status Phase (following SETUP Phase or OUT Data Phase)

For the IN Status Phase of a control transaction (Figure 33-13), the software driving the USB Host device needs to:

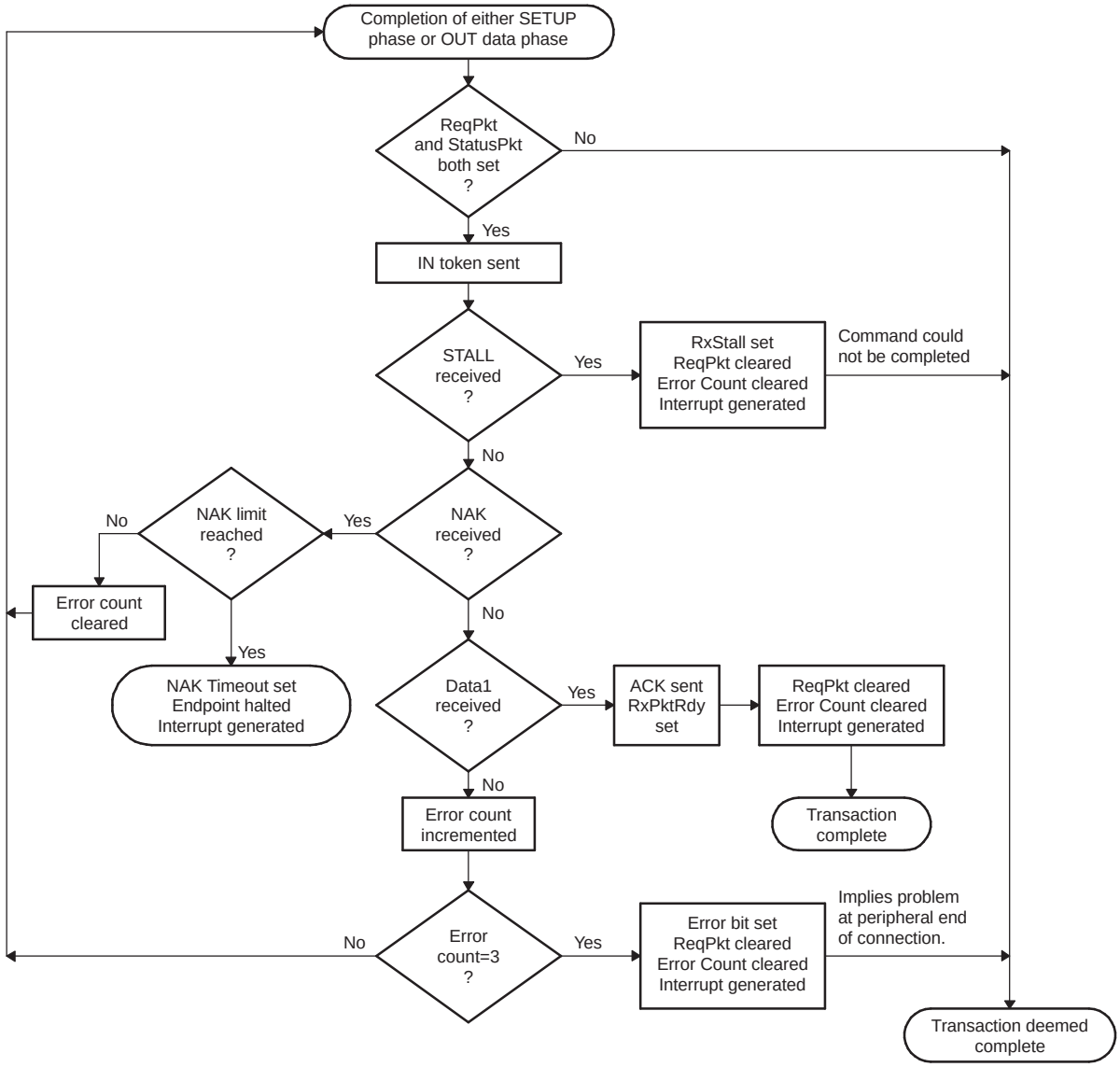
1. Set the STATUSPKT and REQPKT bits of HOST_CSR0 (bit 6 and bit 5, respectively).
2. Wait while the controller sends an IN token and receives a response from the USB peripheral device.
3. When the controller generates the Endpoint 0 interrupt, read HOST_CSR0 to establish whether the RXSTALL bit (bit 2), the ERROR bit (bit 4), the NAK_TIMEOUT bit (bit 7) or RXPKTRDY bit (bit 0) has been set.

   If RXSTALL bit is set, it indicates that the target could not complete the command and so has issued a STALL response.

   If ERROR bit is set, it means that the controller has tried to send the required IN token three times without getting any response.

   If NAK_TIMEOUT bit is set, it means that the controller has received a NAK response to each attempt to send the IN token, for longer than the time set in the HOST_NAKLIMIT0 register. The controller can then be directed either to continue trying this transaction (until it times out again) by clearing the NAK_TIMEOUT bit or to abort the transaction by clearing REQPKT bit and STATUSPKT bit before clearing the NAK_TIMEOUT bit.
4. If RxPktRdy has been set, the CPU should simply clear RxPktRdy.

Figure 33-13. Completion of SETUP or OUT Data Phase Flow Chart



33.2.7.2.1.5 OUT Status Phase (following IN Data Phase)

For the OUT Status Phase of a control transaction (Figure 33-14) , the CPU driving the host device needs to:

1. Set STATUSPKT and TXPKTRDY bits of HOST_CSR0 (bit 6 and bit 1, respectively).

   NOTE: These bits need to be set together.

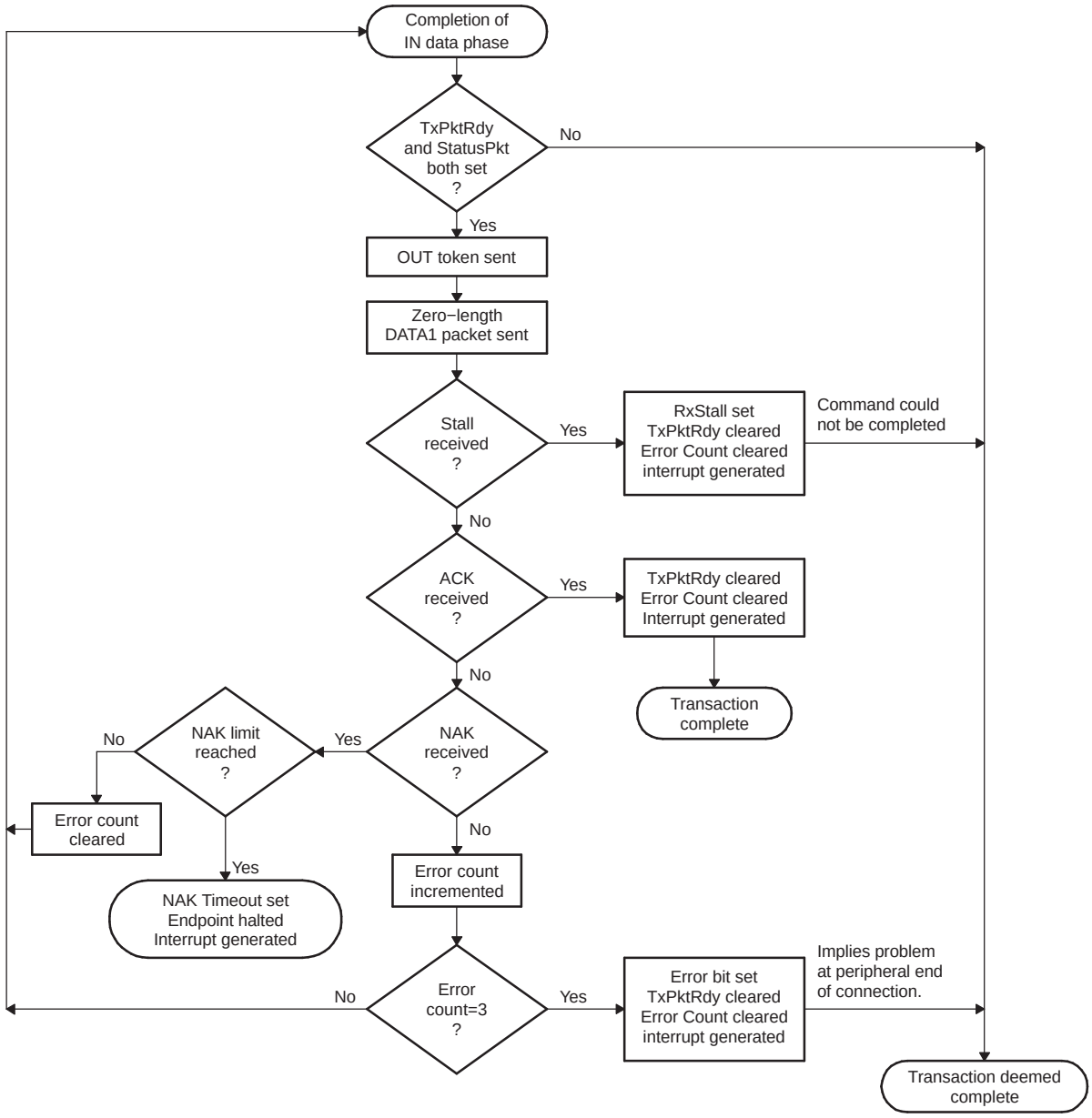
2. Wait while the controller sends the OUT token and a zero-length DATA1 packet.
3. At the end of the attempt to send the data, the controller will generate an Endpoint 0 interrupt. The software should then read HOST_CSR0 to establish whether the RXSTALL bit (bit 2), the ERROR bit (bit 4) or the NAK_TIMEOUT bit (bit 7) has been set.

   If RXSTALL bit is set, it indicates that the target could not complete the command and so has issued a STALL response.

   If ERROR bit is set, it means that the controller has tried to send the STATUS Packet and the following data packet three times without getting any response.

   If NAK_TIMEOUT bit is set, it means that the controller has received a NAK response to each attempt to send the IN token, for longer than the time set in the HOST_NAKLIMIT0 register. The controller can then be directed either to continue trying this transaction (until it times out again) by clearing the NAK_TIMEOUT bit or to abort the transaction by flushing the FIFO before clearing the NAK_TIMEOUT bit.
4. If none of RXSTALL, ERROR or NAK_TIMEOUT bits is set, the STATUS Phase has been correctly ACKed.

Figure 33-14. Completion of IN Data Phase Flow Chart



33.2.7.2.2 Bulk Transactions

33.2.7.2.2.1 Bulk IN Transactions

A Bulk IN transaction may be used to transfer non-periodic data from the external USB peripheral to the host.

The following optional features are available for use with an Rx endpoint used in host mode to receive the data:

- Double packet buffering: When enabled, up to two packets can be stored in the FIFO on reception from the host. This allows that one packet can be received while another is being read. Double packet buffering is enabled by setting the DPB bit of RXFIFOSZ register (bit 4).
- DMA: If DMA is enabled for the endpoint, a DMA request will be generated whenever the endpoint has a packet in its FIFO. This feature can be used to allow the DMA controller to unload packets from the FIFO without processor intervention.

  When DMA is enabled, endpoint interrupt will not be generated for completion of packet reception. Endpoint interrupt will be generated only in the error conditions.
- AutoRequest: When the AutoRequest feature is enabled, the REQPKT bit of HOST_RXCSR (bit 5) will be automatically set when the RXPKTRDY bit is cleared.

  This feature is applicable only when DMA is enabled. To enable AutoRequest feature, set the AUTOREQ register for the DMA channel associated for the endpoint.

33.2.7.2.2.1.1 Setup

Before initiating any Bulk IN Transactions in Host mode:

- The target function address needs to be set in the RXFUNCADDR register for the selected controller endpoint. (RXFUNCADDR register is available for all endpoints from EP0 to EP4.)
- The HOST_RXTYPE register for the endpoint that is to be used needs to be programmed as:
  - Operating speed in the SPEED bit field (bits 7 and 6).
  - Set 10 (binary value) in the PROT field for bulk transfer.
  - Endpoint Number of the target device in RENDPN field. This is the endpoint number contained in the Rx endpoint descriptor returned by the target device during enumeration.
- The RXMAXP register for the controller endpoint must be written with the maximum packet size (in bytes) for the transfer. This value should be the same as the wMaxPacketSize field of the Standard Endpoint Descriptor for the target endpoint.
- The HOST_RXINTERVAL register needs to be written with the required value for the NAK limit (2-215 frames/microframes), or set to zero if the NAK timeout feature is not required.
- The relevant interrupt enable bit in the INTRRXE register should be set (if an interrupt is required for this endpoint).
- The following bits of HOST_RXCSR register should be set as:
  - Set DMAEN (bit 13) to 1 if a DMA request is required for this endpoint.
  - Clear DSINYET (bit 12) to 0 to allow normal PING flow control. This will affect only High Speed transactions.
  - Always clear DMAMODE (bit 11) to 0.
- If DMA is enabled, the AUTOREQ register can be set for generating IN tokens automatically after receiving the data. Set the bit field RXn_AUTOREQ (where n is the endpoint number) with binary value 01 or 11.

When the endpoint is first configured, the endpoint data toggle should be cleared to 0 either by using the DATATOGWREN and DATATOG bits of HOST_RXCSR (bit 10 and bit 9) to toggle the current setting or by setting the CLRDATATOG bit of HOST_RXCSR (bit 7). This will ensure that the data toggle (which is handled automatically by the controller) starts in the correct state. Also if there are any data packets in the FIFO (indicated by the RXPKTRDY bit (bit 0 of HOST_RXCSR) being set), they should be flushed by setting the FLUSHFIFO bit of HOST_RXCSR (bit 4).

NOTE: It may be necessary to set this bit twice in succession if double buffering is enabled.

33.2.7.2.2.1.2 Operation

When Bulk data is required from the USB peripheral device, the software should set the REQPKT bit in the corresponding HOST_RXCSR register (bit 5). The controller will then send an IN token to the selected peripheral endpoint and waits for data to be returned.

If data is correctly received, RXPKTRDY bit of HOST_RXCSR (bit 0) is set. If the USB peripheral device responds with a STALL, RXSTALL bit (bit 6 of HOST_RXCSR) is set. If a NAK is received, the controller tries again and continues to try until either the transaction is successful or the POLINTVL_NAKLIMIT set in the HOST_RXINTERVAL register is reached. If no response at all is received, two further attempts are made before the controller reports an error by setting the ERROR bit of HOST_RXCSR (bit 2).

The controller then generates the appropriate endpoint interrupt, whereupon the software should read the corresponding HOST_RXCSR register to determine whether the RXPKTRDY, RXSTALL, ERROR or DATAERR_NAKTIMEOUT bit is set and act accordingly. If the DATAERR_NAKTIMEOUT bit is set, the controller can be directed either to continue trying this transaction (until it times out again) by clearing the DATAERR_NAKTIMEOUT bit or to abort the transaction by clearing REQPKT bit before clearing the DATAERR_NAKTIMEOUT bit.

The packets received should not exceed the size specified in the RXMAXP register (as this should be the value set in the wMaxPacketSize field of the endpoint descriptor sent to the host).

In the general case, the application software will need to read each packet from the FIFO individually. If large blocks of data are being transferred, the overhead of calling an interrupt service routine to unload each packet can be avoided by using DMA.

33.2.7.2.2.1.3 Error Handling

If the target wants to shut down the Bulk IN pipe, it will send a STALL response to the IN token. This will result in the RXSTALL bit of HOST_RXCSR (bit 6) being set.

33.2.7.2.2.2 Host Mode: Bulk OUT Transactions

A Bulk OUT transaction may be used to transfer non-periodic data from the host to the USB peripheral.

Following optional features are available for use with a Tx endpoint used in Host mode to transmit this data:

- Double packet buffering: When enabled, up to two packets can be stored in the FIFO awaiting transmission to the peripheral device. Double packet buffering is enabled by setting the DPB bit of TXFIFOSZ register (bit 4).
- DMA: If DMA is enabled for the endpoint, a DMA request will be generated whenever the endpoint is able to accept another packet in its FIFO. This feature can be used to allow the DMA controller to load packets into the FIFO without processor intervention.

  When DMA is enabled and DMAMODE bit in HOST_TXCSR register is set, an endpoint interrupt will not be generated for completion of packet reception. An endpoint interrupt will be generated only in the error conditions.

33.2.7.2.2.2.1 Setup

Before initiating any bulk OUT transactions:

- The target function address needs to be set in the TXFUNCADDR register for the selected controller endpoint. (TXFUNCADDR register is available for all endpoints from EP0 to EP4.)
- The HOST_TXTYPE register for the endpoint that is to be used needs to be programmed as:
  - Operating speed in the SPEED bit field (bits 7 and 6).
  - Set 10b in the PROT field for bulk transfer.
  - Endpoint Number of the target device in TENDPN field. This is the endpoint number contained in the OUT(Tx) endpoint descriptor returned by the target device during enumeration.
- The TXMAXP register for the controller endpoint must be written with the maximum packet size (in bytes) for the transfer. This value should be the same as the wMaxPacketSize field of the Standard Endpoint Descriptor for the target endpoint.
- The HOST_TXINTERVAL register needs to be written with the required value for the NAK limit (2-215 frames/microframes), or set to zero if the NAK timeout feature is not required.
- The relevant interrupt enable bit in the INTRTXE register should be set (if an interrupt is required for this endpoint).
- The following bits of HOST_TXCSR register should be set as:
  - Set the MODE bit (bit 13) to 1 to ensure the FIFO is enabled (only necessary if the FIFO is shared with an Rx endpoint).
  - Set the DMAEN bit (bit 12) to 1 if a DMA request is required for this endpoint.
  - Clear the FRCDATATOG bit (bit 11) to 0 to allow normal data toggle operations.
  - Set the DMAMODE bit (bit 10) to 1 when DMA is enabled.

When the endpoint is first configured, the endpoint data toggle should be cleared to 0 either by using the DATATOGWREN bit and DATATOG bit of HOST_TXCSR (bit 9 and bit 8) to toggle the current setting or by setting the CLRDATATOG bit of HOST_TXCSR (bit 6). This will ensure that the data toggle (which is handled automatically by the controller) starts in the correct state. Also, if there are any data packets in the FIFO (indicated by the FIFONOTEMPTY bit of HOST_TXCSR register (bit 1) being set), they should be flushed by setting the FLUSHFIFO bit (bit 3 of HOST_TXCSR).

NOTE: It may be necessary to set this bit twice in succession if double buffering is enabled.

33.2.7.2.2.2 Operation

When Bulk data is required to be sent to the USB peripheral device, the software should write the first packet of the data to the FIFO (or two packets if double-buffered) and set the TXPKTRDY bit in the corresponding HOST_TXCSR register (bit 0). The controller will then send an OUT token to the selected peripheral endpoint, followed by the first data packet from the FIFO.

If data is correctly received by the peripheral device, an ACK should be received whereupon the controller will clear TXPKTRDY bit of HOST_TXCSR (bit 0). If the USB peripheral device responds with a STALL, the RXSTALL bit (bit 5) of HOST_TXCSR is set. If a NAK is received, the controller tries again and continues to try until either the transaction is successful or the NAK limit set in the HOST_TXINTERVAL register is reached. If no response at all is received, two further attempts are made before the controller reports an error by setting ERROR bit in HOST_TXCSR (bit 2).

The controller then generates the appropriate endpoint interrupt, whereupon the software should read the corresponding HOST_TXCSR register to determine whether the RXSTALL (bit 5), ERROR (bit 2) or NAK_TIMEOUT (bit 7) bit is set and act accordingly. If the NAK_TIMEOUT bit is set, the controller can be directed either to continue trying this transaction (until it times out again) by clearing the NAK_TIMEOUT bit or to abort the transaction by flushing the FIFO before clearing the NAK_TIMEOUT bit.

If large blocks of data are being transferred, then the overhead of calling an interrupt service routine to load each packet can be avoided by using DMA.

33.2.7.2.2.3 Error Handling

If the target wants to shut down the Bulk OUT pipe, it will send a STALL response. This is indicated by the RXSTALL bit of HOST_TXCSR register (bit 5) being set.

33.2.7.2.3 Interrupt Transactions

When the controller is operating as the host, interactions with an Interrupt endpoint on the USB peripheral device are handled in very much the same way as the equivalent Bulk transactions (described in previous sections).

The principal difference as far as operational steps are concerned is that the PROT field of HOST_RXTYPE and HOST_TXTYPE (bits 5-4) need to be set (binary value) to represent an Interrupt transaction. The required polling interval also needs to be set in the HOST_RXINTERVAL and HOST_TXINTERVAL registers.

33.2.7.2.4 Isochronous Transactions

33.2.7.2.4.1 Isochronous IN Transactions

An Isochronous IN transaction is used to transfer periodic data from the USB peripheral to the host.

The following optional features are available for use with an Rx endpoint used in Host mode to receive this data:

- Double packet buffering: When enabled, up to two packets can be stored in the FIFO on reception from the host. This allows that one packet can be received while another is being read. Double packet buffering is enabled by setting the DPB bit of RXFIFOSZ register (bit 4).
- DMA: If DMA is enabled for the endpoint, a DMA request will be generated whenever the endpoint has a packet in its FIFO. This feature can be used to allow the DMA controller to unload packets from the FIFO without processor intervention. However, this feature is not particularly useful with isochronous endpoints because the packets transferred are often not maximum packet size.

  When DMA is enabled, endpoint interrupt will not be generated for completion of packet reception. Endpoint interrupt will be generated only in the error conditions.
- AutoRequest: When the AutoRequest feature is enabled, the REQPKT bit of HOST_RXCSR (bit 5) will be automatically set when the RXPKTRDY bit is cleared.

  This feature is applicable only when DMA is enabled. To enable AutoRequest feature, set the AUTOREQ register for the DMA channel associated for the endpoint.

33.2.7.2.4.1.1 Setup

Before initiating an Isochronous IN Transactions in Host mode:

- The target function address needs to be set in the RXFUNCADDR register for the selected controller endpoint (RXFUNCADDR register is available for all endpoints from EP0 to EP4).
- The HOST_RXTYPE register for the endpoint that is to be used needs to be programmed as:
  - Operating speed in the SPEED bit field (bits 7 and 6).
  - Set 01 (binary value) in the PROT field for isochronous transfer.
  - Endpoint Number of the target device in RENDPN field. This is the endpoint number contained in the Rx endpoint descriptor returned by the target device during enumeration.
- The RXMAXP register for the controller endpoint must be written with the maximum packet size (in bytes) for the transfer. This value should be the same as the wMaxPacketSize field of the Standard Endpoint Descriptor for the target endpoint.
- The HOST_RXINTERVAL register needs to be written with the required transaction interval (usually one transaction per frame/microframe).
- The relevant interrupt enable bit in the INTRRXE register should be set (if an interrupt is required for this endpoint).
- The following bits of HOST_RXCSR register should be set as:
  - Set the DMAEN bit (bit 13) to 1 if a DMA request is required for this endpoint.
  - Clear the DISNYET it (bit 12) to 0 to allow normal PING flow control. This will only affect High Speed transactions.
  - Always clear the DMAMODE bit (bit 11) to 0.
- If DMA is enabled, AUTOREQ register can be set for generating IN tokens automatically after receiving the data. Set the bit field RX*n*_AUTOREQ (where *n* is the endpoint number) with binary value 01 or 11.

33.2.7.2.4.1.2 Operation

The operation starts with the software setting REQPKT bit of HOST_RXCSR (bit 5). This causes the controller to send an IN token to the target.

When a packet is received, an interrupt is generated which the software may use to unload the packet from the FIFO and clear the RXPKTRDY bit in the HOST_RXCSR register (bit 0) in the same way as for a Bulk Rx endpoint. As the interrupt could occur almost any time within a frame(/microframe), the timing of FIFO unload requests will probably be irregular. If the data sink for the endpoint is going to some external hardware, it may be better to minimize the requirement for additional buffering by waiting until the end of each frame before unloading the FIFO. This can be done by using the SOF_PULSE signal from the controller to trigger the unloading of the data packet. The SOF_PULSE is generated once per frame(/microframe). The interrupts may still be used to clear the RXPKTRDY bit in HOST_RXCSR.

33.2.7.2.4.1.3 Error Handling

If a CRC or bit-stuff error occurs during the reception of a packet, the packet will still be stored in the FIFO but the DATAERR_NAKTIMEOUT bit of HOST_RXCSR (bit 3) is set to indicate that the data may be corrupt.

33.2.7.2.4.2 Isochronous OUT Transactions

An Isochronous OUT transaction may be used to transfer periodic data from the host to the USB peripheral.

Following optional features are available for use with a Tx endpoint used in Host mode to transmit this data:

- Double packet buffering: When enabled, up to two packets can be stored in the FIFO awaiting transmission to the peripheral device. Double packet buffering is enabled by setting the DPB bit of TXFIFOSZ register (bit 4).
- DMA: If DMA is enabled for the endpoint, a DMA request will be generated whenever the endpoint is able to accept another packet in its FIFO. This feature can be used to allow the DMA controller to load packets into the FIFO without processor intervention.

  However, this feature is not particularly useful with isochronous endpoints because the packets transferred are often not maximum packet size.

  When DMA is enabled and DMAMODE bit in HOST_TXCSR register is set, endpoint interrupt will not be generated for completion of packet reception. Endpoint interrupt will be generated only in the error conditions.

33.2.7.2.4.2.1 Setup

Before initiating any Isochronous OUT transactions:

- The target function address needs to be set in the TXFUNCADDR register for the selected controller endpoint (TXFUNCADDR register is available for all endpoints from EP0 to EP4).
- The HOST_TXTYPE register for the endpoint that is to be used needs to be programmed as:
  - Operating speed in the SPEED bit field (bits 7 and 6).
  - Set 01 (binary value) in the PROT field for isochronous transfer.
  - Endpoint Number of the target device in TENDPN field. This is the endpoint number contained in the OUT(Tx) endpoint descriptor returned by the target device during enumeration.
- The TXMAXP register for the controller endpoint must be written with the maximum packet size (in bytes) for the transfer. This value should be the same as the wMaxPacketSize field of the Standard Endpoint Descriptor for the target endpoint.
- The HOST_TXINTERVAL register needs to be written with the required transaction interval (usually one transaction per frame/microframe).
- The relevant interrupt enable bit in the INTRTXE register should be set (if an interrupt is required for this endpoint).
- The following bits of HOST_TXCSR register should be set as:
  - Set the MODE bit (bit 13) to 1 to ensure the FIFO is enabled (only necessary if the FIFO is shared with an Rx endpoint).
  - Set the DMAEN bit (bit 12) to 1 if a DMA request is required for this endpoint.
  - The FRCDATATOG bit (bit 12) is ignored for isochronous transactions.

– Set the DMAMODE bit (bit 10) to 1 when DMA is enabled.

33.2.7.2.4.2.2 Operation

The operation starts when the software writes to the FIFO and sets TXPKTRDY bit of HOST_TXCSR (bit 0). This triggers the controller to send an OUT token followed by the first data packet from the FIFO.

An interrupt is generated whenever a packet is sent and the software may use this interrupt to load the next packet into the FIFO and set the TXPKTRDY bit in the HOST_TXCSR register (bit 0) in the same way as for a Bulk Tx endpoint. As the interrupt could occur almost any time within a frame, depending on when the host has scheduled the transaction, this may result in irregular timing of FIFO load requests. If the data source for the endpoint is coming from some external hardware, it may be more convenient to wait until the end of each frame before loading the FIFO as this will minimize the requirement for additional buffering. This can be done by using the SOF_PULSE signal from the controller to trigger the loading of the next data packet. The SOF_PULSE is generated once per frame(/microframe). The interrupts may still be used to set the TXPKTRDY bit in HOST_TXCSR.

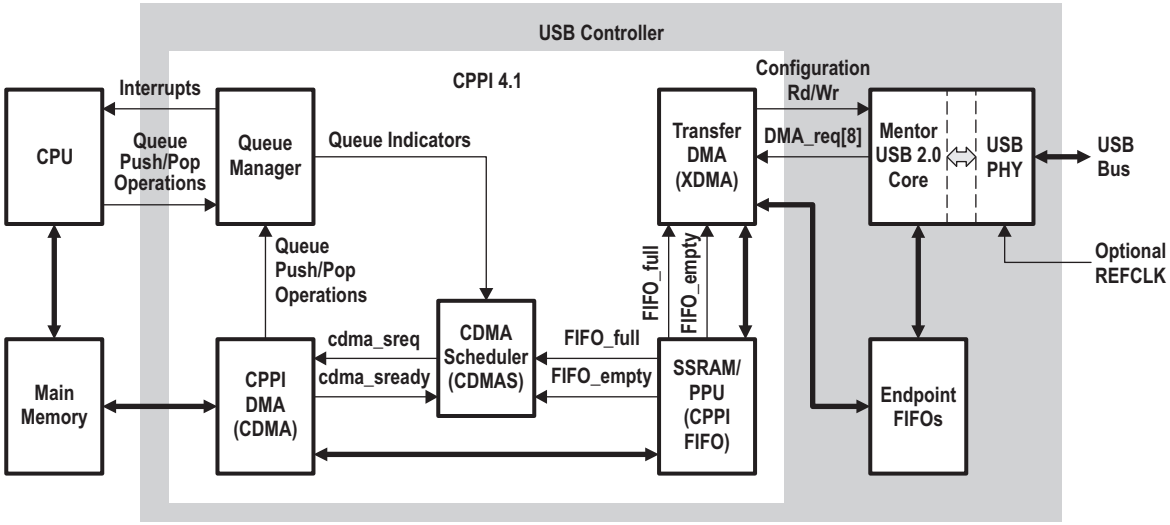
33.2.8 Communications Port Programming Interface (CPPI) 4.1 DMA Overview

The CPPI DMA module supports the transmission and reception of USB packets. The CPPI DMA is designed to facilitate the segmentation and reassembly of CPPI compliant packets to/from smaller data blocks that are natively compatible with the specific requirements of each networking port. Multiple Tx and Rx channels are provided within the DMA which allow multiple segmentation or reassembly operations to be effectively performed in parallel (but not actually simultaneously). The DMA controller maintains state information for each of the ports/channels which allows packet segmentation and reassembly operations to be time division multiplexed between channels in order to share the underlying DMA hardware. A DMA scheduler is used to control the ordering and rate at which this multiplexing occurs.

The CPPI (version 4.1) DMA controller sub-module is a common 4 dual-port DMA controller. It supports 4 Tx and 4 Rx Ports and each port attaches to the associated endpoint in the controller. Port 1 maps to endpoint 1 and Port 2 maps to endpoint 2 and Port 3 maps to endpoint 3 and Port 4 maps to endpoint 4, while endpoint 0 can not utilize the DMA and the firmware is responsible to load or offload the endpoint 0 FIFO via CPU.

Figure 33-15 displays the USB controller block diagram.

Figure 33-15. USB Controller Block Diagram



Host— The host is an intelligent system resource that configures and manages each communications control module. The host is responsible for allocating memory, initializing all data structures, and responding to port interrupts.

Main Memory— The area of data storage managed by the CPU. The CPPI DMA (CDMA) reads and writes CPPI packets from and to main memory. This memory can exist internal or external from the device.

Queue Manager (QM)— The QM is responsible for accelerating management of a variety of Packet Queues and Free Descriptor / Buffer Queues. It provides status indications to the CDMA Scheduler when queues are empty or full.

CPPI DMA (CDMA)— The CDMA is responsible for transferring data between the CPPI FIFO and Main Memory. It acquires free Buffer Descriptor from the QM (Receive Submit Queue) for storage of received data, posts received packets pointers to the Receive Completion Queue, transmits packets stored on the Transmit Submit Queue (Transmit Queue) , and posts completed transmit packets to the Transmit Completion Queue.

CDMA Scheduler (CDMAS)— The CDMAS is responsible for scheduling CDMA transmit and receive operations. It uses Queue Indicators from the QM and the CDMA to determine the types of operations to schedule.

CPPI FIFO— The CPPI FIFO provides 8 FIFO interfaces (one for each of the 4 transmit and receive endpoints). Each FIFO contains two 64-byte memory storage elements (ping-pong buffer storage).

Transfer DMA (XDMA)— The XDMA receives DMA requests from the Mentor USB 2.0 Core and initiates DMAs to the CPPI FIFO.

Endpoint FIFOs— The Endpoint FIFOs are the USB packet storage elements used by the Mentor USB 2.0 Core for packet transmission or reception. The XDMA transfers data between the CPPI FIFO and the Endpoint FIFOs for transmit operations and between the Endpoint FIFOs and the CPPI FIFO for receive operations.

Mentor USB 2.0 Core— This controller is responsible for processing USB bus transfers (control, bulk, interrupt, and isochronous). It supports 4 transmit and 4 receive endpoints in addition to endpoint 0 (control).

33.2.8.1 CPPI Terminology

The following terms are important in the discussion of DMA CPPI.

Port— A port is the communications module (peripheral hardware) that contains the control logic for Direct Memory Access for a single transmit/receive interface or set of interfaces. Each port may have multiple communication channels that transfer data using homogenous or heterogeneous protocols. A port is usually subdivided into transmit and receive pairs which are independent of each other. Each endpoint, excluding endpoint 0, has its own dedicated port.

Channel— A channel refers to the sub-division of information (flows) that is transported across ports. Each channel has associated state information. Channels are used to segregate information flows based on the protocol used, scheduling requirements (example: CBR, VBR, ABR), or concurrency requirements (that is, blocking avoidance). All four ports have dedicated single channels, channel 0, associated for their use in a USB application.

Data Buffer— A data buffer is a single data structure that contains payload information for transmission to or reception from a port. A data buffer is a byte aligned contiguous block of memory used to store packet payload data. A data buffer may hold any portion of a packet and may be linked together (via descriptors) with other buffers to form packets. Data buffers may be allocated anywhere within the 32-bit memory space. The Buffer Length field of the packet descriptor indicates the number of valid data bytes in the buffer. There may be from 1 to 4M-1 valid data bytes in each buffer.

Host Buffer Descriptor— A buffer descriptor is a single data structure that contains information about one or more data buffers. This type of descriptor is required when more than one descriptor is needed to define an entire packet, i.e., it either defines the middle of a packet or end of a packet.

Host Packet Descriptor— A packet descriptor is another name for the first buffer descriptor within a packet. Some fields within a data buffer descriptor are only valid when it is a packet descriptor including the tags, packet length, packet type, and flags. This type of descriptor is always used to define a packet since it provides packet level information that is useful to both the ports and the Host in order to properly process the packet. It is the only descriptor used when single descriptor solely defines a packet. When multiple descriptors are needed to define a packet, the packet descriptor is the first descriptor used to define a packet.

Free Descriptor/Buffer Queue— A free descriptor/buffer queue is a hardware managed list of available descriptors with pre-linked empty buffers that are to be used by the receive ports for host type descriptors. Free Descriptor/Buffer Queues are implemented by the Queue Manager.

Teardown Descriptor— Teardown Descriptor is a special structure which is not used to describe either a packet or a buffer but is instead used to describe the completion of a channel halt and teardown event. Channel teardown is an important function because it ensures that when a connection is no longer needed that the hardware can be reliably halted and any remaining packets which had not yet been transmitted can be reclaimed by the Host without the possibility of losing buffer or descriptor references (which results in a memory leak).

Packet Queue— A packet queue is hardware managed list of valid (i.e. populated) packet descriptors that is used for forwarding a packet from one entity to another for any number of purposes.

Queue Manager— The queue manager is a hardware module that is responsible for accelerating management of the packet queues. Packets are added to a packet queue by writing the 32-bit descriptor address to a particular memory mapped location in the Queue Manager module. Packets are de-queued by reading the same location for that particular queue. A single Queue Manager is used for a USB application.

NOTE: All descriptors (regardless of type) must be allocated at addresses that are naturally aligned to the smallest power of 2 that is equal to or greater than the descriptor size.

33.2.8.2 Host Packet Descriptor (SOP Descriptor)

Host Packet Descriptors are designed to be used when USB like application requires support for true, unlimited fragment count scatter/gather type operations. The Host Packet Descriptor is the first descriptor on multiple descriptors setup or the only descriptor in a single descriptors setup. The Host Packet Descriptor contains the following information:

- Indicator which identifies the descriptor as a Host Packet Descriptor (always 10h)
- Source and Destination Tags (Reserved)
- Packet Type
- Packet Length
- Protocol Specific Region Size
- Protocol Specific Control/Status Bits
- Pointer to the first valid byte in the SOP data buffer
- Length of the SOP data buffer
- Pointer to the next buffer descriptor in the packet

Host Packet Descriptors can vary in size of their defined fields from 32 bytes up to 104 bytes. Within this range, Host Packet Descriptors always contain 32 bytes of required information and may also contain 8 bytes of software specific tagging information and up to 64 bytes (indicated in 4 byte increments) of protocol specific information. How much protocol specific information (and therefore the allocated size of the descriptors) is application dependent.

The Host Packet Descriptor layout is shown in Figure 33-16 and described in Table 33-8 to Table 33-15.

Figure 33-16. Host Packet Descriptor Layout

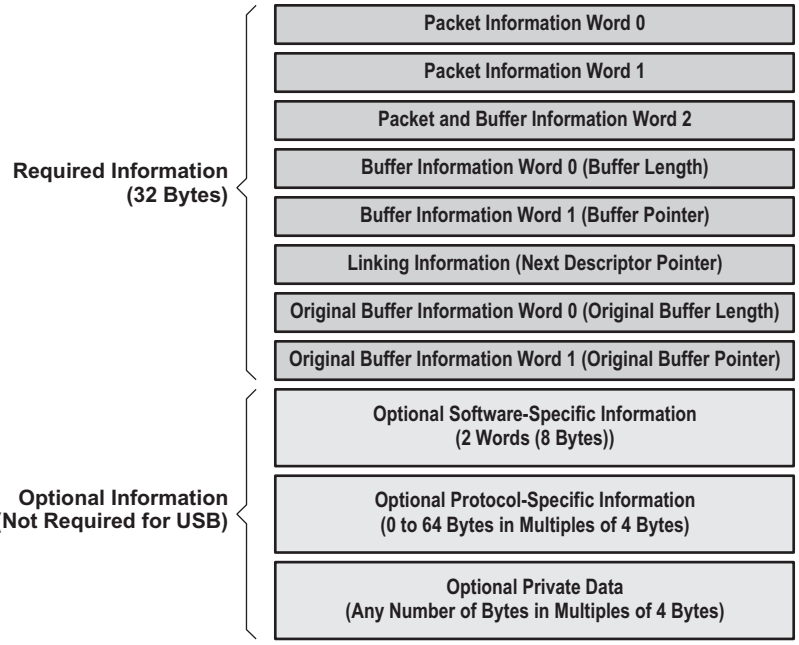


Table 33-8. Host Packet Descriptor Word 0 (HPD Word 0)

Bits	Name	Description
31-27	Descriptor Type	The Host Packet Descriptor Type is 16 decimal (10h). The CPU initializes this field.
26-22	Protocol Specific Valid Word Count	This field indicates the valid numberof 32-bit words in the protocol specific region. The CPU initializes this field. This is encoded in increments of 4 bytes as: 0 = 0 byte 1 = 4 bytes ... 16 = 64 bytes 17-31 = Reserved
21-0	Packet Length	The length of the packet in bytes. If the Packet Length is less than the sum of the buffer lengths, then the packet data will be truncated. A Packet Length greater than the sum of the buffers is an error. The valid range for the packet length is 0 to (4M - 1) bytes. The CPU initializes this field for transmitted packets; the DMA overwrites this field on packet reception.

Table 33-9. Host Packet Descriptor Word 1 (HPD Word 1)

Bits	Name	Description
31-27	Source Tag: Port #	This field indicates the port number (0-31) from which the packet originated. The DMA overwrites this field on packet reception. This is the RX Endpoint number from which the packet originated.
26-21	Source Tag: Channel #	This field indicates the channel number within the port from which the packet originated. The DMA overwrites this field on packet reception. This field is always 0-67.
20-16	Source Tag: Sub-channel #	This field indicates the sub-channel number (0-31) within the channel from which the packet originated. The DMA overwrites this field on packet reception. This field is always 0.
15-0	Destination Tag	This field is application specific. This field is always 0.

Table 33-10. Host Packet Descriptor Word 2 (HPD Word 2)

Bits	Name	Description
31	Packet Error	This bit indicates if an error occurred during reception of this packet (0 = No error occurred, 1 = Error occurred). The DMA overwrites this field on packet reception. Additional information about different errors may be encoded in the protocol specific fields in the descriptor.
30-26	Packet Type	This field indicates the type of this packet. The CPU initializes this field for transmitted packets; the DMA overwrites this field on packet reception. This field is encoded as: 5 = USB 8-31 = Reserved
25-20	Reserved	Reserved
19	Zero-length packet indicator	If a zero-length USB packet is received, the XDMA will send the CDMA a data block with a byte count of 0 and this bit is set. The CDMA will then perform normal EOP termination of the packet without transferring data. For transmit, if a packet has this bit set, the XDMA will ignore the CPPI packet size and send a zero-length packet to the USB controller.
18-16	Protocol Specific	This field contains protocol specific flags/information that can be assigned based on the packet type. Not used for USB.
15	Return Policy	This field indicates the return policy for this packet. The CPU initializes this field. 0 = Entire packet (still linked together) should be returned to the queue specified in bits 13-0. 1 = Each buffer should be returned to the queue specified in bits 13-0 of Word 2 in their respective descriptors. The Tx DMA will return each buffer in sequence.
14	On-chip	This field indicates whether or not this descriptor is in a region which is in on-chip memory space (1) or in external memory (0).
13-12	Packet Return Queue Mgr #	This field indicates which queue manager in the system the descriptor is to be returned to after transmission is complete. This field is not altered by the DMA during transmission or reception and is initialized by the CPU. There is only 1 Queue Manager in the USB HS/FS Device Controller, this field must always be 0.
11-0	Packet Return Queue #	This field indicates the queue number within the selected queue manager that the descriptor is to be returned to after transmission is complete. This field is not altered by the DMA during transmission or reception and is initialized by the CPU.

Table 33-11. Host Packet Descriptor Word 3 (HPD Word 3)

Bits	Name	Description
31-22	Reserved	Reserved
21-0	Buffer 0 Length	The Buffer Length field indicates how many valid data bytes are in the buffer. The CPU initializes this field for transmitted packets; the DMA overwrites this field on packet reception.

Table 33-12. Host Packet Descriptor Word 4 (HPD Word 4)

Bits	Name	Description
31-0	Buffer 0 Pointer	The Buffer Pointer is the byte aligned memory address of the buffer associated with the buffer descriptor. The CPU initializes this field for transmitted packets; the DMA overwrites this field on packet reception.

Table 33-13. Host Packet Descriptor Word 5 (HPD Word 5)

Bits	Name	Description
31-0	Next Descriptor Pointer	The 32-bit word aligned memory address of the next buffer descriptor in the packet. If the value of this pointer is zero, then the current buffer is the last buffer in the packet. The CPU initializes this field for transmitted packets; the DMA overwrites this field on packet reception.

Table 33-14. Host Packet Descriptor Word 6 (HPD Word 6)

Bits	Name	Description
31-22	Reserved	Reserved
21-0	Original Buffer 0 Length	The Buffer Length field indicates the original size of the buffer in bytes. This value is not overwritten during reception. This value is read by the Rx DMA to determine the actual buffer size as allocated by the CPU at initialization. Since the buffer length in Word 3 is overwritten by the Rx port during reception, this field is necessary to permanently store the buffer size information.

Table 33-15. Host Packet Descriptor Word 7 (HPD Word 7)

Bits	Name	Description
31-22	Reserved	Reserved
21-0	Original Buffer 0 Pointer	The Buffer Pointer is the byte aligned memory address of the buffer associated with the buffer descriptor. This value is not overwritten during reception. This value is read by the Rx DMA to determine the actual buffer location as allocated by the CPU at initialization. Since the buffer pointer in Word 4 is overwritten by the Rx port during reception, this field is necessary to permanently store the buffer pointer information.

33.2.8.3 Host Buffer Descriptor (Non-SOP Descriptor)

The Host Buffer Descriptor is identical in size and organization to a Host Packet Descriptor but does not include valid information in the packet level fields and does not include a populated region for protocol specific information. The packet level fields is not needed since the SOP descriptor contain this information and additional copy of this data is not needed/necessary.

Host Buffer Descriptors are designed to be linked onto a Host Packet Descriptor or another Host Buffer Descriptor to provide support for unlimited scatter / gather type operations. Host Buffer Descriptors provide information about a single corresponding data buffer. Every Host buffer descriptor stores the following information:

- Pointer to the first valid byte in the data buffer
- Length of the data buffer
- Pointer to the next buffer descriptor in the packet

Host Buffer Descriptors always contain 32 bytes of required information. Since it is a requirement that it is possible to convert a Host descriptor between a Buffer Descriptor and a Packet Descriptor (by filling in the appropriate fields) in practice, Host Buffer Descriptors will be allocated using the same sizes as Host Packet Descriptors. In addition, since the 5 LSBs of the Descriptor Pointers are used in CPPI 4.1 for the purpose of indicating the length of the descriptor, the minimum size of a descriptor is always 32 bytes. (For more information on Descriptor Size, see Section 33.4.87).

The Host Buffer Descriptor layout is shown in Figure 33-17 and described in Table 33-16 to Table 33-23.

Figure 33-17. Host Buffer Descriptor Layout

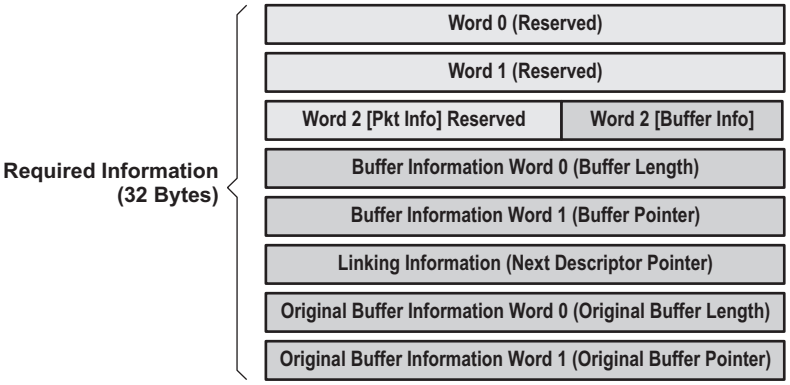


Table 33-16. Host Buffer Descriptor Word 0 (HBD Word 0)

Bits	Name	Description
31-0	Reserved	Reserved

Table 33-17. Host Buffer Descriptor Word 1 (HBD Word 1)

Bits	Name	Description
31-0	Reserved	Reserved

Table 33-18. Host Buffer Descriptor Word 2 (HBD Word 2)

Bits	Name	Description
31-15	Reserved	Reserved
14	On-chip	This field indicates whether or not this descriptor is in a region which is in on-chip memory space (1) or in external memory (0).
13-12	Packet Return Queue Mgr #	This field indicates which queue manager in the system the descriptor is to be returned to after transmission is complete. This field is not altered by the DMA during transmission or reception and is initialized by the CPU. There is only 1 Queue Manager in the USB HS/FS Device Controller, this field must always be 0.
11-0	Packet Return Queue #	This field indicates the queue number within the selected queue manager that the descriptor is to be returned to after transmission is complete. This field is not altered by the DMA during transmission or reception and is initialized by the CPU.

Table 33-19. Host Buffer Descriptor Word 3 (HBD Word 3)

Bits	Name	Description
31-22	Reserved	Reserved
21-0	Buffer 0 Length	The Buffer Length field indicates how many valid data bytes are in the buffer. The CPU initializes this field for transmitted packets; the DMA overwrites this field on packet reception.

Table 33-20. Host Buffer Descriptor Word 4 (HBD Word 4)

Bits	Name	Description
31-0	Buffer 0 Pointer	The Buffer Pointer is the byte aligned memory address of the buffer associated with the buffer descriptor. The CPU initializes this field for transmitted packets; the DMA overwrites this field on packet reception.

Table 33-21. Host Buffer Descriptor Word 5 (HBD Word 5)

Bits	Name	Description
31-0	Next Descriptor Pointer	The 32-bit word aligned memory address of the next buffer descriptor in the packet. If the value of this pointer is zero, then the current descriptor is the last descriptor in the packet. The CPU initializes this field for transmitted packets; the DMA overwrites this field on packet reception.

Table 33-22. Host Buffer Descriptor Word 6 (HBD Word 6)

Bits	Name	Description
31-22	Reserved	Reserved
21-0	Original Buffer 0 Length	The Buffer Length field indicates the original size of the buffer in bytes. This value is not overwritten during reception. This value is read by the Rx DMA to determine the actual buffer size as allocated by the CPU at initialization. Since the buffer length in Word 3 is overwritten by the Rx port during reception, this field is necessary to permanently store the buffer size information.

Table 33-23. Host Buffer Descriptor Word 7 (HBD Word 7)

Bits	Name	Description
31-0	Original Buffer 0 Pointer	The Buffer Pointer is the byte aligned memory address of the buffer associated with the buffer descriptor. This value is not overwritten during reception. This value is read by the Rx DMA to determine the actual buffer location as allocated by the CPU at initialization. Since the buffer pointer in Word 4 is overwritten by the Rx port during reception, this field is necessary to permanently store the buffer pointer information.

33.2.8.4 Teardown Descriptor

The Teardown Descriptor is not like the Host Packet or Buffer Descriptors since it is not used to describe either a packet or a buffer. The Teardown Descriptor is always 32 bytes long and is comprised of 4 bytes of actual teardown information and 28 bytes of pad. The Teardown Descriptor layout is shown in Figure 33-18 and described in Table 33-24 and Table 33-25. Since the 5 LSBs of the Descriptor Pointers are used in CPPI 4.1 for the purpose of indicating the length of the descriptor, the minimum size of a descriptor is 32 bytes.

The Teardown Descriptor is used to describe a channel halt and teardown event. Channel teardown ensures that when a connection is no longer needed that the hardware can be reliably halted and any remaining packets which had not yet been transmitted can be reclaimed by the Host without the possibility of losing buffer or descriptor references (which results in a memory leak).

The Teardown Descriptor contains the following information:

- Indicator which identifies the descriptor as a Teardown Packet Descriptor
- DMA Controller Number where teardown occurred
- Channel number within DMA where teardown occurred
- Indicator of whether this teardown was for the Tx or Rx channel

Figure 33-18. Teardown Descriptor Layout

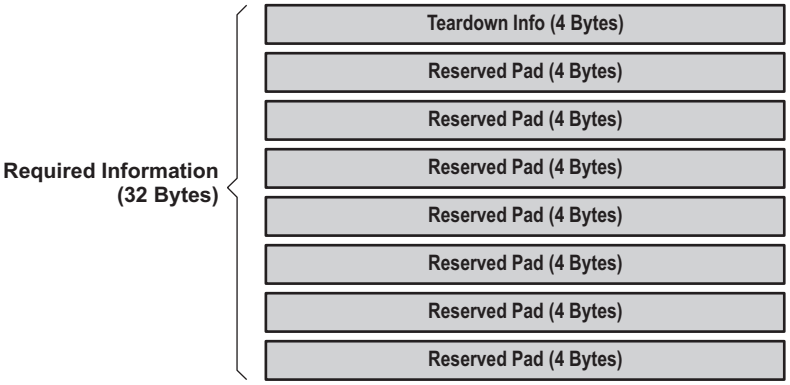


Table 33-24. Teardown Descriptor Word 0

Bits	Name	Description
31-27	Descriptor Type	The teardown descriptor type is 19 decimal (13h).
26-17	Reserved	Reserved
16	TX_RX	Indicates whether teardown is a TX (0) or RX (1).
15-10	DMA Number	Indicates the DMA number for this teardown.
9-6	Reserved	Reserved
5-0	Channel Number	Indicates the channel number within the DMA that was torn down.

Table 33-25. Teardown Descriptor Words 1-7

Bits	Name	Description
31-0	Reserved	Reserved

Teardown operation of an endpoint requires three operations. The teardown register in the CPPI DMA must be written, the corresponding endpoint bit in TEARDOWN of the USB module must be set, and the FlushFIFO bit in the Mentor USB controller Tx/RxCSR register must be set.

The following is the Transmit teardown procedure highlighting the steps required to be followed.

1. Set the TX_TEARDOWN bit in the CPPI DMA TX channel *n* global configuration register (TXGCR*n*).
2. Set the appropriate TX_TDOWN bit in the USBOTG controller's USB teardown register (TEARDOWN). Write Tx Endpoint Number to teardown to TEARDOWN[TX_TDOWN] fileld.
3. Check if the teardown descriptor has been received on the teardown queue: The completion queue (Queues 24 or 25) is usually used as the Teardown queue when the Teardown descriptor has been received, the descriptor address will be loaded onto CTRLD[24/25] register:
   (a) If not, go to step 2.
   (b) If so, go to step 4.
4. Set the appropriate TX_TDOWN bit in the USBOTG controller's USB teardown register (TEARDOWN). Set the bit corresponding to the Channel Number within TEARDOWN[TX_TDOWN] field.
5. Flush the TX FIFO in the Mentor OTG core: Set PERI_TXCSR[FLUSHFIFO] for the corresponding Endpoint.

6. Re-enable the Tx DMA channel:
   (a) Clear TXGCR*n*[TX_TEARDOWN and TX_ENABLE] bit.
   (b) Set TXGCR*n*[TX_ENABLE] bit.

33.2.8.5 Queues

Several types of queues exist (a total of 64 queues) within the CPPI 4.1 DMA. Regardless of the type of queue a queue is, queues are used to hold pointers to host or buffer packet descriptors while they are being passed between the Host and / or any of the ports in the system. All queues are maintained within the Queue Manager module.

The following type of Queues exist:

- Receive Free Descriptor/Buffer Queue
- Receive Completion (Return) Queue
- Transmit Submit Queue (also referred as Transmit Queue)
- Transmit Completion (Return) Queue
- Free Descriptor Queue (Unassigned: Can be used for Completion or Application Specific purposes)

Table 33-26 displays the allocation (partition) of the available Queues.

Table 33-26. Allocation of Queues

Starting Queue Number	Number of Queues	Function
0	16	RX + Free Descriptor/Buffer (submit) queues
16	2	USB Endpoint 1 TX (submit) queues
18	2	USB Endpoint 2 TX (submit) queues
20	2	USB Endpoint 3 TX (submit) queues
22	2	USB Endpoint 4 TX (submit) queues
24	2	TX Completion (return) queues
26	2	RX Completion (return) queues
28	36	Unassigned (application-defined) queues

33.2.8.5.1 Queuing Packets

Prior to queuing packets, the host/firmware should construct data buffer as well host packet/buffer descriptors within memory that is external to the CPPI 4.1 DMA module.

Queuing of packets onto a packet queue is accomplished by writing a pointer to the Packet Descriptor into a specific address within the selected queue (Register D of Queue N). Packet is always queued onto the tail of the queue. The Queue Manager provides a unique set of addresses for adding packets for each queue that it manages.

33.2.8.5.2 De-Queuing Packets

De-queuing of packets from a packet queue is accomplished by reading the head packet pointer from a specific address within the selected queue (Register D of Queue N). After the head pointer has been read, the Queue Manager will invalidate the head pointer and will replace it with the next packet pointer in the queue. This functionality which is implemented in the Queue Manager prevents the ports from needing to traverse linked lists and allows for certain optimizations to be performed within the Queue Manager.

33.2.8.5.3 Type of Queues

Several types of queues exist and all are managed by the Queue Manager which is part of the CPPI 4.1 DMA. All accesses to the queues are through memory mapped registers and no external memory setup is required by the firmware.

33.2.8.5.3.1 Receive Free Descriptor/Buffer (Submit) Queue

Receive ports use queues referred to as "receive free descriptor / buffer queues" to forward completed receive packets to the host or another peer port entity. The entries on the Free Descriptor / Buffer Queues have pre-attached empty buffers whose size and location are described in the "original buffer information" fields in the descriptor. The host is required to allocate both the descriptor and buffer and pre-link them prior to adding (submitting) a descriptor to one of the available receive free descriptor / buffer queue. The first 16 queues (Queue 0 up to Queue 15) are reserved for all four receive ports to handle incoming packets.

33.2.8.5.3.2 Transmit (Submit) Queue

Transmit ports use packet queues referred to as "transmit (submit) queues" to store the packets that are waiting to be transmitted. Each port has dedicated queues (2 queues per port) that are reserved exclusively for a use by a single port. Multiple queues per port/channel are allocated to facilitate Quality of Service (QoS) for applications that require QoS. Queue 16 and 17 are allocated for port 1, Queue 18 and 19 are allocated for port 2 and Queue 20 and Queue 21 are allocated for port 3 and Queue 22 and 23 are allocated for port 4.

33.2.8.5.3.3 Transmit Completion Queue

Transmit ports also use packet queues referred to as "transmit completion queues" to return packets to the host after they have been transmitted. Even though, non-allocated queues can be used for this purpose, a total of two dedicated queues (Queue 24 and Queue 25), that is to be shared amongst all four transmit ports, have been reserved for returning transmit packets after end of transmit operation when the firmware desires to receive interrupt when transmission completes.

33.2.8.5.3.4 Receive Completion Queue

Receive ports also use packet queues referred to as "receive completion queues" to return packets to the port after they have been received. Even though, non-allocated queues can be used for this purpose, a total of two dedicated queues (Queue 26 and Queue 27), that is to be shared amongst all four transmit ports, have been reserved for returning received packets to the receive ports after end of receive operation when the firmware desires to receive interrupt when transmission completes.

33.2.8.5.3.5 Unassigned (Application Defined) Queue

Thirty-six additional queues (Queue 28 to Queue 63) exist that have not been dedicated for exclusive use. The user can use these queues as a Completion Queues or Free Descriptor/Buffer queue.

When these queues are used as Completion Queues, interrupt will not be generated. However, the queues will have the list of descriptor pointers for the packets that have completed transmission or reception. The firmware can use polling method by continually performing the de-queuing technique onto the particular unassigned queue used to identify if the reception or transmission has completed.

When unassigned queues are used as free descriptor/buffer queue, the user can use these queues to queue/store available descriptors for future receive and transmit operations by the firmware popping the respective assigned queue and retrieving and populating descriptor prior to submitting the updated descriptor.

33.2.8.5.3.6 Teardown Queue

The Teardown Queue is used by the DMA to communicate a completion of a channel teardown after a channel teardown is invoked on to a channel. The pointer to the teardown descriptor is written to the teardown queue, which is also the Completion Queue, when the channel teardown completes.

33.2.8.5.3.7 Diverting Queue Packets from one Queue to Another

The host can move the entire contents of one queue to another queue by writing the source queue number and the destination queue number to the Queue Diversion Register. When diverting packets, the host can choose whether the source queue contents should be pushed onto the tail of the destination queue.

33.2.8.6 Memory Regions and Linking RAM

In addition to allocating memory for raw data, the host is responsible for allocating additional memory for exclusive use of the CPPI DMA Queue Manager to be used as a scratch PAD RAM. The Queue Manager uses this memory to manage states of Descriptors submitted within the submit queues. In other words, this memory needs not to be managed by your software and your software responsibility is only for allocation of memory. The allocated memory can be a single block of memory that is contiguous or two blocks of memory that are not contiguous. These two blocks of memory are referred as a Linking RAM Regions and should not be confused with Memory Regions that are used to store Descriptors and the use of the term Region should be used in the context of its use.

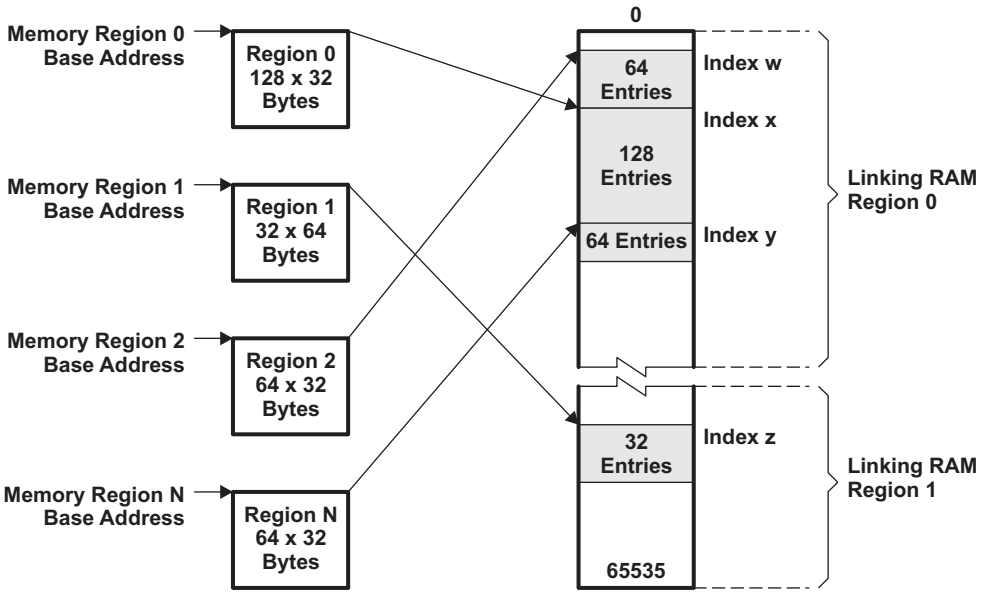
The physical size of the Linking RAM region(s) to be allocated depends on the total number of Descriptors defined within all memory regions. A minimum of four bytes of memory needs to be allocated for each Descriptor defined within all 16 Memory Regions.

The Queue Manager has the capability of managing up to 16 Memory Regions. These Memory Regions are used to store descriptors of variable sizes. The total number of Descriptors that can be managed by the Queue Manager should not exceed 16K. Each Memory Region has Descriptors of one configurable size, that is, Descriptors with different sizes cannot be housed within a single Memory Region. These 16K Descriptors are referenced internally in the Queue Manager by a 16-bit quantity index.

The information about the Linking RAM regions and the size that are allocated is communicated to the CPPI DMA via three registers dedicated for this purpose. Two of the three registers are used to store the 32-bit aligned start addresses of the Linking RAM regions. The remaining one register is used to store the size of the first Linking RAM. The size value stored here is the number of Descriptors that is to be managed by the Queue Manager within that region not the physical size of the buffer, which is four times the number of descriptors.

Note that you are not required to use both Linking RAM Regions, if the size of the Linking RAM for the first Region is large enough to accommodate all Descriptors defined. No Linking RAM size register for Linking RAM Region 2 exists. The size of the second Linking RAM, when used, is indirectly computed from the total number of Descriptors defined less the number of Descriptors managed by the first Linking RAM.

Figure 33-19. Relationship Between Memory Regions and Linking RAM



33.2.8.7 Zero Length Packets

A special case is the handling of null packets with the CPPI 4.1 compliant DMA controller. Upon receiving a zero length USB packet, the XFER DMA will send a data block to the DMA controller with byte count of zero and the zero byte packet bit of INFO Word 2 set. The DMA controller will then perform normal End of Packet termination of the packet, without transferring data.

If a zero-length USB packet is received, the XDMA will send the CDMA a data block with a byte count of 0 and this bit set. The CDMA will then perform normal EOP termination of the packet without transferring data. For transmit, if a packet has this bit set, the XDMA will ignore the CPPI packet size and send a zero-length packet to the USB controller.

33.2.8.8 CPPI DMA Scheduler

The CPPI DMA scheduler is responsible for controlling the rate and order between the different Tx and Rx threads that are provided in the CPPI DMA controller. The scheduler table RAM exists within the scheduler.

33.2.8.8.1 CPPI DMA Scheduler Initialization

Before the scheduler can be used, the host is required to initialize and enable the block. This initialization is performed as follows:

1. The Host initializes entries within an internal memory array in the scheduler. This array contains up to 256 entries (4 entries per table word *n*) and each entry consists of a DMA channel number and a bit indicating if this is a Tx or Rx opportunity. These entries represent both the order and frequency that various Tx and Rx channels will be processed. A table size of 256 entries allows channel bandwidth to be allocated with a maximum precision of 1/256th of the total DMA bandwidth. The more entries that are present for a given channel, the bigger the slice of the bandwidth that channel will be given. Larger tables can be accommodated to allow for more precision. This array can only be written by the Host, it cannot be read.
2. If the application does not need to use the entire 256 entries, firmware can initialize the portion of the 256 entries and indicate the size of the entries used by writing onto an internal register in the scheduler which sets the actual size of the array (it can be less than 256 entries).
3. The host writes an internal register bit to enable the scheduler. The scheduler is not required to be disabled in order to change the scheduler array contents.

33.2.8.8.2 Example of Scheduler Programming

Consider a three endpoints use on a system with the following configurations: EP1-Tx, EP2-Rx, and EP2-Tx. Two assumptions are considered:

Case 1: Assume that you would like to service each enabled endpoints (EP1-Tx, EP2-Rx, and EP2-Tx) with equal priority.

The scheduler handles the rate at which an endpoint is serviced by the number of credits programmed (entries) for that particular endpoint within the scheduler Table Words. The scheduler has up to 256 credits that it can grant and for this example the number of entries/credits could be anywhere from 3 to 256. However, the optimum and direct programming for this scenario would be programming only the first three entries of the scheduler via scheduler Table WORD[0]. Since this case expects the Scheduler to use only the first three entries, you communicate that by programming DMA_SCHED_CTRL.LAST_ENTRY with 2 (that is, 3 - 1). The Enabled Endpoint numbers and the data transfer direction is then communicated by programming the first three entries of WORD[0] (ENTRY0_CHANNEL = 1: ENTRY0_RXTX = 0; ENTRY1_CHANNEL = 2: ENTRY1_RXTX = 1;ENTRY2_CHANNEL = 2: ENTRY2_RXTX = 0). With this programming, the Scheduler will only service the first three entries in a round-robin fashion, checking each credited endpoint for transfer one after the other, and servicing the endpoint that has data to transfer.

Case 2: Enabled endpoint EP1-Tx is serviced at twice the rate as the other enabled endpoints (EP2-Rx and EP2-Tx).

The number of entries/credit that has to be awarded to EP1-Tx has to be twice as much of the others. Since only four entries/credits are required, two for EP1-Tx, one for EP2-Rx, and one for EP2-Tx, the use of scheduler Table WORD[0] would still suffice. Even though several scenarios exist to programming the order of service for this case, one scenario would be to allow EP1-Tx to be serviced back-to-back followed by the other enabled endpoints. Program DMA_SCHED_CTRL.LAST_ENTRY with 3 (that is, 4 - 1). Program WORD[0] (ENTRY0_CHANNEL = 1: ENTRY0_RXTX = 0; ENTRY1_CHANNEL = 1: ENTRY1_RXTX = 0; ENTRY2_CHANNEL = 2: ENTRY2_RXTX = 1; ENTRY3_CHANNEL = 2: ENTRY3_RXTX = 0).

33.2.8.8.3 Scheduler Operation

Once the scheduler is enabled it will begin processing the entries in the table and when appropriate passing credits to the DMA controller to perform a Tx or Rx operation. The operation of the DMA controller is as follows:

1. After the DMA scheduler is enabled it begins with the table index set to 0.
2. The scheduler reads the entry pointed to by the index and checks to see if the channel in question is currently in a state where a DMA operation can be accepted. The following must both be true:
   - The DMA channel must be enabled.
   - The CPPI FIFO that the channel talks to has free space on TX (FIFO full signal is not asserted) or a valid block on Rx (FIFO empty signal is not asserted).
3. If the DMA channel is capable of processing a credit to transfer a block, the DMA scheduler will issue that credit via the DMA scheduling interface. These are the steps:
   (a) The DMA controller may not be ready to accept the credit immediately and is provided a sched_ready signal which is used to stall the scheduler until it can accept the credit. The DMA controller only asserts the sched_ready signal when it is in the IDLE state.
   (b) Once a credit has been accepted (indicated by sched_req and sched_ready both asserted), the scheduler will increment the index to the next entry and will start at step 2.
4. If the channel in question is not currently capable of processing a credit, the scheduler will increment the index in the scheduler table to the next entry and will start at step 2.
5. When the scheduler attempts to increment its index to the value programmed in the table size register, the index will reset to 0.

33.2.8.9 CPPI DMA Transfer Interrupt Handling

The CPPI DMA 4.1 Interrupt handling mechanism does not go through the PDR interrupt handler built into the core. The DMA interrupt line is directly routed to the Interrupt Dispatcher in a PDR compliant manner. The DMA interrupt is not maskable. The firmware needs to use queues reserved by hardware as Completion Queues, if required for the DMA interrupt to be generated on a completion of a transfer.

Queues 24 and 25 are reserved by hardware for DMA transmit operations and queues 26 and 27 are reserved by hardware for DMA receive operations. If firmware uses these queues as Completion Queues, an interrupt will be generated when the transfer completes. If you need not to generate an interrupt, firmware is required to use queues that are not reserved as Completion Queues.

33.2.8.10 DMA State Registers

The port must store and maintain state information for each transmit and receive port/channel. The state information is referred to as the Tx DMA State and Rx DMA State.

33.2.8.10.1 Transmit DMA State Registers

The Tx DMA State is a combination of control fields and protocol specific port scratchpad space used to manipulate data structures and transmit packets. Each transmit channel has two queues. Each queue has a one head descriptor pointer and one completion pointer. There are four Tx DMA State registers; one for each port/channel.

The following information is stored in the Tx DMA State:

- Tx Queue Head Descriptor Pointer(s)
- Tx Completion Pointer(s)
- Protocol specific control/status (port scratchpad)

33.2.8.10.2 Receive DMA State Registers

The Rx DMA State is a combination of control fields and protocol specific port scratchpad space used to manipulate data structures in order to receive packets. Each receive channel has only one queue. Each channel queue has one head descriptor pointer and one completion pointer. There are four Rx DMA State registers; one for each port/channel.

The following information is stored in the Rx DMA State:

- Rx Queue Head Descriptor Pointer
- Rx Queue Completion Pointer
- Rx Buffer Offset

33.2.8.11 USB DMA Protocols Supported

Four different type of DMA transfers are supported by the CPPI 4.1 DMA; Transparent, RNDIS, Generic RNDIS, and Linux CDC. The following sections will outline the details on these DMA transfer types.

33.2.8.11.1 Transparent DMA

Transparent Mode DMA operation is the default DMA mode where DMA interrupt is generated whenever a DMA packet is transferred. In the transparent mode, DMA packet size cannot be greater than USB MaxPktSize for the endpoint. This transfer type is ideal for transfer (not packet) sizes that are less than a max packet size.

Transparent DMA Transfer Setup

The following will configure all four ports/channels for Transparent DMA Transfer type.

- Make sure that RNDIS Mode is disabled globally. RNDIS bit in the control register (CTRLR) is cleared to 0.
- Configure the DMA Mode Register (MODE) for the Endpoint field in use is programmed for Transparent Mode. MODE = 0000 0000h

33.2.8.11.2 RNDIS

RNDIS mode DMA is used for large transfers (i.e., total data size to be transferred is greater than USB MaxPktSize where the MzxPktSize is a multiple of 64 bytes) that requires multiple USB packets. This is accomplished by breaking the larger packet into smaller packets, where each packet size being USB MaxPktSize except the last packet where its size is less than USB MaxPktSize, including zero bytes. This implies that multiple USB packets of MaxPktSize will be received and transferred together as a single large DMA transfer and the DMA interrupt is generated only at the end of the complete reception of DMA transfer. The protocol defines the end of the complete transfer by receiving a short USB packet (smaller than USB MaxPktSize as mentioned in USB specification 2.0). If the DMA packet size is an exact multiple of USB MaxPktSize, the DMA controller waits for a zero byte packet at the end of complete transfer to signify the completion of the transfer.

NOTE: RNDIS Mode DMA is supported only when USB MaxPktSize is an integral multiple of 64 bytes.

RNDIS DMA Transfer Setup

The following will configure all four ports/channels for RNDIS DMA Transfer type. If all endpoints are to be configured with the same RNDIS DMA transfer type, then you can enable for RNDIS mode support from the Control Register and the content of the Mode Register will be ignored.

If you need to enable RNDIS support globally.

- Enable RNDIS Mode globally. RNDIS bit in the control register (CTRLR) is set to 1.

If you need to enable RNDIS support at the port/channel (endpoint) level.

- Disable RNDIS Mode globally. RNDIS bit in the control register (CTRLR) is cleared to 0.
- Configure the DMA Mode Register (MODE) for the Endpoint field in use is programmed for RNDIS Mode. MODE = 1111 1111h

The above two setups yield the same result.

33.2.8.11.3 Generic RNDIS

Generic RNDIS DMA transfer mode is identical to the normal RNDIS mode in nearly all respects, except for the exception case where the last packet of the transfer can either be a short packet or the MaxPktSize. Generic RNDIS transfer makes use of a RNDIS EP Size register (there exists a register for each endpoint) that must be programmed with a value that is an integer multiple of the endpoint size for the DMA to know the end of the transfer when the last packet size is equal to the USB MaxPktSize. For example, it the Tx/RxMaxP is programmed with a value of 64, the Generic RNDIS EP Size register for that endpoint must be programmed with a value that is an integer multiple of 64 (for example, 64, 128, 192, 256, etc.).

In other words, when using Generic RNDIS mode and the DMA is tasked to transfer data transfer size that is less than a value programmed within the RNDIS EP Size register and this transfer will be resulting with a short packet, the DMA will terminate the transfer when encountering the short packet behaving exactly as the RNDIS DMA transfer type.

This means that Generic RNDIS mode will perform data transfer in the same manner as RNDIS mode, closing the CPPI packet when a USB packet is received that is less than the USB MaxPktSize size. Otherwise, the packet will be closed when the value in the Generic RNDIS EP Size register is reached.

Using RNDIS EP Size register, a packet of up to 64K bytes can be transferred. This is to allow the host software to program the USB module to transfer data that is an exact multiple of the USB MaxPktSize (Tx/RxMaxP programmed value) without having to send an additional short packet to terminate.

NOTE: As in RNDIS mode, the USB max packet size of any Generic RNDIS mode enabled endpoints must be a multiple of 64 bytes. Generic RNDIS acceleration should not be enabled for endpoints where the max packet size is not a multiple of 64 bytes. Only transparent mode should be used for such endpoints.

Generic RNDIS DMA Transfer Setup

The following will configure all four ports/channels for Generic RNDIS DMA Transfer type.

- Disable RNDIS Mode globally. RNDIS bit in the control register (CTRLR) is cleared to 0.
- Configure the DMA Mode Register (MODE) for the Endpoint field in use is programmed for Generic RNDIS Mode. MODE = 3333 3333h

33.2.8.11.4 Linux CDC

Linux CDC DMA transfer mode acts in the same manner as RNDIS packets, except for the case where the last data matches the max USB packet size. If the last data packet of a transfer is a short packet where the data size is greater than zero and less the USB MaxPktSize, then the behavior of the Linux CDC DMA transfer type is identical with the RNDIS DMA transfer type. The only exception is when the short packet length terminating the transfer is a Null Packet. In this case, instead of transferring the Null Packet, it will transfer a data packet of size 1 byte with the data value of 0x00.

In transmit operation, if an endpoint is configured or CDC Linux mode, upon receiving a Null Packet from the CPPI DMA, the XFER DMA will then generate a packet containing 1 byte of data, whose value is 0x00, indicating the end of the transfer. During receive operation, the XFER DMA will recognize the one byte zero packet as a termination of the data transfer, and sends a block of data with the EOP indicator set and a byte count of one to the CPPI DMA controller. The CPPI DMA realizing the end of the transfer termination will not update/increase the packet size count of the Host Packet Descriptor.

Linux CDC DMA Transfer Setup

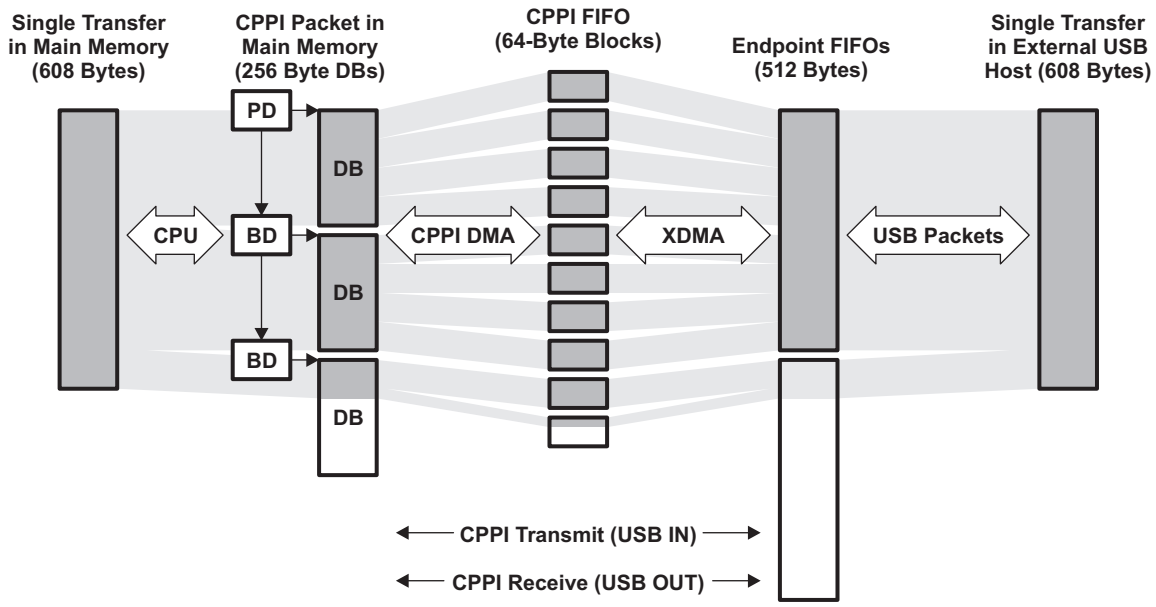
The following will configure all four ports/channels for Linux CDC DMA Transfer type.

- Disable RNDIS Mode globally. RNDIS bit in the control register (CTRLR) is cleared to 0.
- Configure the DMA Mode Register (MODE) for the Endpoint field in use is programmed for Linux CDC Mode. MODE = 2222 2222h

33.2.8.12 USB Data Flow Using DMA

The necessary steps required to perform a USB data transfer using the CPPI 4.1 DMA is expressed using an example for both transmit and receive cases. Assume a device is ready to perform a data transfer of size 608 bytes (see Figure 33-20).

Figure 33-20. High-Level Transmit and Receive Data Transfer Example



Example assumptions:

- The CPPI data buffers are 256 bytes in length.
- The USB endpoint 1 Tx and Rx endpoint 1 size are 512 bytes.
- A single transfer length is 608 bytes.
- The SOP offset is 0.

This translates to the following:

- Transmit Case:
  - 1 Host Packet Descriptor with Packet Length field of 608 bytes and a Data Buffer of size 256 Bytes linked to the 1st Host Buffer Descriptor.
  - First Host Buffer Descriptor with a Data Buffer size of 256 Bytes linked to the 2nd Buffer Descriptor.
  - Second Host Buffer Descriptor with a Data Buffer size of 96 bytes (can be greater, the Packet Descriptor contain the size of the packet) linked with its link word set to Null.
- Receive Case:
  - Two Host Buffer Descriptors with 256 bytes of Data Buffer Size
  - One Host Buffer Descriptor with 96 bytes (can be greater) of Data Buffer size

Within the rest of this section, the following nomenclature is used.

BD— Host Buffer Descriptor

DB— Data Buffer Size of 256 Bytes

PBD— Pointer to Host Buffer Descriptor

PD— Host Packet Descriptor

PPD— Pointer to Host Packet Descriptor

RXCQ— Receive Completion Queue or Receive Return Queue (for all Rx EPs, use 26 or 27)

RXSQ— Receive Free Packet/Buffer Descriptor Queue or Receive Submit Queue. (for all Rx EPs, use 0 to 15)

TXCQ— Transmit Completion Queue or Transmit Return Queue (for all Tx EPs, use 24 or 25)

TXSQ— Transmit Queue or Transmit Submit Queue (for EP1, use 16 or 17)

33.2.8.12.1 Transmit USB Data Flow Using DMA

The transmit descriptors and queue status configuration prior to the transfer taking place is shown in Figure 33-21. An example of initialization for a transmit USB data flow is shown in Figure 33-22.

Figure 33-21. Transmit Descriptors and Queue Status Configuration

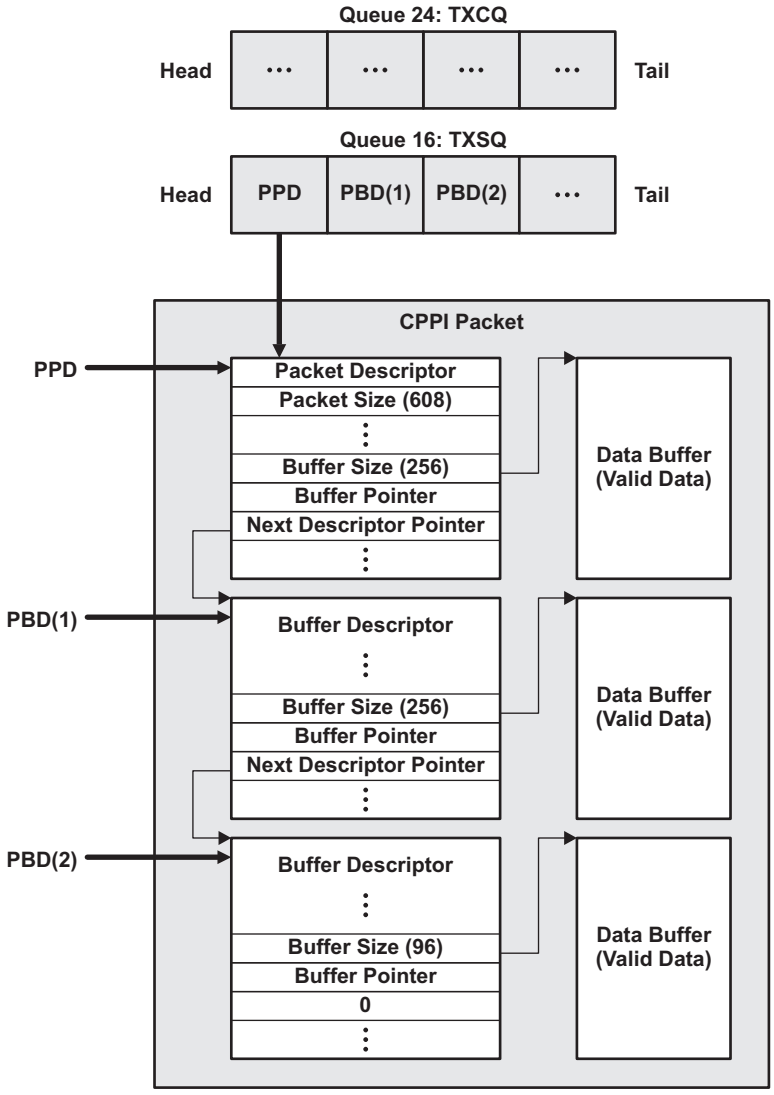
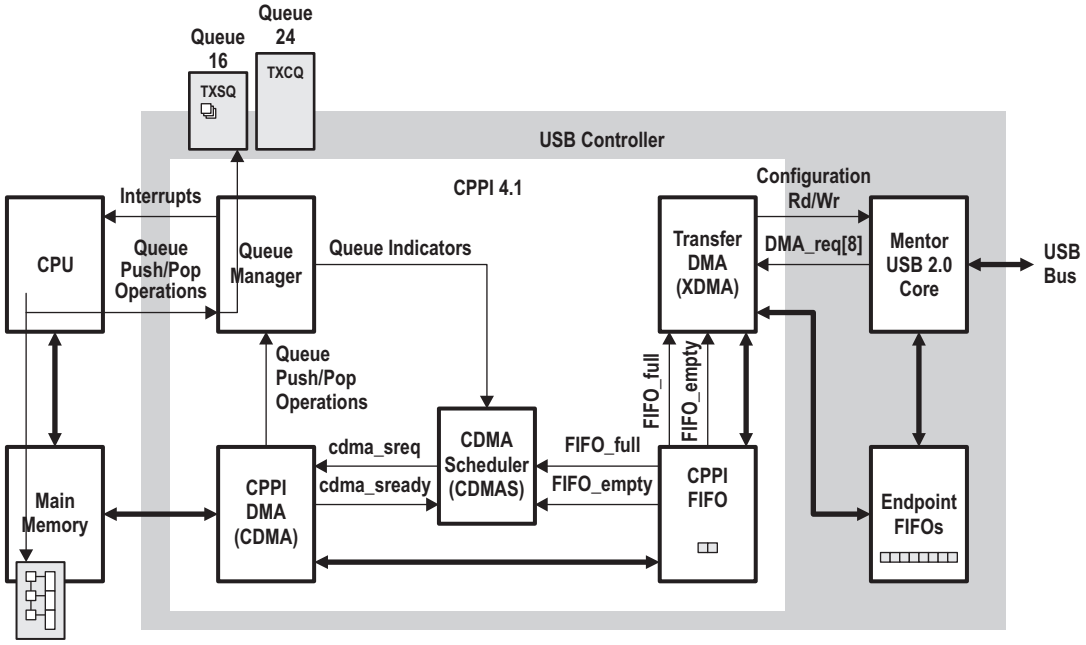


Figure 33-22. Transmit USB Data Flow Example (Initialization)



Step 1 (Initialization for Tx):

1. The CPU initializes Queue Manager with the Memory Region 0 base address and Memory Region 0 size, Link RAM0 Base address, Link RAM0 data size, and Link RAM1 Base address.
2. The CPU creates PD, BDs, and DBs in main memory and link as indicated in Figure 33-22.
3. It then initializes and configures the Queue Manager, Channel Setup, DMA Scheduler, and Mentor USB 2.0 Core.
4. It then adds (pushes) the PPD and the two PBDs to the TXSQ

NOTE: You can create more BD/DB pairs and push them on one of the unassigned queues. The firmware can pop a BD/DP pair from this chosen queue and can create its HPD or HBDs and pre link them prior to submitting the pointers to the HPD and HBD on to the TXSQ.

Step 2 (CDMA and XDMA transfers packet data into Endpoint FIFO for Tx):

1. The Queue Manager informs the CDMAS that the TXSQ is not empty.
2. CDMAS checks that the CPPI FIFO FIFO_full is not asserted, then issues a credit to the CDMA.
3. CDMA reads the packet descriptor pointer and descriptor size hint from the Queue Manager.
4. CMDA reads the packet descriptor from memory.
5. For each 64-byte block of data in the packet data payload:
   (a) The CDMA transfers a max burst of 64-byte block from the data to be transferred in main memory to the CPPI FIFO.
   (b) The XDMA sees FIFO_empty not asserted and transfers 64-byte block from CPPI FIFO to Endpoint FIFO.
   (c) The CDMA performs the above 2 steps 3 more times since the data size of the HPD is 256 bytes.
6. The CDMA reads the first buffer descriptor pointer.
7. CDMA reads the buffer descriptor from memory.
8. For each 64-byte block of data in the packet data payload:
   (a) The CDMA transfers a max burst of 64-byte block from the data to be transferred in main memory to the CPPI FIFO.

(b) The XDMA sees FIFO_empty not asserted and transfers 64-byte block from CPPI FIFO to Endpoint FIFO.

(c) The CDMA performs the above 2 steps 2 more times since data size of the HBD is 256 bytes.

9. The CDMA reads the second buffer descriptor pointer.
10. CDMA reads the buffer descriptor from memory.
11. For each 64-byte block of data in the packet data payload:

(a) The CDMA transfers a max burst of 64-byte block from the data to be transferred in main memory to the CPPI FIFO.

(b) The XDMA sees FIFO_empty not asserted and transfers 64-byte block from CPPI FIFO to Endpoint FIFO.

(c) The CDMA transfers the last remaining 32-byte from the data to be transferred in main memory to the CPPI FIFO.

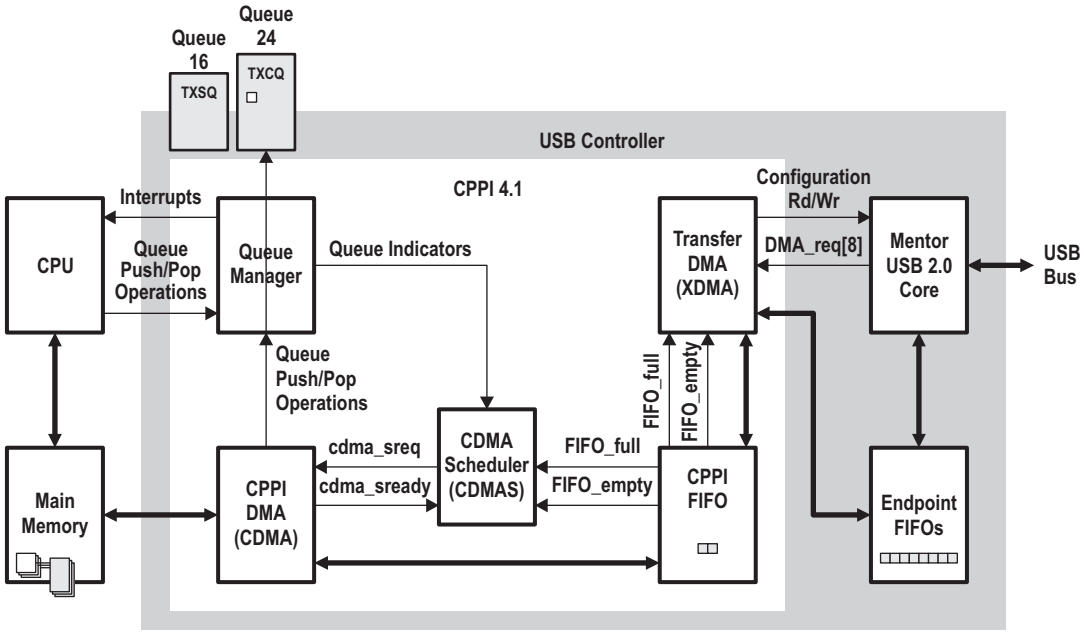
(d) The XDMA sees FIFO_empty not asserted and transfers 32-byte block from CPPI FIFO to Endpoint FIFO.

Step 3 (Mentor USB 2.0 Core transmits USB packets for Tx):

1. Once the XDMA has transferred enough 64-byte blocks of data from the CPPI FIFO to fill the Endpoint FIFO, it signals the Mentor USB 2.0 Core that a TX packet is ready (sets the endpoint's TxPktRdy bit).
2. The Mentor USB 2.0 Core will transmit the packet from the Endpoint FIFO out on the USB BUS when it receives a corresponding IN request from the attached USB Host.
3. After the USB packet is transferred, the Mentor USB 2.0 Core issues a TX DMA_req to the XDMA.
4. This process is repeated until the entire packet has been transmitted. The XDMA will also generate the required termination packet depending on the termination mode configured for the endpoint.

An example of the completion for a transmit USB data flow is shown in Figure 33-23.

Figure 33-23. Transmit USB Data Flow Example (Completion)



Step 4 (Return packet to completion queue and interrupt CPU for Tx):

1. After all data for the packet has been transmitted (as specified by the packet size field), the CDMA will write the pointer to the packet descriptor to the TX Completion Queue specified in the return queue manager / queue number fields of the packet descriptor.

2. The Queue Manager then indicates the status of the TXSQ (empty) to the CDMAS and the TXCQ to the CPU via an interrupt.

33.2.8.12.2 Receive USB Data Flow Using DMA

The receive descriptors and queue status configuration prior to the transfer taking place is shown in Figure 33-24. An example of initialization for a receive USB data flow is shown in Figure 33-25.

Figure 33-24. Receive Descriptors and Queue Status Configuration

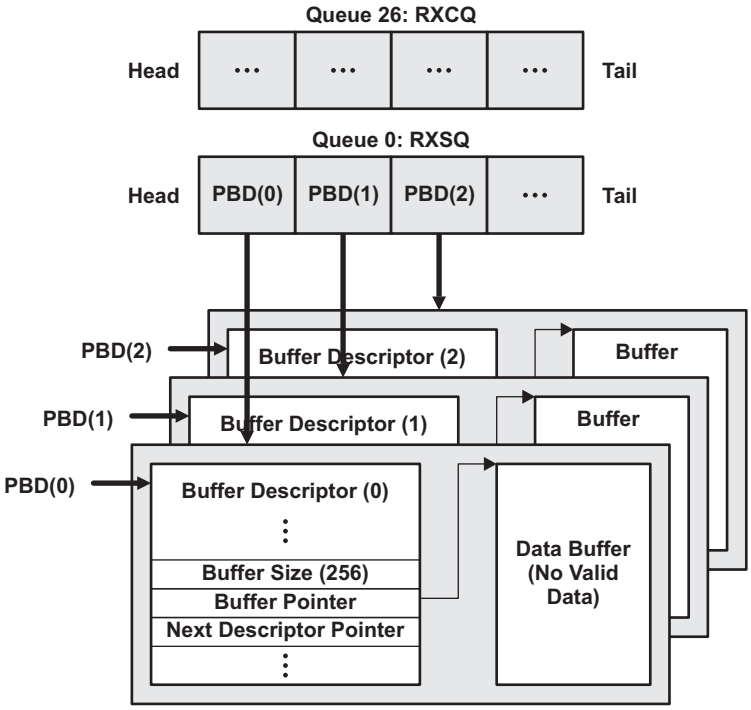
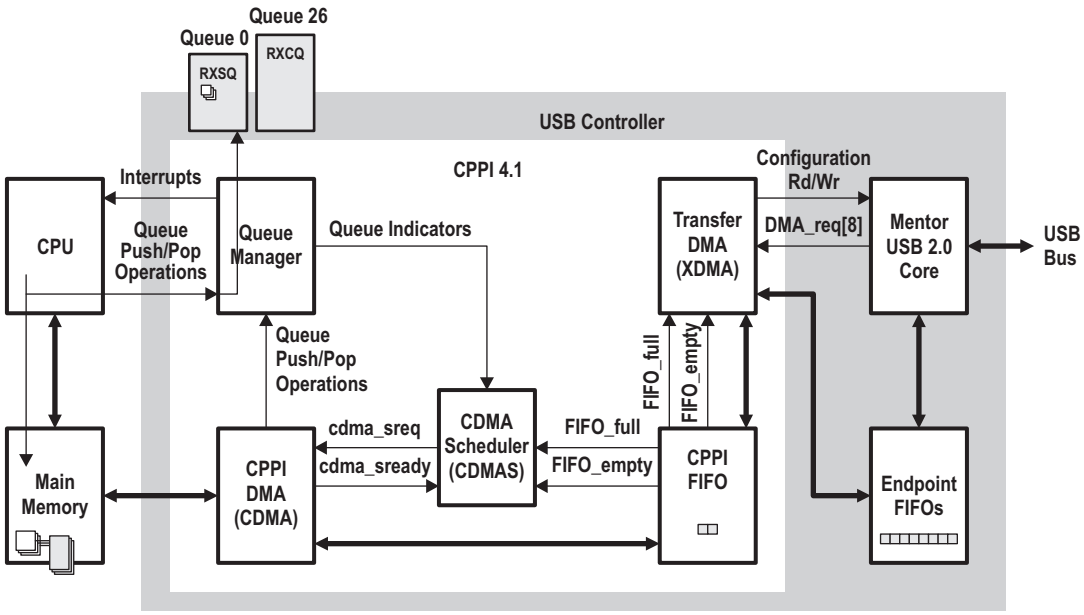


Figure 33-25. Receive USB Data Flow Example (Initialization)



Step 1 (Initialization for Rx):

1. The CPU initializes Queue Manager with the Memory Region 0 base address and Memory Region 0 size, Link RAM0 Base address, Link RAM0 data size, and Link RAM1 Base address.
2. The CPU creates BDs, and DBs in main memory and link them as indicated in Figure 33-25.
3. It then initializes the RXCQ queue and configures the Queue Manager, Channel Setup, DMA Scheduler, and Mentor USB 2.0 Core.
4. It then adds (pushes) the address of the three PHDs into the RXSQ.

Step 2 (Mentor USB 2.0 Core receives a packet, XDMA starts data transfer for Receive):

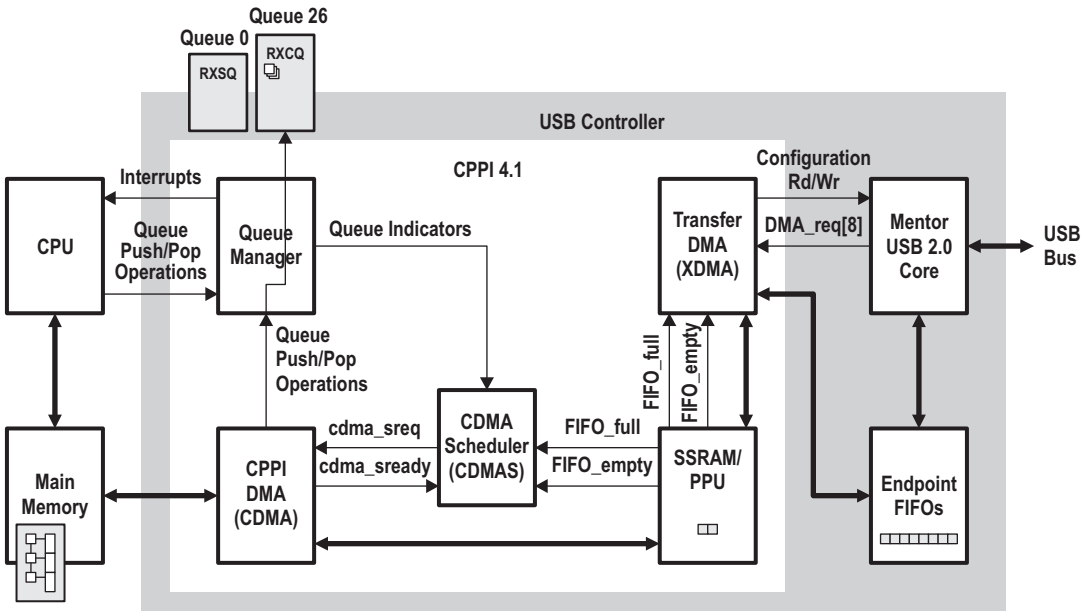
1. The Mentor USB 2.0 Core receives a USB packet from the USB Host and stores it in the Endpoint FIFO.
2. It then asserts a DMA_req to the XDMA informing it that data is available in the Endpoint FIFO.
3. The XDMA verifies the corresponding CPPI FIFO is not full via the FIFO_full signal, then starts transferring 64-byte data blocks from the Endpoint FIFO into the CPPI FIFO.

Step 3 (CDMA transfers data from SSRAM / PPU to main memory for Receive):

1. The CDMAS see FIFO_empty de-asserted (there is RX data in the FIFO) and issues a transaction credit to the CDMA.
2. The CDMA begins packet reception by fetching the first PBD from the Queue Manager using the Free Descriptor / Buffer Queue 0 (Rx Submit Queue) index that was initialized in the RX port DMA state for that channel.
3. The CDMA will then begin writing the 64-byte block of packet data into this DB.
4. The CDMA will continue filling the buffer with additional 64-byte blocks of data from the CPPI FIFO and will fetch additional PBD as needed using the Free Descriptor / Buffer Queue 1, 2, and 3 indexes for the 2nd, 3rd, and remaining buffers in the packet. After each buffer is filled, the CDMA writes the buffer descriptor to main memory.

An example of the completion for a receive USB data flow is shown in Figure 33-26.

Figure 33-26. Receive USB Data Flow Example (Completion)



Step 4 (CDMA completes the packet transfer for Receive):

1. After the entire packet has been received, the CDMA writes the packet descriptor to main memory.
2. The CDMA then writes the packet descriptor to the RXCQ specified in the Queue Manager / Queue Number fields in the RX Global Configuration Register.
3. The Queue Manager then indicates the status of the RXCQ to the CPU via an interrupt.
4. The CPU can then process the received packet by popping the received packet information from the RXCQ and accessing the packet's data from main memory.

33.2.8.13 Interrupt Handling

Table 33-27 lists the interrupts generated by the USB controller.

Table 33-27. Interrupts Generated by the USB Controller

Interrupt	Description
Tx Endpoint [4-0]	Tx endpoint ready or error condition. For endpoints 4 to 0. (Rx and Tx for endpoint 0)
Rx Endpoint [4-1]	Rx endpoint ready or error condition. For endpoints 4 to 1. (Endpoint 0 has interrupt status in Tx interrupt)
USB Core[8-0]	Interrupts for 9 USB conditions

Whenever any of these interrupt conditions are generated, the host processor is interrupted. The software needs to read the different interrupt status registers (discussed in later section) to determine the source of the interrupt.

The nine USB interrupt conditions are listed in Table 33-28.

Table 33-28. USB Interrupt Conditions

Interrupt	Description
USB[8]	DRVVBUS level change
USB[7]	VBus voltage < VBus Valid Threshold (VBus error)
USB[6]	SRP detected
USB[5]	Device Disconnected (Valid in Host Mode)
USB[4]	Device Connected (Valid in Host Mode)
USB[3]	SOF started
USB[2]	Reset Signaling detected (In Peripheral Mode) Babble detected (In Host Mode)
USB[1]	Resume signaling detected
USB[0]	Suspend Signaling detected

33.2.8.13.1 USB Core Interrupts

Interrupt status can be determined using the INTSRCR (interrupt source) register. This register is non-masked. To clear the interrupt source, set the corresponding interrupt bit in INTCLRR register. For debugging purposes, interrupt can be set manually through INTSETR register.

The interrupt controller provides the option of masking the interrupts. A mask can be set using INTMSKSETR register and can be cleared by setting the corresponding bit in the INTMSKCLRR register. The mask can be read from INTMSKR register. The masked interrupt status is determined using the INTMASKEDR register.

The host processor software should write to the End Of Interrupt Register (EOIR) to acknowledge the completion of an interrupt.

NOTE: While EOIR is not written, the interrupt from the USB controller remains asserted.

33.2.9 Test Modes

The USB2.0 controller supports the four USB 2.0 test modes defined for high-speed functions. It also supports an additional “FIFO access” test mode that can be used to test the operation of the CPU interface, the DMA controller (if configured), and the RAM block.

The test modes are entered by writing to the TESTMODE register. A test mode is usually requested by the host sending a SET_FEATURE request to Endpoint 0. When the software receives the request, it should wait until the Endpoint 0 transfer has completed (when it receives the Endpoint 0 interrupt indicating the status phase has completed) then write to the TESTMODE register.

NOTE: These test modes have no purpose in normal operation.

33.2.9.1 TEST_SE0_NAK

To enter the Test_SE0_NAK test mode, the software should set the TEST_SE0_NAK bit in the TESTMODE register to 1. The USB controller will then go into a mode in which it responds to any valid IN token with a NAK.

33.2.9.2 TEST_J

To enter the Test_J test mode, the software should set the TEST_J bit in the TESTMODE register to 1. The USB controller will then go into a mode in which it transmits a continuous J on the bus.

33.2.9.3 TEST_K

To enter the Test_K test mode, the software should set the TEST_K bit in the TESTMODE register to 1. The USB controller will then go into a mode in which it transmits a continuous K on the bus.

33.2.9.4 TEST_PACKET

To execute the Test_Packet, the software should:

1. Start a session (if the core is being used in Host mode).
2. Write the standard test packet (shown below) to the Endpoint 0 FIFO.
3. Write 8h to the TESTMODE register (TEST_PACKET = 1) to enter Test_Packet test mode.
4. Set the TxPktRdy bit in the CSR0 register (D1).

The 53 by test packet to load is as follows (all bytes in hex). The test packet only has to be loaded once; the USB controller will keep re-sending the test packet without any further intervention from the software.

This data sequence is defined in Universal Serial Bus Specification Revision 2.0, Section 7.1.20. The USB controller will add the DATAA0 PID to the head of the data sequence and the CRC to the end.

00	00	00	00	00	00	00	00
00	AA	AA	AA	AA	AA	AA	AA
AA	EE	EE	EE	EE	EE	EE	EE
EE	FE	FF	FF	FF	FF	FF	FF
FF	FF	FF	FF	FF	7F	BF	DF
EF	F7	FB	FD	FC	7E	BF	DF
EF	F7	FB	FD	7E			

33.2.9.5 FIFO_ACCESS

The FIFO Access test mode allows you to test the operation of CPU Interface, the DMA controller (if configured), and the RAM block by loading a packet of up to 64 bytes into the Endpoint 0 FIFO and then reading it back out again. Endpoint 0 is used because it is a bidirectional endpoint that uses the same area of RAM for its Tx and Rx FIFOs.

NOTE: The core does not need to be connected to the USB bus to run this test. If it is connected, then no session should be in progress when the test is run.

The test procedure is as follows:

1. Load a packet of up to 64 bytes into the Endpoint 0 Tx FIFO.
2. Set CSR0.TxPktRdy.
3. Write 40h to the TESTMODE register (FIFO_ACCESS = 1).
4. Unload the packet from the Endpoint Rx FIFO, again.
5. Set CSR0.ServicedRxPktRdy.

Writing 40h to the TESTMODE register causes the following sequence of events:

1. The Endpoint 0 CPU pointer (that records the number of bytes to be transmitted) is copied to the Endpoint 0 USB pointer (that records the number of bytes received).
2. The Endpoint 0 CPU pointer is reset.
3. CSR0.TxPktRdy is cleared.
4. CSR0.RxPktRdy is set.
5. An Endpoint 0 interrupt is generated (if enabled).

The effect of these steps is to make the Endpoint 0 controller act as if the packet loaded into the Tx FIFO has flushed and the same packet received over the USB. The data that was loaded in the Tx FIFO can now be read out of the Rx FIFO.

33.2.9.6 FORCE_HOST

The Force Host test mode enables you to instruct the core to operate in Host mode, regardless of whether it is actually connected to any peripheral; that is, the state of the CID input and the LINESTATE and HOSTDISCON signals are ignored. (While in this mode, the state of the HOSTDISCON signal can be read from the BDEVICE bit in the device control register (DEVCTL).)

This mode, which is selected by writing 80h to the TESTMODE register (FORCE_HOST = 1), allows implementation of the USB Test_Force_Enable (7.1.20). It can also be used for debugging PHY problems in hardware.

While the FORCE_HOST bit remains set, the core enters the Host mode when the SESSION bit in DEVCTL is set to 1 and remains in the Host mode until the SESSION bit is cleared to 0 even if a connected device is disconnected during the session. The operating speed while in this mode is determined by the FORCE_HS and FORCE_FS bits in the TESTMODE register.

33.2.10 Reset Considerations

The USB controller has two reset sources: hardware reset and the soft reset.

33.2.10.1 Software Reset Considerations

When the RESET bit in the control register (CTRLR) is set, all the USB controller registers and DMA operations are reset. The bit is cleared automatically.

A software reset on the ARM or DSP CPU does not affect the register values and operation of the USB controller.

33.2.10.2 Hardware Reset Considerations

When a hardware reset is asserted, all the registers are set to their default values.

33.2.11 Interrupt Support

The USB peripheral provides the interrupts listed in Table 33-29 to the interrupt distributor module (INTD). For information on the mapping of interrupts, see your device-specific data manual.

Table 33-29. USB Interrupts

Event	Acronym	Source
ARM Event = 58	USB0_INT	USB 2.0 Controller
DSP Event = 19	USB0_INT	USB 2.0 Controller

33.2.12 DMA Event Support

The USB is an internal bus master peripheral and does not utilize EDMA events. The USB has its own dedicated DMA, CPPI 4.1 DMA, that it utilizes for DMA driven data transfer.

33.2.13 Power Management

The USB controller can be placed in reduced power modes to conserve power during periods of low activity. The power management of the peripheral is controlled by the processor Power and Sleep Controller (PSC). The PSC acts as a master controller for power management for all of the peripherals on the device. For detailed information on power management procedures using the PSC, see the *Power and Sleep Controller (PSC)* chapter.

33.3 Use Cases

The USB supports the following use cases.

33.3.1 User Case 1: Example of How to Initialize the USB Controller

Example 33-1. Initializing the USB2.0 Controller

```
void usb_init()
{
       Uint16 I;

// ****************************************************************************
// Configure DRVVBUS Pin to be used for USB
// ****************************************************************************
// MAKE SURE WRITE ACCESS KEY IS INITIALIZED PRIOR TO ACCESSING ANY OF THE
// BOOTCFG REGISTERS.


   BootCfg->KICK0R = KICK0KEY;      // Write Access Key 0
   BootCfg->KICK1R = KICK1KEY;      // Write Access Key 1
   /* CONFIGURE THE DRVVBUS PIN HERE.*/
   /* See the System Configuration (SYSCFG) Module chapter for more information on how to set up
the pinmux. */


// Reset the USB controller:
        usbRegs->CTRLR |= 0x00000001;


//Wait until controller is finished with Reset. When done, it will clear the RESET bit field.
        while ((usbRegs->CTRLR & 0x1) == 1);


        // RESET: Hold PHY in Reset
        BootCfg->CFGCHIP2 |= 0x00008000;   // Hold PHY in Reset
        // Drive Reset for few clock cycles
        for (I=0; i<50; I++);
        // RESET: Release PHY from Reset
        BootCfg->CFGCHIP2 &= 0xFFFF7FFF;   // Release PHY from Reset


/* Configure PHY with the Desired Operation */
              // OTGMODE
              BootCfg->CFGCHIP2 &= 0xFFFF9FFF;   // 00=> Do Not Override PHY Values

              // PHYPWDN
              BootCfg->CFGCHIP2 &= 0xFFFFFBFF;   // 1/0 => PowerdDown/ NormalOperation
              // OTGPWRDN
              BootCfg->CFGCHIP2 &= 0xFFFFFDFF;   // 1/0 => PowerDown/ NormalOperation
              // DATAPOL
              BootCfg->CFGCHIP2 |= 0x00000100;   // 1/0 => Normal/ Reversed
              // SESNDEN
              BootCfg->CFGCHIP2 |= 0x00000020;   // 1/0 => NormalOperation/ SessionEnd
              // VBDTCTEN
              BootCfg->CFGCHIP2 |= 0x00000010;   // 1/0 => VBUS Comparator Enable/ Disable



/* Configure PHY PLL use and Select Source */
        // REF_FREQ[3:0]
        BootCfg->CFGCHIP2 |= 0x00000002;        // 0010b => 24MHz Input Source

        // USB2PHYCLKMUX: Select External Source
        BootCfg->CFGCHIP2 &= 0xFFFFF7FF;        // 1/0 => Internal/External(Pin)
```

Example 33-1. Initializing the USB2.0 Controller (continued)

```
        // PHY_PLLON: On Simulation PHY PLL is OFF
        BootCfg->CFGCHIP2 |= 0x00000040;        // 1/0 => On/ Off



/* Wait Until PHY Clock is Good */
        while ((BootCfg->CFGCHIP2 & 0x00020000) == 0); // Wait Until PHY Clock is Good.

        #ifndef HS_ENABLE
                // Disable high-speed
                CSL_FINS(usbRegs->POWER,USB_OTG_POWER_HSEN,0);
        #else
                // Enable high-speed
                CSL_FINS(usbRegs->POWER,USB_OTG_POWER_HSEN,1);
        #endif


// Enable Interrupts
        // Enable interrupts in OTG block
        usbRegs->CTRLR &= 0xFFFFFFF7; // Enable PDR2.0 Interrupt

        usbRegs-
>INTRTXE = 0x1F;              // Enable All Core Tx Endpoints Interrupts + EP0 Tx/Rx interrupt
        usbRegs->INTRRXE = 0x1E;              // Enable All Core Rx Endpoints Interrupts

        // Enable all interrupts in OTG block
        usbRegs->INTMSKSETR = 0x01FF1E1F;

        // Enable all USB interrupts in MUSBMHDRC
        usbRegs->INTRUSBE = 0xFF;

        // Enable SUSPENDM so that suspend can be seen UTMI signal
        CSL_FINS(usbRegs->POWER,USB_OTG_POWER_ENSUSPM,1);

        //Clear all pending interrupts
        usbRegs->INTCLRR = usbRegs->INTSRCR;

        #if (_USB_PERIPHERAL_)   // defined within project file if need to function as Peripheral.
                // Set softconn bit
                CSL_FINS(usbRegs->POWER,USB_OTG_POWER_SOFTCONN,1);
                while ((usbRegs-
>DEVCTL & 0x01) == 0);  //Stay here until controller goes in Session.
        #else
                // Start a session
                CSL_FINS(usbRegs->DEVCTL,USB_OTG_DEVCTL_SESSION,1);
        #endif

}
```

Example 33-2. Initializing the CPPI 4.1 DMA Controller

```
void cppiDmaInit() {

       switch (DMAmode) {
              case RNDIS:
                     usbRegs->CTRLR |=0x00000010; // Enable RNDIS from Global Level
                     usbRegs->RNDISR=0x11111111;
                     break;

              case GENERIC_RNDIS:
                     usbRegs->CTRLR &= ~0x00000010; // Disable RNDIS from Global Level
                     usbRegs->RNDISR=0x33333333;
                     usbRegs->GENRNDISSZ[chan_num].SIZE=descPacketLength;
                     break;

              case LINUX_CDC:
                     usbRegs->CTRLR &= ~0x00000010; // Disable RNDIS from Global Level
                     usbRegs->RNDISR=0x22222222;
                     break;

              case TRANSPARENT:
                     usbRegs->CTRLR &= ~0x00000010; // Disable RNDIS from Global Level
                     usbRegs->RNDISR=0x00000000;
                     break;

              default:
                     usbRegs->CTRLR |=0x00000010; // Enable RNDIS from Global Level
                     break;
       }
       #ifndef _USB_PERIPHERAL_            // If Controller is assuming Host Role
              #ifdef TRANSPARENT
                     usbRegs->AUTOREQ=00;      // No Auto Req
              #else
                     usbRegs->AUTOREQ=01;      // Auto Req on all but EOP
             #endif
       #endif

       A Single Queue Manager (00b) exist and 16 Regions; no particular assignment exists.

       Program Link Ram0 and Link Ram1, Base & Size.
       No Link Ram1 Size Register exists. Most likely is using the same Size Register used
       //    Link Ram1 Base
       usbRegs->QMGR.LRAM0BASE = (Uint32)queueMgrLinkRam0;
       usbRegs->QMGR.LRAM0SIZE = LINKRAM0SIZE/4;
       usbRegs->QMGR.LRAM1BASE = (Uint32)queueMgrLinkRam1;

// Allocate Resource to Region 0 (can use any of the 16 available) (memory location for Host
Packet Descriptors)
// DESC_SIZE value should be [1-8]. Values of 9 - 15 are reserved.
// Since a minimum of 32 Bytes is required, only program values above 32.
// Host Packet Descriptor sizes: Min/Max = 32/(104 + Opt S/W Data)
// REG_SIZE is the total # of Descriptors the Region can accommodate. At the minimum should be
capable of handling 32 Descriptors.

// This example is allocating specific regions for each port
       usbRegs->QMEMREGION[chan_num].QMEMRBASE=((Uint32)region0DescriptorSpace);
       usbRegs->QMEMREGION[chan_num].QMEMRCTRL=(REG0START_INDEX<<16) | (DESC_SIZE<<8) | REG_SIZE;

Configure the Scheduler
// Configure the Tx/Rx Word[x=0,1] and Scheduler Configuration Register
// Priorities are handled by programming more of the channel number wanting to see serviced
// 64 Words exist for a total of 256 entries.

       // Credit can be given to both Tx and Rx Channel within the same Register.
       // Here Rx Credit is given first for the single Rx Channel defined by chan_num.
```

Example 33-2. Initializing the CPPI 4.1 DMA Controller (continued)

```
        // Here we are using the first 8 credits and is assigned to the Channel/Endpoint
        //  being serviced.
        usbRegs-
>DMA_SCHED.ENTRY[0]= (0x80808080 | (chan_num | (chan_num << 8) | (chan_num << 16) | (chan_num <<
24)));
        // Corresponds to WORD0 Offset 0x2800

        usbRegs-
>DMA_SCHED.ENTRY[1]=(0x00000000 | (chan_num | (chan_num << 8) | (chan_num << 16) | (chan_num <<
24)));
        // Corresponds to WORD1 Offset 0x2804, etc

        // Scheduler is Enabled and number of Credits entered (since 8 of the 256 credits are used
program 8-1=7 and enable Scheduler)
        usbRegs->DMA_SCHED.DMA_SCHED_CTRL=0x80000007; // Scheduler Control Register Offset 0x2000

// Configure Tx and Rx DMA State Registers
// The Rx Channel Global Configuration Registers are used to initialize the global
// (non descriptor type specific) behavior of each of the Rx DMA channels.  If the
// enable bit is being set, the Rx/Tx Channel Global Configuration Register SHOULD ONLY
// BE WRITTEN AFTER ALL OF THE OTHER Rx/Tx CONFIGURATION REGISTERS HAVE BEEN INITIALIZED.
// Only a Single Queue Manager exists & its value is 0.


// RxHPCRA/B requires for Queue Manager (have only one and is 00b) and Receive Submit Queues for
the
// first 4 Host Buffer Descriptors to be programmed. Since Queues 0 to 15 are alloted for Receive
// operations and there exist no dedicated queue assignments for each channel, a user can
// associate any Queue with any Channel and this association is not fixed for the Receive
Operations.
// Queue[15:0]<==>Any Rx Channel

// However, for Tx Operations, Dedicated Submit Queues have been assigned for Each Channel,
Endpoints.
// Queue[17:16]<==>TxCh[0], Queue[19:18]<==>TxCh[1], Queue[21:20]<==>TxCh[2],
Queue[23:22]<==>TxCh[3]

// CDMA Rx Chanel x Host Packet Configuration Registers A & B
// For a Single Descriptor setup, all you will be needing is RXHPCRA[13,12 & 11:00]

// Assumed that all Descriptors are going to be using the same Queue, but this is configurable.

        usbRegs-
>DMA_CTRL[chan_num].RXHPCRA=(rxSubmitQ | (rxSubmitQ<<16)); // Rx Channel 0 Host Pkt Cfg Reg A
Offset 0x180C
        usbRegs-
>DMA_CTRL[chan_num].RXHPCRB=(rxSubmitQ | (rxSubmitQ<<16)); // Rx Channel 0 Host Pkt Cfg Reg B
Offset 0x1810

        // For Loopback purposes, the same data buffer will be used for receiving and transmitting.
        //  However, different descriptors (tx) and queues will be used to process the same data
from the same buffer
        // Rx Submit Queues are assigned by H/W but they are not port specific. Queues 0-
15 are available for any channel.
        usbRegs->DMA_CTRL[chan_num].RXGCR=(0x81004000 | rxCompQ);
        // Rx Channel 0 Host Pkt Cfg Register Offset 0x1808 (Use Queue 26 for Completion/Return
Queue)

        // Tx Submit Queues are assigned by H/W and are Channel Specific. 2 Submit Queues for each
port. Queues 16, 17 for port 0, etc
        usbRegs-
>DMA_CTRL[chan_num].TXGCR=(0x80000000 | txCompQ); // Tx Channel 0 Host Pkt Cfg Register Offset
0x1800
}
```

33.3.2 User Case 2: Example of How to Program the USB Endpoints in Peripheral Mode

Example 33-3. Programming the USB Endpoints in Peripheral Mode

```
// DMA channel number.  Valid values are 0, 1, 2, or 3.
int CHAN_NUM = 0;

// Fifo sizes: uncomment the desired size.
// This example uses 64-byte fifo.
// int fifosize = 0;    // 8 bytes
// int fifosize = 1;    // 16 bytes
// int fifosize = 2;    // 32 bytes
   int fifosize = 3;    // 64 bytes
// int fifosize = 4;    // 128 bytes
// int fifosize = 5;    // 256 bytes
// int fifosize = 6;    // 512 bytes
// int fifosize = 7;    // 1024 bytes
// int fifosize = 8;    // 2048 bytes
// int fifosize = 9;    // 4096 bytes

// FIFO address.  Leave 64-bytes for endpoint 0.
int fifo_start_address = 8;

// Uncomment the desired buffering.  If double-buffer is selected, actual
// FIFO space will be twice the value listed above for fifosize.
// This example uses single buffer.
   int double_buffer = 0;  // Single-buffer
// int double_buffer = 1;  // Double-buffer

// For maximum packet size this formula will usually work, but it can also be
// set to another value if needed.  If non power of 2 value is needed (such as
// 1023) set it explicitly.
#define FIFO_MAXP 8*(1<<fifosize);

// Set the following variable to the device address.
int device_address = 0;


// The following code should be run after receiving a USB reset from the host.


// Initialize the endpoint FIFO.  RX and TX will be allocated the same sizes.
usbRegs->INDEX = CHAN_NUM+1;
usbRegs->RXFIFOSZ = fifosize | ((double_buffer & 1)<<4);
usbRegs->RXFIFOADDR = fifo_start_address;
usbRegs->TXFIFOSZ =    fifosize | ((double_buffer & 1)<<4);
usbRegs->TXFIFOADDR = fifo_start_address + (1<<(fifosize+double_buffer));
usbRegs->RXMAXP = FIFO_MAXP;
usbRegs->TXMAXP = FIFO_MAXP;

// Force Data Toggle is optional for interrupt traffic.  Uncomment if needed.
// CSL_FINS(usbRegs->PERI_TXCSR,USB_PERI_TXCSR_FRCDATATOG,1);

// Uncomment below to configure the endpoint for ISO and not respond with a
// handshake packet.
// CSL_FINS(usbRegs->PERI_RXCSR,USB_PERI_RXCSR_ISO,1);
// CSL_FINS(usbRegs->PERI_TXCSR,USB_PERI_TXCSR_ISO,1);

// After receiving a successful set-address command, set the following register
// to the specified address immediately following the status stage.
usbRegs->FADDR = device_address;
```

33.3.3 User Case 3: Example of How to Program the USB Endpoints in Host Mode

Example 33-4. Programming the USB Endpoints in Host Mode

```
// DMA channel number.  Valid values are 0, 1, 2, or 3.
int CHAN_NUM = 0;

// Fifo sizes: uncomment the desired size.
// This example uses 64-byte fifo.
// int fifosize = 0;    // 8 bytes
// int fifosize = 1;    // 16 bytes
// int fifosize = 2;    // 32 bytes
   int fifosize = 3;    // 64 bytes
// int fifosize = 4;    // 128 bytes
// int fifosize = 5;    // 256 bytes
// int fifosize = 6;    // 512 bytes
// int fifosize = 7;    // 1024 bytes
// int fifosize = 8;    // 2048 bytes
// int fifosize = 9;    // 4096 bytes

// FIFO address.  Leave 64-bytes for endpoint 0.
int fifo_start_address = 8;

// Uncomment the desired buffering.  If double-buffer is selected, actual
// FIFO space will be twice the value listed above for fifosize.
// This example uses single buffer.
   int double_buffer = 0;  // Single-buffer
// int double_buffer = 1;  // Double-buffer

// Set the following variable to the device endpoint type: CONTROL ISO BULK or IN
  int device_protocol = BULK;
//int device_protocol = ISO;
//int device_protocol = INT;

// USB speeds
#define LOW_SPEED 0
#define FULL_SPEED 1
#define HIGH_SPEED 2

// TXTYPE protocol
#define CONTROL 0
#define ISO 1
#define BULK 2
#define INT 3

// For maximum packet size this formula will usually work, but it can also be
// set to another value if needed.  If non power of 2 value is needed (such as
// 1023) set it explicitly.
#define FIFO_MAXP 8*(1<<fifosize);

// Set the following variable to the device address.
int device_address = 1;

// Set the following variable to the device endpoint number.
int device_ep = 1;

// Variable used for endpoint configuration
Uint8 type = 0;

// Variable to keep track of errors
int error = 0;


// The following code should be run after resetting the attached device
```

Example 33-4. Programming the USB Endpoints in Host Mode (continued)

```
// Initialize the endpoint FIFO.  RX and TX will be allocated the same sizes.
usbRegs->INDEX = CHAN_NUM+1;
usbRegs->RXFIFOSZ = fifosize | ((double_buffer & 1)<<4);
usbRegs->RXFIFOADDR = fifo_start_address;
usbRegs->TXFIFOSZ =    fifosize | ((double_buffer & 1)<<4);
usbRegs->TXFIFOADDR = fifo_start_address + (1<<(fifosize+double_buffer));
usbRegs->RXMAXP = FIFO_MAXP;
usbRegs->TXMAXP = FIFO_MAXP;


//Configure the endpoint
switch (device_speed) {
    case LOW_SPEED : type = (3<<6) | ((device_protocol & 3) << 4) | (device_ep & 0xf); break;
    case FULL_SPEED: type = (2<<6) | ((device_protocol & 3) << 4) | (device_ep & 0xf); break;
    case HIGH_SPEED: type = (1<<6) | ((device_protocol & 3) << 4) | (device_ep & 0xf); break;
    default:error++;
}
usbRegs->EPCSR[CHAN_NUM+1].HOST_TYPE0 = type;  // TXTYPE
usbRegs->EPCSR[CHAN_NUM+1].HOST_RXTYPE = type;

// Set NAK limit / Polling interval (Interrupt & Iso protocols)
if ((device_protocol == INT) || (device_protocol == ISO)) {
    usbRegs->EPCSR[CHAN_NUM+1].HOST_NAKLIMIT0 = TXINTERVAL;    // TX Polling interval
    usbRegs->EPCSR[CHAN_NUM+1].HOST_RXINTERVAL = RXINTERVAL;    // RX Polling interval
} else {
    usbRegs->EPCSR[CHAN_NUM+1].HOST_NAKLIMIT0 = 2;    // Frames to timeout from NAKs
    usbRegs->EPCSR[CHAN_NUM+1].HOST_RXINTERVAL = 2;    // Frames to timeout from NAKs
}

//Set the address for transactions after SET ADDRESS successfully completed
usbRegs->EPTRG[CHAN_NUM+1].TXFUNCADDR = device_address;
usbRegs->EPTRG[CHAN_NUM+1].RXFUNCADDR = device_address;
```

33.3.4 User Case 4: Example of How to Program the USB DMA Controller

Example 33-5. Programming the USB DMA Controller

```
typedef struct {
        Uint32 PktLength:22;
        Uint32 ProtSize:5;
        Uint32 HostPktType:5; // This should be 16
}HPDWord0;

typedef struct {
        Uint32 DstTag:16;        //bits[15:0] always Zero
        Uint32 SrcSubChNum:5;    //bits[20:16] always Zero
        Uint32 SrcChNum:6;       //bits[26:21]
        Uint32 SrcPrtNum:5;      //bits[31:27]
}HPDWord1;

typedef struct {
        Uint32 PktRetQueue:12;   //bits[11:0]
        Uint32 PktRetQM:2;       //bits[13:12]
        Uint32 OnChip:1;         //bit[14]
        Uint32 RetPolicy:1;      //bit[15]
        Uint32 ProtoSpecific:4;  //bits[19:16]
        Uint32 Rsv:6;            //bits[25:20]
        Uint32 PktType:5;        //bits[30:26]
        Uint32 PktErr:1;         //bit[31]
}HPDWord2;

typedef struct hostPacketDesc {
        HPDWord0 HPDword0;
        HPDWord1 HPDword1;
        HPDWord2 HPDword2;
        Uint32 HPDword3buffLength;
        Uint32 HPDword4buffAdd;
        Uint32 HPDword5nextHBDptr;
        Uint32 HPDword6orgBuffLength;
        Uint32 HPDword7orgBuffAdd;
} HostPacketDesc;


// The following sample code uses region 0 for all of the ports. Ports/Channels/EPs are not
limited to a single region


void initSingleHPDorHBD(Uint16 descNum, dataDir dir, descType desc, Uint16 returnQueue) {

/*

*********************************************************************************************

 Initialize a Single Transmit and Receive Host Packet or Buffer Descriptor

*/

            if ((desc==PACKET_DESC) & (dir==TRANSMIT))
                        region0DescriptorSpace[descNum].HPDword0.HostPktType=16;   //This value
is always fixed. For Packet Type Decriptors=16
            else
                        region0DescriptorSpace[descNum].HPDword0.HostPktType=0;     //Word0,
Word1, and Half of Word2 are Reserved for Buffer Descriptors.


            region0DescriptorSpace[descNum].HPDword0.ProtSize=0;


            if ((dir==TRANSMIT) & (desc==PACKET_DESC)) {
```

Example 33-5. Programming the USB DMA Controller (continued)

```
                        if (DMAmode==TRANSPARENT)

region0DescriptorSpace[descNum].HPDword0.PktLength=singlePktLength;           //Packet Length
(For Transparent Mode this is <= Tx/RxMaxP Value. For RNDIS or like it is = Tx/RxMaxP Value).
                        else

region0DescriptorSpace[descNum].HPDword0.PktLength=descPacketLength;       //Actual Packet
Length: This is the size of the Packet noted at descriptor level to be Transmitted.



                                                              // This is different from the USB Max
Packet Size. This is the total data length.

            }



            else      // This and other Packet related info will be updated by the PORT for
Receive and can be any value.
                        region0DescriptorSpace[descNum].HPDword0.PktLength=0;
// This is actual Packet Length. It will be populated by the Rx Port of the CPPI DMA


            region0DescriptorSpace[descNum].HPDword1.DstTag=0;             //Always programmed
to ZERO.
            region0DescriptorSpace[descNum].HPDword1.SrcSubChNum=0;  //Always programmed to ZERO.
            region0DescriptorSpace[descNum].HPDword1.SrcChNum=0;                    //Always
programmed to ZERO.


            if(desc==BUFFER_DESC)
                        region0DescriptorSpace[descNum].HPDword1.SrcPrtNum=0;        //Word1 is
Reserved for Buffer DESC.
            else
                        region0DescriptorSpace[descNum].HPDword1.SrcPrtNum=chan_num+1;
//Ports[1,2,3,4] is associated with Endpoints[1,2,3,4] respectively.



            region0DescriptorSpace[descNum].HPDword2.PktRetQueue=returnQueue; //24 and 25 for Tx -
 26 and 27 for Rx Completion
            region0DescriptorSpace[descNum].HPDword2.PktRetQM=0;
            region0DescriptorSpace[descNum].HPDword2.OnChip=1;             // Descriptor is
located On-Chip
            region0DescriptorSpace[descNum].HPDword2.RetPolicy=0;
            region0DescriptorSpace[descNum].HPDword2.ProtoSpecific=0;
            region0DescriptorSpace[descNum].HPDword2.Rsv=0;


            if(desc==BUFFER_DESC)
                        region0DescriptorSpace[descNum].HPDword2.PktType=0;
 // Half of Word 3 is Reserved for Buffer DESC.
            else
                        region0DescriptorSpace[descNum].HPDword2.PktType=5;
 // USB Packet ID is 5


            region0DescriptorSpace[descNum].HPDword2.PktErr=0;


            if(DESCsetup==SINGLE_DESC_SETUP)
                        region0DescriptorSpace[descNum].HPDword3buffLength=descPacketLength;
            else
```

Example 33-5. Programming the USB DMA Controller (continued)

```
                        region0DescriptorSpace[descNum].HPDword3buffLength=singlePktLength;


            if ((dir==TRANSMIT) & (prevDescTxNum==0)) {
                        region0DescriptorSpace[descNum].HPDword4buffAdd=(Uint32)rxBuffer;
                        prevDescTxNum++;
            } else if ((dir==TRANSMIT) & (prevDescTxNum!=0)) {

region0DescriptorSpace[descNum].HPDword4buffAdd=region0DescriptorSpace[descNum-
1].HPDword4buffAdd + region0DescriptorSpace[descNum-1].HPDword3buffLength;
                        prevDescTxNum++;
            }



            if ((dir==RECEIVE) & (prevDescRxNum==0)) {
                        region0DescriptorSpace[descNum].HPDword4buffAdd=(Uint32)rxBuffer;
                        prevDescRxNum++;
            } else if ((dir==RECEIVE) & (prevDescRxNum!=0)) {

region0DescriptorSpace[descNum].HPDword4buffAdd=region0DescriptorSpace[descNum-
1].HPDword4buffAdd + region0DescriptorSpace[descNum-1].HPDword3buffLength;
                        prevDescRxNum++;
            }


            if ((dir==TRANSMIT) & ((prevDescTxNum-1)>0))
                        region0DescriptorSpace[descNum-
1].HPDword5nextHBDptr=(Uint32)&region0DescriptorSpace[descNum];            //Modify Previous Link
Address


            region0DescriptorSpace[descNum].HPDword5nextHBDptr=0;        //Current Descriptor is
the Last Descriptor: Null Value is used as the Next Buffer Descriptor Address
region0DescriptorSpace[descNum].HPDword6orgBuffLength=region0DescriptorSpace[descNum].HPDword3buff
Length;

region0DescriptorSpace[descNum].HPDword7orgBuffAdd=region0DescriptorSpace[descNum].HPDword4buffAdd
;;
}




// usage: qDesc2SubmitQ(rx/txSubmitQ,HPD/HBD);  //Queue Number, HPDdescriptorNumber
void qDesc2SubmitQ(Uint16 queueNum, Uint16 hpdDescriptorNum) {
        usbRegs-
>QCTRL[queueNum].CTRLD=(Uint32)&region0DescriptorSpace[hpdDescriptorNum] | 0x2; //
bits[4:0]=dec_size=[0-31]=[24,28,32,...,148]
}

void enableCoreTxDMA(Uint16 endPoint) {
        Uint16 index_save;
        index_save=usbRegs->INDEX;
        usbRegs->INDEX=endPoint;
        usbRegs->TXCSR.PERI_TXCSR&=0x7FFF; // Clear AUTOSET
        usbRegs->TXCSR.PERI_TXCSR|=0x1400; // Set DMAReqEnab & DMAReqMode
        usbRegs->INDEX=index_save;
}

void enableCoreRxDMA(Uint16 endPoint) {
        Uint16 index_save;
        index_save=usbRegs->INDEX;
        usbRegs->INDEX=endPoint;
```

Example 33-5. Programming the USB DMA Controller (continued)

```
        usbRegs->RXCSR.PERI_RXCSR&=0x77FF;  // Clear AUTOCLEAR and DMAReqMode
        usbRegs->RXCSR.PERI_RXCSR|=0x2000;  // Set DMAReqEnab
        usbRegs->INDEX=index_save;
}

Uint32 readCompletionQueue(Uint16 queueNum) {
        Uint32 DescAddress;
        DescAddress=(Uint32)usbRegs->QCTRL[queueNum].CTRLD;
        DescAddress&=0xFFFFFFE0;
        return(DescAddress);
}

void disableCoreRxDMA(Uint16 endPoint) {
        Uint16 index_save;
        index_save=usbRegs->INDEX;
        usbRegs->INDEX=endPoint;
        usbRegs->RXCSR.PERI_RXCSR &= 0xDFFF;  // Clear DMAReqEnab
        usbRegs->INDEX=index_save;
}

void disableCoreTxDMA(Uint16 endPoint) {
        Uint16 index_save;
        index_save=usbRegs->INDEX;
        usbRegs->INDEX=endPoint;
        usbRegs->TXCSR.PERI_TXCSR&=0x7FFF;  // Clear AUTOSET
        usbRegs->TXCSR.PERI_TXCSR&=0xEBFF;  // Clear DMAReqEnab & DMAReqMode
        usbRegs->INDEX=index_save;
}

// sample peripheral code
Uint16 usbMain(void) {
        usb_init();
        usb_device_init();  // initialize usb core related vars: index, fifo, etc and DMA related
vars, data buff, rx/txSubmitQ, etc
        wait_for_reset();   // wait here until host performs a reset.
        cppiDmaInit();  // Init CPPI 4.1 DMA
// ****************** Initialize Receive Buffer Descriptors ***********************************
// Host is performing a transfer and the device is going to loop it back out.
// The example below (non commented part of the code) applies for a data transfer made of two 64
bytes packet.
// These two packets are treated as part of a single transfer for Non-
Transparent DMA modes and as two transfers for Transparent
//   DMA mode. This needs to be understood for the below to make sense, especially the last
Descriptor shown below.
// Initialize receive descriptors (HBDs)
        initSingleHPDorHBD(0,RECEIVE,BUFFER_DESC,rxCompQ);  //Usage:
initSingleHPDorHBD(descNum,dir,TypeOfDesc,returnQueue)
        if (DESCsetup==MULTIPLE_DESC_SETUP) {
              initSingleHPDorHBD(1,RECEIVE,BUFFER_DESC,rxCompQ);  //Usage:
initSingleHPDorHBD(descNum,dir,TypeOfDesc,returnQueue)
        //    initSingleHPDorHBD(2,RECEIVE,BUFFER_DESC,rxCompQ);  //Usage:
initSingleHPDorHBD(descNum,dir,TypeOfDesc,returnQueue)
        //    initSingleHPDorHBD(3,RECEIVE,BUFFER_DESC,rxCompQ);  //Usage:
initSingleHPDorHBD(descNum,dir,TypeOfDesc,returnQueue)

        //       :
        //       :
        }

// Last Receive Descriptor creation (this is the case where two or three Buffer Descriptors are
needed).
// Note again that this example is for a two packet data transfer.
        if (DMAmode!=TRANSPARENT) {   // Need to Create the Descriptor to be used for the Null
Packet.
```

Example 33-5. Programming the USB DMA Controller (continued)

```
            if (DESCsetup==SINGLE_DESC_SETUP)     // One additonal Rx Desc Needs to be Queued for
Handling Null Packet
                initSingleHPDorHBD(1,RECEIVE,BUFFER_DESC,rxCompQ);         //Usage:
initSingleHPDorHBD(descNum,dir,TypeOfDesc,returnQueue)
                        else
                                    initSingleHPDorHBD(2,RECEIVE,BUFFER_DESC,rxCompQ);
//Usage: initSingleHPDorHBD(descNum,dir,TypeOfDesc,returnQueue)
            }

// ****************** Initialize Transmit Packet and Buffer Descriptors************************
// See comment above to understand the reasons for the total number of descriptors.
// Initialize transmit descriptors (HPD and HBDs)
        //Initialize HPD Descriptor 16 for Transmit.
        initSingleHPDorHBD(16,TRANSMIT,PACKET_DESC,txCompQ);   //Usage:
initSingleHPDorHBD(descNum,dir,TypeOfDesc,returnQueue)
        if (DESCsetup==MULTIPLE_DESC_SETUP) {
                if(DMAmode==TRANSPARENT) {
                        initSingleHPDorHBD(17,TRANSMIT,PACKET_DESC,txCompQ);   //Usage:
initSingleHPDorHBD(descNum,dir,TypeOfDesc,returnQueue)
//                      initSingleHPDorHBD(18,TRANSMIT,PACKET_DESC,txCompQ);   //Usage:
initSingleHPDorHBD(descNum,dir,TypeOfDesc,returnQueue)
//                      initSingleHPDorHBD(19,TRANSMIT,PACKET_DESC,txCompQ);   //Usage:
initSingleHPDorHBD(descNum,dir,TypeOfDesc,returnQueue)
                }
                else {
                        initSingleHPDorHBD(17,TRANSMIT,BUFFER_DESC,txCompQ);    //Usage:
initSingleHPDorHBD(descNum,dir,TypeOfDesc,returnQueue)
//                      initSingleHPDorHBD(18,TRANSMIT,BUFFER_DESC,txCompQ);    //Usage:
initSingleHPDorHBD(descNum,dir,TypeOfDesc,returnQueue)
//                      initSingleHPDorHBD(19,TRANSMIT,BUFFER_DESC,txCompQ);    //Usage:
initSingleHPDorHBD(descNum,dir,TypeOfDesc,returnQueue)
                }
            }
// ****************** Submit Receive Buffer Descriptors ***************************************
        //Submit Receive Descriptors
        qDesc2SubmitQ(rxSubmitQ,0);            //Queue Number, HPDdescriptorNumber
        if (DESCsetup==MULTIPLE_DESC_SETUP)
                qDesc2SubmitQ(rxSubmitQ,1);            //Queue Number, HPDdescriptorNumber

        if (DMAmode!=TRANSPARENT) {   // Need to Submit the Descriptor to be used for the Null
Packet.
                if (DESCsetup==SINGLE_DESC_SETUP)     // One additonal Rx Desc Needs to be Queued
for Handling Null Packet
                        qDesc2SubmitQ(rxSubmitQ,1);            //Queue Number, HPDdescriptorNumber
                else
                        qDesc2SubmitQ(rxSubmitQ,2);            //Queue Number, HPDdescriptorNumber
        }

        //Enable Rx DMA
        enableCoreRxDMA(endpoint);
// ****************** Submit Transmit Buffer Descriptors ************************************

// wait till all data is received here <<<<<<<


        //Submit Transmit Descriptors
        qDesc2SubmitQ(txSubmitQ,16);  //Queue Number, HPDdescriptorNumber
        if (DESCsetup==MULTIPLE_DESC_SETUP)
                qDesc2SubmitQ(txSubmitQ,17);  //Queue Number, HPDdescriptorNumber
//      qDesc2SubmitQ(txSubmitQ,18);  //Queue Number, HPDdescriptorNumber
        enableCoreTxDMA(endpoint);
// ******************************************************************************************

// wait till all data is received here <<<<<<<
```

33.4 Registers

Table 33-30 lists the memory-mapped registers for the universal serial bus OTG controller (USB0). See your device-specific data manual for the memory address of these registers. The base address is 01E0 0000h.

NOTE: In some cases, a single register address can have different names or meanings depending on the mode (host/peripheral) or the setting of the index register. The meaning of some bit fields varies with the mode.

Table 33-30. Universal Serial Bus OTG (USB0) Registers

VBUS Slave Address Offset	Acronym	Register Description	Section
0h	REVID	Revision Identification Register	Section 33.4.1
4h	CTRLR	Control Register	Section 33.4.2
8h	STATR	Status Register	Section 33.4.3
Ch	EMUR	Emulation Register	Section 33.4.4
10h	MODE	Mode Register	Section 33.4.5
14h	AUTOREQ	Autorequest Register	Section 33.4.6
18h	SRPFIXTIME	SRP Fix Time Register	Section 33.4.7
1Ch	TEARDOWN	Teardown Register	Section 33.4.8
20h	INTSRCR	USB Interrupt Source Register	Section 33.4.9
24h	INTSETR	USB Interrupt Source Set Register	Section 33.4.10
28h	INTCLRR	USB Interrupt Source Clear Register	Section 33.4.11
2Ch	INTMSKR	USB Interrupt Mask Register	Section 33.4.12
30h	INTMSKSETR	USB Interrupt Mask Set Register	Section 33.4.13
34h	INTMSKCLRR	USB Interrupt Mask Clear Register	Section 33.4.14
38h	INTMASKEDR	USB Interrupt Source Masked Register	Section 33.4.15
3Ch	EOIR	USB End of Interrupt Register	Section 33.4.16
50h	GENRNDISSZ1	Generic RNDIS Size EP1	Section 33.4.17
54h	GENRNDISSZ2	Generic RNDIS Size EP2	Section 33.4.18
58h	GENRNDISSZ3	Generic RNDIS Size EP3	Section 33.4.19
5Ch	GENRNDISSZ4	Generic RNDIS Size EP4	Section 33.4.20
		Common USB Registers	
400h	FADDR	Function Address Register	Section 33.4.21
401h	POWER	Power Management Register	Section 33.4.22
402h	INTRTX	Interrupt Register for Endpoint 0 plus Transmit Endpoints 1 to 4	Section 33.4.23
404h	INTRRX	Interrupt Register for Receive Endpoints 1 to 4	Section 33.4.24
406h	INTRTXE	Interrupt Enable Register for INTRTX	Section 33.4.25
408h	INTRRXE	Interrupt Enable Register for INTRRX	Section 33.4.26
40Ah	INTRUSB	Interrupt Register for Common USB Interrupts	Section 33.4.27
40Bh	INTRUSBE	Interrupt Enable Register for INTRUSB	Section 33.4.28
40Ch	FRAME	Frame Number Register	Section 33.4.29
40Eh	INDEX	Index Register for Selecting the Endpoint Status and Control Registers	Section 33.4.30
40Fh	TESTMODE	Register to Enable the USB 2.0 Test Modes	Section 33.4.31

Table 33-30. Universal Serial Bus OTG (USB0) Registers (continued)

VBUS Slave Address Offset	Acronym	Register Description	Section
		Indexed Registers	
		These registers operate on the endpoint selected by the INDEX register	
410h	TXMAXP	Maximum Packet Size for Peripheral/Host Transmit Endpoint (Index register set to select Endpoints 1-4 only)	Section 33.4.32
412h	PERI_CSR0	Control Status Register for Endpoint 0 in Peripheral Mode. (Index register set to select Endpoint 0)	Section 33.4.33
	HOST_CSR0	Control Status Register for Endpoint 0 in Host Mode. (Index register set to select Endpoint 0)	Section 33.4.34
	PERI_TXCSR	Control Status Register for Peripheral Transmit Endpoint. (Index register set to select Endpoints 1-4)	Section 33.4.35
	HOST_TXCSR	Control Status Register for Host Transmit Endpoint. (Index register set to select Endpoints 1-4)	Section 33.4.36
414h	RXMAXP	Maximum Packet Size for Peripheral/Host Receive Endpoint (Index register set to select Endpoints 1-4 only)	Section 33.4.37
416h	PERI_RXCSR	Control Status Register for Peripheral Receive Endpoint. (Index register set to select Endpoints 1-4)	Section 33.4.38
	HOST_RXCSR	Control Status Register for Host Receive Endpoint. (Index register set to select Endpoints 1-4)	Section 33.4.39
418h	COUNT0	Number of Received Bytes in Endpoint 0 FIFO. (Index register set to select Endpoint 0)	Section 33.4.40
	RXCOUNT	Number of Bytes in Host Receive Endpoint FIFO. (Index register set to select Endpoints 1- 4)	Section 33.4.41
41Ah	HOST_TYPE0	Defines the speed of Endpoint 0	Section 33.4.42
	HOST_TXTYPE	Sets the operating speed, transaction protocol and peripheral endpoint number for the host Transmit endpoint. (Index register set to select Endpoints 1-4 only)	Section 33.4.43
41Bh	HOST_NAKLIMIT0	Sets the NAK response timeout on Endpoint 0. (Index register set to select Endpoint 0)	Section 33.4.44
	HOST_TXINTERVAL	Sets the polling interval for Interrupt/ISOC transactions or the NAK response timeout on Bulk transactions for host Transmit endpoint. (Index register set to select Endpoints 1-4 only)	Section 33.4.45
41Ch	HOST_RXTYPE	Sets the operating speed, transaction protocol and peripheral endpoint number for the host Receive endpoint. (Index register set to select Endpoints 1-4 only)	Section 33.4.46
41Dh	HOST_RXINTERVAL	Sets the polling interval for Interrupt/ISOC transactions or the NAK response timeout on Bulk transactions for host Receive endpoint. (Index register set to select Endpoints 1-4 only)	Section 33.4.47
41Fh	CONFIGDATA	Returns details of core configuration. (Index register set to select Endpoint 0)	Section 33.4.48
		FIFOn	
420h	FIFO0	Transmit and Receive FIFO Register for Endpoint 0	Section 33.4.49
424h	FIFO1	Transmit and Receive FIFO Register for Endpoint 1	Section 33.4.50
428h	FIFO2	Transmit and Receive FIFO Register for Endpoint 2	Section 33.4.51
42Ch	FIFO3	Transmit and Receive FIFO Register for Endpoint 3	Section 33.4.52
430h	FIFO4	Transmit and Receive FIFO Register for Endpoint 4	Section 33.4.53
		OTG Device Control	
460h	DEVCTL	Device Control Register	Section 33.4.54

Table 33-30. Universal Serial Bus OTG (USB0) Registers (continued)

VBUS Slave Address Offset	Acronym	Register Description	Section
		Dynamic FIFO Control	
462h	TXFIFOSZ	Transmit Endpoint FIFO Size (Index register set to select Endpoints 1-4 only)	Section 33.4.55
463h	RXFIFOSZ	Receive Endpoint FIFO Size (Index register set to select Endpoints 1-4 only)	Section 33.4.56
464h-465h	TXFIFOADDR	Transmit Endpoint FIFO Address (Index register set to select Endpoints 1-4 only)	Section 33.4.57
466h-467h	RXFIFOADDR	Receive Endpoint FIFO Address (Index register set to select Endpoints 1-4 only)	Section 33.4.58
46Ch-46Dh	HWVERS	Hardware Version Register	Section 33.4.59
		Target Endpoint 0 Control Registers, Valid Only in Host Mode	
480h	TXFUNCADDR	Address of the target function that has to be accessed through the associated Transmit Endpoint.	Section 33.4.60
482h	TXHUBADDR	Address of the hub that has to be accessed through the associated Transmit Endpoint. This is used only when full speed or low speed device is connected via a USB2.0 high-speed hub.	Section 33.4.61
483h	TXHUBPORT	Port of the hub that has to be accessed through the associated Transmit Endpoint. This is used only when full speed or low speed device is connected via a USB2.0 high-speed hub.	Section 33.4.62
484h	RXFUNCADDR	Address of the target function that has to be accessed through the associated Receive Endpoint.	Section 33.4.63
486h	RXHUBADDR	Address of the hub that has to be accessed through the associated Receive Endpoint. This is used only when full speed or low speed device is connected via a USB2.0 high-speed hub.	Section 33.4.64
487h	RXHUBPORT	Port of the hub that has to be accessed through the associated Receive Endpoint. This is used only when full speed or low speed device is connected via a USB2.0 high-speed hub.	Section 33.4.65
		Target Endpoint 1 Control Registers, Valid Only in Host Mode	
488h	TXFUNCADDR	Address of the target function that has to be accessed through the associated Transmit Endpoint.	Section 33.4.60
48Ah	TXHUBADDR	Address of the hub that has to be accessed through the associated Transmit Endpoint. This is used only when full speed or low speed device is connected via a USB2.0 high-speed hub.	Section 33.4.61
48Bh	TXHUBPORT	Port of the hub that has to be accessed through the associated Transmit Endpoint. This is used only when full speed or low speed device is connected via a USB2.0 high-speed hub.	Section 33.4.62
48Ch	RXFUNCADDR	Address of the target function that has to be accessed through the associated Receive Endpoint.	Section 33.4.63
48Eh	RXHUBADDR	Address of the hub that has to be accessed through the associated Receive Endpoint. This is used only when full speed or low speed device is connected via a USB2.0 high-speed hub.	Section 33.4.64
48Fh	RXHUBPORT	Port of the hub that has to be accessed through the associated Receive Endpoint. This is used only when full speed or low speed device is connected via a USB2.0 high-speed hub.	Section 33.4.65

Table 33-30. Universal Serial Bus OTG (USB0) Registers (continued)

VBUS Slave Address Offset	Acronym	Register Description	Section
		Target Endpoint 2 Control Registers, Valid Only in Host Mode	
490h	TXFUNCADDR	Address of the target function that has to be accessed through the associated Transmit Endpoint.	Section 33.4.60
492h	TXHUBADDR	Address of the hub that has to be accessed through the associated Transmit Endpoint. This is used only when full speed or low speed device is connected via a USB2.0 high-speed hub.	Section 33.4.61
493h	TXHUBPORT	Port of the hub that has to be accessed through the associated Transmit Endpoint. This is used only when full speed or low speed device is connected via a USB2.0 high-speed hub.	Section 33.4.62
494h	RXFUNCADDR	Address of the target function that has to be accessed through the associated Receive Endpoint.	Section 33.4.63
496h	RXHUBADDR	Address of the hub that has to be accessed through the associated Receive Endpoint. This is used only when full speed or low speed device is connected via a USB2.0 high-speed hub.	Section 33.4.64
497h	RXHUBPORT	Port of the hub that has to be accessed through the associated Receive Endpoint. This is used only when full speed or low speed device is connected via a USB2.0 high-speed hub.	Section 33.4.65
		Target Endpoint 3 Control Registers, Valid Only in Host Mode	
498h	TXFUNCADDR	Address of the target function that has to be accessed through the associated Transmit Endpoint.	Section 33.4.60
49Ah	TXHUBADDR	Address of the hub that has to be accessed through the associated Transmit Endpoint. This is used only when full speed or low speed device is connected via a USB2.0 high-speed hub.	Section 33.4.61
49Bh	TXHUBPORT	Port of the hub that has to be accessed through the associated Transmit Endpoint. This is used only when full speed or low speed device is connected via a USB2.0 high-speed hub.	Section 33.4.62
49Ch	RXFUNCADDR	Address of the target function that has to be accessed through the associated Receive Endpoint.	Section 33.4.63
49Eh	RXHUBADDR	Address of the hub that has to be accessed through the associated Receive Endpoint. This is used only when full speed or low speed device is connected via a USB2.0 high-speed hub.	Section 33.4.64
49Fh	RXHUBPORT	Port of the hub that has to be accessed through the associated Receive Endpoint. This is used only when full speed or low speed device is connected via a USB2.0 high-speed hub.	Section 33.4.65
		Target Endpoint 4 Control Registers, Valid Only in Host Mode	
4A0h	TXFUNCADDR	Address of the target function that has to be accessed through the associated Transmit Endpoint.	Section 33.4.60
4A2h	TXHUBADDR	Address of the hub that has to be accessed through the associated Transmit Endpoint. This is used only when full speed or low speed device is connected via a USB2.0 high-speed hub.	Section 33.4.61
4A3h	TXHUBPORT	Port of the hub that has to be accessed through the associated Transmit Endpoint. This is used only when full speed or low speed device is connected via a USB2.0 high-speed hub.	Section 33.4.62
4A4h	RXFUNCADDR	Address of the target function that has to be accessed through the associated Receive Endpoint.	Section 33.4.63

Table 33-30. Universal Serial Bus OTG (USB0) Registers (continued)

VBUS Slave Address Offset	Acronym	Register Description	Section
4A6h	RXHUBADDR	Address of the hub that has to be accessed through the associated Receive Endpoint. This is used only when full speed or low speed device is connected via a USB2.0 high-speed hub.	Section 33.4.64
4A7h	RXHUBPORT	Port of the hub that has to be accessed through the associated Receive Endpoint. This is used only when full speed or low speed device is connected via a USB2.0 high-speed hub.	Section 33.4.65
		Control and Status Register for Endpoint 0	
502h	PERI_CSR0	Control Status Register for Endpoint 0 in Peripheral Mode	Section 33.4.33
	HOST_CSR0	Control Status Register for Endpoint 0 in Host Mode	Section 33.4.34
508h	COUNT0	Number of Received Bytes in Endpoint 0 FIFO	Section 33.4.40
50Ah	HOST_TYPE0	Defines the Speed of Endpoint 0	Section 33.4.42
50Bh	HOST_NAKLIMIT0	Sets the NAK Response Timeout on Endpoint 0	Section 33.4.44
50Fh	CONFIGDATA	Returns details of core configuration	Section 33.4.48
		Control and Status Register for Endpoint 1	
510h	TXMAXP	Maximum Packet Size for Peripheral/Host Transmit Endpoint	Section 33.4.32
512h	PERI_TXCSR	Control Status Register for Peripheral Transmit Endpoint (peripheral mode)	Section 33.4.35
	HOST_TXCSR	Control Status Register for Host Transmit Endpoint (host mode)	Section 33.4.36
514h	RXMAXP	Maximum Packet Size for Peripheral/Host Receive Endpoint	Section 33.4.37
516h	PERI_RXCSR	Control Status Register for Peripheral Receive Endpoint (peripheral mode)	Section 33.4.38
	HOST_RXCSR	Control Status Register for Host Receive Endpoint (host mode)	Section 33.4.39
518h	RXCOUNT	Number of Bytes in Host Receive endpoint FIFO	Section 33.4.41
51Ah	HOST_TXTYPE	Sets the operating speed, transaction protocol and peripheral endpoint number for the host Transmit endpoint.	Section 33.4.43
51Bh	HOST_TXINTERVAL	Sets the polling interval for Interrupt/ISOC transactions or the NAK response timeout on Bulk transactions for host Transmit endpoint.	Section 33.4.45
51Ch	HOST_RXTYPE	Sets the operating speed, transaction protocol and peripheral endpoint number for the host Receive endpoint.	Section 33.4.46
51Dh	HOST_RXINTERVAL	Sets the polling interval for Interrupt/ISOC transactions or the NAK response timeout on Bulk transactions for host Receive endpoint.	Section 33.4.47
		Control and Status Register for Endpoint 2	
520h	TXMAXP	Maximum Packet Size for Peripheral/Host Transmit Endpoint	Section 33.4.32
522h	PERI_TXCSR	Control Status Register for Peripheral Transmit Endpoint (peripheral mode)	Section 33.4.35
	HOST_TXCSR	Control Status Register for Host Transmit Endpoint (host mode)	Section 33.4.36
524h	RXMAXP	Maximum Packet Size for Peripheral/Host Receive Endpoint	Section 33.4.37
526h	PERI_RXCSR	Control Status Register for Peripheral Receive Endpoint (peripheral mode)	Section 33.4.38
	HOST_RXCSR	Control Status Register for Host Receive Endpoint (host mode)	Section 33.4.39
528h	RXCOUNT	Number of Bytes in Host Receive endpoint FIFO	Section 33.4.41
52Ah	HOST_TXTYPE	Sets the operating speed, transaction protocol and peripheral endpoint number for the host Transmit endpoint.	Section 33.4.43

Table 33-30. Universal Serial Bus OTG (USB0) Registers (continued)

VBUS Slave Address Offset	Acronym	Register Description	Section
52Bh	HOST_TXINTERVAL	Sets the polling interval for Interrupt/ISOC transactions or the NAK response timeout on Bulk transactions for host Transmit endpoint.	Section 33.4.45
52Ch	HOST_RXTYPE	Sets the operating speed, transaction protocol and peripheral endpoint number for the host Receive endpoint.	Section 33.4.46
52Dh	HOST_RXINTERVAL	Sets the polling interval for Interrupt/ISOC transactions or the NAK response timeout on Bulk transactions for host Receive endpoint.	Section 33.4.47
		Control and Status Register for Endpoint 3	
530h	TXMAXP	Maximum Packet Size for Peripheral/Host Transmit Endpoint	Section 33.4.32
532h	PERI_TXCSR	Control Status Register for Peripheral Transmit Endpoint (peripheral mode)	Section 33.4.35
	HOST_TXCSR	Control Status Register for Host Transmit Endpoint (host mode)	Section 33.4.36
534h	RXMAXP	Maximum Packet Size for Peripheral/Host Receive Endpoint	Section 33.4.37
536h	PERI_RXCSR	Control Status Register for Peripheral Receive Endpoint (peripheral mode)	Section 33.4.38
	HOST_RXCSR	Control Status Register for Host Receive Endpoint (host mode)	Section 33.4.39
538h	RXCOUNT	Number of Bytes in Host Receive endpoint FIFO	Section 33.4.41
53Ah	HOST_TXTYPE	Sets the operating speed, transaction protocol and peripheral endpoint number for the host Transmit endpoint.	Section 33.4.43
53Bh	HOST_TXINTERVAL	Sets the polling interval for Interrupt/ISOC transactions or the NAK response timeout on Bulk transactions for host Transmit endpoint.	Section 33.4.45
53Ch	HOST_RXTYPE	Sets the operating speed, transaction protocol and peripheral endpoint number for the host Receive endpoint.	Section 33.4.46
53Dh	HOST_RXINTERVAL	Sets the polling interval for Interrupt/ISOC transactions or the NAK response timeout on Bulk transactions for host Receive endpoint.	Section 33.4.47
		Control and Status Register for Endpoint 4	
540h	TXMAXP	Maximum Packet Size for Peripheral/Host Transmit Endpoint	Section 33.4.32
542h	PERI_TXCSR	Control Status Register for Peripheral Transmit Endpoint (peripheral mode)	Section 33.4.35
	HOST_TXCSR	Control Status Register for Host Transmit Endpoint (host mode)	Section 33.4.36
544h	RXMAXP	Maximum Packet Size for Peripheral/Host Receive Endpoint	Section 33.4.37
546h	PERI_RXCSR	Control Status Register for Peripheral Receive Endpoint (peripheral mode)	Section 33.4.38
	HOST_RXCSR	Control Status Register for Host Receive Endpoint (host mode)	Section 33.4.39
548h	RXCOUNT	Number of Bytes in Host Receive endpoint FIFO	Section 33.4.41
54Ah	HOST_TXTYPE	Sets the operating speed, transaction protocol and peripheral endpoint number for the host Transmit endpoint.	Section 33.4.43
54Bh	HOST_TXINTERVAL	Sets the polling interval for Interrupt/ISOC transactions or the NAK response timeout on Bulk transactions for host Transmit endpoint.	Section 33.4.45
54Ch	HOST_RXTYPE	Sets the operating speed, transaction protocol and peripheral endpoint number for the host Receive endpoint.	Section 33.4.46
54Dh	HOST_RXINTERVAL	Sets the polling interval for Interrupt/ISOC transactions or the NAK response timeout on Bulk transactions for host Receive endpoint.	Section 33.4.47

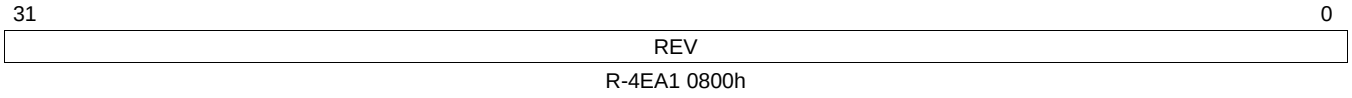
Table 33-30. Universal Serial Bus OTG (USB0) Registers (continued)

VBUS Slave Address Offset	Acronym	Register Description	Section
		CDMA Registers	
1000h	DMAREVID	CDMA Revision Identification Register	Section 33.4.66
1004h	TDFDQ	CDMA Teardown Free Descriptor Queue Control Register	Section 33.4.67
1008h	DMAEMU	CDMA Emulation Control Register	Section 33.4.68
1800h	TXGCR[0]	Transmit Channel 0 Global Configuration Register	Section 33.4.69
1808h	RXGCR[0]	Receive Channel 0 Global Configuration Register	Section 33.4.70
180Ch	RXHPCRA[0]	Receive Channel 0 Host Packet Configuration Register A	Section 33.4.71
1810h	RXHPCRB[0]	Receive Channel 0 Host Packet Configuration Register B	Section 33.4.72
1820h	TXGCR[1]	Transmit Channel 1 Global Configuration Register	Section 33.4.69
1828h	RXGCR[1]	Receive Channel 1 Global Configuration Register	Section 33.4.70
182Ch	RXHPCRA[1]	Receive Channel 1 Host Packet Configuration Register A	Section 33.4.71
1830h	RXHPCRB[1]	Receive Channel 1 Host Packet Configuration Register B	Section 33.4.72
1840h	TXGCR[2]	Transmit Channel 2 Global Configuration Register	Section 33.4.69
1848h	RXGCR[2]	Receive Channel 2 Global Configuration Register	Section 33.4.70
184Ch	RXHPCRA[2]	Receive Channel 2 Host Packet Configuration Register A	Section 33.4.71
1850h	RXHPCRB[2]	Receive Channel 2 Host Packet Configuration Register B	Section 33.4.72
1860h	TXGCR[3]	Transmit Channel 3 Global Configuration Register	Section 33.4.69
1868h	RXGCR[3]	Receive Channel 3 Global Configuration Register	Section 33.4.70
186Ch	RXHPCRA[3]	Receive Channel 3 Host Packet Configuration Register A	Section 33.4.71
1870h	RXHPCRB[3]	Receive Channel 3 Host Packet Configuration Register B	Section 33.4.72
2000h	DMA_SCHED_CTRL	CDMA Scheduler Control Register	Section 33.4.73
2800h-28FCh	WORD[0]-WORD[63]	CDMA Scheduler Table Word 0-63 Registers	Section 33.4.74
		Queue Manager (QMGR) Registers	
4000h	QMGRREVID	QMGR Revision Identification Register	Section 33.4.75
4008h	DIVERSION	QMGR Queue Diversion Register	Section 33.4.76
4020h	FDBSC0	QMGR Free Descriptor/Buffer Starvation Count Register 0	Section 33.4.77
4024h	FDBSC1	QMGR Free Descriptor/Buffer Starvation Count Register 1	Section 33.4.78
4028h	FDBSC2	QMGR Free Descriptor/Buffer Starvation Count Register 2	Section 33.4.79
402Ch	FDBSC3	QMGR Free Descriptor/Buffer Starvation Count Register 3	Section 33.4.80
4080h	LRAM0BASE	QMGR Linking RAM Region 0 Base Address Register	Section 33.4.81
4084h	LRAM0SIZE	QMGR Linking RAM Region 0 Size Register	Section 33.4.82
4088h	LRAM1BASE	QMGR Linking RAM Region 1 Base Address Register	Section 33.4.83
4090h	PEND0	QMGR Queue Pending Register 0	Section 33.4.84
4094h	PEND1	QMGR Queue Pending Register 1	Section 33.4.85
5000h + 16 × *R*	QMEMRBASE[*R*]	QMGR Memory Region *R* Base Address Register (*R* = 0 to 15)	Section 33.4.86
5004h + 16 × *R*	QMEMRCTRL[*R*]	QMGR Memory Region *R* Control Register (*R* = 0 to 15)	Section 33.4.87
600Ch + 16 × *N*	CTRLD[*N*]	QMGR Queue *N* Control Register D (*N* = 0 to 63)	Section 33.4.88
6800h + 16 × *N*	QSTATA[*N*]	QMGR Queue *N* Status Register A (*N* = 0 to 63)	Section 33.4.89
6804h + 16 × *N*	QSTATB[*N*]	QMGR Queue *N* Status Register B (*N* = 0 to 63)	Section 33.4.90
6808h + 16 × *N*	QSTATC[*N*]	QMGR Queue *N* Status Register C (*N* = 0 to 63)	Section 33.4.91

33.4.1 Revision Identification Register (REVID)

The revision identification register (REVID) contains the revision for the USB 2.0 OTG controller module. The REVID is shown in Figure 33-27 and described in Table 33-31.

Figure 33-27. Revision Identification Register (REVID)



LEGEND: R = Read only; -*n* = value after reset

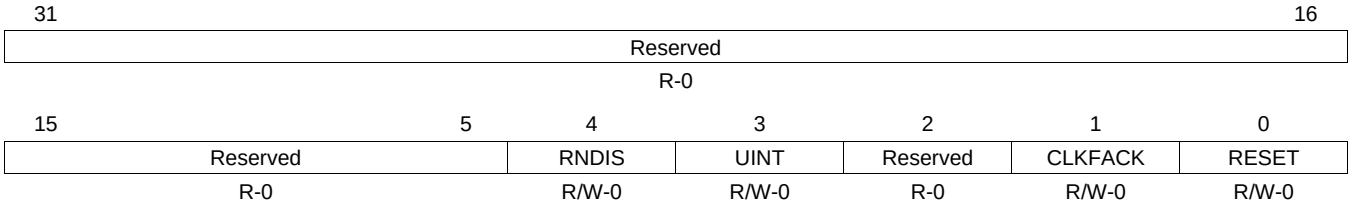
Table 33-31. Revision Identification Register (REVID) Field Descriptions

Bit	Field	Value	Description
31-0	REV	4EA1 0800h	Revision ID of the USB module.

33.4.2 Control Register (CTRLR)

The control register (CTRLR) allows the CPU to control various aspects of the module. The CTRLR is shown in Figure 33-28 and described in Table 33-32.

Figure 33-28. Control Register (CTRLR)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 33-32. Control Register (CTRLR) Field Descriptions

Bit	Field	Value	Description
31-5	Reserved	0	Reserved
4	RNDIS		Global RNDIS mode enable for all endpoints.
		0	Global RNDIS mode is disabled.
		1	Global RNDIS mode is enabled.
3	UINT		USB non-PDR interrupt handler enable.
		0	PDR interrupt handler is enabled.
		1	PDR interrupt handler is disabled.
2	Reserved	0	Reserved
1	CLKFACK		Clock stop fast ACK enable.
		0	Clock stop fast ACK is disabled.
		1	Clock stop fast ACK is enabled.
0	RESET		Soft reset.
		0	No effect.
		1	Writing a 1 starts a module reset. The USB controller will clear this bit when it completes reset.

33.4.3 Status Register (STATR)

The status register (STATR) allows the CPU to check various aspects of the module. The STATR is shown in Figure 33-29 and described in Table 33-33.

Figure 33-29. Status Register (STATR)

31	16
Reserved	
R-0	

15	1	0
Reserved		DRVVBUS
R-0		R-0

LEGEND: R = Read only; -*n* = value after reset

Table 33-33. Status Register (STATR) Field Descriptions

Bit	Field	Value	Description
31-1	Reserved	0	Reserved
0	DRVVBUS		Current DRVVBUS value.
		0	DRVVBUS value is logic 0.
		1	DRVVBUS value is logic 1.

33.4.4 Emulation Register (EMUR)

The emulation register (EMUR) allows the CPU to configure the CBA 3.0 emulation interface. The EMUR is shown in Figure 33-30 and described in Table 33-34.

Figure 33-30. Emulation Register (EMUR)

31	16
Reserved	
R-0	

15	3	2	1	0
Reserved		RT_SEL	SOFT	FREERUN
R-0		R/W-0	R/W-1	R/W-1

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 33-34. Emulation Register (EMUR) Field Descriptions

Bit	Field	Value	Description
31-3	Reserved	0	Reserved
2	RT_SEL		Real-time enable
		0	Enable
		1	No effect
1	SOFT		Soft stop
		0	No effect
		1	Soft stop enable
0	FREERUN		Free run
		0	No effect
		1	Free run enable

33.4.5 Mode Register (MODE)

The mode register (MODE) allows the CPU to individually enable RNDIS/Generic/CDC modes for each endpoint. Using the global RNDIS bit in the control register (CTRLR) overrides this register and enables RNDIS mode for all endpoints. The MODE is shown in Figure 33-31 and described in Table 33-35.

Figure 33-31. Mode Register (MODE)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved		RX4_MODE		Reserved		RX3_MODE		Reserved		RX2_MODE		Reserved		RX1_MODE	
R-0		R/W-0		R-0		R/W-0		R-0		R/W-0		R-0		R/W-0	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved		TX4_MODE		Reserved		TX3_MODE		Reserved		TX2_MODE		Reserved		TX1_MODE	
R-0		R/W-0		R-0		R/W-0		R-0		R/W-0		R-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 33-35. Mode Register (MODE) Field Descriptions

Bit	Field	Value	Description
31-30	Reserved	0	Reserved
29-28	RX4_MODE	0-3h	Receive endpoint 4 mode control
		0	Transparent mode on Receive endpoint 4
		1h	RNDIS mode on Receive endpoint 4
		2h	CDC mode on Receive endpoint 4
		3h	Generic RNDIS mode on Receive endpoint 4
27-26	Reserved	0	Reserved
25-24	RX3_MODE	0-3h	Receive endpoint 3 mode control
		0	Transparent mode on Receive endpoint 3
		1h	RNDIS mode on Receive endpoint 3
		2h	CDC mode on Receive endpoint 3
		3h	Generic RNDIS mode on Receive endpoint 3
23-22	Reserved	0	Reserved
21-20	RX2_MODE	0-3h	Receive endpoint 2 mode control
		0	Transparent mode on Receive endpoint 2
		1h	RNDIS mode on Receive endpoint 2
		2h	CDC mode on Receive endpoint 2
		3h	Generic RNDIS mode on Receive endpoint 2
19-18	Reserved	0	Reserved
17-16	RX1_MODE	0-3h	Receive endpoint 1 mode control
		0	Transparent mode on Receive endpoint 1
		1h	RNDIS mode on Receive endpoint 1
		2h	CDC mode on Receive endpoint 1
		3h	Generic RNDIS mode on Receive endpoint 1
15-14	Reserved	0	Reserved
13-12	TX4_MODE	0-3h	Transmit endpoint 4 mode control
		0	Transparent mode on Transmit endpoint 4
		1h	RNDIS mode on Transmit endpoint 4
		2h	CDC mode on Transmit endpoint 4
		3h	Generic RNDIS mode on Transmit endpoint 4
11-10	Reserved	0	Reserved

Table 33-35. Mode Register (MODE) Field Descriptions (continued)

Bit	Field	Value	Description
9-8	TX3_MODE	0-3h	Transmit endpoint 3 mode control
		0	Transparent mode on Transmit endpoint 3
		1h	RNDIS mode on Transmit endpoint 3
		2h	CDC mode on Transmit endpoint 3
		3h	Generic RNDIS mode on Transmit endpoint 3
7-6	Reserved	0	Reserved
5-4	TX2_MODE	0-3h	Transmit endpoint 2 mode control
		0	Transparent mode on Transmit endpoint 2
		1h	RNDIS mode on Transmit endpoint 2
		2h	CDC mode on Transmit endpoint 2
		3h	Generic RNDIS mode on Transmit endpoint 2
3-2	Reserved	0	Reserved
1-0	TX1_MODE	0-3h	Transmit endpoint 1 mode control
		0	Transparent mode on Transmit endpoint 1
		1h	RNDIS mode on Transmit endpoint 1
		2h	CDC mode on Transmit endpoint 1
		3h	Generic RNDIS mode on Transmit endpoint 1

33.4.6 Auto Request Register (AUTOREQ)

The auto request register (AUTOREQ) allows the CPU to enable an automatic IN token request generation for host mode RX operation per each RX endpoint. This feature has the DMA set the REQPKT bit in the control status register for host receive endpoint (HOST_RXCSR) when it clears the RXPKTRDY bit after reading out a packet. The REQPKT bit is used by the core to generate an IN token to receive data. By using this feature, the host can automatically generate an IN token after the DMA finishes receiving data and empties an endpoint buffer, thus receiving the next data packet as soon as possible from the connected device. Without this feature, the CPU will have to manually set the REQPKT bit for every USB packet.

There are two modes that auto request can function in: always or all except an EOP. The always mode sets the REQPKT bit after every USB packet the DMA receives thus generating a new IN token after each USB packet. The EOP mode sets the REQPKT bit after every USB packet that is not an EOP (end of packet) in the CPPI descriptor. For RNDIS, CDC, and Generic RNDIS modes, the auto request stops when the EOP is received (either via a short packet for RNDIS, CDC, and Generic RNDIS or the count is reached for Generic RNDIS), making it useful for starting a large RNDIS packet and having it auto generate IN tokens until the end of the RNDIS packet. For transparent mode, every USB packet is an EOP CPPI packet so the auto request never functions and acts like auto request is disabled.

The AUTOREQ is shown in Figure 33-32 and described in Table 33-36.

Figure 33-32. Auto Request Register (AUTOREQ)

31	16
Reserved	
R-0	

15	8	7	6	5	4	3	2	1	0
Reserved		RX4_AUTREQ		RX3_AUTREQ		RX2_AUTREQ		RX1_AUTREQ	
R-0		R/W-0		R/W-0		R/W-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 33-36. Auto Request Register (AUTOREQ) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved
7-6	RX4_AUTREQ	0-3h	Receive endpoint 4 auto request enable
		0	No auto request
		1h	Auto request on all but EOP
		2h	Reserved
		3h	Auto request always
5-4	RX3_AUTREQ	0-3h	Receive endpoint 3 auto request enable
		0	No auto request
		1h	Auto request on all but EOP
		2h	Reserved
		3h	Auto request always
3-2	RX2_AUTREQ	0-3h	Receive endpoint 2 auto request enable
		0	No auto request
		1h	Auto request on all but EOP
		2h	Reserved
		3h	Auto request always
1-0	RX1_AUTREQ	0-3h	Receive endpoint 1 auto request enable
		0	No auto request
		1h	Auto request on all but EOP
		2h	Reserved
		3h	Auto request always

33.4.7 SRP Fix Time Register (SRPFIXTIME)

The SRP fix time register (SRPFIXTIME) allows the CPU to configure the maximum amount of time the SRP fix logic blocks the Avalid from the PHY to the OTG core. The SRPFIXTIME is shown in Figure 33-33 and described in Table 33-37.

Figure 33-33. SRP Fix Time Register (SRPFIXTIME)

31	0
SRPFIXTIME	
R/W-280 DE80h	

LEGEND: R/W = Read/Write; *-n* = value after reset

Table 33-37. SRP Fix Time Register (SRPFIXTIME) Field Descriptions

Bit	Field	Value	Description
31-0	SRPFIXTIME	0-FFFF FFFFh	SRP fix maximum time in 60 MHz cycles. Default is 700 ms (280 DE80h).

33.4.8 Teardown Register (TEARDOWN)

The teardown register (TEARDOWN) controls the tearing down of receive and transmit FIFOs in the USB controller. When a 1 is written to a valid bit in TEARDOWN, the CPPI FIFO pointers for that endpoint are cleared. TEARDOWN must be used in conjunction with the CPPI DMA teardown mechanism. The Host should also write the FLUSHFIFO bits in the TXCSR and RXCSR registers to ensure a complete teardown of the endpoint.

The TEARDOWN is shown in Figure 33-34 and described in Table 33-38.

Figure 33-34. Teardown Register (TEARDOWN)

31	21	20	17	16
Reserved		TX_TDOWN		Rsvd
R-0		R/W-0		R-0

15	5	4	1	0
Reserved		RX_TDOWN		Rsvd
R-0		R/W-0		R-0

LEGEND: R/W = Read/Write; R = Read only; *-n* = value after reset

Table 33-38. Teardown Register (TEARDOWN) Field Descriptions

Bit	Field	Value	Description
31-21	Reserved	0	Reserved
20-17	TX_TDOWN		Transmit endpoint teardown. Set the bit that corresponds to the Endpoint (for EP1, set bit 17; for EP2, set bit 18; for EP3, set bit 19; for EP4, set bit 20).
		0	Disable
		1	Enable
16-5	Reserved	0	Reserved
4-1	RX_TDOWN		Receive endpoint teardown
		0	Disable
		1	Enable
0	Reserved	0	Reserved

33.4.9 USB Interrupt Source Register (INTSRCR)

The USB interrupt source register (INTSRCR) contains the status of the interrupt sources generated by the USB core (not by the DMA). The INTSRCR is shown in Figure 33-35 and described in Table 33-39.

NOTE: Other than the USB bit field, to make use of INTSRCR, the PDR interrupt handler must be enabled (the UINT bit in the control register (CTRLR) is cleared to 0). If the UINT bit in CTRLR is set to 1, you need to use the interrupt status/flag from the core register space.

Figure 33-35. USB Interrupt Source Register (INTSRCR)

31	25	24	16
Reserved		USB	
R-0		R-0	

15	13	12	9	8	5	4	1	0
Reserved		RXEP[*n*]		Reserved		TXEP[*n*]		EP0
R-0		R-0		R-0		R-0		R-0

LEGEND: R = Read only; -*n* = value after reset

Table 33-39. USB Interrupt Source Register (INTSRCR) Field Descriptions

Bit	Field	Value	Description
31-25	Reserved	0	Reserved
24-16	USB	0-1FFh	USB interrupt sources. Generated by the USB core (not by the DMA). Note: INTRUSB core interrupts are mapped onto bits 23-16 and bit 24 is the USBDRVVBUS interrupt status.
15-13	Reserved	0	Reserved
12-9	RXEP[*n*]		Receive endpoint *n* interrupt source.
		0	RXEP*n* interrupt is not generated by the USB core.
		1	RXEP*n* interrupt is generated by the USB core (not by the DMA).
8-5	Reserved	0	Reserved
4-1	TXEP[*n*]		Transmit endpoint *n* interrupt source.
		0	TXEP*n* interrupt is not generated by the USB core.
		1	TXEP*n* interrupt is generated by the USB core (not by the DMA).
0	EP0		Endpoint 0 interrupt source.
		0	Endpoint 0 interrupt is not generated by the USB core.
		1	Endpoint 0 interrupt is generated by the USB core (not by the DMA).

33.4.10 USB Interrupt Source Set Register (INTSETR)

The USB interrupt source set register (INTSETR) allows the USB interrupt sources to be manually triggered. A read of this register returns the USB interrupt source register value. The INTSETR is shown in Figure 33-36 and described in Table 33-40.

NOTE: Other than the USB bit field, to make use of INTSETR, the PDR interrupt handler must be enabled (the UINT bit in the control register (CTRLR) is cleared to 0). If the UINT bit in CTRLR is set to 1, you need to use the interrupt status/flag from the core register space.

Figure 33-36. USB Interrupt Source Set Register (INTSETR)

31–25	24–16
Reserved	USB
R-0	R/W-0

15–13	12–9	8–5	4–1	0
Reserved	RXEP[*n*]	Reserved	TXEP[*n*]	EP0
R-0	R/W-0	R-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 33-40. USB Interrupt Source Set Register (INTSETR) Field Descriptions

Bit	Field	Value	Description
31-25	Reserved	0	Reserved
24-16	USB	0-1FFh	Write a 1 to set equivalent USB interrupt source. Allows the USB interrupt sources to be manually triggered.
15-13	Reserved	0	Reserved
12-9	RXEP[*n*]		Set receive endpoint *n* interrupt source. Allows the receive endpoint *n* interrupt sources to be manually triggered.
		0	RXEP*n* interrupt is not set.
		1	RXEP*n* interrupt is set.
8-5	Reserved	0	Reserved
4-1	TXEP[*n*]		Set transmit endpoint *n* interrupt source. Allows the transmit endpoint *n* interrupt sources to be manually triggered.
		0	TXEP*n* interrupt is not set.
		1	TXEP*n* interrupt is set.
0	EP0		Set endpoint 0 interrupt source. Allows the endpoint 0 interrupt source to be manually triggered.
		0	Endpoint 0 interrupt is not set.
		1	Endpoint 0 interrupt is set.

33.4.11 USB Interrupt Source Clear Register (INTCLRR)

The USB interrupt source clear register (INTCLRR) allows the CPU to acknowledge an interrupt source and turn it off. A read of this register returns the USB interrupt source register value. The INTCLRR is shown in Figure 33-37 and described in Table 33-41.

NOTE: Other than the USB bit field, to make use of INTCLRR, the PDR interrupt handler must be enabled (the UINT bit in the control register (CTRLR) is cleared to 0). If the UINT bit in CTRLR is set to 1, you need to use the interrupt status/flag from the core register space.

Figure 33-37. USB Interrupt Source Clear Register (INTCLRR)

31	25	24	16
Reserved		USB	
R-0		R/W-0	

15	13	12	9	8	5	4	1	0
Reserved		RXEP[*n*]		Reserved		TXEP[*n*]		EP0
R-0		R/W-0		R-0		R/W-0		R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 33-41. USB Interrupt Source Clear Register (INTCLRR) Field Descriptions

Bit	Field	Value	Description
31-25	Reserved	0	Reserved
24-16	USB	0-1FFh	Write a 1 to clear equivalent USB interrupt source. Allows the CPU to acknowledge a USB interrupt source and turn it off.
15-13	Reserved	0	Reserved
12-9	RXEP[*n*]		Clear receive endpoint *n* interrupt source. Allows the CPU to acknowledge a receive endpoint *n* interrupt source and turn it off.
		0	RXEP*n* interrupt is not cleared.
		1	RXEP*n* interrupt is cleared.
8-5	Reserved	0	Reserved
4-1	TXEP[*n*]		Clear transmit endpoint *n* interrupt source. Allows the CPU to acknowledge a transmit endpoint *n* interrupt source and turn it off.
		0	TXEP*n* interrupt is not cleared.
		1	TXEP*n* interrupt is cleared.
0	EP0		Clear endpoint 0 interrupt source. Allows the CPU to acknowledge the endpoint 0 interrupt source and turn it off.
		0	Endpoint 0 interrupt is not cleared.
		1	Endpoint 0 interrupt is cleared.

33.4.12 USB Interrupt Mask Register (INTMSKR)

The USB interrupt mask register (INTMSKR) contains the masks of the interrupt sources generated by the USB core (not by the DMA). These masks are used to enable or disable interrupt sources generated on the masked source interrupts (the raw source interrupts are never masked). The bit positions are maintained in the same position as the interrupt sources in the USB interrupt source register (INTSRCR).

The INTMSKR is shown in Figure 33-38 and described in Table 33-42.

NOTE: Other than the USB bit field, to make use of INTMSKR, the PDR interrupt handler must be enabled (the UINT bit in the control register (CTRLR) is cleared to 0). If the UINT bit in CTRLR is set to 1, you need to use the interrupt status/flag from the core register space.

Figure 33-38. USB Interrupt Mask Register (INTMSKR)

31	25	24	16
Reserved		USB	
R-0		R-0	

15	13	12	9	8	5	4	1	0
Reserved		RXEP[*n*]		Reserved		TXEP[*n*]		EP0
R-0		R-0		R-0		R-0		R-0

LEGEND: R = Read only; -*n* = value after reset

Table 33-42. USB Interrupt Mask Register (INTMSKR) Field Descriptions

Bit	Field	Value	Description
31-25	Reserved	0	Reserved
24-16	USB	0-1FFh	USB interrupt source masks. Generated by the USB core (not by the DMA).
15-13	Reserved	0	Reserved
12-9	RXEP[*n*]		Receive endpoint *n* interrupt source mask.
		0	RXEP*n* interrupt mask is not generated by the USB core.
		1	RXEP*n* interrupt mask is generated by the USB core (not by the DMA).
8-5	Reserved	0	Reserved
4-1	TXEP[*n*]		Transmit endpoint *n* interrupt source mask.
		0	TXEP*n* interrupt mask is not generated by the USB core.
		1	TXEP*n* interrupt mask is generated by the USB core (not by the DMA).
0	EP0		Endpoint 0 interrupt source mask.
		0	Endpoint 0 interrupt mask is not generated by the USB core.
		1	Endpoint 0 interrupt mask is generated by the USB core (not by the DMA).

33.4.13 USB Interrupt Mask Set Register (INTMSKSETR)

The USB interrupt mask set register (INTMSKSETR) allows the USB masks to be individually enabled. A read to this register returns the USB interrupt mask register value. The INTMSKSETR is shown in Figure 33-39 and described in Table 33-43.

NOTE: Other than the USB bit field, to make use of INTMSKSETR, the PDR interrupt handler must be enabled (the UINT bit in the control register (CTRLR) is cleared to 0). If the UINT bit in CTRLR is set to 1, you need to use the interrupt status/flag from the core register space.

Figure 33-39. USB Interrupt Mask Set Register (INTMSKSETR)

31	25	24	16
Reserved		USB	
R-0		R/W-0	

15	13	12	9	8	5	4	1	0
Reserved		RXEP[*n*]		Reserved		TXEP[*n*]		EP0
R-0		R/W-0		R-0		R/W-0		R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 33-43. USB Interrupt Mask Set Register (INTMSKSETR) Field Descriptions

Bit	Field	Value	Description
31-25	Reserved	0	Reserved
24-16	USB	0-1FFh	Write a 1 to set equivalent USB interrupt source mask. Allows the USB interrupt source masks to be manually enabled.
15-13	Reserved	0	Reserved
12-9	RXEP[*n*]		Set receive endpoint *n* interrupt source mask. Allows the receive endpoint *n* interrupt source masks to be manually enabled.
		0	RXEP*n* interrupt mask is not enabled.
		1	RXEP*n* interrupt mask is enabled.
8-5	Reserved	0	Reserved
4-1	TXEP[*n*]		Set transmit endpoint *n* interrupt source mask. Allows the transmit endpoint *n* interrupt source masks to be manually enabled.
		0	TXEP*n* interrupt mask is not enabled.
		1	TXEP*n* interrupt mask is enabled.
0	EP0		Set endpoint 0 interrupt source mask. Allows the endpoint 0 interrupt source mask to be manually enabled.
		0	Endpoint 0 interrupt mask is not enabled.
		1	Endpoint 0 interrupt mask is enabled.

33.4.14 USB Interrupt Mask Clear Register (INTMSKCLRR)

The USB interrupt mask clear register (INTMSKCLRR) allows the USB interrupt masks to be individually disabled. A read to this register returns the USB interrupt mask register value. The INTMSKCLRR is shown in Figure 33-40 and described in Table 33-44.

NOTE: Other than the USB bit field, to make use of INTMSKCLRR, the PDR interrupt handler must be enabled (the UINT bit in the control register (CTRLR) is cleared to 0). If the UINT bit in CTRLR is set to 1, you need to use the interrupt status/flag from the core register space.

Figure 33-40. USB Interrupt Mask Clear Register (INTMSKCLRR)

31	25	24	16
Reserved		USB	
R-0		R/W-0	

15	13	12	9	8	5	4	1	0
Reserved		RXEP[*n*]		Reserved		TXEP[*n*]		EP0
R-0		R/W-0		R-0		R/W-0		R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 33-44. USB Interrupt Mask Clear Register (INTMSKCLRR) Field Descriptions

Bit	Field	Value	Description
31-25	Reserved	0	Reserved
24-16	USB	0-1FFh	Write a 1 to clear equivalent USB interrupt source mask. Allows the USB interrupt source masks to be manually disabled.
15-13	Reserved	0	Reserved
12-9	RXEP[*n*]		Clear receive endpoint *n* interrupt source mask. Allows the receive endpoint *n* interrupt source masks to be manually disabled.
		0	RXEP*n* interrupt mask is not disabled.
		1	RXEP*n* interrupt mask is disabled.
8-5	Reserved	0	Reserved
4-1	TXEP[*n*]		Clear transmit endpoint *n* interrupt source mask. Allows the transmit endpoint *n* interrupt source masks to be manually disabled.
		0	TXEP*n* interrupt mask is not disabled.
		1	TXEP*n* interrupt mask is disabled.
0	EP0		Clear endpoint 0 interrupt source mask. Allows the endpoint 0 interrupt source mask to be manually disabled.
		0	Endpoint 0 interrupt mask is not disabled.
		1	Endpoint 0 interrupt mask is disabled.

33.4.15 USB Interrupt Source Masked Register (INTMASKEDR)

The USB interrupt source masked register (INTMASKEDR) contains the status of the interrupt sources generated by the USB core masked by the USB interrupt mask register (INTMSKR) values. The INTMASKEDR is shown in Figure 33-41 and described in Table 33-45.

NOTE: Other than the USB bit field, to make use of INTMASKEDR, the PDR interrupt handler must be enabled (the UINT bit in the control register (CTRLR) is cleared to 0). If the UINT bit in CTRLR is set to 1, you need to use the interrupt status/flag from the core register space.

Figure 33-41. USB Interrupt Source Masked Register (INTMASKEDR)

31	25	24	16
Reserved		USB	
R-0		R-0	

15	13	12	9	8	5	4	1	0
Reserved		RXEP[*n*]		Reserved		TXEP[*n*]		EP0
R-0		R-0		R-0		R-0		R-0

LEGEND: R = Read only; -*n* = value after reset

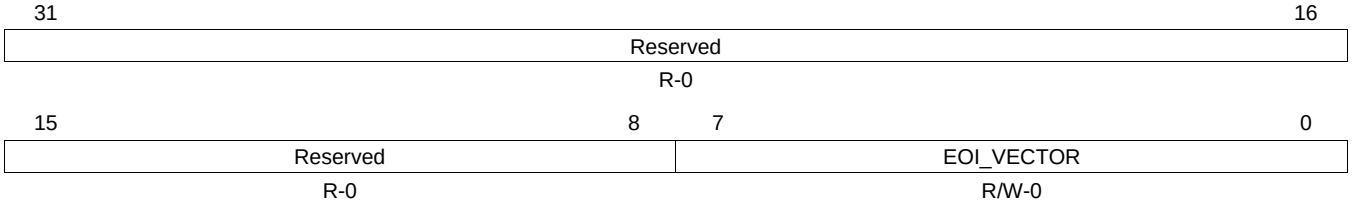
Table 33-45. USB Interrupt Source Masked Register (INTMASKEDR) Field Descriptions

Bit	Field	Value	Description
31-25	Reserved	0	Reserved
24-16	USB	0-1FFh	USB interrupt sources masked.
15-13	Reserved	0	Reserved
12-9	RXEP[*n*]		Receive endpoint *n* interrupt source masked.
		0	RXEP*n* interrupt source is not masked.
		1	RXEP*n* interrupt source is masked.
8-5	Reserved	0	Reserved
4-1	TXEP[*n*]		Transmit endpoint *n* interrupt source masked.
		0	TXEP*n* interrupt source is not masked.
		1	TXEP*n* interrupt source is masked.
0	EP0		Endpoint 0 interrupt source masked.
		0	Endpoint 0 interrupt source is not masked.
		1	Endpoint 0 interrupt source is masked.

33.4.16 USB End of Interrupt Register (EOIR)

The USB end of interrupt register (EOIR) allows the CPU to acknowledge completion of a non-DMA interrupt by writing 0 to the EOI_VECTOR field. The EOIR is shown in Figure 33-42 and described in Table 33-46.

Figure 33-42. USB End of Interrupt Register (EOIR)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

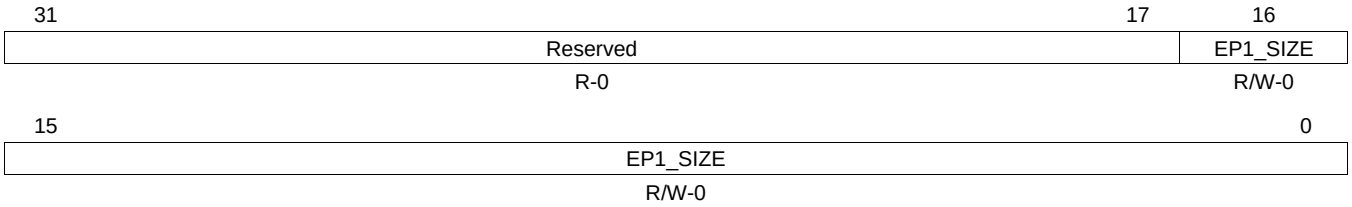
Table 33-46. USB End of Interrupt Register (EOIR) Field Descriptions

Bit	Field	Value	Description
31-8	Reserved	0	Reserved
7-0	EOI_VECTOR	0-FFh	End of Interrupt (EOI) Vector.

33.4.17 Generic RNDIS EP1 Size Register (GENRNDISSZ1)

The generic RNDIS EP1 size register (GENRNDISSZ1) is programmed with a RNDIS packet size in bytes. When EP1 is in Generic RNDIS mode, the received USB packets are collected into a single CPPI packet that is completed when the number of bytes equal to the value of this register have been received, or a *short* packet is received. This register must be programmed with a value that is an integer multiple of the endpoint size. The maximum value this register can be programmed with is 10000h, or 65536. The GENRNDISSZ1 is shown in Figure 33-43 and described in Table 33-47.

Figure 33-43. Generic RNDIS EP1 Size Register (GENRNDISSZ1)



LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 33-47. Generic RNDIS EP1 Size Register (GENRNDISSZ1) Field Descriptions

Bit	Field	Value	Description
31-17	Reserved	0	Reserved
16-0	EP1_SIZE	0-10000h	Generic RNDIS packet size

33.4.18 Generic RNDIS EP2 Size Register (GENRNDISSZ2)

The generic RNDIS EP2 size register (GENRNDISSZ2) is programmed with a RNDIS packet size in bytes. When EP2 is in Generic RNDIS mode, the received USB packets are collected into a single CPPI packet that is completed when the number of bytes equal to the value of this register have been received, or a *short* packet is received. This register must be programmed with a value that is an integer multiple of the endpoint size. The maximum value this register can be programmed with is 10000h, or 65536. The GENRNDISSZ2 is shown in Figure 33-44 and described in Table 33-48.

Figure 33-44. Generic RNDIS EP2 Size Register (GENRNDISSZ2)

31	17	16
Reserved		EP2_SIZE
R-0		R/W-0

15	0
EP2_SIZE	
R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 33-48. Generic RNDIS EP2 Size Register (GENRNDISSZ2) Field Descriptions

Bit	Field	Value	Description
31-17	Reserved	0	Reserved
16-0	EP2_SIZE	0-10000h	Generic RNDIS packet size

33.4.19 Generic RNDIS EP3 Size Register (GENRNDISSZ3)

The generic RNDIS EP3 size register (GENRNDISSZ3) is programmed with a RNDIS packet size in bytes. When EP3 is in Generic RNDIS mode, the received USB packets are collected into a single CPPI packet that is completed when the number of bytes equal to the value of this register has been received, or a *short* packet is received. This register must be programmed with a value that is an integer multiple of the endpoint size. The maximum value this register can be programmed with is 10000h, or 65536. The GENRNDISSZ3 is shown in Figure 33-45 and described in Table 33-49.

Figure 33-45. Generic RNDIS EP3 Size Register (GENRNDISSZ3)

31	17	16
Reserved		EP3_SIZE
R-0		R/W-0

15	0
EP3_SIZE	
R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 33-49. Generic RNDIS EP3 Size Register (GENRNDISSZ3) Field Descriptions

Bit	Field	Value	Description
31-17	Reserved	0	Reserved
16-0	EP3_SIZE	0-10000h	Generic RNDIS packet size

33.4.20 Generic RNDIS EP4 Size Register (GENRNDISSZ4)

The generic RNDIS EP4 size register (GENRNDISSZ4) is programmed with a RNDIS packet size in bytes. When EP4 is in Generic RNDIS mode, the received USB packets are collected into a single CPPI packet that is completed when the number of bytes equal to the value of this register has been received, or a *short* packet is received. This register must be programmed with a value that is an integer multiple of the endpoint size. The maximum value this register can be programmed with is 10000h, or 65536. The GENRNDISSZ4 is shown in Figure 33-46 and described in Table 33-50.

Figure 33-46. Generic RNDIS EP4 Size Register (GENRNDISSZ4)

31	17	16
Reserved		EP4_SIZE
R-0		R/W-0

15	0
EP4_SIZE	
R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 33-50. Generic RNDIS EP4 Size Register (GENRNDISSZ4) Field Descriptions

Bit	Field	Value	Description
31-17	Reserved	0	Reserved
16-0	EP4_SIZE	0-10000h	Generic RNDIS packet size

33.4.21 Function Address Register (FADDR)

The function address register (FADDR) is shown in Figure 33-47 and described in Table 33-51.

Figure 33-47. Function Address Register (FADDR)

7	6	0
Reserved	FUNCADDR	
R-0	R/W-0	

LEGEND: R/W = Read/Write; -*n* = value after reset

Table 33-51. Function Address Register (FADDR) Field Descriptions

Bit	Field	Value	Description
7	Reserved	0	Reserved
6-0	FUNCADDR	0-7Fh	7_bit address of the peripheral part of the transaction. When used in Peripheral mode, this register should be written with the address received through a SET_ADDRESS command, which will then be used for decoding the function address in subsequent token packets. When used in Host mode, this register should be set to the value sent in a SET_ADDRESS command during device enumeration as the address for the peripheral device.

33.4.22 Power Management Register (POWER)

The power management register (POWER) is shown in Figure 33-48 and described in Table 33-52.

Figure 33-48. Power Management Register (POWER)

7	6	5	4	3	2	1	0
ISOUPDATE	SOFTCONN	HSEN	HSMODE	RESET	RESUME	SUSPENDM	ENSUSPM
R/W-0	R/W-0	R/W-1	R-0	R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; *-n* = value after reset

Table 33-52. Power Management Register (POWER) Field Descriptions

Bit	Field	Value	Description
7	ISOUPDATE	0-1	When set, the USB controller will wait for an SOF token from the time TxPktRdy is set before sending the packet. If an IN token is received before an SOF token, then a zero length data packet will be sent. Note: this is only valid in Peripheral Mode. This bit only affects endpoints performing Isochronous transfers.
6	SOFTCONN	0-1	If Soft Connect/Disconnect feature is enabled, then the USB D+/D- lines are enabled when this bit is set and tri-stated when this bit is cleared. Note: this is only valid in Peripheral Mode.
5	HSEN	0-1	When set, the USB controller will negotiate for high-speed mode when the device is reset by the hub. If not set, the device will only operate in full-speed mode.
4	HSMODE	0-1	This bit is set when the USB controller has successfully negotiated for high-speed mode.
3	RESET	0-1	This bit is set when Reset signaling is present on the bus. Note: this bit is Read/Write in Host Mode, but read-only in Peripheral Mode.
2	RESUME	0-1	Set to generate Resume signaling when the controller is in Suspend mode. The bit should be cleared after 10 ms (a maximum of 15 ms) to end Resume signaling. In Host mode, this bit is also automatically set when Resume signaling from the target is detected while the USB controller is suspended.
1	SUSPENDM	0-1	In Host mode, this bit should be set to enter Suspend mode. In Peripheral mode, this bit is set on entry into Suspend mode. It is cleared when the interrupt register is read, or the RESUME bit is set.
0	ENSUSPM	0-1	Set to enable the SUSPENDM output.

33.4.23 Interrupt Register for Endpoint 0 Plus Transmit Endpoints 1 to 4 (INTRTX)

The interrupt register for endpoint 0 plus transmit endpoints 1 to 4 (INTRTX) is shown in Figure 33-49 and described in Table 33-53.

NOTE: Unless the UINT bit in the control register (CTRLR) is set to 1 (non-PDR interrupt mode is enabled), do not read this register directly. Performing a read clears the pending interrupt. Use INTRTX only when in the non-PDR interrupt mode, that is, when handling the interrupt directly from the controller.

Figure 33-49. Interrupt Register for Endpoint 0 Plus Tx Endpoints 1 to 4 (INTRTX)

15						8
Reserved						
R-0						

7	5	4	3	2	1	0
Reserved		EP4TX	EP3TX	EP2TX	EP1TX	EP0
R-0		R-0	R-0	R-0	R-0	R-0

LEGEND: R = Read only; -*n* = value after reset

Table 33-53. Interrupt Register for Endpoint 0 Plus Transmit Endpoints 1 to 4 (INTRTX) Field Descriptions

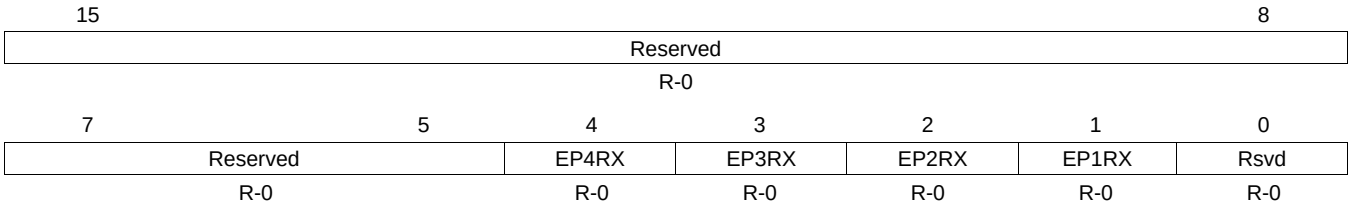
Bit	Field	Value	Description
15-5	Reserved	0	Reserved
4	EP4TX	0-1	Transmit Endpoint 4 interrupt active
3	EP3TX	0-1	Transmit Endpoint 3 interrupt active
2	EP2TX	0-1	Transmit Endpoint 2 interrupt active
1	EP1TX	0-1	Transmit Endpoint 1 interrupt active
0	EP0	0-1	Endpoint 0 interrupt active

33.4.24 Interrupt Register for Receive Endpoints 1 to 4 (INTRRX)

The interrupt register for receive endpoints 1 to 4 (INTRRX) is shown in Figure 33-50 and described in Table 33-54.

NOTE: Unless the UINT bit in the control register (CTRLR) is set to 1 (non-PDR interrupt mode is enabled), do not read this register directly. Performing a read clears the pending interrupt. Use INTRRX only when in the non-PDR interrupt mode, that is, when handling the interrupt directly from the controller.

Figure 33-50. Interrupt Register for Receive Endpoints 1 to 4 (INTRRX)



LEGEND: R = Read only; -*n* = value after reset

Table 33-54. Interrupt Register for Receive Endpoints 1 to 4 (INTRRX) Field Descriptions

Bit	Field	Value	Description
15-5	Reserved	0	Reserved
4	EP4RX	0-1	Receive Endpoint 4 interrupt active
3	EP3RX	0-1	Receive Endpoint 3 interrupt active
2	EP2RX	0-1	Receive Endpoint 2 interrupt active
1	EP1RX	0-1	Receive Endpoint 1 interrupt active
0	Reserved	0	Reserved

33.4.25 Interrupt Enable Register for INTRTX (INTRTXE)

The interrupt enable register for INTRTX (INTRTXE) is shown in Figure 33-51 and described in Table 33-55.

Figure 33-51. Interrupt Enable Register for INTRTX (INTRTXE)

15	8
Reserved	
R-0	

7	5	4	3	2	1	0
Reserved		EP4TX	EP3TX	EP2TX	EP1TX	EP0
R-0		R/W-1	R/W-1	R/W-1	R/W-1	R/W-1

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 33-55. Interrupt Enable Register for INTRTX (INTRTXE) Field Descriptions

Bit	Field	Value	Description
15-5	Reserved	0	Reserved
4	EP4TX	0-1	Transmit Endpoint 4 interrupt active
3	EP3TX	0-1	Transmit Endpoint 3 interrupt active
2	EP2TX	0-1	Transmit Endpoint 2 interrupt active
1	EP1TX	0-1	Transmit Endpoint 1 interrupt active
0	EP0	0-1	Endpoint 0 interrupt active

33.4.26 Interrupt Enable Register for INTRRX (INTRRXE)

The interrupt enable register for INTRRX (INTRRXE) is shown in Figure 33-52 and described in Table 33-56.

Figure 33-52. Interrupt Enable Register for INTRRX (INTRRXE)

15	8
Reserved	
R-0	

7	5	4	3	2	1	0
Reserved		EP4RX	EP3RX	EP2RX	EP1RX	Reserved
R-0		R/W-1	R/W-1	R/W-1	R/W-1	R-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 33-56. Interrupt Enable Register for INTRRX (INTRRXE) Field Descriptions

Bit	Field	Value	Description
15-5	Reserved	0	Reserved
4	EP4RX	0-1	Receive Endpoint 4 interrupt active
3	EP3RX	0-1	Receive Endpoint 3 interrupt active
2	EP2RX	0-1	Receive Endpoint 2 interrupt active
1	EP1RX	0-1	Receive Endpoint 1 interrupt active
0	Reserved	0	Reserved

33.4.27 Interrupt Register for Common USB Interrupts (INTRUSB)

The interrupt register for common USB interrupts (INTRUSB) is shown in Figure 33-53 and described in Table 33-57.

NOTE: Unless the UINT bit in the control register (CTRLR) is set to 1 (non-PDR interrupt mode is enabled), do not read this register directly. Performing a read clears the pending interrupt. Use INTRUSB only when in the non-PDR interrupt mode, that is, when handling the interrupt directly from the controller.

Figure 33-53. Interrupt Register for Common USB Interrupts (INTRUSB)

7	6	5	4	3	2	1	0
VBUSERR	SESSREQ	DISCON	CONN	SOF	RESET_BABBLE	RESUME	SUSPEND
R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0

LEGEND: R = Read only; -*n* = value after reset

Table 33-57. Interrupt Register for Common USB Interrupts (INTRUSB) Field Descriptions

Bit	Field	Value	Description
7	VBUSERR	0-1	Set when VBus drops below the VBus valid threshold during a session. Only valid when the USB controller is 'A' device. All active interrupts will be cleared when this register is read.
6	SESSREQ	0-1	Set when session request signaling has been detected. Only valid when USB controller is 'A' device.
5	DISCON	0-1	Set in host mode when a device disconnect is detected. Set in peripheral mode when a session ends.
4	CONN	0-1	Set when a device connection is detected. Only valid in host mode.
3	SOF	0-1	Set when a new frame starts.
2	RESET_BABBLE	0-1	Set in peripheral mode when reset signaling is detected on the bus set in host mode when babble is detected.
1	RESUME	0-1	Set when resume signaling is detected on the bus while the USB controller is in suspend mode.
0	SUSPEND	0-1	Set when suspend signaling is detected on the bus only valid in peripheral mode.

33.4.28 Interrupt Enable Register for INTRUSB (INTRUSBE)

The interrupt enable register for INTRUSB (INTRUSBE) is shown in Figure 33-54 and described in Table 33-58.

Figure 33-54. Interrupt Enable Register for INTRUSB (INTRUSBE)

7	6	5	4	3	2	1	0
VBUSERR	SESSREQ	DISCON	CONN	SOF	RESET_BABBLE	RESUME	SUSPEND
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-1	R/W-1	R/W-0

LEGEND: R/W = Read/Write; -*n* = value after reset

Table 33-58. Interrupt Enable Register for INTRUSB (INTRUSBE) Field Descriptions

Bit	Field	Value	Description
7	VBUSERR	0-1	Vbus error interrupt enable
6	SESSREQ	0-1	Session request interrupt enable
5	DISCON	0-1	Disconnect interrupt enable
4	CONN	0-1	Connect interrupt enable
3	SOF	0-1	Start of frame interrupt enable
2	RESET_BABBLE	0-1	Reset interrupt enable
1	RESUME	0-1	Resume interrupt enable
0	SUSPEND	0-1	Suspend interrupt enable

33.4.29 Frame Number Register (FRAME)

The frame number register (FRAME) is shown in Figure 33-55 and described in Table 33-59.

Figure 33-55. Frame Number Register (FRAME)

15	11	10	0
Reserved		FRAMENUMBER	
R-0		R-0	

LEGEND: R = Read only; -*n* = value after reset

Table 33-59. Frame Number Register (FRAME) Field Descriptions

Bit	Field	Value	Description
15-11	Reserved	0	Reserved
10-0	FRAMENUMBER	0-7FFh	Last received frame number

33.4.30 Index Register for Selecting the Endpoint Status and Control Registers (INDEX)

The index register for selecting the endpoint status and control registers (INDEX) is shown in Figure 33-56 and described in Table 33-60.

Figure 33-56. Index Register for Selecting the Endpoint Status and Control Registers (INDEX)

7	4	3	0
Reserved		EPSEL	
R-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 33-60. Index Register for Selecting the Endpoint Status and Control Registers (INDEX) Field Descriptions

Bit	Field	Value	Description
7-4	Reserved	0	Reserved
3-0	EPSEL	0-4h	Each transmit endpoint and each receive endpoint have their own set of control/status registers. EPSEL determines which endpoint control/status registers are accessed. Before accessing an endpoint's control/status registers, the endpoint number should be written to the Index register to ensure that the correct control/status registers appear in the memory-map.

33.4.31 Register to Enable the USB 2.0 Test Modes (TESTMODE)

The register to enable the USB 2.0 test modes (TESTMODE) is shown in Figure 33-57 and described in Table 33-61.

Figure 33-57. Register to Enable the USB 2.0 Test Modes (TESTMODE)

7	6	5	4	3	2	1	0
FORCE_HOST	FIFO_ACCESS	FORCE_FS	FORCE_HS	TEST_PACKET	TEST_K	TEST_J	TEST_SE0_NAK
R/W-0	W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; W = Write only; -*n* = value after reset

Table 33-61. Register to Enable the USB 2.0 Test Modes (TESTMODE) Field Descriptions

Bit	Field	Value	Description
7	FORCE_HOST	0-1	Set this bit to forcibly put the USB controller into Host mode when SESSION bit is set, regardless of whether it is connected to any peripheral. The controller remains in Host mode until the Session bit is cleared, even if a device is disconnected. And if the FORCE_HOST but remains set, it will re-enter Host mode next time the SESSION bit is set. The operating speed is determined using the FORCE_HS and FORCE_FS bits.
6	FIFO_ACCESS	0-1	Set this bit to transfer the packet in EP0 Tx FIFO to EP0 Receive FIFO. It is cleared automatically.
5	FORCE_FS	0-1	Set this bit to force the USB controller into full-speed mode when it receives a USB reset.
4	FORCE_HS	0-1	Set this bit to force the USB controller into high-speed mode when it receives a USB reset.
3	TEST_PACKET	0-1	Set this bit to enter the Test_Packet test mode. In this mode, the USB controller repetitively transmits a 53-byte test packet on the bus, the form of which is defined in the Universal Serial Bus Specification Revision 2.0. Note: The test packet has a fixed format and must be loaded into the Endpoint 0 FIFO before the test mode is entered.
2	TEST_K	0-1	Set this bit to enter the Test_K test mode. In this mode, the USB controller transmits a continuous K on the bus.
1	TEST_J	0-1	Set this bit to enter the Test_J test mode. In this mode, the USB controller transmits a continuous J on the bus.
0	TEST_SE0_NAK	0-1	Set this bit to enter the Test_SE0_NAK test mode. In this mode, the USB controller remains in high-speed mode, but responds to any valid IN token with a NAK.

33.4.32 Maximum Packet Size for Peripheral/Host Transmit Endpoint (TXMAXP)

The maximum packet size for peripheral/host transmit endpoint (TXMAXP) is shown in Figure 33-58 and described in Table 33-62.

Figure 33-58. Maximum Packet Size for Peripheral/Host Transmit Endpoint (TXMAXP)

15	11	10	0
Reserved		MAXPAYLOAD	
R-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 33-62. Maximum Packet Size for Peripheral/Host Transmit Endpoint (TXMAXP) Field Descriptions

Bit	Field	Value	Description
15-11	Reserved	0	Reserved
10-0	MAXPAYLOAD	0-400h	The maximum payload transmitted in a single transaction. The value set can be up to 1024 bytes, but is subject to the constraints placed by the USB Specification on packet sizes for Bulk, Interrupt, and Isochronous transfers in full-speed and high-speed operations. The value written to this register should match the wMaxPacketSize field of the Standard Endpoint Descriptor for the associated endpoint. A mismatch could cause unexpected results.

33.4.33 Control Status Register for Endpoint 0 in Peripheral Mode (PERI_CSR0)

The control status register for endpoint 0 in peripheral mode (PERI_CSR0) is shown in Figure 33-59 and described in Table 33-63.

Figure 33-59. Control Status Register for Endpoint 0 in Peripheral Mode (PERI_CSR0)

15						9	8
Reserved							FLUSHFIFO
R-0							W-0
7	6	5	4	3	2	1	0
SERV_SETUPEND	SERV_RXPKTRDY	SENDSTALL	SETUPEND	DATAEND	SENTSTALL	TXPKTRDY	RXPKTRDY
W-0	W-0	W-0	R-0	W-0	R/W-0	R/W-0	R-0

LEGEND: R/W = Read/Write; R = Read only; W = Write only; -*n* = value after reset

Table 33-63. Control Status Register for Endpoint 0 in Peripheral Mode (PERI_CSR0) Field Descriptions

Bit	Field	Value	Description
15-9	Reserved	0	Reserved
8	FLUSHFIFO	0-1	Set this bit to flush the next packet to be transmitted/read from the Endpoint 0 FIFO. The FIFO pointer is reset and the TXPKTRDY/RXPKTRDY bit is cleared. Note: FLUSHFIFO has no effect unless TXPKTRDY/RXPKTRDY is set.
7	SERV_SETUPEND	0-1	Set this bit to clear the SETUPEND bit. It is cleared automatically.
6	SERV_RXPKTRDY	0-1	Set this bit to clear the RXPKTRDY bit. It is cleared automatically.
5	SENDSTALL	0-1	Set this bit to terminate the current transaction. The STALL handshake will be transmitted and then this bit will be cleared automatically.
4	SETUPEND	0-1	This bit will be set when a control transaction ends before the DATAEND bit has been set. An interrupt will be generated, and the FIFO will be flushed at this time. The bit is cleared by the writing a 1 to the SERV_SETUPEND bit.
3	DATAEND	0-1	Set this bit to 1: a. When setting TXPKTRDY for the last data packet. b. When clearing RXPKTRDY after unloading the last data packet. c. When setting TXPKTRDY for a zero length data packet. It is cleared automatically.
2	SENTSTALL	0-1	This bit is set when a STALL handshake is transmitted. This bit should be cleared.
1	TXPKTRDY	0-1	Set this bit after loading a data packet into the FIFO. It is cleared automatically when the data packet has been transmitted. An interrupt is generated (if enabled) when the bit is cleared.
0	RXPKTRDY	0-1	This bit is set when a data packet has been received. An interrupt is generated when this bit is set. This bit is cleared by setting the SERV_RXPKTRDY bit.

33.4.34 Control Status Register for Endpoint 0 in Host Mode (HOST_CSR0)

The control status register for endpoint 0 in host mode (HOST_CSR0) is shown in Figure 33-60 and described in Table 33-64.

Figure 33-60. Control Status Register for Endpoint 0 in Host Mode (HOST_CSR0)

15	12	11	10	9	8
Reserved		DISPING	DATATOGWREN	DATATOG	FLUSHFIFO
R-0		R/W-0	W-0	R/W-0	W-0

7	6	5	4	3	2	1	0
NAK_TIMEOUT	STATUSPKT	REQPKT	ERROR	SETUPPKT	RXSTALL	TXPKTRDY	RXPKTRDY
W-0	R/W-0	R/W-0	W-0	R/W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; W = Write only; -*n* = value after reset

Table 33-64. Control Status Register for Endpoint 0 in Host Mode (HOST_CSR0) Field Descriptions

Bit	Field	Value	Description
15-12	Reserved	0	Reserved
11	DISPING	0-1	The CPU writes a 1 to the DSPING bit to instruct the core not to issue PING tokens in the data and status phases of a high-speed control transfer (for use with devices that do not respond to PING).
10	DATATOGWREN	0-1	Write 1 to this bit to enable the DATATOG bit to be written. This bit is automatically cleared once the new value is written to DATATOG.
9	DATATOG	0-1	When read, this bit indicates the current state of the EP0 data toggle. If DATATOGWREN is high, this bit can be written with the required setting of the data toggle. If DATATOGWREN is low, any value written to this bit is ignored.
8	FLUSHFIFO	0-1	Write 1 to this bit to flush the next packet to be transmitted/read from the Endpoint 0 FIFO. The FIFO pointer is reset and the TXPKTRDY/RXPKTRDY bit is cleared. Note: FLUSHFIFO has no effect unless TXPKTRDY/RXPKTRDY is set.
7	NAK_TIMEOUT	0-1	This bit will be set when Endpoint 0 is halted following the receipt of NAK responses for longer than the time set by the NAKLIMIT0 register. This bit should be cleared to allow the endpoint to continue.
6	STATUSPKT	0-1	Set this bit at the same time as the TXPKTRDY or REQPKT bit is set, to perform a status stage transaction. Setting this bit ensures that the data toggle is set so that a DATA1 packet is used for the Status Stage transaction.
5	REQPKT	0-1	Set this bit to request an IN transaction. It is cleared when RXPKTRDY is set.
4	ERROR	0-1	This bit will be set when three attempts have been made to perform a transaction with no response from the peripheral. You should clear this bit. An interrupt is generated when this bit is set.
3	SETUPPKT	0-1	Set this bit, at the same time as the TXPKTRDY bit is set, to send a SETUP token instead of an OUT token for the transaction.
2	RXSTALL	0-1	This bit is set when a STALL handshake is received. You should clear this bit.
1	TXPKTRDY	0-1	Set this bit after loading a data packet into the FIFO. It is cleared automatically when the data packet has been transmitted. An interrupt is generated (if enabled) when the bit is cleared.
0	RXPKTRDY	0-1	This bit is set when a data packet has been received. An interrupt is generated when this bit is set. Clear this bit by setting the SERV_RXPKTRDY bit.

33.4.35 Control Status Register for Peripheral Transmit Endpoint (PERI_TXCSR)

The control status register for peripheral transmit endpoint (PERI_TXCSR) is shown in Figure 33-61 and described in Table 33-65.

Figure 33-61. Control Status Register for Peripheral Transmit Endpoint (PERI_TXCSR)

15	14	13	12	11	10	9 7
AUTOSET	ISO	MODE	DMAEN	FRCDATATOG	DMAMODE	Reserved
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R-0

6	5	4	3	2	1	0
CLRDATATOG	SENTSTALL	SENDSTALL	FLUSHFIFO	UNDERRUN	FIFONOTEMPTY	TXPKTRDY
W-0	R/W-0	R/W-0	W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; W = Write only; *-n* = value after reset

Table 33-65. Control Status Register for Peripheral Transmit Endpoint (PERI_TXCSR) Field Descriptions

Bit	Field	Value	Description
15	AUTOSET	0	DMA Mode: The CPU needs to set the AUTOSET bit prior to enabling the Tx DMA.
		1	CPU Mode: If the CPU sets the AUTOSET bit, the TXPKTRDY bit will be automatically set when data of the maximum packet size (value in TXMAXP) is loaded into the Tx FIFO. If a packet of less than the maximum packet size is loaded, then the TXPKTRDY bit will have to be set manually.
14	ISO	0-1	Set this bit to enable the Tx endpoint for Isochronous transfers, and clear it to enable the Tx endpoint for Bulk or Interrupt transfers.
13	MODE	0-1	Set this bit to enable the endpoint direction as Tx, and clear the bit to enable it as Rx. Note: This bit has any effect only where the same endpoint FIFO is used for both Transmit and Receive transactions.
12	DMAEN	0-1	Set this bit to enable the DMA request for the Tx endpoint.
11	FRCDATATOG	0-1	Set this bit to force the endpoint data toggle to switch and the data packet to be cleared from the FIFO, regardless of whether an ACK was received. This can be used by Interrupt Tx endpoints that are used to communicate rate feedback for Isochronous endpoints.
10	DMAMODE	0-1	This bit should always be set to 1 when the DMA is enabled.
9-7	Reserved	0	Reserved
6	CLRDATATOG	0-1	Write a 1 to this bit to reset the endpoint data toggle to 0.
5	SENTSTALL	0-1	This bit is set automatically when a STALL handshake is transmitted. The FIFO is flushed and the TXPKTRDY bit is cleared. You should clear this bit.
4	SENDSTALL	0-1	Write a 1 to this bit to issue a STALL handshake to an IN token. Clear this bit to terminate the stall condition. Note: This bit has no effect where the endpoint is being used for Isochronous transfers.
3	FLUSHFIFO	0-1	Write a 1 to this bit to flush the next packet to be transmitted from the endpoint Tx FIFO. The FIFO pointer is reset and the TXPKTRDY bit is cleared. Note: FlushFIFO has no effect unless the TXPKTRDY bit is set. Also note that, if the FIFO is double-buffered, FlushFIFO may need to be set twice to completely clear the FIFO.
2	UNDERRUN	0-1	This bit is set automatically if an IN token is received when TXPKTRDY is not set. You should clear this bit.
1	FIFONOTEMPTY	0-1	This bit is set when there is at least 1 packet in the Tx FIFO. You should clear this bit.
0	TXPKTRDY	0-1	Set this bit after loading a data packet into the FIFO. It is cleared automatically when a data packet has been transmitted. An interrupt is generated (if enabled) when the bit is cleared.

33.4.36 Control Status Register for Host Transmit Endpoint (HOST_TXCSR)

The control status register for host transmit endpoint (HOST_TXCSR) is shown in Figure 33-62 and described in Table 33-66.

Figure 33-62. Control Status Register for Host Transmit Endpoint (HOST_TXCSR)

15	14	13	12	11	10	9	8
AUTOSET	Reserved	MODE	DMAEN	FRCDATATOG	DMAMODE	DATATOGWREN	DATATOG
R/W-0	R-0	R/W-0	R/W-0	R/W-0	R/W-0	W-0	R/W-0
7	6	5	4	3	2	1	0
NAK_TIMEOUT	CLRDATATOG	RXSTALL	SETUPPKT	FLUSHFIFO	ERROR	FIFONOTEMPTY	TXPKTRDY
R/W-0	W-0	R/W-0	R/W-0	W-0	R/W-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; W = Write only; -*n* = value after reset

Table 33-66. Control Status Register for Host Transmit Endpoint (HOST_TXCSR) Field Descriptions

Bit	Field	Value	Description
15	AUTOSET	0	DMA Mode: The CPU needs to set the AUTOSET bit prior to enabling the Tx DMA.
		1	CPU Mode: If the CPU sets the AUTOSET bit, the TXPKTRDY bit will be automatically set when data of the maximum packet size (value in TXMAXP) is loaded into the Tx FIFO. If a packet of less than the maximum packet size is loaded, then the TXPKTRDY bit will have to be set manually.
14	Reserved	0	Reserved
13	MODE	0-1	Set this bit to enable the endpoint direction as Tx, and clear the bit to enable it as Rx. Note: This bit has any effect only where the same endpoint FIFO is used for both Transmit and Receive transactions.
12	DMAEN	0-1	Set this bit to enable the DMA request for the Tx endpoint.
11	FRCDATATOG	0-1	Set this bit to force the endpoint data toggle to switch and the data packet to be cleared from the FIFO, regardless of whether an ACK was received. This can be used by Interrupt Tx endpoints that are used to communicate rate feedback for Isochronous endpoints.
10	DMAMODE	0-1	This bit should always be set to 1 when the DMA is enabled.
9	DATATOGWREN	0-1	Write 1 to this bit to enable the DATATOG bit to be written. This bit is automatically cleared once the new value is written to DATATOG.
8	DATATOG	0-1	When read, this bit indicates the current state of the Tx EP data toggle. If DATATOGWREN is high, this bit can be written with the required setting of the data toggle. If DATATOGWREN is low, any value written to this bit is ignored.
7	NAK_TIMEOUT	0-1	This bit will be set when the Tx endpoint is halted following the receipt of NAK responses for longer than the time set as the NAKLIMIT by the TXINTERVAL register. It should be cleared to allow the endpoint to continue. Note: This is valid only for Bulk endpoints.
6	CLRDATATOG	0-1	Write a 1 to this bit to reset the endpoint data toggle to 0.
5	RXSTALL	0-1	This bit is set when a STALL handshake is received. The FIFO is flushed and the TXPKTRDY bit is cleared (see below). You should clear this bit.
4	SETUPPKT	0-1	Set this bit at the same time as TXPKTRDY is set, to send a SETUP token instead of an OUT token for the transaction. Note: Setting this bit also clears the DATATOG bit.
3	FLUSHFIFO	0-1	Write a 1 to this bit to flush the next packet to be transmitted from the endpoint Tx FIFO. The FIFO pointer is reset and the TXPKTRDY bit (below) is cleared. Note: FlushFIFO has no effect unless the TXPKTRDY bit is set. Also note that, if the FIFO is double-buffered, FLUSHFIFO may need to be set twice to completely clear the FIFO.
2	ERROR	0-1	The USB controller sets this bit when 3 attempts have been made to send a packet and no handshake packet has been received. You should clear this bit. An interrupt is generated when the bit is set. This is valid only when the endpoint is operating in Bulk or Interrupt mode.
1	FIFONOTEMPTY	0-1	The USB controller sets this bit when there is at least 1 packet in the Tx FIFO.
0	TXPKTRDY	0-1	Set this bit after loading a data packet into the FIFO. It is cleared automatically when a data packet has been transmitted. An interrupt is generated (if enabled) when the bit is cleared.

33.4.37 Maximum Packet Size for Peripheral Host Receive Endpoint (RXMAXP)

The maximum packet size for peripheral host receive endpoint (RXMAXP) is shown in Figure 33-63 and described in Table 33-67.

Figure 33-63. Maximum Packet Size for Peripheral Host Receive Endpoint (RXMAXP)

15	11	10	0
Reserved		MAXPAYLOAD	
R-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 33-67. Maximum Packet Size for Peripheral Host Receive Endpoint (RXMAXP) Field Descriptions

Bit	Field	Value	Description
15-11	Reserved	0	Reserved
10-0	MAXPAYLOAD	0-400h	Defines the maximum amount of data that can be transferred through the selected Receive endpoint in a single frame/microframe (high-speed transfers). The value set can be up to 1024 bytes, but is subject to the constraints placed by the USB Specification on packet sizes for Bulk, Interrupt, and Isochronous transfers in full-speed and high-speed operations. The value written to this register should match the wMaxPacketSize field of the Standard Endpoint Descriptor for the associated endpoint. A mismatch could cause unexpected results.

33.4.38 Control Status Register for Peripheral Receive Endpoint (PERI_RXCSR)

The control status register for peripheral receive endpoint (PERI_RXCSR) is shown in Figure 33-64 and described in Table 33-68.

Figure 33-64. Control Status Register for Peripheral Receive Endpoint (PERI_RXCSR)

15	14	13	12	11	10	9	8
AUTOCLEAR	ISO	DMAEN	DISNYET	DMAMODE	Reserved		
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R-0		
7	6	5	4	3	2	1	0
CLRDATATOG	SENTSTALL	SENDSTALL	FLUSHFIFO	DATAERROR	OVERRUN	FIFOFULL	RXPKTRDY
W-0	R/W-0	R/W-0	W-0	R-0	R/W-0	R-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; W = Write only; -*n* = value after reset

Table 33-68. Control Status Register for Peripheral Receive Endpoint (PERI_RXCSR) Field Descriptions

Bit	Field	Value	Description
15	AUTOCLEAR	0	DMA Mode: The CPU sets the AUTOCLEAR bit prior to enabling the Rx DMA.
		1	CPU Mode: If the CPU sets the AUTOCLEAR bit, then the RXPKTRDY bit will be automatically cleared when a packet of RXMAXP bytes has been unloaded from the Receive FIFO. When packets of less than the maximum packet size are unloaded, RXPKTRDY will have to be cleared manually.
14	ISO	0-1	Set this bit to enable the Receive endpoint for Isochronous transfers, and clear it to enable the Receive endpoint for Bulk/Interrupt transfers.
13	DMAEN	0-1	Set this bit to enable the DMA request for the Receive endpoints.
12	DISNYET	0	DISNYET: Applies only for Bulk/Interrupt Transactions: The CPU sets this bit to disable the sending of NYET handshakes. When set, all successfully received Rx packets are ACK'd including at the point at which the FIFO becomes full. Note: This bit only has any effect in high-speed mode, in which mode it should be set for all Interrupt endpoints.
		1	PID_ERROR: Applies only for ISO Transactions: The core sets this bit to indicate a PID error in the received packet.
11	DMAMODE	0-1	Always clear this bit to 0.
10-8	Reserved	0	Reserved
7	CLRDATATOG	0-1	Write a 1 to this bit to reset the endpoint data toggle to 0.
6	SENTSTALL	0-1	This bit is set when a STALL handshake is transmitted. The FIFO is flushed and the TXPKTRDY bit is cleared. You should clear this bit.
5	SENDSTALL	0-1	Write a 1 to this bit to issue a STALL handshake. Clear this bit to terminate the stall condition. Note: This bit has no effect where the endpoint is being used for Isochronous transfers.
4	FLUSHFIFO	0-1	Write a 1 to this bit to flush the next packet to be read from the endpoint Receive FIFO. The FIFO pointer is reset and the RXPKTRDY bit is cleared. Note: FLUSHFIFO has no effect unless RXPKTRDY is set. Also note that, if the FIFO is double-buffered, FLUSHFIFO may need to be set twice to completely clear the FIFO.
3	DATAERROR	0-1	This bit is set when RXPKTRDY is set if the data packet has a CRC or bit-stuff error. It is cleared when RXPKTRDY is cleared. Note: This bit is only valid when the endpoint is operating in ISO mode. In Bulk mode, it always returns zero.
2	OVERRUN	0-1	This bit is set if an OUT packet cannot be loaded into the Receive FIFO. You should clear this bit. Note: This bit is only valid when the endpoint is operating in ISO mode. In Bulk mode, it always returns zero.
1	FIFOFULL	0-1	This bit is set when no more packets can be loaded into the Receive FIFO.
0	RXPKTRDY	0-1	This bit is set when a data packet has been received. You should clear this bit when the packet has been unloaded from the Receive FIFO. An interrupt is generated when the bit is set.

33.4.39 Control Status Register for Host Receive Endpoint (HOST_RXCSR)

The control status register for host receive endpoint (HOST_RXCSR) is shown in Figure 33-65 and described in Table 33-69.

Figure 33-65. Control Status Register for Host Receive Endpoint (HOST_RXCSR)

15	14	13	12	11	10	9	8
AUTOCLEAR	AUTOREQ	DMAEN	DISNYET	DMAMODE	DATATOGWREN	DATATOG	Reserved
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	W-0	R/W-0	R-0
7	6	5	4	3	2	1	0
CLRDATATOG	RXSTALL	REQPKT	FLUSHFIFO	DATAERR_ NAKTIMEOUT	ERROR	FIFOFULL	RXPKTRDY
W-0	R/W-0	R/W-0	W-0	R-0	R/W-0	R-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; W = Write only; -*n* = value after reset

Table 33-69. Control Status Register for Host Receive Endpoint (HOST_RXCSR) Field Descriptions

Bit	Field	Value	Description
15	AUTOCLEAR	0	DMA Mode: The CPU sets the AUTOCLEAR bit prior to enabling the Rx DMA.
		1	CPU Mode: If the CPU sets the AUTOCLEAR bit, then the RXPKTRDY bit will be automatically cleared when a packet of RXMAXP bytes has been unloaded from the Receive FIFO. When packets of less than the maximum packet size are unloaded, RXPKTRDY will have to be cleared manually.
14	AUTOREQ	1	If the CPU sets the AUTOREQ bit, then the REQPKT bit will be automatically set when the RXPKTRDY bit is cleared. Note: This bit is automatically cleared when a short packet is received.
13	DMAEN	0-1	Set this bit to enable the DMA request for the Receive endpoints.
12	DISNYET	0-1	Set this bit to disable the sending of NYET handshakes. When set, all successfully received Receive packets are ACKED including at the point at which the FIFO becomes full. Note: This bit only has any effect in high-speed mode, in which mode it should be set for all Interrupt endpoints.
11	DMAMODE	0-1	Always clear this bit to 0.
10	DATATOGWREN	0-1	Write 1 to this bit to enable the DATATOG bit to be written. This bit is automatically cleared once the new value is written to DATATOG.
9	DATATOG	0-1	When read, this bit indicates the current state of the Receive EP data toggle. If DATATOGWREN is high, this bit can be written with the required setting of the data toggle. If DATATOGWREN is low, any value written to this bit is ignored.
8	Reserved	0	Reserved
7	CLRDATATOG	0-1	Write a 1 to this bit to reset the endpoint data toggle to 0.
6	RXSTALL	0-1	When a STALL handshake is received, this bit is set and an interrupt is generated. You should clear this bit.
5	REQPKT	0-1	Write a 1 to this bit to request an IN transaction. It is cleared when RXPKTRDY is set.
4	FLUSHFIFO	0-1	Write a 1 to this bit to flush the next packet to be read from the endpoint Receive FIFO. The FIFO pointer is reset and the RXPKTRDY bit is cleared. Note: FLUSHFIFO has no effect unless RXPKTRDY is set. Also note that, if the FIFO is double-buffered, FLUSHFIFO may need to be set twice to completely clear the FIFO.
3	DATAERR_NAKTIMEOUT	0-1	When operating in ISO mode, this bit is set when RXPKTRDY is set if the data packet has a CRC or bit-stuff error and cleared when RXPKTRDY is cleared. In Bulk mode, this bit will be set when the Receive endpoint is halted following the receipt of NAK responses for longer than the time set as the NAK Limit by the RXINTERVAL register. You should clear this bit to allow the endpoint to continue.
2	ERROR	0-1	The USB controller sets this bit when 3 attempts have been made to receive a packet and no data packet has been received. You should clear this bit. An interrupt is generated when the bit is set. Note: This bit is only valid when the transmit endpoint is operating in Bulk or Interrupt mode. In ISO mode, it always returns zero.
1	FIFOFULL	0-1	This bit is set when no more packets can be loaded into the Receive FIFO.

Table 33-69. Control Status Register for Host Receive Endpoint (HOST_RXCSR) Field Descriptions (continued)

Bit	Field	Value	Description
0	RXPKTRDY	0-1	This bit is set when a data packet has been received. You should clear this bit when the packet has been unloaded from the Receive FIFO. An interrupt is generated when the bit is set.

33.4.40 Count 0 Register (COUNT0)

The count 0 register (COUNT0) is shown in Figure 33-66 and described in Table 33-70.

Figure 33-66. Count 0 Register (COUNT0)

15	7	6	0
Reserved		EP0RXCOUNT	
R-0		R-0	

LEGEND: R = Read only; -*n* = value after reset

Table 33-70. Count 0 Register (COUNT0) Field Descriptions

Bit	Field	Value	Description
15-7	Reserved	0	Reserved
6-0	EP0RXCOUNT	0-7Fh	Indicates the number of received data bytes in the Endpoint 0 FIFO. The value returned changes as the contents of the FIFO change and is only valid while RXPKTRDY of PERI_CSR0 or HOST_CSR0 is set.

33.4.41 Receive Count Register (RXCOUNT)

The receive count register (RXCOUNT) is shown in Figure 33-67 and described in Table 33-71.

Figure 33-67. Receive Count Register (RXCOUNT)

15	13	12	0
Reserved		EPRXCOUNT	
R-0		R-0	

LEGEND: R = Read only; -*n* = value after reset

Table 33-71. Receive Count Register (RXCOUNT) Field Descriptions

Bit	Field	Value	Description
15-13	Reserved	0	Reserved
12-0	EPRXCOUNT	0-1FFFh	Holds the number of received data bytes in the packet in the Receive FIFO. The value returned changes as the contents of the FIFO change and is only valid while RXPKTRDY of PERI_RXCSR or HOST_RXCSR is set.

33.4.42 Type Register (Host mode only) (HOST_TYPE0)

The type register (Host mode only) (HOST_TYPE0) is shown in Figure 33-68 and described in Table 33-72.

Figure 33-68. Type Register (Host mode only) (HOST_TYPE0)

7	6	5	0
SPEED		Reserved	
R/W-0		R-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 33-72. Type Register (Host mode only) (HOST_TYPE0) Field Descriptions

Bit	Field	Value	Description
7-6	SPEED	0-3h	Operating Speed of Target Device
		0	Illegal
		1h	High
		2h	Full
		3h	Low
5-0	Reserved	0	Reserved

33.4.43 Transmit Type Register (Host mode only) (HOST_TXTYPE)

The transmit type register (Host mode only) (HOST_TXTYPE) is shown in Figure 33-69 and described in Table 33-73.

Figure 33-69. Transmit Type Register (Host mode only) (HOST_TXTYPE)

7	6	5	4	3	0
SPEED		PROT		TENDPN	
R/W-0		R/W-0		R/W-0	

LEGEND: R/W = Read/Write; -*n* = value after reset

Table 33-73. Transmit Type Register (Host mode only) (HOST_TXTYPE) Field Descriptions

Bit	Field	Value	Description
7-6	SPEED	0-3h	Operating Speed of Target Device
		0	Illegal
		1h	High
		2h	Full
		3h	Low
5-4	PROT	0-3h	Set this to select the required protocol for the transmit endpoint
		0	Control
		1h	Isochronous
		2h	Bulk
		3h	Interrupt
3-0	TENDPN	0-Fh	Set this value to the endpoint number contained in the transmit endpoint descriptor returned to the USB controller during device enumeration.

33.4.44 NAKLimit0 Register (Host mode only) (HOST_NAKLIMIT0)

The NAKlimit0 register (Host mode only) (HOST_NAKLIMIT0) is shown in Figure 33-70 and described in Table 33-74.

Figure 33-70. NAKLimit0 Register (Host mode only) (HOST_NAKLIMIT0)

7	5	4	0
Reserved		EP0NAKLIMIT	
R-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 33-74. NAKLimit0 Register (Host mode only) (HOST_NAKLIMIT0) Field Descriptions

Bit	Field	Value	Description
7-5	Reserved	0	Reserved
4-0	EP0NAKLIMIT	0-1Fh	Sets the number of frames/microframes (high-speed transfers) after which Endpoint 0 should time out on receiving a stream of NAK responses. The number of frames/microframes selected is $2^{(-1)}$ (where m is the value set in the register, valid values 2-16). If the host receives NAK responses from the target for more frames than the number represented by the Limit set in this register, the endpoint will be halted. Note: A value of 0 or 1 disables the NAK timeout function.

33.4.45 Transmit Interval Register (Host mode only) (HOST_TXINTERVAL)

The transmit interval register (Host mode only) (HOST_TXINTERVAL) is shown in Figure 33-71 and described in Table 33-75.

Figure 33-71. Transmit Interval Register (Host mode only) (HOST_TXINTERVAL)

7	0
POLINTVL_NAKLIMIT	
R/W-0	

LEGEND: R/W = Read/Write; -*n* = value after reset

Table 33-75. Transmit Interval Register (Host mode only) (HOST_TXINTERVAL) Field Descriptions

Bit	Field	Value	Description
7-0	POLINTVL_NAKLIMIT	0-FFh	For Interrupt and Isochronous transfers, defines the polling interval for the currently-selected transmit endpoint. For Bulk endpoints, sets the number of frames/microframes after which the endpoint should timeout on receiving a stream of NAK responses. There is a transmit interval register for each configured transmit endpoint (except Endpoint 0). In each case, the value that is set defines a number of frames/microframes (High-Speed transfers), as follows:

Transfer Type	Speed	Valid values (m)	Interpretation
Interrupt	Low Speed or Full Speed	1-255	Polling interval is m frames
	High Speed	1-16	Polling interval is $2^{(-1)}$ microframes
Isochronous	Full Speed or High Speed	1-16	Polling interval is $2^{(-1)}$ frames/microframes
Bulk	Full Speed or High Speed	2-16	NAK Limit is $2^{(-1)}$ frames/microframes

Note: A value of 0 or 1 disables the NAK timeout function.

33.4.46 Receive Type Register (Host mode only) (HOST_RXTYPE)

The receive type register (Host mode only) (HOST_RXTYPE) is shown in Figure 33-72 and described in Table 33-76.

Figure 33-72. Receive Type Register (Host mode only) (HOST_RXTYPE)

7	6	5	4	3	0
SPEED		PROT		RENDPN	
R/W-0		R/W-0		R/W-0	

LEGEND: R/W = Read/Write; *-n* = value after reset

Table 33-76. Receive Type Register (Host mode only) (HOST_RXTYPE) Field Descriptions

Bit	Field	Value	Description
7-6	SPEED	0-3h	Operating Speed of Target Device
		0	Illegal
		1h	High
		2h	Full
		3h	Low
5-4	PROT	0-3h	Set this to select the required protocol for the transmit endpoint
		0	Control
		1h	Isochronous
		2h	Bulk
		3h	Interrupt
3-0	RENDPN	0-Fh	Set this value to the endpoint number contained in the Receive endpoint descriptor returned to the USB controller during device enumeration

33.4.47 Receive Interval Register (Host mode only) (HOST_RXINTERVAL)

The receive interval register (Host mode only) (HOST_RXINTERVAL) is shown in Figure 33-73 and described in Table 33-77.

Figure 33-73. Receive Interval Register (Host mode only) (HOST_RXINTERVAL)

7	0
POLINTVL_NAKLIMIT	
R/W-0	

LEGEND: R/W = Read/Write; -*n* = value after reset

Table 33-77. Receive Interval Register (Host mode only) (HOST_RXINTERVAL) Field Descriptions

Bit	Field	Value	Description
7-0	POLINTVL_NAKLIMIT	0-FFh	For Interrupt and Isochronous transfers, defines the polling interval for the currently-selected transmit endpoint. For Bulk endpoints, sets the number of frames/microframes after which the endpoint should timeout on receiving a stream of NAK responses. There is a transmit interval register for each configured transmit endpoint (except Endpoint 0). In each case, the value that is set defines a number of frames/microframes (High-Speed transfers), as follows:

Transfer Type	Speed	Valid values (m)	Interpretation
Interrupt	Low Speed or Full Speed	1-255	Polling interval is m frames
	High Speed	1-16	Polling interval is $2^{(m-1)}$ microframes
Isochronous	Full Speed or High Speed	1-16	Polling interval is $2^{(m-1)}$ frames/microframes
Bulk	Full Speed or High Speed	2-16	NAK Limit is $2^{(m-1)}$ frames/microframes

Note: A value of 0 or 1 disables the NAK timeout function.

33.4.48 Configuration Data Register (CONFIGDATA)

The configuration data register (CONFIGDATA) is shown in Figure 33-74 and described in Table 33-78.

Figure 33-74. Configuration Data Register (CONFIGDATA)

7	6	5	4	3	2	1	0
MPRXE	MPTXE	BIGENDIAN	HBRXE	HBTXE	DYNFIFO	SOFTCONE	UTMIDATAWIDTH
R-0	R-0	R-0	R-0	R-0	R-1	R-1	R-0

LEGEND: R = Read only; -*n* = value after reset

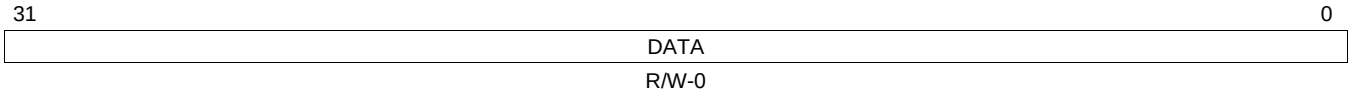
Table 33-78. Configuration Data Register (CONFIGDATA) Field Descriptions

Bit	Field	Value	Description
7	MPRXE		Indicates automatic amalgamation of bulk packets.
		0	Automatic amalgamation of bulk packets is not selected.
		1	Automatic amalgamation of bulk packets is selected.
6	MPTXE		Indicates automatic splitting of bulk packets.
		0	Automatic splitting of bulk packets is not selected.
		1	Automatic splitting of bulk packets is selected.
5	BIGENDIAN		Indicates endian ordering.
		0	Little-endian ordering is selected.
		1	Big-endian ordering is selected.
4	HBRXE		Indicates high-bandwidth Rx ISO endpoint support.
		0	High-bandwidth Rx ISO endpoint support is not selected.
		1	High-bandwidth Rx ISO endpoint support is selected.
3	HBTXE		Indicates high-bandwidth Tx ISO endpoint support.
		0	High-bandwidth Tx ISO endpoint support is not selected.
		1	High-bandwidth Tx ISO endpoint support is selected.
2	DYNFIFO		Indicates dynamic FIFO sizing.
		0	Dynamic FIFO sizing option is not selected.
		1	Dynamic FIFO sizing option is selected.
1	SOFTCONE		Indicates soft connect/disconnect.
		0	Soft connect/disconnect option is not selected
		1	Soft connect/disconnect option is selected
0	UTMIDATAWIDTH		Indicates selected UTMI data width.
		0	8 bits
		1	16 bits

33.4.49 Transmit and Receive FIFO Register for Endpoint 0 (FIFO0)

The transmit and receive FIFO register for endpoint 0 (FIFO0) is shown in Figure 33-75 and described in Table 33-79.

Figure 33-75. Transmit and Receive FIFO Register for Endpoint 0 (FIFO0)



LEGEND: R/W = Read/Write; -*n* = value after reset

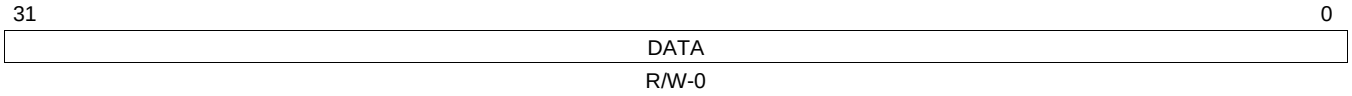
Table 33-79. Transmit and Receive FIFO Register for Endpoint 0 (FIFO0) Field Descriptions

Bit	Field	Value	Description
31-0	DATA	0-FFFF FFFFh	Writing to these addresses loads data into the Transmit FIFO for the corresponding endpoint. Reading from these addresses unloads data from the Receive FIFO for the corresponding endpoint.

33.4.50 Transmit and Receive FIFO Register for Endpoint 1 (FIFO1)

The transmit and receive FIFO register for endpoint 1 (FIFO1) is shown in Figure 33-76 and described in Table 33-80.

Figure 33-76. Transmit and Receive FIFO Register for Endpoint 1 (FIFO1)



LEGEND: R/W = Read/Write; -*n* = value after reset

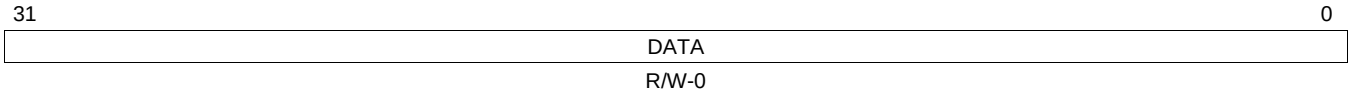
Table 33-80. Transmit and Receive FIFO Register for Endpoint 1 (FIFO1) Field Descriptions

Bit	Field	Value	Description
31-0	DATA	0-FFFF FFFF	Writing to these addresses loads data into the Transmit FIFO for the corresponding endpoint. Reading from these addresses unloads data from the Receive FIFO for the corresponding endpoint.

33.4.51 Transmit and Receive FIFO Register for Endpoint 2 (FIFO2)

The transmit and receive FIFO register for endpoint 2 (FIFO2) is shown in Figure 33-77 and described in Table 33-81.

Figure 33-77. Transmit and Receive FIFO Register for Endpoint 2 (FIFO2)



LEGEND: R/W = Read/Write; -*n* = value after reset

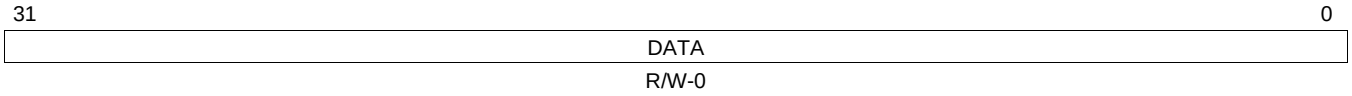
Table 33-81. Transmit and Receive FIFO Register for Endpoint 2 (FIFO2) Field Descriptions

Bit	Field	Value	Description
31-0	DATA	0-FFFF FFFFh	Writing to these addresses loads data into the Transmit FIFO for the corresponding endpoint. Reading from these addresses unloads data from the Receive FIFO for the corresponding endpoint.

33.4.52 Transmit and Receive FIFO Register for Endpoint 3 (FIFO3)

The transmit and receive FIFO register for endpoint 3 (FIFO3) is shown in Figure 33-78 and described in Table 33-82.

Figure 33-78. Transmit and Receive FIFO Register for Endpoint 3 (FIFO3)



LEGEND: R/W = Read/Write; -*n* = value after reset

Table 33-82. Transmit and Receive FIFO Register for Endpoint 3 (FIFO3) Field Descriptions

Bit	Field	Value	Description
31-0	DATA	0-FFFF FFFFh	Writing to these addresses loads data into the Transmit FIFO for the corresponding endpoint. Reading from these addresses unloads data from the Receive FIFO for the corresponding endpoint.

33.4.53 Transmit and Receive FIFO Register for Endpoint 4 (FIFO4)

The transmit and receive FIFO register for endpoint 4 (FIFO4) is shown in Figure 33-79 and described in Table 33-83.

Figure 33-79. Transmit and Receive FIFO Register for Endpoint 4 (FIFO4)

31	0
DATA	
R/W-0	

LEGEND: R/W = Read/Write; *-n* = value after reset

Table 33-83. Transmit and Receive FIFO Register for Endpoint 4 (FIFO4) Field Descriptions

Bit	Field	Value	Description
31-0	DATA	0-FFFF FFFFh	Writing to these addresses loads data into the Transmit FIFO for the corresponding endpoint. Reading from these addresses unloads data from the Receive FIFO for the corresponding endpoint.

33.4.54 Device Control Register (DEVCTL)

The device control register (DEVCTL) is shown in Figure 33-80 and described in Table 33-84.

Figure 33-80. Device Control Register (DEVCTL)

7	6	5	4	3	2	1	0
BDEVICE	FSDEV	LSDEV	VBUS		HOSTMODE	HOSTREQ	SESSION
R-0	R-0	R-0	R-0		R-0	R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; *-n* = value after reset

Table 33-84. Device Control Register (DEVCTL) Field Descriptions

Bit	Field	Value	Description
7	BDEVICE		This read-only bit indicates whether the USB controller is operating as the 'A' device or the 'B' device.
		0	A device
		1	B device
			Only valid while a session is in progress.
6	FSDEV	0-1	This read-only bit is set when a full-speed or high-speed device has been detected being connected to the port (high-speed devices are distinguished from full-speed by checking for high-speed chirps when the device is reset). Only valid in Host mode.
5	LSDEV	0-1	This read-only bit is set when a low-speed device has been detected being connected to the port. Only valid in Host mode.
4-3	VBUS	0-3h	These read-only bits encode the current VBus level as follows:
		0	Below Session End
		1h	Above Session End, below AValid
		2h	Above AValid, below VBusValid
		3h	Above VBusValid
2	HOSTMODE	0-1	This read-only bit is set when the USB controller is acting as a Host.
1	HOSTREQ	0-1	When set, the USB controller will initiate the Host Negotiation when Suspend mode is entered. It is cleared when Host Negotiation is completed. ('B' device only)
0	SESSION	0-1	When operating as an 'A' device, you must set or clear this bit start or end a session. When operating as a 'B' device, this bit is set/cleared by the USB controller when a session starts/ends. You must also set this bit to initiate the Session Request Protocol (SRP). When the USB controller is in Suspend mode, you may clear the bit to perform a software disconnect. A special software routine is required to perform SRP.

33.4.55 Transmit Endpoint FIFO Size (TXFIFOSZ)

Section 33.2.6 describes dynamically setting endpoint FIFO sizes. The option of dynamically setting endpoint FIFO sizes only applies to Endpoints 1-4. The Endpoint 0 FIFO has a fixed size (64 bytes) and a fixed location (start address 0). It is the responsibility of the firmware to ensure that all the Tx and Rx endpoints that are active in the current USB configuration have a block of RAM assigned exclusively to that endpoint. The RAM must be at least as large as the maximum packet size set for that endpoint.

The transmit endpoint FIFO size (TXFIFOSZ) is shown in Figure 33-81 and described in Table 33-85.

Figure 33-81. Transmit Endpoint FIFO Size (TXFIFOSZ)

7	5	4	3	0
Reserved		DPB	SZ	
R-0		R/W-0	R-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 33-85. Transmit Endpoint FIFO Size (TXFIFOSZ) Field Descriptions

Bit	Field	Value	Description
7-5	Reserved	0	Reserved
4	DPB		Double packet buffering enable
		0	Single packet buffering is supported
		1	Double packet buffering is enabled
3-0	SZ	0-Fh	Maximum packet size to be allowed (before any splitting within the FIFO of Bulk packets prior to transmission). If m = SZ, the FIFO size is calculated as $2^{(m+3)}$ for single packet buffering and $2^{(m+4)}$ for dual packet buffering.

33.4.56 Receive Endpoint FIFO Size (RXFIFOSZ)

Section 33.2.6 describes dynamically setting endpoint FIFO sizes. The option of dynamically setting endpoint FIFO sizes only applies to Endpoints 1-4. The Endpoint 0 FIFO has a fixed size (64 bytes) and a fixed location (start address 0). It is the responsibility of the firmware to ensure that all the Tx and Rx endpoints that are active in the current USB configuration have a block of RAM assigned exclusively to that endpoint. The RAM must be at least as large as the maximum packet size set for that endpoint.

The receive endpoint FIFO size (RXFIFOSZ) is shown in Figure 33-82 and described in Table 33-86.

Figure 33-82. Receive Endpoint FIFO Size (RXFIFOSZ)

7	5	4	3	0
Reserved		DPB	SZ	
R-0		R/W-0	R-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 33-86. Receive Endpoint FIFO Size (RXFIFOSZ) Field Descriptions

Bit	Field	Value	Description
7-5	Reserved	0	Reserved
4	DPB		Double packet buffering enable
		0	Single packet buffering is supported
		1	Double packet buffering is enabled
3-0	SZ	0-Fh	Maximum packet size to be allowed (before any splitting within the FIFO of Bulk packets prior to transmission). If m = SZ, the FIFO size is calculated as $2^{(m+3)}$ for single packet buffering and $2^{(m+4)}$ for dual packet buffering.

33.4.57 Transmit Endpoint FIFO Address (TXFIFOADDR)

Section 33.2.6 describes dynamically setting endpoint FIFO sizes.

The transmit endpoint FIFO address (TXFIFOADDR) is shown in Figure 33-83 and described in Table 33-87.

Figure 33-83. Transmit Endpoint FIFO Address (TXFIFOADDR)

15	13	12	0
Reserved		ADDR	
R-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 33-87. Transmit Endpoint FIFO Address (TXFIFOADDR) Field Descriptions

Bit	Field	Value	Description
15-13	Reserved	0	Reserved
12-0	ADDR	0-1FFFh	Start Address of endpoint FIFO in units of 8 bytes If m = ADDR, then the start address is 8 × m

33.4.58 Receive Endpoint FIFO Address (RXFIFOADDR)

Section 33.2.6 describes dynamically setting endpoint FIFO sizes.

The receive endpoint FIFO address (RXFIFOADDR) is shown in Figure 33-84 and described in Table 33-88.

Figure 33-84. Receive Endpoint FIFO Address (RXFIFOADDR)

15	13	12	0
Reserved		ADDR	
R-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 33-88. Receive Endpoint FIFO Address (RXFIFOADDR) Field Descriptions

Bit	Field	Value	Description
15-13	Reserved	0	Reserved
12-0	ADDR	0-1FFFh	Start Address of endpoint FIFO in units of 8 bytes If m = ADDR, then the start address is 8 × m

33.4.59 Hardware Version Register (HWVERS)

The hardware version register (HWVERS) contains the RTL major and minor version numbers for the USB 2.0 OTG controller module. The RTL version number is REVMAJ.REVMIN. The HWVERS is shown in Figure 33-85 and described in Table 33-89.

Figure 33-85. Hardware Version Register (HWVERS)

15	14 10	9 0
RC	REVMAJ	REVMIN
R-0	R-0	R-0

LEGEND: R = Read only; -*n* = value after reset

Table 33-89. Hardware Version Register (HWVERS) Field Descriptions

Bit	Field	Value	Description
15	RC	0-1	Set to 1 if RTL is used from a Release Candidate, rather than from a full release of the core.
14-10	REVMAJ	0-1Fh	Major version of RTL. Range is 0-31.
9-0	REVMIN	0-3E7h	Minor version of RTL. Range is 0-999.

33.4.60 Transmit Function Address (TXFUNCADDR)

The transmit function address (TXFUNCADDR) is shown in Figure 33-86 and described in Table 33-90.

Figure 33-86. Transmit Function Address (TXFUNCADDR)

7	6	0
Reserved	FUNCADDR	
R-0	R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 33-90. Transmit Function Address (TXFUNCADDR) Field Descriptions

Bit	Field	Value	Description
7	Reserved	0	Reserved
6-0	FUNCADDR	0-7Fh	Address of target function

33.4.61 Transmit Hub Address (TXHUBADDR)

The transmit hub address (TXHUBADDR) is shown in Figure 33-87 and described in Table 33-91.

Figure 33-87. Transmit Hub Address (TXHUBADDR)

7	6	0
MULT_TRANS	HUBADDR	
R/W-0	R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 33-91. Transmit Hub Address (TXHUBADDR) Field Descriptions

Bit	Field	Value	Description
7	MULT_TRANS	0-1	Set to 1 if hub has multiple transaction translators. Cleared to 0 if only single transaction translator is available.
6-0	HUBADDR	0-7Fh	Address of hub

33.4.62 Transmit Hub Port (TXHUBPORT)

The transmit hub port (TXHUBPORT) is shown in Figure 33-88 and described in Table 33-92.

Figure 33-88. Transmit Hub Port (TXHUBPORT)

7	6	0
Reserved	HUBPORT	
R-0	R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 33-92. Transmit Hub Port (TXHUBPORT) Field Descriptions

Bit	Field	Value	Description
7	Reserved	0	Reserved
6-0	HUBPORT	0-7Fh	Port number of the hub

33.4.63 Receive Function Address (RXFUNCADDR)

The receive function address (RXFUNCADDR) is shown in Figure 33-89 and described in Table 33-93.

Figure 33-89. Receive Function Address (RXFUNCADDR)

7	6	0
Reserved	FUNCADDR	
R-0	R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 33-93. Receive Function Address (RXFUNCADDR) Field Descriptions

Bit	Field	Value	Description
7	Reserved	0	Reserved
6-0	FUNCADDR	0-7Fh	Address of target function

33.4.64 Receive Hub Address (RXHUBADDR)

The receive hub address (RXHUBADDR) is shown in Figure 33-90 and described in Table 33-94.

Figure 33-90. Receive Hub Address (RXHUBADDR)

7	6	0
MULT_TRANS	HUBADDR	
R/W-0	R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 33-94. Receive Hub Address (RXHUBADDR) Field Descriptions

Bit	Field	Value	Description
7	MULT_TRANS	0-1	Set to 1 if hub has multiple transaction translators. Cleared to 0 if only single transaction translator is available.
6-0	HUBADDR	0-7Fh	Address of hub

33.4.65 Receive Hub Port (RXHUBPORT)

The receive hub port (RXHUBPORT) is shown in Figure 33-91 and described in Table 33-95.

Figure 33-91. Receive Hub Port (RXHUBPORT)

7	6	0
Reserved	HUBPORT	
R-0	R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 33-95. Receive Hub Port (RXHUBPORT) Field Descriptions

Bit	Field	Value	Description
7	Reserved	0	Reserved
6-0	HUBPORT	0-7Fh	Port number of hub

33.4.66 CDMA Revision Identification Register (DMAREVID)

The CDMA revision identification register (DMAREVID) contains the revision for the module. The DMAREVID is shown in Figure 33-92 and described in Table 33-96.

Figure 33-92. CDMA Revision Identification Register (DMAREVID)

31	0
REV	
R-0053 1900h	

LEGEND: R = Read only; -*n* = value after reset

Table 33-96. CDMA Revision Identification Register (DMAREVID) Field Descriptions

Bit	Field	Value	Description
31-0	REV	0053 1900h	Revision ID of the CPPI DMA (CDMA) module.

33.4.67 CDMA Teardown Free Descriptor Queue Control Register (TDFDQ)

The CDMA teardown free descriptor queue control register (TDFDQ) is used to inform the DMA of the location in memory or descriptor array which is to be used for signaling of a teardown complete for each transmit and receive channel. The CDMA teardown free descriptor queue control register (TDFDQ) is shown in Figure 33-93 and described in Table 33-97.

Figure 33-93. CDMA Teardown Free Descriptor Queue Control Register (TDFDQ)

31	16
Reserved	
R-0	

15	14	13	12	11	0
Reserved		TD_DESC_QMGR		TD_DESC_QNUM	
R-0		R/W-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 33-97. CDMA Teardown Free Descriptor Queue Control Register (TDFDQ) Field Descriptions

Bit	Field	Value	Description
31-14	Reserved	0	Reserved
13-12	TD_DESC_QMGR	0-3h	Controls which of the four queue managers the DMA accesses to allocate a channel teardown descriptor from the teardown descriptor queue.
11-0	TD_DESC_QNUM	0-FFFh	Controls which of the 2K queues in the indicated queue manager should be read to allocate the channel teardown descriptors.

33.4.68 CDMA Emulation Control Register (DMAEMU)

The CDMA emulation controls the behavior of the DMA when the emususp input is asserted. The CDMA emulation control register (DMAEMU) is shown in Figure 33-94 and described in Table 33-98.

Figure 33-94. CDMA Emulation Control Register (DMAEMU)

31	2	1	0
Reserved		SOFT	FREE
R-0		R/W-0	R/W-0

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 33-98. CDMA Emulation Control Register (DMAEMU) Field Descriptions

Bit	Field	Value	Description
31-2	Reserved	0	Reserved
1	SOFT		Determines emulation mode functionality. When the FREE bit is cleared to 0, the SOFT bit selects the mode.
		0	Upon emulation suspend, operation is not affected.
		1	In response to an emulation suspend event, the logic halts after the current transaction is completed.
0	FREE		Free run emulation control. Determines emulation mode functionality. When the FREE bit is cleared to 0, the SOFT bit selects the mode.
		0	The SOFT bit selects the mode.
		1	Runs free regardless of the SOFT bit.

33.4.69 CDMA Transmit Channel n Global Configuration Registers (TXGCR[0]-TXGCR[3])

The transmit channel *n* configuration registers (TXGCR[*n*]) initialize the behavior of each of the transmit DMA channels. There are four configuration registers, one for each transmit DMA channels. The transmit channel *n* configuration registers (TXGCR[*n*]) are shown in Figure 33-95 and described in Table 33-99.

Figure 33-95. CDMA Transmit Channel *n* Global Configuration Registers (TXGCR[*n*])

31	30	29	16
TX_ENABLE	TX_TEARDOWN	Reserved	
R/W-0	R/W-0	R-0	

15	14	13	12	11	0
Reserved		TX_DEFAULT_QMGR		TX_DEFAULT_QNUM	
R-0		W-0		W-0	

LEGEND: R/W = Read/Write; R = Read only; W = Write only; -*n* = value after reset

Table 33-99. CDMA Transmit Channel *n* Global Configuration Registers (TXGCR[*n*]) Field Descriptions

Bit	Field	Value	Description
31	TX_ENABLE		Channel control. The TX_ENABLE field is cleared after a channel teardown is complete.
		0	Disables channel
		1	Enables channel
30	TX_TEARDOWN	0-1	Setting this bit requests the channel to be torn down. The TX_TEARDOWN field remains set after a channel teardown is complete.
29-14	Reserved	0	Reserved
13-12	TX_DEFAULT_QMGR	0-3h	Controls the default queue manager number that is used to queue teardown descriptors back to the host.
11-0	TX_DEFAULT_QNUM	0-FFFh	Controls the default queue number within the selected queue manager onto which teardown descriptors are queued back to the host. This is the Tx Completion Queue.

33.4.70 CDMA Receive Channel n Global Configuration Registers (RXGCR[0]-RXGCR[3])

The receive channel *n* global configuration registers (RXGCR[*n*]) initialize the global (non-descriptor-type specific) behavior of each of the receive DMA channels. There are four configuration registers, one for each receive DMA channels. If the enable bit is being set, the receive channel *n* global configuration register should only be written after all of the other receive configuration registers have been initialized. The receive channel *n* global configuration registers (RXGCR[*n*]) are shown in Figure 33-96 are described in Table 33-100.

Figure 33-96. CDMA Receive Channel *n* Global Configuration Registers (RXGCR[*n*])

31	30	29–25	24	23–16
RX_ENABLE	RX_TEARDOWN	Reserved	RX_ERROR_HANDLING	RX_SOP_OFFSET
R/W-0	R/W-0	R-0	W-0	W-0

15–14	13–12	11–0
RX_DEFAULT_DESC_TYPE	RX_DEFAULT_RQ_QMGR	RX_DEFAULT_RQ_QNUM
R-0	W-0	W-0

LEGEND: R/W = Read/Write; R = Read only; W = Write only; -*n* = value after reset

Table 33-100. CDMA Receive Channel *n* Global Configuration Registers (RXGCR[*n*]) Field Descriptions

Bit	Field	Value	Description
31	RX_ENABLE		Channel control. Field is cleared after a channel teardown is complete.
		0	Disables channel
		1	Enables channel
30	RX_TEARDOWN	0-1	Indicates whether a receive operation is complete. Field should be cleared when a channel is initialized. Field is set after a channel teardown is complete.
29-25	Reserved	0	Reserved
24	RX_ERROR_HANDLING		Controls the error handling mode for the channel and is only used when channel errors (i.e. descriptor or buffer starvation occur):
		0	Starvation errors result in dropping packet and reclaiming any used descriptor or buffer resources back to the original queues/pools they were allocated to.
		1	Starvation errors result in subsequent retry of the descriptor allocation operation. In this mode, the DMA will return to the IDLE state without saving its internal operational state back to the internal state RAM and without issuing an advance operation on the FIFO interface. This results in the DMA re-initiating the FIFO block transfer at a later time with the intention that additional free buffers and/or descriptors will have been added.
23-16	RX_SOP_OFFSET	0–FFh	Specifies the number of bytes that are to be skipped in the SOP buffer before beginning to write the payload. This value must be less than the minimum size of a buffer in the system.
15-14	RX_DEFAULT_DESC_TYPE	0-3h	Indicates the default descriptor type to use. The actual descriptor type that is used for reception can be overridden by information provided in the CPPI FIFO data block.
		0	Reserved
		1h	Host
		2h-3h	Reserved
13-12	RX_DEFAULT_RQ_QMGR	0-3h	Indicates the default receive queue manager that this channel should use. The actual receive queue manager index can be overridden by information provided in the CPPI FIFO data block.
11-0	RX_DEFAULT_RQ_QNUM	0-FFFh	Indicates the default receive queue that this channel should use. The actual receive queue that is used for reception can be overridden by information provided in the CPPI FIFO data block. This is the Rx Completion Queue.

33.4.71 CDMA Receive Channel n Host Packet Configuration Registers A (RXHPCRA[0]-RXHPCRA[3])

The receive channel *n* host packet configuration registers A (RXHPCRA[*n*]) initialize the behavior of each of the receive DMA channels for reception of host type packets. There are four configuration A registers, one for each receive DMA channels. The receive channel *n* host packet configuration registers A (RXHPCRA[*n*]) are shown in Figure 33-97 and described in Table 33-101.

Figure 33-97. Receive Channel *n* Host Packet Configuration Registers A (RXHPCRA[*n*])

31	30	29	28	27	16
Reserved		RX_HOST_FDQ1_QMGR		RX_HOST_FDQ1_QNUM	
R-0		W-0		W-0	

15	14	13	12	11	0
Reserved		RX_HOST_FDQ0_QMGR		RX_HOST_FDQ0_QNUM	
R-0		W-0		W-0	

LEGEND: R = Read only; W = Write only; -*n* = value after reset

Table 33-101. Receive Channel *n* Host Packet Configuration Registers A (RXHPCRA[*n*]) Field Descriptions

Bit	Field	Value	Description
31-30	Reserved	0	Reserved
29-28	RX_HOST_FDQ1_QMGR	0-3h	Specifies which buffer manager should be used for the second receive buffer in a host type packet.
27-16	RX_HOST_FDQ1_QNUM	0-FFFh	Specifies which free descriptor/buffer pool should be used for the second receive buffer in a host type packet. This is the Rx Submit Queue for the second Incoming Packet.
15-14	Reserved	0	Reserved
13-12	RX_HOST_FDQ0_QMGR	0-3h	Specifies which buffer manager should be used for the first receive buffer in a host type packet.
11-0	RX_HOST_FDQ0_QNUM	0-FFFh	Specifies which free descriptor/buffer pool should be used for the first receive buffer in a host type packet. This is the Rx Submit Queue for the first Incoming Packet.

33.4.72 CDMA Receive Channel n Host Packet Configuration Registers B (RXHPCRB[0]-RXHPCRB[3])

The receive channel *n* host packet configuration registers B (RXHPCRB[*n*]) initialize the behavior of each of the receive DMA channels for reception of host type packets. There are four configuration B registers, one for each receive DMA channels. The receive channel *n* host packet configuration registers B (RXHPCRB[*n*]) are shown in Figure 33-98 and described in Table 33-102.

Figure 33-98. Receive Channel *n* Host Packet Configuration Registers B (RXHPCRB[*n*])

31	30	29	28	27	16
Reserved		RX_HOST_FDQ3_QMGR		RX_HOST_FDQ3_QNUM	
R-0		W-0		W-0	

15	14	13	12	11	0
Reserved		RX_HOST_FDQ2_QMGR		RX_HOST_FDQ2_QNUM	
R-0		W-0		W-0	

LEGEND: R = Read only; W = Write only; -*n* = value after reset

Table 33-102. Receive Channel *n* Host Packet Configuration Registers B (RXHPCRB[*n*]) Field Descriptions

Bit	Field	Value	Description
31-30	Reserved	0	Reserved
29-28	RX_HOST_FDQ3_QMGR	0-3h	Specifies which buffer manager should be used for the fourth or later receive buffer in a host type packet.
27-16	RX_HOST_FDQ3_QNUM	0-FFFh	Specifies which free descriptor/buffer pool should be used for the fourth or later receive buffer in a host type packet. This is the Rx Submit Queue for the fourth and remaining Incoming Packet.
15-14	Reserved	0	Reserved
13-12	RX_HOST_FDQ2_QMGR	0-3h	Specifies which buffer manager should be used for the third receive buffer in a host type packet.
11-0	RX_HOST_FDQ2_QNUM	0-FFFh	Specifies which free descriptor/buffer pool should be used for the third receive buffer in a host type packet. This is the Rx Submit Queue for the third Incoming Packet.

33.4.73 CDMA Scheduler Control Register (DMA_SCHED_CTRL)

The CDMA scheduler control register (DMA_SCHED_CTRL) enables the scheduler and indicates the last entry in the scheduler table. The CDMA scheduler control register (DMA_SCHED_CTRL) is shown in Figure 33-99 and described in Table 33-103.

Figure 33-99. CDMA Scheduler Control Register (DMA_SCHED_CTRL)

31	30	16
ENABLE	Reserved	
R/W-0	R-0	

15	8	7	0
Reserved		LAST_ENTRY	
R-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 33-103. CDMA Scheduler Control Register (DMA_SCHED_CTRL) Field Descriptions

Bit	Field	Value	Description
31	ENABLE		This is the enable bit for the scheduler and is encoded as follows:
		0	Scheduler is disabled and will no longer fetch entries from the scheduler table or pass credits to the DMA controller
		1	Scheduler is enabled. This bit should only be set after the table has been initialized.
30-8	Reserved	0	Reserved
7-0	LAST_ENTRY	0-FFh	Indicates the last valid entry in the scheduler table. There are 64 words in the table and there are 4 entries in each word. The table can be programmed with any integer number of entries from 1 to 256. The corresponding encoding for this field is as follows:
		0	1 entry
		1h	2 entries
		2h-FFh	3 entries to 256 entries

33.4.74 CDMA Scheduler Table Word n Registers (WORD[0]-WORD[63])

The CDMA scheduler table word *n* registers (WORD[*n*]) has 4 entries (ENTRY[0] to ENTRY[3]) that provide information about the scheduler. The CDMA scheduler table word *n* registers (WORD[*n*]) are shown in Figure 33-100 and described in Table 33-104.

Figure 33-100. CDMA Scheduler Table Word *n* Registers (WORD[*n*])

31	30	28	27	24	23	22	20	19	16
ENTRY3_RXTX	Reserved		ENTRY3_CHANNEL		ENTRY2_RXTX	Reserved		ENTRY2_CHANNEL	
W-0	R-0		W-0		W-0	R-0		W-0	

15	14	12	11	8	7	6	4	3	0
ENTRY1_RXTX	Reserved		ENTRY1_CHANNEL		ENTRY0_RXTX	Reserved		ENTRY0_CHANNEL	
W-0	R-0		W-0		W-0	R-0		W-0	

LEGEND: R = Read only; W = Write only; -*n* = value after reset

Table 33-104. CDMA Scheduler Table Word *n* Registers (WORD[*n*]) Field Descriptions

Bit	Field	Value	Description
31	ENTRY3_RXTX		This entry is for a transmit or a receive channel.
		0	Transmit channel
		1	Receive channel
30-28	Reserved	0	Reserved

Table 33-104. CDMA Scheduler Table Word *n* Registers (WORD[*n*]) Field Descriptions (continued)

Bit	Field	Value	Description
27-24	ENTRY3_CHANNEL	0-Fh	Indicates the channel number that is to be given an opportunity to transfer data. If this is a transmit entry, the DMA will be presented with a scheduling credit for that exact transmit channel. If this is a receive entry, the DMA will be presented with a scheduling credit for the receive FIFO that is associated with this channel. For receive FIFOs which carry traffic for more than one receive DMA channel, the exact channel number that is given in the receive credit will actually be the channel number which is currently on the head element of that Rx FIFO, which is not necessarily the channel number given in the scheduler table entry.
23	ENTRY2_RXTX		This entry is for a transmit or a receive channel.
		0	Transmit channel
		1	Receive channel
22-20	Reserved	0	Reserved
19-16	ENTRY2_CHANNEL	0-Fh	Indicates the channel number that is to be given an opportunity to transfer data. If this is a transmit entry, the DMA will be presented with a scheduling credit for that exact transmit channel. If this is a receive entry, the DMA will be presented with a scheduling credit for the receive FIFO that is associated with this channel. For receive FIFOs which carry traffic for more than one receive DMA channel, the exact channel number that is given in the receive credit will actually be the channel number which is currently on the head element of that Rx FIFO, which is not necessarily the channel number given in the scheduler table entry.
15	ENTRY1_RXTX		This entry is for a transmit or a receive channel.
		0	Transmit channel
		1	Receive channel
14-12	Reserved	0	Reserved
11-8	ENTRY1_CHANNEL	0-Fh	Indicates the channel number that is to be given an opportunity to transfer data. If this is a transmit entry, the DMA will be presented with a scheduling credit for that exact transmit channel. If this is a receive entry, the DMA will be presented with a scheduling credit for the receive FIFO that is associated with this channel. For receive FIFOs which carry traffic for more than one receive DMA channel, the exact channel number that is given in the receive credit will actually be the channel number which is currently on the head element of that Rx FIFO, which is not necessarily the channel number given in the scheduler table entry.
7	ENTRY0_RXTX		This entry is for a transmit or a receive channel.
		0	Transmit channel
		1	Receive channel
6-4	Reserved	0	Reserved
3-0	ENTRY0_CHANNEL	0-Fh	Indicates the channel number that is to be given an opportunity to transfer data. If this is a transmit entry, the DMA will be presented with a scheduling credit for that exact transmit channel. If this is a receive entry, the DMA will be presented with a scheduling credit for the receive FIFO that is associated with this channel. For receive FIFOs which carry traffic for more than one receive DMA channel, the exact channel number that is given in the receive credit will actually be the channel number which is currently on the head element of that Rx FIFO, which is not necessarily the channel number given in the scheduler table entry.

33.4.75 Queue Manager Revision Identification Register (QMGRREVID)

The queue manager revision identification register (QMGRREVID) contains the major and minor revisions for the module. The QMGRREVID is shown in Figure 33-101 and described in Table 33-105.

Figure 33-101. Queue Manager Revision Identification Register (QMGRREVID)

31	0
REV	
R-0052 1200h	

LEGEND: R = Read only; -*n* = value after reset

Table 33-105. Queue Manager Revision Identification Register (QMGRREVID) Field Descriptions

Bit	Field	Value	Description
31-0	REV	0052 1200h	Revision ID of the queue manager.

33.4.76 Queue Manager Queue Diversion Register (DIVERSION)

The queue manager queue diversion register (DIVERSION) is used to transfer the contents of one queue onto another queue. It does not support byte accesses. The queue manager queue diversion register (DIVERSION) is shown in Figure 33-102and described in Table 33-106.

Figure 33-102. Queue Manager Queue Diversion Register (DIVERSION)

31	30	29	16
HEAD_TAIL	Rsvd	DEST_QNUM	
W-0	R-0	W-0	

15	14	13	0
Reserved		SOURCE_QNUM	
R-0		W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 33-106. Queue Manager Queue Diversion Register (DIVERSION) Field Descriptions

Bit	Field	Value	Description
31	HEAD_TAIL		Indicates whether queue contents should be merged on to the head or tail of the destination queue.
		0	Head
		1	Tail
30	Reserved	0	Reserved
29-16	DEST_QNUM	0-3FFFh	Destination Queue Number
15-14	Reserved	0	Reserved
13-0	SOURCE_QNUM	0-3FFFh	Source Queue Number

33.4.77 Queue Manager Free Descriptor/Buffer Starvation Count Register 0 (FDBSC0)

The free descriptor/buffer queue starvation count register (FDBSC0) provides statistics about how many starvation events are occurring on the receive free descriptor/buffer queues. It does not support byte accesses. The free descriptor/buffer queue starvation count register (FDBSC0) is shown in Figure 33-103 and described in Table 33-107.

Figure 33-103. Queue Manager Free Descriptor/Buffer Starvation Count Register 0 (FDBSC0)

31	24	23	16
FDBQ3_STARVE_CNT		FDBQ2_STARVE_CNT	
RC-0		RC-0	

15	8	7	0
FDBQ1_STARVE_CNT		FDBQ0_STARVE_CNT	
RC-0		RC-0	

LEGEND: RC = Cleared on read; *-n* = value after reset

Table 33-107. Queue Manager Free Descriptor/Buffer Starvation Count Register 0 (FDBSC0) Field Descriptions

Bit	Field	Value	Description
31-24	FDBQ3_STARVE_CNT	0-FFh	This field increments each time the Free Descriptor/Buffer Queue 3 is read while it is empty. This field is cleared when read.
23-16	FDBQ2_STARVE_CNT	0-FFh	This field increments each time the Free Descriptor/Buffer Queue 2 is read while it is empty. This field is cleared when read.
15-8	FDBQ1_STARVE_CNT	0-FFh	This field increments each time the Free Descriptor/Buffer Queue 1 is read while it is empty. This field is cleared when read.
7-0	FDBQ0_STARVE_CNT	0-FFh	This field increments each time the Free Descriptor/Buffer Queue 0 is read while it is empty. This field is cleared when read.

33.4.78 Queue Manager Free Descriptor/Buffer Starvation Count Register 1 (FDBSC1)

The free descriptor/buffer queue starvation count register 1 (FDBSC1) provides statistics about how many starvation events are occurring on the receive free descriptor/buffer queues. It does not support byte accesses. The free descriptor/buffer queue starvation count register 1 (FDBSC1) is shown in Figure 33-104 and described in Table 33-108.

Figure 33-104. Queue Manager Free Descriptor/Buffer Starvation Count Register 1 (FDBSC1)

31	24	23	16
FDBQ7_STARVE_CNT		FDBQ6_STARVE_CNT	
RC-0		RC-0	

15	8	7	0
FDBQ5_STARVE_CNT		FDBQ4_STARVE_CNT	
RC-0		RC-0	

LEGEND: RC = Cleared on read; *-n* = value after reset

Table 33-108. Queue Manager Free Descriptor/Buffer Starvation Count Register 1 (FDBSC1) Field Descriptions

Bit	Field	Value	Description
31-24	FDBQ7_STARVE_CNT	0-FFh	This field increments each time the Free Descriptor/Buffer Queue 7 is read while it is empty. This field is cleared when read.
23-16	FDBQ6_STARVE_CNT	0-FFh	This field increments each time the Free Descriptor/Buffer Queue 6 is read while it is empty. This field is cleared when read.
15-8	FDBQ5_STARVE_CNT	0-FFh	This field increments each time the Free Descriptor/Buffer Queue 5 is read while it is empty. This field is cleared when read.
7-0	FDBQ4_STARVE_CNT	0-FFh	This field increments each time the Free Descriptor/Buffer Queue 4 is read while it is empty. This field is cleared when read.

33.4.79 Queue Manager Free Descriptor/Buffer Starvation Count Register 2 (FDBSC2)

The free descriptor/buffer queue starvation count register 2 (FDBSC2) provides statistics about how many starvation events are occurring on the receive free descriptor/buffer queues. It does not support byte accesses. The free descriptor/buffer queue starvation count register 2 (FDBSC2) is shown in Figure 33-105 and described in Table 33-109.

Figure 33-105. Queue Manager Free Descriptor/Buffer Starvation Count Register 2 (FDBSC2)

31	24	23	16
FDBQ11_STARVE_CNT		FDB10_STARVE_CNT	
RC-0		RC-0	

15	8	7	0
FDBQ9_STARVE_CNT		FDBQ8_STARVE_CNT	
RC-0		RC-0	

LEGEND: RC = Cleared on read; *-n* = value after reset

Table 33-109. Queue Manager Free Descriptor/Buffer Starvation Count Register 2 (FDBSC2) Field Descriptions

Bit	Field	Value	Description
31-24	FDBQ11_STARVE_CNT	0-FFh	This field increments each time the Free Descriptor/Buffer Queue 11 is read while it is empty. This field is cleared when read.
23-16	FDBQ10_STARVE_CNT	0-FFh	This field increments each time the Free Descriptor/Buffer Queue 10 is read while it is empty. This field is cleared when read.
15-8	FDBQ9_STARVE_CNT	0-FFh	This field increments each time the Free Descriptor/Buffer Queue 9 is read while it is empty. This field is cleared when read.
7-0	FDBQ8_STARVE_CNT	0-FFh	This field increments each time the Free Descriptor/Buffer Queue 8 is read while it is empty. This field is cleared when read.

33.4.80 Queue Manager Free Descriptor/Buffer Starvation Count Register 3 (FDBSC3)

The free descriptor/buffer queue starvation count register 3 (FDBSC3) provides statistics about how many starvation events are occurring on the receive free descriptor/buffer queues. It does not support byte accesses. The free descriptor/buffer queue starvation count register 3 (FDBSC3) is shown in Figure 33-106 and described in Table 33-110.

Figure 33-106. Queue Manager Free Descriptor/Buffer Starvation Count Register 3 (FDBSC3)

31	24	23	16
FDBQ15_STARVE_CNT		FDB14_STARVE_CNT	
RC-0		RC-0	

15	8	7	0
FDBQ13_STARVE_CNT		FDBQ12_STARVE_CNT	
RC-0		RC-0	

LEGEND: RC = Cleared on read; *-n* = value after reset

Table 33-110. Queue Manager Free Descriptor/Buffer Starvation Count Register 3 (FDBSC3) Field Descriptions

Bit	Field	Value	Description
31-24	FDBQ15_STARVE_CNT	0-FFh	This field increments each time the Free Descriptor/Buffer Queue 15 is read while it is empty. This field is cleared when read.
23-16	FDBQ14_STARVE_CNT	0-FFh	This field increments each time the Free Descriptor/Buffer Queue 14 is read while it is empty. This field is cleared when read.
15-8	FDBQ13_STARVE_CNT	0-FFh	This field increments each time the Free Descriptor/Buffer Queue 13 is read while it is empty. This field is cleared when read.
7-0	FDBQ12_STARVE_CNT	0-FFh	This field increments each time the Free Descriptor/Buffer Queue 12 is read while it is empty. This field is cleared when read.

33.4.81 Queue Manager Linking RAM Region 0 Base Address Register (LRAM0BASE)

The queue manager linking RAM region 0 base address register (LRAM0BASE) sets the base address for the first portion of the Linking RAM. This address must be 32-bit aligned. It is used by the Queue Manager to calculate the 32-bit linking address for a given descriptor index. It does not support byte accesses. The queue manager linking RAM region 0 base address register (LRAM0BASE) is shown in Figure 33-107 and described in Table 33-111.

Figure 33-107. Queue Manager Linking RAM Region 0 Base Address Register (LRAM0BASE)

31	0
REGION0_BASE	
R/W-0	

LEGEND: R/W = Read/Write; *-n* = value after reset

Table 33-111. Queue Manager Linking RAM Region 0 Base Address Register (LRAM0BASE) Field Descriptions

Bit	Field	Value	Description
31-0	REGION0_BASE	0-FFFF FFFFh	This field stores the base address for the first region of the linking RAM. This may be anywhere in 32-bit address space but would be typically located in on-chip memory.

33.4.82 Queue Manager Linking RAM Region 0 Size Register (LRAM0SIZE)

The queue manager linking RAM region 0 size register (LRAM0SIZE) sets the size of the array of linking pointers that are located in Region 0 of Linking RAM. The size specified the number of descriptors for which linking information is stored in this region. It does not support byte accesses. The queue manager linking RAM region 0 size register (LRAM0SIZE) is shown in Figure 33-108 and described in Table 33-112.

Figure 33-108. Queue Manager Linking RAM Region 0 Size Register (LRAM0SIZE)

31	16
Reserved	
R-0	

15	14	13	0
Reserved		REGION0_SIZE	
R-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

Table 33-112. Queue Manager Linking RAM Region 0 Size Register (LRAM0SIZE) Field Descriptions

Bit	Field	Value	Description
31-14	Reserved	0	Reserved
13-0	REGION0_SIZE	0-3FFFh	This field indicates the number of entries that are contained in the linking RAM region 0. A descriptor with index less than region0_size value has its linking location in region 0. A descriptor with index greater than region0_size has its linking location in region 1. The queue manager will add the index (left shifted by 2 bits) to the appropriate regionX_base_addr to get the absolute 32-bit address to the linking location for a descriptor.

33.4.83 Queue Manager Linking RAM Region 1 Base Address Register (LRAM1BASE)

The queue manager linking RAM region 1 base address register (LRAM1BASE) is used to set the base address for the first portion of the Linking RAM. This address must be 32-bit aligned. It is used by the Queue Manager to calculate the 32-bit linking address for a given descriptor index. It does not support byte accesses. The queue manager linking RAM region 1 base address register (LRAM1BASE) is shown in Figure 33-109 and described in Table 33-113.

Figure 33-109. Queue Manager Linking RAM Region 1 Base Address Register (LRAM1BASE)

31	0
REGION1_BASE	
R/W-0	

LEGEND: R/W = Read/Write; -*n* = value after reset

Table 33-113. Queue Manager Linking RAM Region 1 Base Address Register (LRAM1BASE) Field Descriptions

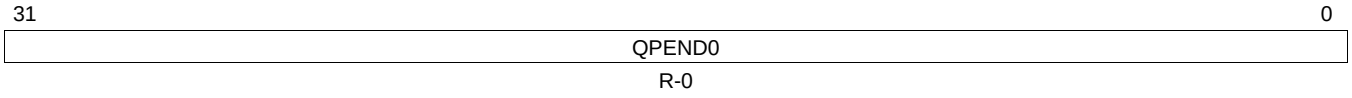
Bit	Field	Value	Description
31-0	REGION1_BASE	0-FFFF FFFFh	This field stores the base address for the second region of the linking RAM. This may be anywhere in 32-bit address space but would be typically located in off-chip memory.

33.4.84 Queue Manager Queue Pending Register 0 (PEND0)

The queue pending register 0 (PEND0) can be read to find the pending status for queues 31 to 0. It does not support byte accesses. The queue pending register 0 (PEND0) is shown in Figure 33-110 and described in Table 33-114.

NOTE: The pending bit gets set when a Descriptor address is loaded in a Queue. The loading action causes the corresponding bit for that Queue to get set. Similarly, the pending bit gets cleared when the Descriptor address is off-loaded from a Queue by reading it. One way to check if the receive or transmit transfer has completed is by checking the bit that corresponds to the desired Completion Queue for that particular transfer. When the Queue Manager is finished with the transfer, it will load the Descriptor address to the Completion Queue.

Figure 33-110. Queue Manager Queue Pending Register 0 (PEND0)



LEGEND: R = Read only; -*n* = value after reset

Table 33-114. Queue Manager Queue Pending Register 0 (PEND0) Field Descriptions

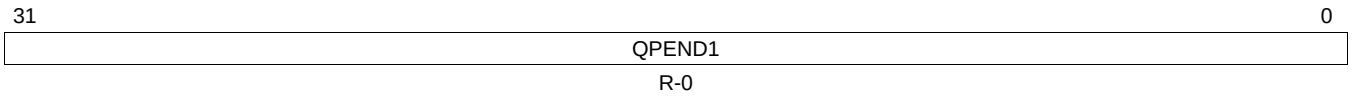
Bit	Field	Value	Description
31-0	QPEND0	0-FFFF FFFFh	This field indicates the queue pending status for queues 31-0.

33.4.85 Queue Manager Queue Pending Register 1 (PEND1)

The queue pending register 1 (PEND1) can be read to find the pending status for queues 63 to 32. It does not support byte accesses. The queue pending register 1 (PEND1) is shown in Figure 33-111 and described in Table 33-115.

NOTE: The pending bit gets set when a Descriptor address is loaded in a Queue. The loading action causes the corresponding bit for that Queue to get set. Similarly, the pending bit gets cleared when the Descriptor address is off-loaded from a Queue by reading it. One way to check if the receive or transmit transfer has completed is by checking the bit that corresponds to the desired Completion Queue for that particular transfer. When the Queue Manager is finished with the transfer, it will load the Descriptor address to the Completion Queue.

Figure 33-111. Queue Manager Queue Pending Register 1 (PEND1)



LEGEND: R = Read only; -*n* = value after reset

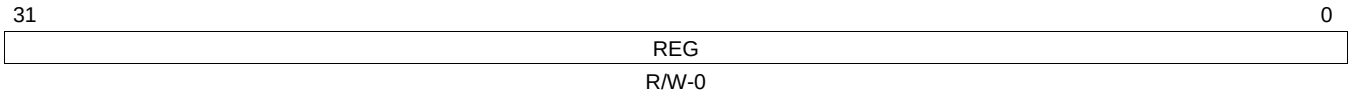
Table 33-115. Queue Manager Queue Pending Register 1 (PEND1) Field Descriptions

Bit	Field	Value	Description
31-0	QPEND1	0-FFFF FFFFh	This field indicates the queue pending status for queues 63-32.

33.4.86 Queue Manager Memory Region *R* Base Address Registers (QMEMRBASE[0]-QMEMRBASE[15])

The memory region *R* base address register (QMEMRBASE[*R*]) is written by the host to set the base address of memory region *R*, where *R* is 0-15. This memory region will store a number of descriptors of a particular size as determined by the memory region *R* control register. It does not support byte accesses. The memory region *R* base address register (QMEMRBASE[*R*]) is shown in Figure 33-112 and described in Table 33-116.

Figure 33-112. Queue Manager Memory Region *R* Base Address Registers (QMEMRBASE[*R*])



LEGEND: R/W = Read/Write; *-n* = value after reset

Table 33-116. Queue Manager Memory Region *R* Base Address Registers (QMEMRBASE[*R*]) Field Descriptions

Bit	Field	Value	Description
31-0	REG	0-FFFF FFFFh	This field contains the base address of the memory region R.

33.4.87 Queue Manager Memory Region *R* Control Registers (QMEMRCTRL[0]-QMEMRCTRL[15])

The memory region *R* control register (QMEMRCTRL[*R*]) is written by the host to configure various parameters of memory region *R*, where *R* is 0-15. It does not support byte accesses. The memory region *R* control register (QMEMRCTRL[*R*])) is shown in Figure 33-113 and described in Table 33-117.

Figure 33-113. Queue Manager Memory Region *R* Control Registers (QMEMRCTRL[*R*])

31	30	29	16
Reserved		START_INDEX	
R-0		R/W-0	

15	12	11	8	7	3	2	0
Reserved		DESC_SIZE		Reserved		REG_SIZE	
R-0		R/W-0		R-0		R/W-0	

LEGEND: R/W = Read/Write; R = Read only; -*n* = value after reset

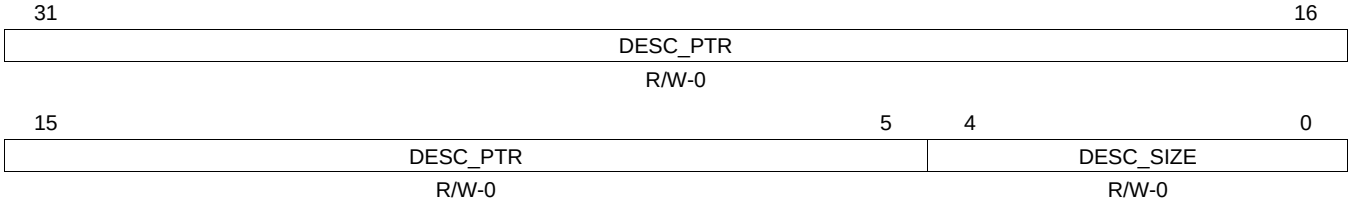
Table 33-117. Queue Manager Memory Region *R* Control Registers (QMEMRCTRL[*R*]) Field Descriptions

Bit	Field	Value	Description
31-30	Reserved	0	Reserved
29-16	START_INDEX	0-3FFFh	This field indicates where in linking RAM the descriptor linking information corresponding to memory region R starts.
15-12	Reserved	0	Reserved
11-8	DESC_SIZE	0-Fh	This field indicates the size of each descriptor in this memory region.
		0	32
		1h	64
		2h	128
		3h	256
		4h	512
		5h	1K
		6h	2K
		7h	4K
		8h	8K
		9h-Fh	Reserved
7-3	Reserved	0	Reserved
2-0	REG_SIZE	0-7h	This field indicates the size of the memory region (in terms of number of descriptors).
		0	32
		1h	64
		2h	128
		3h	256
		4h	512
		5h	1K
		6h	2K
		7h	4K

33.4.88 Queue Manager Queue N Control Register D (CTRLD[0]-CTRLD[63])

The queue manager queue *N* control register D (CTRLD[*N*]) is written to add a packet to the queue and read to pop a packets off a queue. The packet is only pushed or popped to/from the queue when the queue manager queue *N* control register D is written. It does not support byte accesses. The queue manager queue *N* control register D (CTRLD[*N*]) is shown in Figure 33-114 and described in Table 33-118.

Figure 33-114. Queue Manager Queue *N* Control Register D (CTRLD[*N*])



LEGEND: R/W = Read/Write; -*n* = value after reset

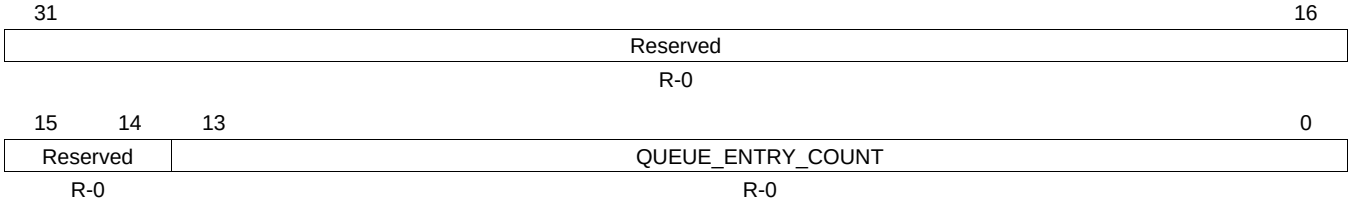
Table 33-118. Queue Manager Queue *N* Control Register D (CTRLD[*N*]) Field Descriptions

Bit	Field	Value	Description
31-5	DESC_PTR		Descriptor Pointer
		0	Queue is empty.
		1	Indicates a 32-bit aligned address that points to a descriptor.
4-0	DESC_SIZE	0-1Fh	The descriptor size is encoded in 4-byte increments. This field returns a 0 when an empty queue is read.
		0	24 bytes
		1h	28 bytes
		2h	32 bytes
		3h-1Fh	36 bytes to 148 bytes

33.4.89 Queue Manager Queue *N* Status Register A (QSTATA[0]-QSTATA[63])

The queue manager queue *N* status register A (QSTATA[*N*]) is an optional register that is only implemented for a queue if the queue supports entry/byte count feature. The entry count feature provides a count of the number of entries that are currently valid in the queue. It does not support byte accesses. The queue manager queue *N* status register A (QSTATA[*N*]) is shown in Figure 33-115 and described in Table 33-119.

Figure 33-115. Queue Manager Queue *N* Status Register A (QSTATA[*N*])



LEGEND: R = Read only; -*n* = value after reset

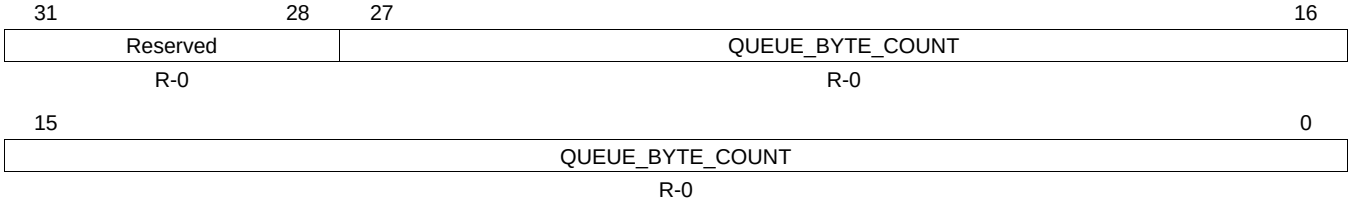
Table 33-119. Queue Manager Queue *N* Status Register A (QSTATA[*N*]) Field Descriptions

Bit	Field	Value	Description
31-14	Reserved	0	Reserved
13-0	QUEUE_ENTRY_COUNT	0-3FFFh	This field indicates how many packets are currently queued on the queue.

33.4.90 Queue Manager Queue *N* Status Register B (QSTATB[0]-QSTATB[63])

The queue manager queue *N* status register B (QSTATB[*N*]) is an optional register that is only implemented for a queue if the queue supports a total byte count feature. The total byte count feature provides a count of the total number of bytes in all of the packets that are currently valid in the queue. It does not support byte accesses. The queue manager queue *N* status register B (QSTATB[*N*]) is shown in Figure 33-116 and described in Table 33-120.

Figure 33-116. Queue Manager Queue *N* Status Register B (QSTATB[*N*])



LEGEND: R = Read only; -*n* = value after reset

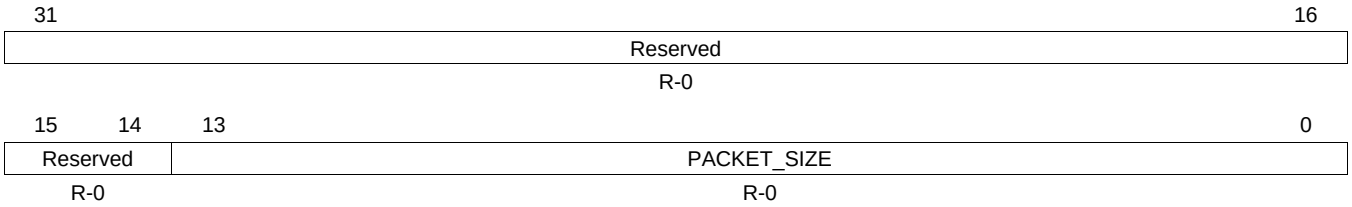
Table 33-120. Queue Manager Queue *N* Status Register B (QSTATB[*N*]) Field Descriptions

Bit	Field	Value	Description
31-28	Reserved	0	Reserved
27-0	QUEUE_BYTE_COUNT	0-FFF FFFFh	Indicates how many bytes total are contained in all of the packets which are currently queued on this queue.

33.4.91 Queue Manager Queue *N* Status Register C (QSTATC[0]-QSTATC[63])

The queue manager queue *N* status register C (QSTATC[*N*]) specifies the packet size for the head element of a queue. It does not support byte accesses. The queue manager queue *N* status register C (QSTATC[*N*]) is shown in Figure 33-117 and described in Table 33-121.

Figure 33-117. Queue Manager Queue *N* Status Register C (QSTATC[*N*])



LEGEND: R = Read only; -*n* = value after reset

Table 33-121. Queue Manager Queue *N* Status Register C (QSTATC[*N*]) Field Descriptions

Bit	Field	Value	Description
31-14	Reserved	0	Reserved
13-0	PACKET_SIZE	0-3FFFh	This field indicates how many packets are currently queued on the queue.

Revision History

Table A-1 lists the changes made since the previous version of this document.

Table A-1. Document Revision History

Reference	Additions/Modifications/Deletions
Figure 1-1	Changed figure. Added Memory Protection block.
Section 7.2	Deleted paragraph before second NOTE.
Table 7-3	Changed Div1 column in table.
Section 7.3.3	Changed first bullet in second paragraph.
Section 7.3.3	Deleted second footnote.
Table 11-1	Added "Silicon Revision Identification Register (CHIPREVID) to table.
Section 11.4	Changed subsection.
Table 11-4	Added "Silicon Revision Identification Register (CHIPREVID) to table.
Section 11.5.4	Added subsection. Subsequent subsections, figures, and tables renumbered.
Section 11.5.8.5	Changed second sentence.
Table 16-2	Changed table. Added Reference column.
Example 16-1	Changed code for CHPEN bit; CBCn and OSHTn bits; and TZA and TZB bits.
Figure 18-44	Changed default value of NUM_EVQUE bit.
	Changed default value of NUM_INTCH bit.
	Changed default value of NUM_DMACH bit.
Table 18-22	Changed Description of NUM_EVQUE bit.
	Changed Description of NUM_INTCH bit.
	Changed Description of NUM_DMACH bit.
Table 20-3	Changed Description of EMA_WAIT pin.
Section 20.2.5.6.6.2	Added new step 10 to read procedure in fifth paragraph. Subsequent steps renumbered.
Section 20.2.6	Changed first paragraph.
Section 20.3.1	Changed third paragraph.
Section 20.3.2.2.1	Changed equations with R_SETUP + R_STROBE.
	Changed equations with W_SETUP + W_STROBE.
Section 20.3.2.2.2	Changed equations with R_SETUP + R_STROBE.
	Changed equations with W_SETUP + W_STROBE.
Table 20-36	Changed minimum value for parameter t_{SU}
	Added footnote.
Section 20.3.2.2.3	Changed equations with R_SETUP + R_STROBE.
	Changed equations with W_SETUP + W_STROBE.
Section 20.3.2.3.2	Changed equations with R_SETUP + R_STROBE.
	Changed equations with W_SETUP + W_STROBE.
Table 20-44	Changed minimum value for parameter t_{SU}
	Added footnote.
Section 20.3.2.3.3	Changed equations with R_SETUP + R_STROBE.
	Changed equations with W_SETUP + W_STROBE.
Table 20-53	Changed Description of EW bit.

Table A-1. Document Revision History (continued)

Reference	Additions/Modifications/Deletions
Table 21-23	Changed table. Added Notes.
Section 25.3.3.2	Changed subsection. Added configuration settings.
Table 25-15	Changed Value of W_STROBE, W_HOLD, R_STROBE, and R_HOLD bits.
	Changed Description of TA bit. Added equation.
Section 26.2.4.1.4	Changed step numbers in first sentence of first paragraph.
Table 26-7	Changed table title.
	Changed table footnotes.
Table 26-8	Changed table title.
	Changed table.
Table 26-9	Updated Offset values.
	Added table NOTE.
Table 26-24	Changed Description of RBUSEL bit.
Table 26-36	Changed Description of XBUSEL bit.
Table 26-48	Changed Description of WNUMDMA bit.
Table 29-22	Changed Description of RXEMPTY bit.
Section 30.2.1.4.1.3	Changed steps 3 and 5.
Section 30.2.1.4.2.1.2	Changed steps 3 and 6.
Section 30.2.1.4.2.2.4	Changed steps 3 and 6 in first paragraph.
	Changed steps 3 and 6 in second paragraph.
Table 31-20	Changed Value range of DLL bit.
Table 31-21	Changed Value range of DLH bit.

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