

Atmel AVR2030: ATRF231USB – Hardware User Manual

8-bit Atmel Microcontrollers

Features

- High-performance, low-power Atmel® 32-bit ARM® CORTEX™-M3 RISC microcontroller ATSAM3S4BA
 - 256kB High-Speed Flash
 - 48kB SRAM
 - Wide variety of peripheral components
- Onboard 2GB flash memory to store user defined data
- Onboard 2.4GHz radio transceiver AT86RF231 and ceramic chip antenna
- Powered over USB connector type A soldered on PCB
- Three free programmable status LEDs
- RF shielding
- Interfaces: DBGU, JTAG, USB

Introduction

This manual describes the RF231USB Reference Design which is equipped with a powerful CORTEX-M3 microcontroller in combination with the Atmel 2.4GHz AT86RF231 radio transceiver and an onboard ceramic chip antenna.

Detailed information is given in the individual sections about the radio stick functionality, the available interfaces, and the stick design.

The USB radio stick comes pre-flashed with a boot loader and a corresponding tool for uploading of application firmware; it is stored on the onboard external 2GB flash memory. The stick can be operated as full functional wireless node via the USB port allowing direct communication with the host PC. It provides the way to demonstrate wireless software applications and allows adding RF-functionality to other hardware.

Figure 1. Top and bottom view of RF231USB-RD stick.



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1. Disclaimer

Typical values contained in this application note are based on simulations and testing of individual examples.

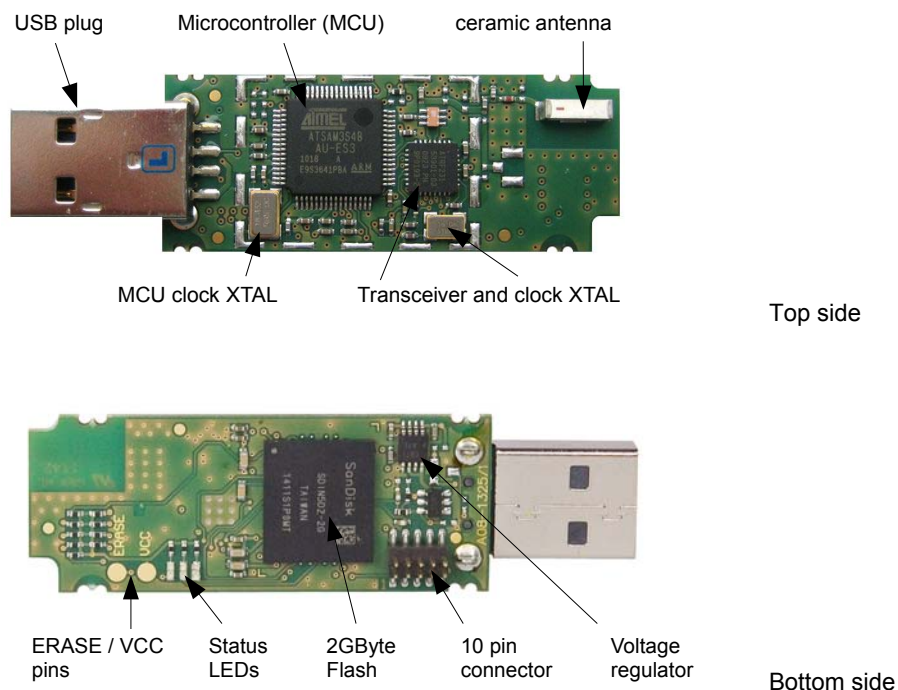
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2. Overview

The compact designed RF231USB radio sticks are based on the efficient CORTEX-M3 microcontroller architecture with 256kB High-Speed flash and 48kB SRAM [1]. Additional 2GB flash memory to store user defined data is provided with the RF231USB-RD; it is usable as mass storage device.

Operating at the transmission frequency of 2.4GHz, the ATMEL low-power transceiver AT86RF231 [2] is integrated. It provides a complete radio transceiver interface between the antenna and the microcontroller and an extended functional range such as a 128-Bit AES hardware engine to assure data security.

Figure 2-1. Main components (RF shield removed).



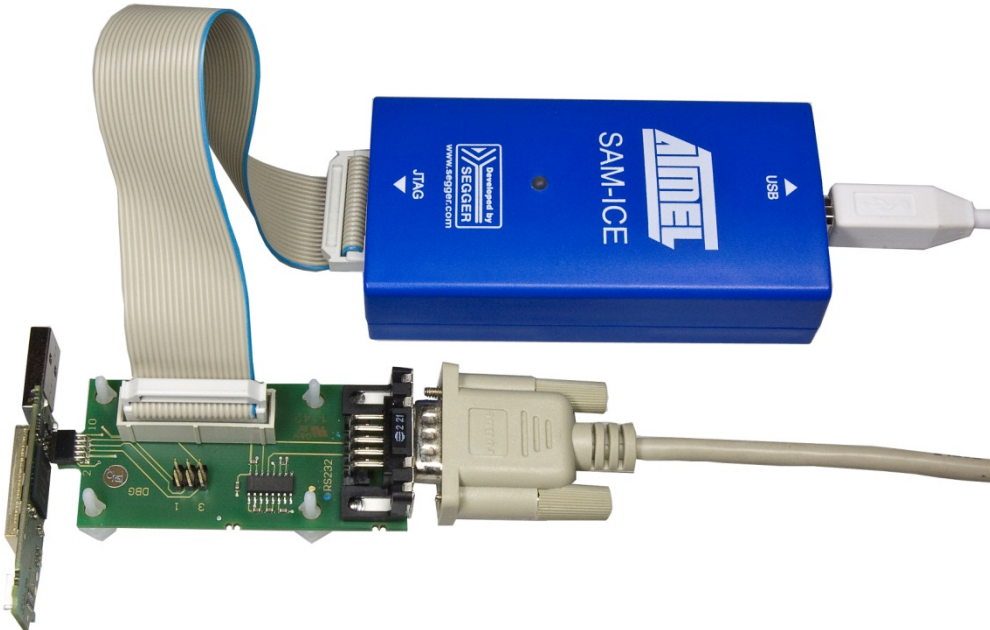
The USB radio stick provides programming and debugging interfaces to the user.

Comprehensive user documentation, device drivers as well as a bootloader application (which is running on the host PC) are stored to the mass storage device.

The serial bootloader functionality allows uploading of application firmware through the USB connection, without the need for extra programming tools. This functionality is provided by the bootloader firmware pre-flashed to the RF231USB board in delivery condition.

A JTAG interface targets software development. Here an Atmel SAM-ICE™ adapter with a suitable programmer has to be connected to the USB stick. The boards have to be assembled as shown in [Figure 2-2](#). The RF231USB-RD board is attached with its JTAG connector to the SAM-ICE adapter. The SAM-ICE JTAG emulator which is used to program a new image into the ARM MCU on RF231USB-RD board is connected to the SAM-ICE adapter and to the PC.

Figure 2-2. USB radio stick (left-hand) with the SAM-ICE programmer.



The RF231USB-RD USB radio stick provides the way to demonstrate software applications like:

- Wireless UART in ASF
- Wireless network sniffer, for example hardware for third party solutions like Luxoft and Perytons
- Complex wireless network solutions, for example ZigBee® Home Automation

The RF231USB-RD stick allows adding RF-functionality to other hardware or kit deliveries:

- Wireless gateway for PC hardware, for example Reference design for wireless passive infrared camera Atmel kit ATSAM4S-WPIR-RD
- Point to point connection between PCs (wireless UART)

3. Mechanical description

The RF231USB-RD is manufactured using a four-layer printed circuit board. The components mounted on the top side are: ATSAM3S4BA microcontroller and low-power radio transceiver AT86RF231 (including their crystal oscillators), 2.45GHz antenna and the SMD-mounted USB type A plug. The bottom side of the board is equipped with the following components and connectors (among other): 2GB additional flash chip, 10-pin connector, three status LEDs, ERASE and VCC pins, voltage regulator for power supply.

3.1 Dimensions

Due to size constraints, components are placed on the top side as well as on the bottom side of the board. The USB plug is mounted on edge of the board. Board width and height were chosen so that multiple USB sticks will fit beside each other in standard USB hubs. Board length is determined by size of the ground plane which is approximately $\lambda/2$ for 2.4GHz band.

Table 3-1. RF231USB-RD mechanical dimensions.

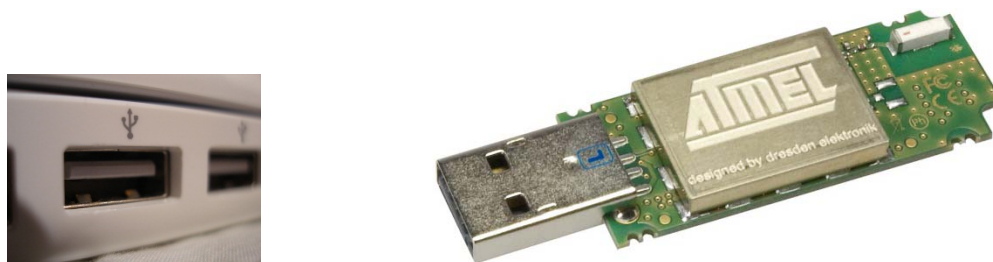
Dimension	Value
Length x	63.5mm (including USB plug)
Width y	19.0mm
Height z	5.5mm (without JTAG/debug header) 9.5mm (with JTAG/debug header)

3.2 Interface connectors

3.2.1 USB interface

The connector for the RF231USB-RD radio stick, X1, is USB type A chassis plug.

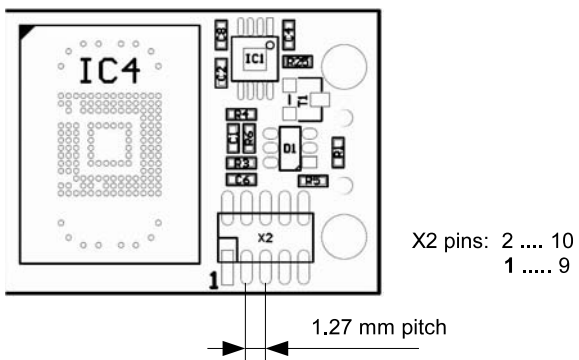
Figure 3-1. USB type A connection.



3.2.2 10-pin connector

The 10-pin connector, X2, with its 2 x 5 pins of 1.27mm (50mil) pitch is directly accessible from the USB stick bottom side.

Figure 3-2. 10-pin connector with footprint receptacle.



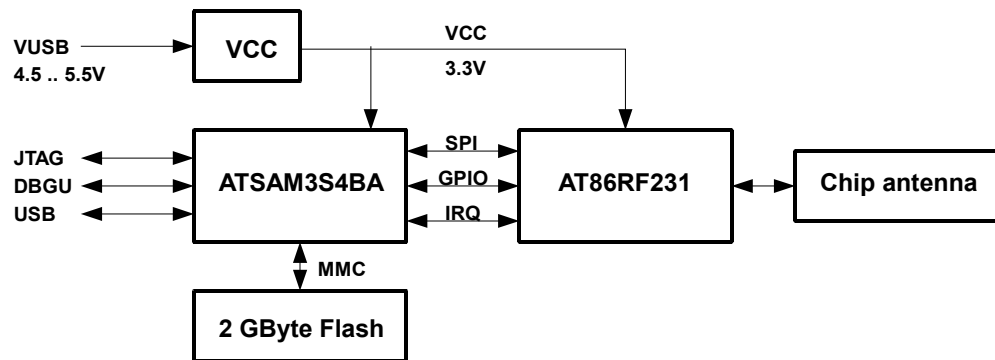
4. Functional description

The Atmel RF231USB-RD stick carries a high-performance Atmel CORTEX-M3 microcontroller, which connects to the radio transceiver AT86RF231 and various peripheral units. The block diagram of the RF231USB-RD USB radio stick is shown in [Figure 4-1](#).

The Atmel AT86RF231 interfaces the ceramic chip antenna which is designed at the outermost location of the RF231USB-RD stick to provide sufficient signal strength and quality to reach line of sight distances of greater than 200m.

The transceiver is interfaced by the MCU via SPI and several GPIO lines. Two separate IRQ lines are available and routed to MCU pins optionally acting as timer inputs. CLKM outputs the transceiver clock.

Figure 4-1. Functional overview block diagram.



The critical RF components mounted on the board are encapsulated. A RF shielding is affixed at the board top side to house these components to guarantee an EMI shielded environment.

The ATSAM3S4BA has a flexible clock system. Primarily the onboard 18.432MHz crystal clocks a phase-locked loop (PLL) from which the microcontroller core and all of its internal peripheral units are sourced. The radio transceiver provides additional clock inputs.

The soldered USB type A plug represents an USB 2.0 interface and can be used as programming and debugging interface by default. It is used to power the RF231USB-RD stick. The 3.3V supply voltage is generated by a LDO voltage regulator mounted at the bottom side of the board.

The USB stick is populated with a 2GB flash memory on its bottom side to store user defined data. The flash is also intended to be used as mass storage device. Board-specific information such as board identifier, the node MAC address, and production calibration values are stored in a special upper memory block of the flash memory.

A 10-pin connector assembled at the bottom side is designed for programming via JTAG interface. A matching programming adapter that is equipped with a 20-pin standard ARM-JTAG connector has to be used for this.

To deliver status information, a basic user interface consisting of three LEDs is provided on the board.

An ERASE pin can be used to delete the flash's content.

4.1 Pin assignment

In [Table 4-1](#) an overview of the RF231USB-RD's pin assignment of components and peripherals together with operating options is given.

Table 4-1. Pin assignment of RF231USB-RD.

µC Pin	Name	Function	Comments
<i>USB connector X1</i>			
56	DDM	USB DM	
57	DDP	USB DP	
<i>10-pin connector X2</i>			
53	PB7/TCK/SWCLK	JTAG TCK	pin 1
	GND		pin 2
49	PB5/TWCK1/PWML0/WKUP13/TDO	JTAG TDO	pin 3
	VCC		pin 4
51	PB6/TMS/SWDIO	JTAG TMS	pin 5
39	NRST	/Reset	pin 6
	VCC		pin 7
30	PA9/URXD0/NPCS1/PWMFIO	Debug RXD	pin 8
33	PB4/TWD1/PWMH2/TDI	JTAG TDI	pin 9
29	PA10/UTXD0/NPCS2	Debug TXD	pin 10
<i>Miscellaneous</i>			
13	PA19/RK/PWML0/A15/AD2	LED1	red
9	PA17/TD/PCK1/PWMH3/AD0	LED2	yellow
10	PA18/RD/PCK2/A14/AD1	LED3	green
35	PA5/RXD0/NPCS3	Hardware ID1	
34	PA6/TXD0/PCK0	Hardware ID2	
32	PA7/RTS0/PWMH3/XIN32	Hardware ID3	
<i>Internal transceiver interface</i>			
20	PA15/TF/TIOA1/PWML3	RXTS/DIG2	Timestamp
11	PA21/RXD1/PCK1/AD8	SLP-TR	
21	PA14/SPCK/PWMH3	SCK	SPI
27	PA12/MISO/PWMH1	MISO	SPI
22	PA13/MOSI/PWMH2	MOSI	SPI
28	PA11/NPCS0/PWMH0	SELN	
47	PA1/PWMH1/TIOB0/A18	IRQ	
23	PA24/RTS1/PWMH1/A20	RST	Transceiver Reset
36	PA4/TWCK0/TCLK0	CLKM	
<i>2GB flash memory</i>			
42	MCDA0	ext. Flash Data 0	
52	MCDA1	ext. Flash Data 1	
26	MCDA2	ext. Flash Data 2	
37	MCDA3	ext. Flash Data 3	
38	MCCDA	ext. Flash Command	
41	MCCK	ext. Flash Clock	
<i>Erase pin</i>			
55	PB12/PWML1/ERASE		Erase MCU flash

For a description of component signals see [Table 4-2](#):

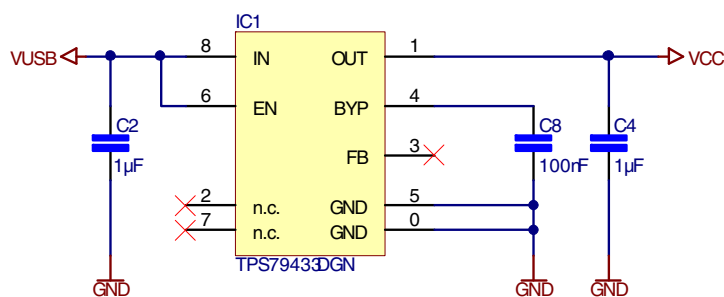
Table 4-2. Signal description list.

Signal name	Function	Type	Active level	Comments
Power – USB connector				
DDM	USB Full Speed Data –	Analog Digital		
DDP	USB Full Speed Data +			
JTAG				
TCK	Test Clock	Input		onboard Pull-up
TDI	Test Data In	Input		onboard Pull-up
TDO	Test Data Out	Output		
TDM	Test Mode Select	Input		onboard Pull-up
Reset				
RSTN	Microcontroller Reset	I/O	Low	Pull-Up resistor
UART0				
URXD0	UART Receive Data	Input		
UTXD0	UART Transmit Data	Output		

4.2 Power supply

Both ATSAM3S4BA microcontroller and AT86RF231 radio transceiver are powered over the USB connector type A, soldered on the PCB. The available 5V (VUSB) voltage is transformed to the required 3.3V by the voltage regulator LDO 3.3V (IC1) which is integrated into the power supply line and mounted at the bottom side of the board.

Figure 4-2. Voltage regulator.



4.3 Microcontroller

The Atmel SAM3S is a family of flash microcontrollers based on the high performance 32-bit ARM Cortex-M3 RISC processor. It operates at a maximum speed of 64MHz and features 256Kbytes of flash and 48Kbytes of SRAM.

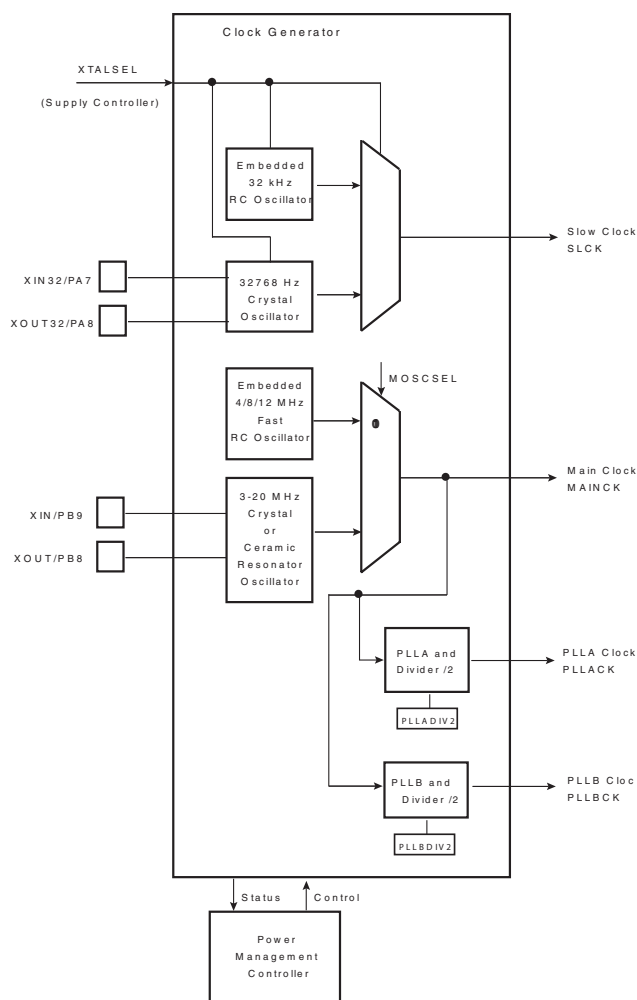
The ATSAM3S4BA device [1] is a medium range general purpose microcontroller with the best ratio in terms of reduced power consumption, processing power and peripheral set. This enables the ATSAM3S4BA to sustain a wide range of applications including consumer, industrial control, and PC peripherals.

4.3.1 Clock generator

The ATSAM3S4BA has a flexible clock system, supporting a large number of clock sources. It incorporates both calibrated integrated and external crystal oscillators and resonators. The Atmel SAM3S family allows dynamic switching between the following clock sources:

- Embedded 32kHz RC oscillator
- 32.768kHz crystal oscillator
- Embedded 4/8/12MHz fast RC oscillator
- 3-20MHz crystal or ceramic oscillator

Figure 4-3. Clock generator block diagram.

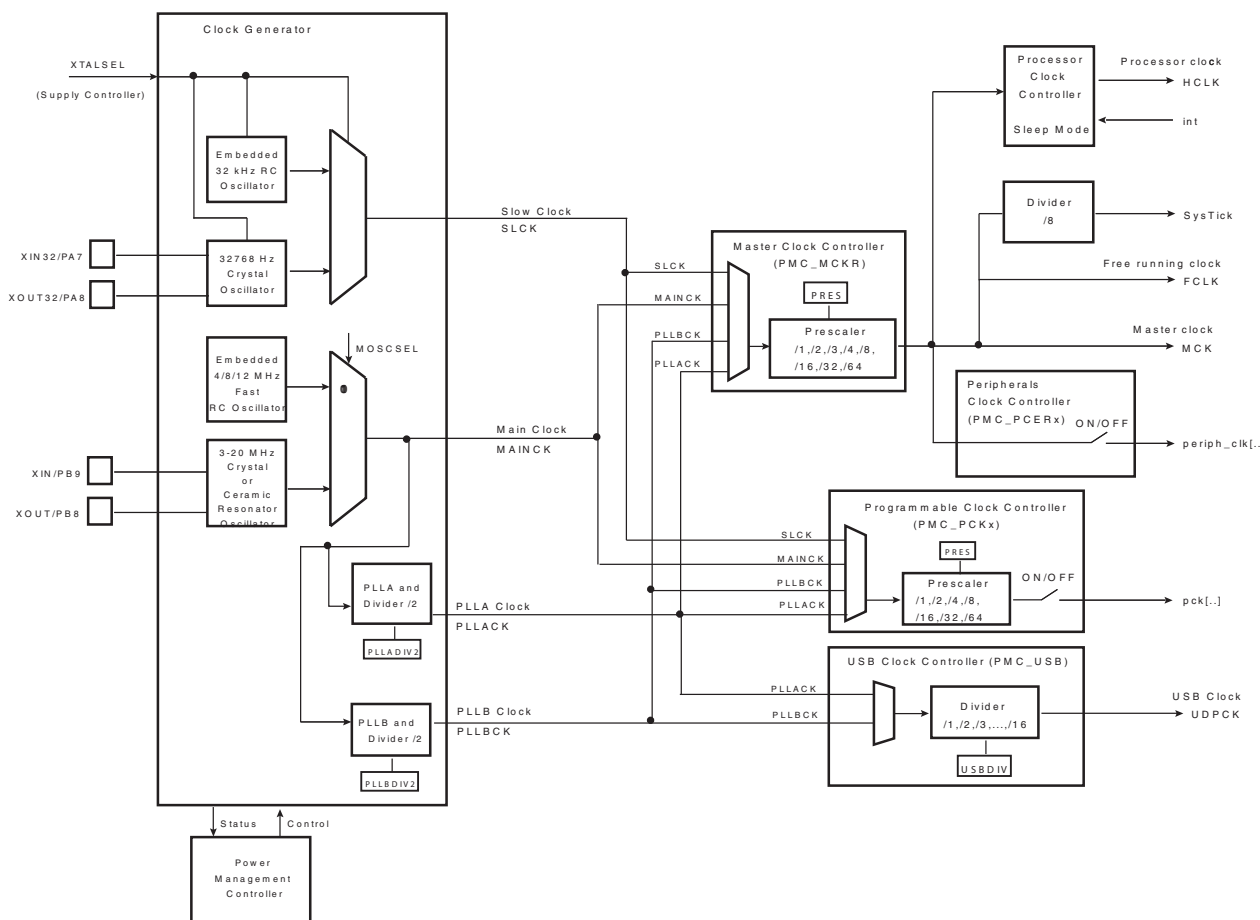


From these, four different internal clocks are generated: Both 32kHz oscillators may trigger the slow clock, suitable for low power modes. The two remaining sources are inputs to the Main clock as well as to two high frequency phase-locked loop (PLL) clocks, whereas variable multipliers and dividers can be applied to generate a wide range of clock frequencies.

After reset, the device will always start up running from slow clock. Usually the other clock sources are set up and switched to during initialization. In normal operation, the system clock source and prescalers can be changed from software at any time.

All clock sources are controlled and may be monitored by the Power Management Controller (PMC) which distributes the clock to all internal functional units.

Figure 4-4. General clock block diagram.

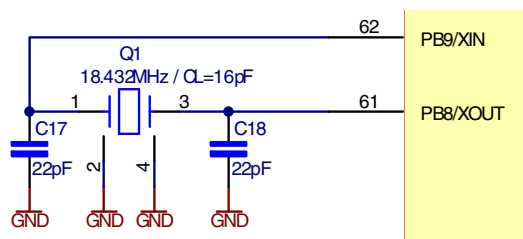


4.3.2 Microcontroller clock

The RF231USB-RD is populated with an external 18.432MHz crystal oscillator, Q1, assembled on the top side of the printed circuit board close to the MCU. Connected to XIN/XOUT (pins 61 and 62) it delivers an accurate clock for the ATSAM3S4BA.

Since the design is a USB device, low power modes are not expected ("always on"). Therefore no external 32.768kHz crystal is provided.

Figure 4-5. 18.432MHz crystal connection.



4.4 On-board radio transceiver

With the AT86RF231, the board is equipped with a low-power 2.4GHz transceiver designed for industrial and consumer IEEE® 802.15.4, ZigBee, RF4CE, SP100 and high data rate ISM applications. It is tuned with the onboard 2.45GHz ceramic chip antenna. Interconnected with the MCU, it provides a compact radio interface on a single chip.

The transceiver comprises the analog radio transceiver and the digital modulation and demodulation including time and frequency synchronization and data buffering. The number of external components is minimized such that only the antenna, the crystal and decoupling capacitors are required. The bidirectional differential antenna pins are used for transmission and reception, thus no external antenna switch is needed.

An internal 128byte RAM for RX and TX buffers the data to be transmitted or the received data. Two on chip low dropout voltage regulators provide the internal analog and digital 1.8V supply.

The transceivers further contain comprehensive hardware-MAC support (Extended Operating Mode) and a security engine (AES) to improve the overall system power efficiency and timing.

4.4.1 Radio transceiver reference clock (CLKM)

The integrated radio transceiver is clocked by a 16MHz reference crystal. The 2.4GHz modulated signal is derived from this clock. Operating the node according to IEEE 802.15.4 [3], the reference frequency must not exceed a deviation of ± 40 ppm. The absolute frequency is mainly determined by the external load capacitance of the crystal, which depends on the crystal type and is given in its datasheet.

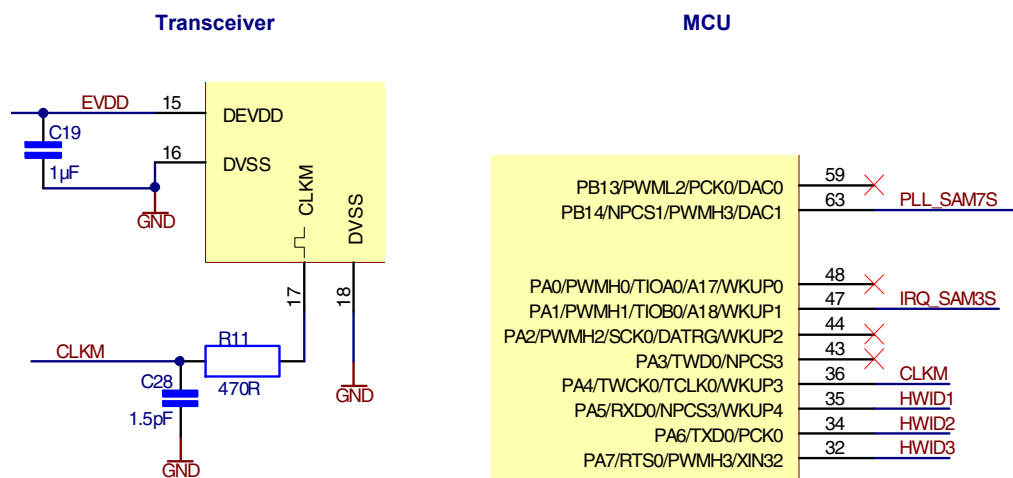
The radio transceiver reference crystal, Q2, shall be isolated from fast switching digital signals and surrounded by a grounded guard trace to minimize disturbances of the oscillation. Detailed layout considerations can be found in Chapter 5.

The RF231USB-RD uses a SIWARD SMD/SX-4025 crystal with two load capacitors of 12pF each. To compensate for fabrication and environment variations, the frequency can be further tuned using the radio transceiver register XOSC_CTRL (0x12) (refer to [2], Appendix C).

The reference frequency is also available at the CLKM pin of the radio transceiver and depending on the related register setting. It is divided by an internal prescaler, thus clock frequencies of 16MHz, 8MHz, 4MHz, 2MHz, 1MHz, 250kHz or 62.5kHz are possible. Initially the transceiver master clock is outputted prescaled by 16 (1MHz clock output; refer to [2] for details).

CLKM is routed to the MCU (pin 36 / TWCK0) where it may be used as timer input. The signal is filtered by a low-pass filter to reduce harmonic emissions within the 2.4GHz ISM band. The filter is designed to provide a stable 1MHz clock signal with correct logic level to a microcontroller pin with sufficiently suppressed harmonics. CLKM frequencies above 1MHz would require a redesign of R11 and C28 which in the current device are covered by the RF shield. In case of RC cut-off frequency adjustments, depending on the specific load and signal routing conditions, one may observe performance degradation of channel 26. Since its possible influence on the radio performance it is recommended to disable CLKM output if not needed.

Figure 4-6. Transceiver clock connection.

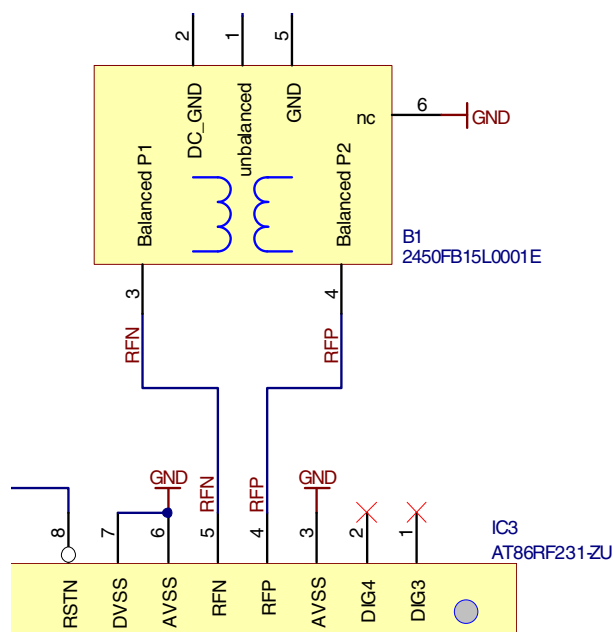


4.5 RF section

The Atmel AT86RF231 radio transceiver incorporates all RF and BB critical components necessary to transmit and receive signals according to IEEE 802.15.4 or proprietary ISM data rates.

A balun, B1, performs the differential to single-ended conversion of the RF signal to connect the Atmel AT86RF231 to the ceramic antenna, passing a tuning line with a network of inductors and capacitors along the line. The balun unit's output connections (RFN, RFP / pins 3, 4) are directly routed to the differential RF I/O pins of the AT86RF231 radio transceiver. Refer to Chapter 5 for further information about the antenna tuning.

Figure 4-7. 50Ω balun.



4.5.1 Ceramic chip antenna connection

The ceramic chip antenna is designed at the outermost location of the RF231USB-RD stick to enable good transmission properties into the environment.

RF tuning and best antenna performance has been achieved by implementing a matching network consisting of inductors and capacitors shown in [Figure 4-8](#). Antenna matching is realized with capacitors effective in the line to the 50Ω balun shown in [Figure 4-7](#).

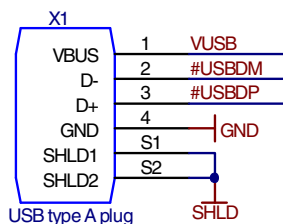
See Section 4.5 for details on the RF signal routing.

To identify the board type by software, a special memory area described in Section 4.7.1 is used. Information about the board contains, but is not limited to, its unique serial number, the MAC address ⁽¹⁾, and calibration values. Stored in the uppermost memory block of the external flash, the data are written during board production testing. These can be used to optimize system performance.

Note: 1. The board-specific information is stored persistently in this flash memory block. It must NOT be used competitively from the mass storage device. This is assured in the board's delivery condition. Pay attention when implementing your own firmware; double-check if necessary.

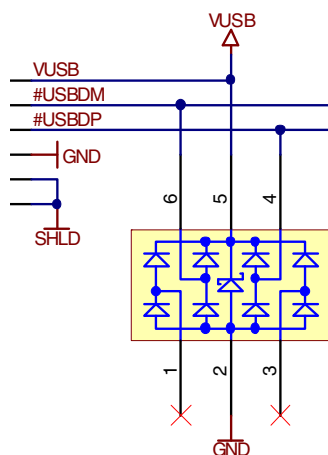
This section describes the important on-board peripherals: memory components, plugs and connectors as well as other interface and access options to the board.

Figure 4-10. USB type A plug.



A suppressor array, D1, is switched to the two USB data lines to safeguard data exchange.

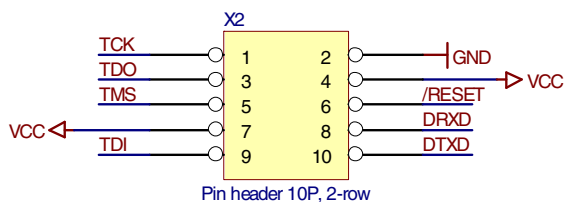
Figure 4-11. Suppressor array.



4.7.3 10-pin connector

The 10-pin connector, X2, is placed at the bottom side of the RF231USB-RD stick, near the USB type A plug (on the top side).

Figure 4-12. 10-pin connector.

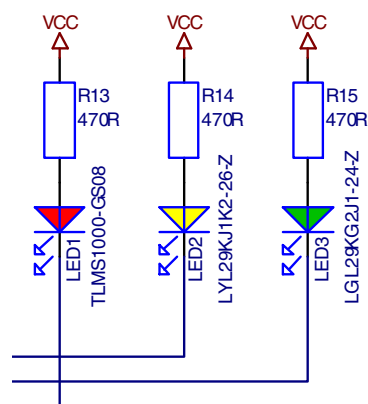


The soldered combined JTAG/Trace connector of the board enables programming, debugging and testing right in the circuit. For programming via JTAG the 10-pin connector has to be plugged into the SAM-ICE female adapter.

4.7.4 Status LEDs

For simple applications and debugging purposes, or just to deliver status information, a basic user interface consisting of three LEDs is provided directly on the board. They are mounted on the bottom side of the printed circuit board.

Figure 4-13. Status LEDs.



The LEDs are connected to the pins 9, 10 and 13 of the SAM3S4B microcontroller.

4.7.5 ERASE and VCC pins

The ERASE pin (see Section 4.1 Pin assignment) is used to reinitialize the MCU flash content - and some of its NVM (Non-Volatile Memory) bits - to an erased state. The flash is transferred to its original state.

To perform a flash erase operation the pin has to be tied high longer than 220ms while the USB stick is connected to the PC.

Note: By electrically connecting the two test points ERASE and VCC the internal MCU flash memory will be deleted. The firmware as originally available in the board's delivery condition will be destroyed.

Caution: Work carefully, also when handling the board! The moisture of your fingers' skin may be sufficient under certain conditions to destroy the internal flash content.

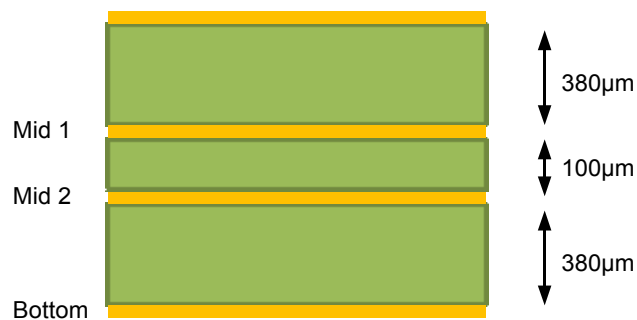
5. PCB layout description

This chapter describes critical layout details to be carefully considered during a PCB design. The PCB design requires an optimal solution for the following topics:

- Create a solid ground plane for the antenna. The PCB has to be considered as a part of the antenna; it interacts with the radiated electromagnetic wave
- Isolate digital noise from the antenna and the radio transceiver to achieve optimum range and RF performance
- Isolate digital noise from the 16.000MHz reference crystal to achieve optimum transmitter and receiver performance
- Reduce any kind of spurious emissions below the limits set by the individual regulatory organizations

The RF231USB is a four-layer FR04-PCB with a thickness of 1.0mm. All layers are used as ground planes, except midlayer two, which is used as supply voltage plane. [Figure 5-1](#) shows its layer stack:

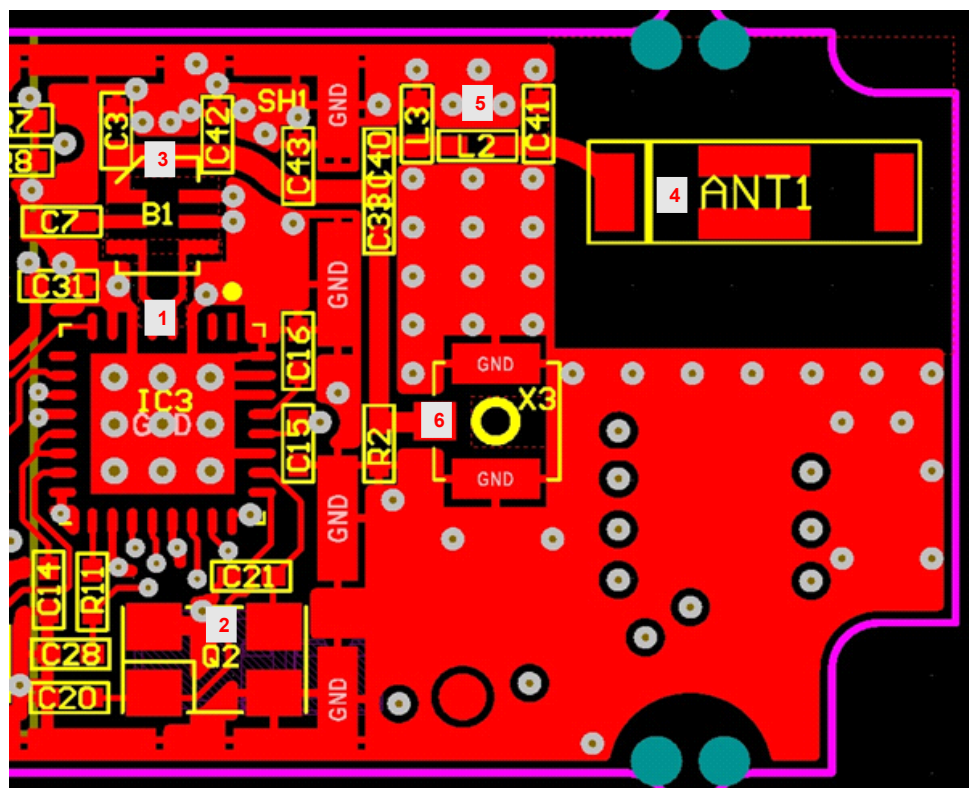
Figure 5-1. PCB layer stack.



The RF section layout is shown in [Figure 5-2](#) where critical sections are marked by numbers: the RF pin fan out of the RF transceiver (1), the 16MHz crystal routing (2), the ground plane routing, feed line design (3), the ceramic antenna (4) with matching network (5) and finally the coaxial connector for test measurements (6).

Each of them is described in detail in one of the following sections.

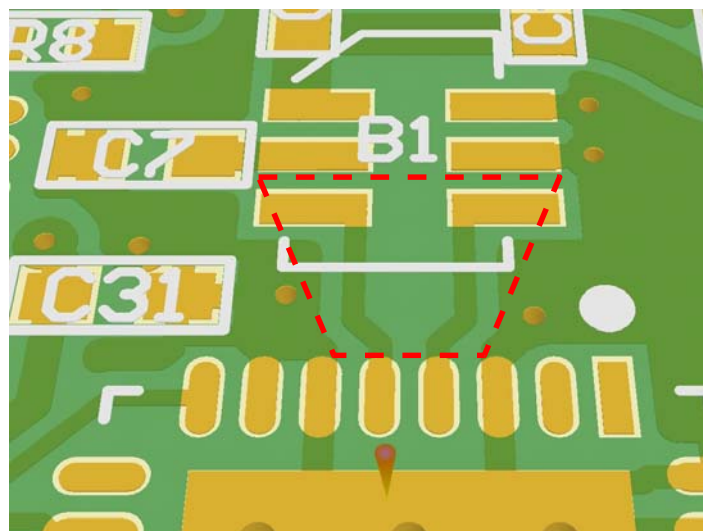
Figure 5-2. Board layout – RF section.



5.1 PCB detail 1 – balanced RF pin fan out

The reference design of a compact USB dongle with RF part requires compromises originating from geometrical limitations. This fact results in deviations from an optimal layout especially for the RF part in this design.

Figure 5-3. Board layout – RF pin fan out.



The Atmel AT86RF231 antenna port should be connected to a 100Ω load with a small series inductance of 1nH to 2nH. This is achieved with the connection fan out in between the IC pins and the filter balun balanced feed pins (B1 pads 3 and 4). The trace width is kept small at 0.2mm for a length of approximately 1.5mm. The dashed area in [Figure 5-3](#) has a midlayer cutout inside the PCB layout. The bottom layer is implemented as ground plane. Therefore, the distributed capacitance between top and bottom is low, and transmission lines are rather inductive.

5.2 PCB detail 2 – crystal routing

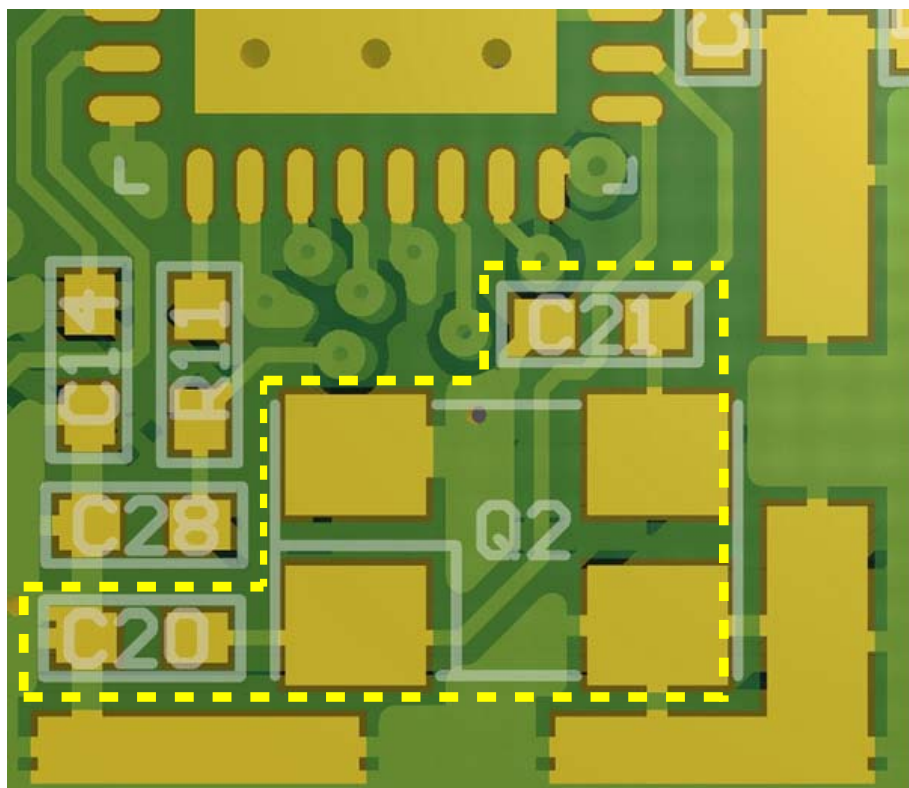
[Figure 5-4](#) shows the reference crystal PCB area which requires optimization to minimize external interference and to keep any radiation of 16.000MHz harmonics low.

The reference crystal Q2 and load capacitors C20/21 form the resonator circuit. These capacitors are to be placed close to the crystal.

The shielded board design ensures immunity against external impairments such as burst and surge. Additionally the crystal housing is connected to ground. The crystal signal lines should be embedded within ground areas to protect against board internal crosstalk. This design rule had to be ignored due to the USB stick space constraints.

If possible, the ground connection in between the capacitors should be the crystal housing contact too, resulting in a robust and stable resonator. The resonator block is enclosed within ground traces around it and a plane on the bottom side. Do not connect the resonator directly to the plane beneath the block.

Figure 5-4. Board layout – XTAL section.



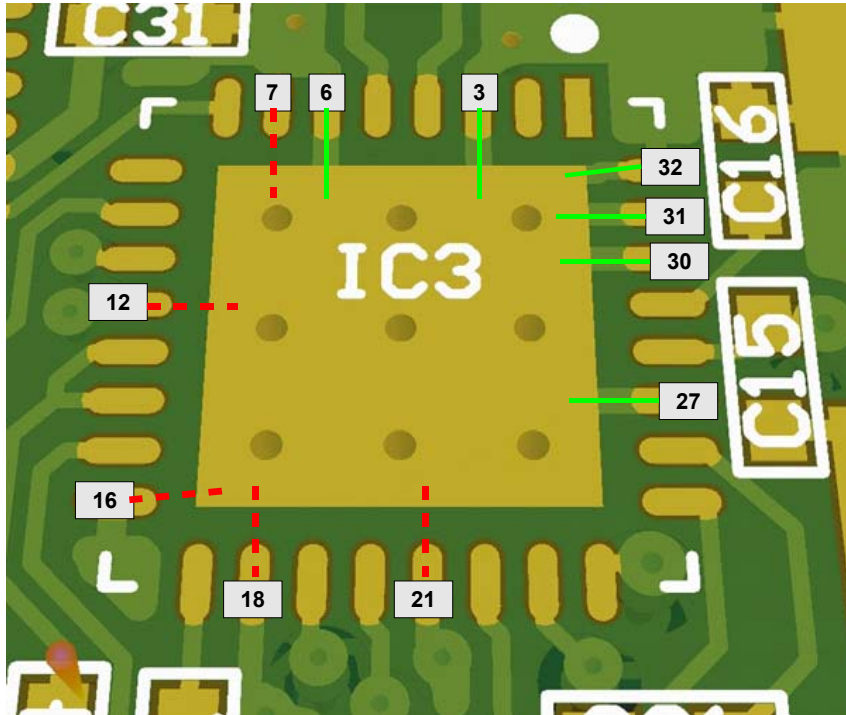
5.3 PCB detail 3 – ground plane routing and feed line design

The following sections provide details about analog and digital ground routing, the ground plane and the RF transmission line.

5.3.1 Analog GND routing

With the Atmel AT86RF231, consider pins 3, 6, 27, 30, 31 and 32 as analog ground pins, see [Figure 5-5](#). Analog ground pins are to be routed to the paddle underneath the IC. The trace width has to be similar to the pad width when connecting the pads, and increase, if possible, some distance from the pad.

Figure 5-5. Board layout – transceiver GND.



Each ground pin should be connected to the bottom plane with at least one via. Move the vias as close as possible. It is always desired to integrate the single-pin ground connections into polygon structures after a short distance. Top, bottom, and on multilayer boards, the inner ground planes, should be tied together with a grid of vias. When ground loops are smaller than one tenth of the wavelength, it is safe to consider this as a solid piece of metal.

The soldering technology used allows the placement of small vias (0.15mm drill) within the ground paddle underneath the chip. During reflow soldering, the vias get filled with solder, having a positive effect on the connection cross section. The small drill size keeps solder losses within an acceptable limit. During the soldering process vias should be open on the bottom side to allow enclosed air to expand.

5.3.2 Digital GND routing

With the Atmel AT86RF231, consider pins 7, 12, 16, 18 and 21 as digital ground pins.

Digital ground pins are not directly connected to the paddle. Digital ground pins may carry digital noise from I/O pad cells or other digital processing units within the chip.

In case of a direct paddle connection, impedances of the paddle ground vias could cause a small voltage drop for this noise and may result in an increased noise level transferred to the analog domain.

5.3.3 GND plane

Besides the function to provide supply ground to the individual parts, the ground plane has to be considered as a counterpart for the antenna. Such an antenna base plate is considered as a continuous metal plane.

For that reason, any unused surface should be filled with a copper plane and connected to the other ground side using sufficient through holes. Larger copper areas should also be connected to the other side layer with a grid of vias. This way, for an external electromagnetic field, the board will behave like a coherent piece of metal.

When a trace is cutting the plane on one side, the design should contain vias along this trace to bridge the interrupted ground on other layers. Place vias especially close to corners and necks to connect loose polygon ends.

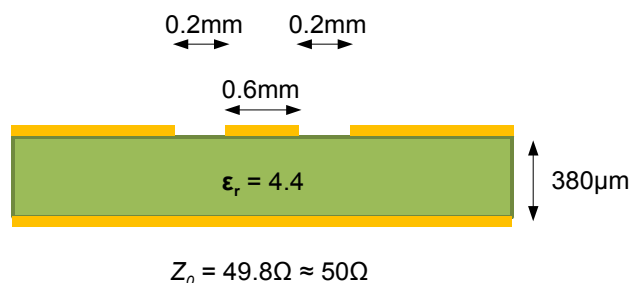
5.3.4 Feed line

Most RF parts are matched to 50Ω impedance. To connect RF parts properly together it is necessary to use a matched RF transmission line, like microstrip or Grounded Coplanar Waveguide (GCPW). Because of the layer construction of the RF231USB PCB and its thickness of 1.0mm, a GCPW is favorable because it requires only a small width compared to a microstrip line.

The calculation of a GCPW refers to top and midlayer 1. The dielectric has a thickness of 380μm and a permittivity of $\epsilon_r = 4.4$ at 2400MHz. The calculation rules for designing a GCPW are very complex. A widespread explanation can be found in [4].

The calculated and designed GCPW according to [4] has the following properties:

Figure 5-6. Board layout – GCPW properties.



The thickness of top layer copper was simplified assumed with zero.

5.4 PCB details 4 and 5 – ceramic antenna with matching network

To evaluate the antenna setup a fully assembled board was used to determine the key design parameters for the antenna configuration. Because the antenna has to operate in an environment different from that of the manufacturer's evaluation board, the correct frequency tuning has to be verified. The antenna tuning was realized by using a matching circuit described in the following sections.

The used ceramic antenna (2450AT43B100 by Johanson Technology) is optimized for PCB edge mounting. There are ground planes on two sides of the antenna, intersected with vias. The space between antenna and ground plane has no copper. The placement as shown in Figure 5-8 occurs according to manufacturer's datasheet [5].

The matching of the chip ceramic antenna is done by inductors L2 and L3 placed near the antenna feed pad (Figure 5-7 and Figure 5-8). The capacitor C41 is not assembled. The matching network in this case has the task to match the antenna feed point impedance to 50Ω to establish a proper RF performance.

Figure 5-7. Board layout – matching circuit schematic.

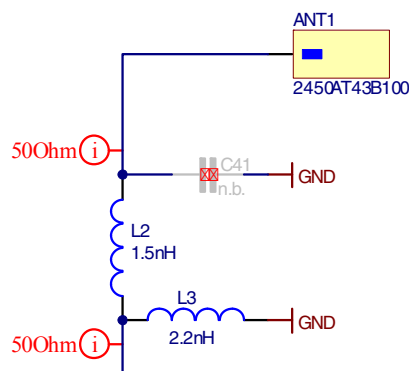
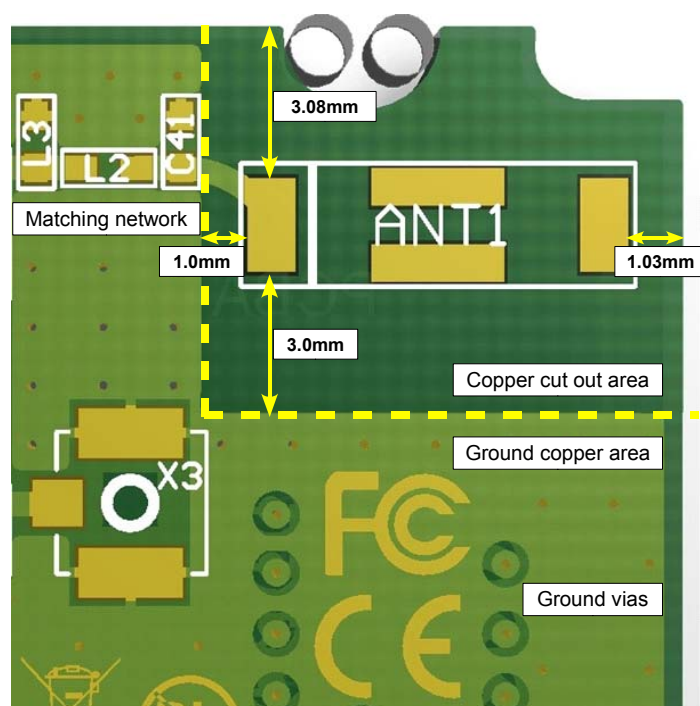


Figure 5-8. Board layout – antenna dimension.



5.4.1 Antenna tuning

The behavior of a radiation device depends on the application environment. In this case the USB dongle was optimized to be plugged directly into an USB port of a laptop. The fact that available laptops have different positions and numbers on USB ports will be neglected.

For antenna measurement the balun was removed (Figure 5-9). Instead a rigid cable with SMA connector was soldered to the balun unbalanced pin (pad 1) to interconnect the RF line with a network analyzer (NWA).

Figure 5-9. Antenna tuning test board (without RF shielding).



To avoid sheath currents it is important to use a ferrite bead fixed on the coaxial cable. The bead should be as close as possible at the DUT (see [Figure 5-10](#)). The use of a second bead at the coaxial port of the NWA is also practical. Furthermore, the RF shielding with a cutout at one side is placed on its appropriate footprint.

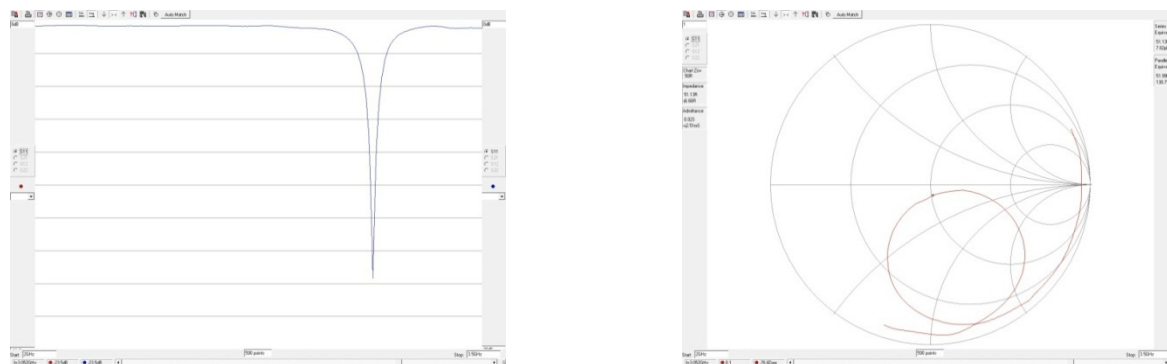
Figure 5-10. DUT with metal shielding plugged into laptop, coaxial cable with ferrite bead.



At first the device has to be calibrated for network analyzer measurements. This is done by preparing three additional devices: one with a 50Ω load, another one with a short circuit and the last one with an open end. The reference point for all devices is the matching part L3. Because of the existing 0402 footprint it is easy to create a load, short and open end.

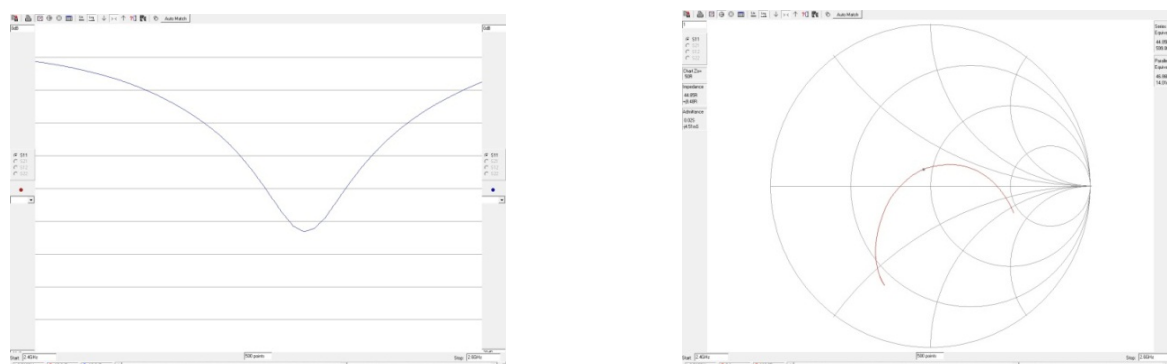
After calibration the DUT has to be measured without matching parts L2, L3 and C41. The resonance behavior depends on the measurement position and all influencing elements in the vicinity. Without matching parts the antenna resonance frequency is too high ([Figure 5-11](#)).

Figure 5-11. S11 and Smith diagram of unmatched antenna.



This measurement results in a matching network consisting of $L2 = 1.5\text{nH}$ and $L3 = 2.2\text{nH}$. The second measurement shows a resonance frequency which is about 50MHz higher than the aimed center frequency of 2.45GHz (Figure 5-12).

Figure 5-12. S11 and Smith diagram of matched antenna.



If the custom application environment meets the environment used during the measurements, the channel dependency of the radiated power can be noticeable. That means that working in channel 20 to 26 may result in a higher transmit and receive range than working in channel 11 to 20.

5.4.2 Range measurement

The resonance behavior of the ceramic antenna itself gives no information about the antenna radiation. One available test option is a range measurement. A good test site is a wide area free of trees and buildings. Compared to an anechoic chamber, the chamber allows quantifiable antenna performance values. But a real (industrial) environment may have quite different results of antenna performance because of undefined walls, machines, humans and other interfering objects in the vicinity. The effect of multipath fading must not be underestimated.

In this case, the range test was performed with a firmware testing the packet error rate. The maximum transmit range is defined by a packet error rate of 1%, that means if 100 packets failed during a transmit test of 10,000 packets the test will be stopped and the maximum distance is reached. The needed hardware consists of two battery powered laptops with side mounted USB sockets where the USB sticks are plugged. Each laptop is placed on the top of a tripod with a height of 1.40 meters.

According to a calculation with the 'Flat Earth Model' in respect to the given values a maximum distance of about 213 meters should be reachable. The Flat Earth Model describes a flat, electrical conducting plane on which two radio devices are placed, located in the height h and the distance d for which applies $d \gg h$. The propagated wave will be received directly and indirectly, respective mirrored on the flat plane. The path loss is higher (fourth power) than within a theoretical free space environment (square power).

Parameters:

Height transmitter	$h_{tx} = 1.40 \text{ m}$
Height receiver	$h_{rx} = 1.40 \text{ m}$
Transmit power	$p_{tx} = +3.0 \text{ dBm}$
Receive power	$p_{rx} [\text{dBm}]$
Transmitter antenna gain ⁽¹⁾	$G_{tx} = -0.5 \text{ dBi}$
Receiver antenna gain	$G_{rx} = -0.5 \text{ dBi}$
Sensitivity ⁽²⁾	$Sens = -97.0 \text{ dBm}$
Distance	$d [\text{m}]$
Path loss	$L_p [\text{dBm}]$

Flat Earth Model ⁽³⁾

$$L_p = G_{tx} + G_{rx} - 20\log(h_{tx}) - 20\log(h_{rx}) - 40\log(d)$$

$$p_{rx} = p_{tx} - L_p$$

Rearranged to d and setting $sens = p_{rx}$:

$$d = 10^{\left(\frac{p_{tx} + G_{tx} + G_{rx} - p_{rx} - 20\log(h_{tx}) - 20\log(h_{rx})}{40}\right)}$$

$$d = 213.24 \text{ m}$$

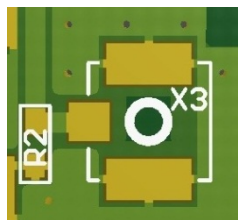
The measured range in the real environment is about 230 meters. That means that calculation and measurement is nearly comparable. Differences may result of position and radiation patterns of the antenna and USB dongle plugged into laptop.

- Notes:
1. According to [5].
 2. Measured at 250kbit/sec.
 3. According to [7].

5.5 PCB detail 6 – coaxial connector

The PCB has a footprint for an U.FL coaxial connector X3 (U.FL-R-SMT-1 by Hirose). This connector was used only for test measurements. The footprint is designed according to manufacturer's datasheet [6]. The resistor R2 near the feeding pad of X3 protects the RF transceiver against electrostatic discharges of coaxial plugged devices or human contacts. The default assembled capacitor C40 enables the antenna feed. For a coaxial connection, capacitor C40 has to be disassembled and C33 mounted. Both capacitors have a value of 22pF.

Figure 5-13. Board layout – coaxial connector.



6. Programming

On the ATSAM3S4BA programming can be done using two physical interfaces: The primary is the JTAG interface which can be used for debugging as well. Optionally programming can be performed using the USB interface.

How to program the device via all mentioned options is described in detail in the RF231USB-RD User Guide [8].

6.1 JTAG interface

The Header X2, see [Figure 4-12](#), provides JTAG access of the SAM3 MCU through the four-pin JTAG interface (TDI, TDO, TCK, TMS) with a JTAG-programmer suitable for ARM-based microcontrollers. The traditional JTAG interface for ARM MCUs is a 20pin 100mil connector; the SAM ICE adapter enclosed within this Kit converts the signals available on X2 mechanically and electrically to this usual JTAG interface. The JTAG interface provided is IEEE 1149.1 standard compliant and supports boundary scan.

In [Figure 6-1](#) the SAM-ICE adapter connected to the RF231USB-RD stick is shown (right hand side). The SAM-ICE adapter (with 20-pin standard ARM-JTAG connector to programmer) is displayed in center, and the D-SUB9 jack (RS232 connection to PC) at the left. Details of the SAM-ICE adapter can be found in the separate hardware user manual [9].

Figure 6-1. SAM-ICE adapter PCBA connected to the RF231USB PCBA.



6.2 USB interface ROM bootloader

The SAM3 MCU comes with an embedded ROM bootloader using USB as communication interface. The bootloader cannot be deleted. Accessing it requires executing one of the following actions first:

- Erasing the device either via the JTAG interface or
- Tying the ERASE pad to VCC or
- Clearing the GPNVM bit 1

During the next power-on, the embedded ROM bootloader is started. Refer to the SAM3S Series User Manual (AT91SAM ARM-based Flash MCU) [1] for details.

7. Electrical characteristics

7.1 Absolute maximum ratings

Stresses beyond those listed in [Table 7-1](#) may cause permanent damage to the board. This is a stress rating only; functional operation of the device at these or any other conditions beyond those indicated in the operational sections of this manual are not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability. For more details about these parameters, refer to individual datasheets of the components used.

Table 7-1. Absolute maximum ratings.

No.	Parameter	Condition	Minimum	Typical	Maximum	Unit
7.1.1	Storage Temperature range		-45		+85	°C
7.1.2	Relative Humidity	Non-condensing			80	% r.H.
7.1.3	Supply voltage		-0.3		5.5	V
7.1.4	EXT I/O pin voltage		-0.3		$V_{USB} + 0.3$	V
7.1.5	Supply current	USB powered			150	mA

7.2 Recommended operating range

Table 7-2. Recommended operating range.

No.	Parameter	Condition	Minimum	Typical	Maximum	Unit
7.2.1	Operating temperature range (T_{OP})		-25		+85	°C
7.2.2	Supply voltage (V_{USB})	USB powered	4.5	5.0	5.5	V

7.3 Current consumption

Test conditions (unless otherwise stated):

$$V_{USB} = 5.0V, T_{OP} = 25^{\circ}C, \text{MCU running at 48MHz, LEDs off}$$

[Table 7-3](#) lists current consumption values for typical scenarios of the RF231USB-RD stick.

Table 7-3. Current consumption specifications.

No.	Parameter	Condition	Minimum	Typical	Maximum	Unit
7.3.1	Current consumption	Transceiver in state TRX_OFF		32		mA
		Transceiver in state RX_ON		49		mA
		Transceiver in state BUSY_TX, TX_PWR = 3dBm		51		mA
		Transceiver in state RX_ON, Flash write access		100		mA

7.4 RF characteristics

Test conditions (unless otherwise stated):

$$V_{USB} = 5.0V, T_{OP} = 25^{\circ}C, \text{MCU running at 48MHz, LEDs off.}$$

Table 7-4. Transceiver characteristics.

No.	Parameter	Condition	Minimum	Typical	Maximum	Unit
7.4.1	Supported data rates			250 500 1 2		kb/s kb/s Mb/s Mb/s
7.4.2	Antenna gain ⁽¹⁾		-0.2	+ 0.5	+0.9	dBi
7.4.3	TX output power ⁽¹⁾				+3.0	dBm
7.4.4	Receiver sensitivity ⁽¹⁾	Datarate 250kb/s Datarate 500kb/s Datarate 1Mb/s Datarate 2Mb/s		-97 -93 -90 -89		dBm dBm dBm dBm
7.4.5	Range ⁽²⁾	line of sight		200		m

- Notes:
1. Conducted, measurements taken with optional U.FL receptacle populated (see Section 4.5.1 for reference).
 2. Determined using a packet error test (10000 transmitted, PER<1%).

8. Abbreviations

802.15.4	-	IEEE 802.15.4-2003 standard, applicable to low-rate wireless Personal Area Network
AES	-	Advanced Encryption Standard
ASF	-	Application Software Framework
BB	-	Baseband
CDC	-	Communication Device Class
CLKM	-	Transceiver clock; Master clock signal output (transceiver)
DBGU	-	Debug Unit
DFU	-	Device Firmware Upgrade
EMI	-	Electromagnetic interference
ETSI	-	European Telecommunications Standards Institute
FCC	-	Federal Communications Commission
GCPW	-	Grounded Coplanar Waveguide
GPIO	-	Generals Purpose Input Output
GPNVM	-	General Purpose Non-volatile Memory (bit; the SAM3S features two GPNVM bits)
IRQ	-	Interrupt Request
ISM	-	Industrial, Scientific and Medical frequency band
JTAG	-	Digital interface for debugging of embedded device, also known as IEEE 1149.1 standard interface
LDO	-	Low-drop Output
MAC	-	Medium Access Control
MCU, μ C	-	Microcontroller Unit
NWA	-	Network Analyzer
PCBA	-	Printed Circuit Board Assembly
PLL	-	Phase-locked Loop
RF	-	Radio Frequency
R&TTE	-	Radio and Telecommunications Terminal Equipment (Directive of the European Union)
SMD	-	Surface Mount Device
SPI	-	Serial Peripheral Interface
TWI	-	Two-Wire Serial Interface
UART	-	Universal Asynchronous Receiver Transmitter
USART	-	Universal Synchronous/Asynchronous Receiver Transmitter
USB	-	Universal Serial Bus
WPAN	-	Wireless Personal Area Network
XTAL	-	Crystal
ZigBee	-	Wireless networking standard targeted at low-power applications

A.2 Assembly drawing

Figure 8-2. RF231USB-RD assembly drawing; top layer.

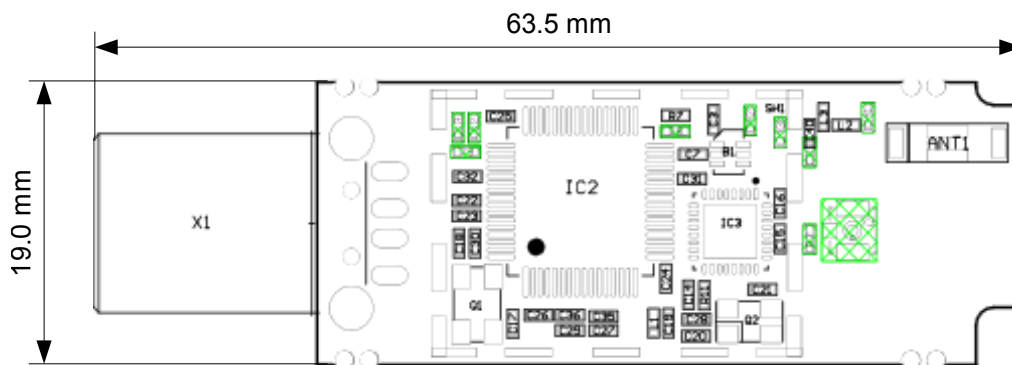
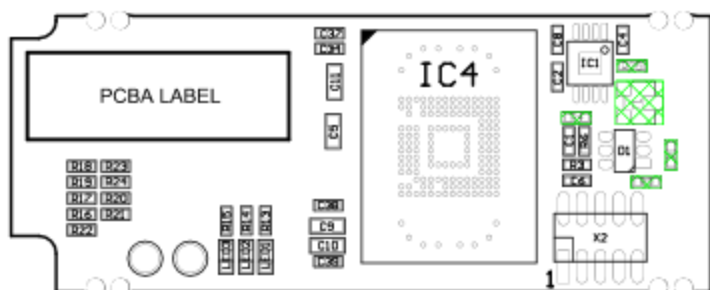


Figure 8-3. RF231USB-RD assembly drawing; bottom layer.



A.3 Bill of materials

Table 8-1. Bill of materials.

Qty.	Designator	Description	Footprint	Manuf. Part#	Manufacturer
1		RF231USB PCB		5 646 19 00.250.01	G&W Leiterplatten Dresden GmbH
1		Solder paste master plate	B side, 150µm	5 646 19 00.985.00	
1		Solder paste master plate	L side, 130µm	5 646 19 00.985.00	
1	C30	Capacitor	0402	1nF/ 10%	Murata
2	C20, C21	Capacitor	0402	12pF/ 5%	Kyocera-elco
13	C8, C23, C24, C25, C26, C31, C32, C34, C35, C36, C37, C38, C39	Capacitor	0402	100nF/ 10%	Murata
4	C7, C17, C18, C40	Capacitor	0402	22pF/ 5%	Kyocera-elco
1	C28	Capacitor	0402	1.5pF/ 0.25pF	Murata
2	C1, C6	Capacitor	0402	15pF/ 2%	AVX
4	C5, C9, C10, C11	Capacitor	0603	2.2µF/ 10%	Murata
9	C2, C4, C14, C15, C16, C19, C22, C27, C29	Capacitor	0402	1µF/ 10%	Kemet
1	C3	Capacitor	0402	0.7pF/ 0.1pF	Murata
1	IC4	iNAND Flash 2GB	TFBGA-153	SDIN5D2-2G	SanDisk
1	IC3	802.15.4 2.4GHz radio transceiver	QFN-32	AT86RF231-ZU	Atmel
1	IC2	32-bit CPU	LQFP-64	ATSAM3S4BA-AU	Atmel
1	IC41	Voltage regulator LDO 3.3V	MSOP-8 /PowerPAD	TPS79433DGN	Texas Instruments
1	D1	Suppressor Array	SOT-23/6(SOT-457)	IP4220CZ6	NXP
1	LED1	Light emitting diode-red	0603	TLMS1000-GS08	Vishay
1	LED2	Light emitting diode-yellow	0603	LYL29KJ1K2-26-Z	Osram
1	LED3	Light emitting diode-green	0603	LG L29KG2J1-24-Z	Osram
1	L2	Ceramic SMD inductance	WE-MK/0402	1.5nH/±0.3nH	Würth Elektronik
1	L1	EMI ferrite impedance	0402	BLM15HG102SN1D	Murata
1	L3	SMD inductance	0402	2.2nH/±0.3nH	Taiyo TYuden
1	R7	Resistor	0402	0R00	Samsung
2	R3, R6	Resistor	0402	27R0	Samsung
4	R11, R13, R14, R15	Resistor	0402	470R	Samsung
1	R24	Resistor	0402	10K0	Samsung
8	R16, R17, R18, R19, R20, R21, R22, R23	Resistor	0402	100K	Samsung
1	Q2	Crystal 16.0MHz	SMD/SX-4025		SIWARD
1	Q1	Crystal 18.432MHz	SMD-KX-9A		GEYER ELECTRONIC
1	X1	USB 2.0 connector type A	win	2410 07	Lumberg

Qty.	Designator	Description	Footprint	Manuf. Part#	Manufacturer
1	X2	Pin header 2 x 5, 90 degree	2-line SMD		Harwin
1	B1	2.4GHz Filter Balun 50Ω	SMD-6	2450FB15L0001E	Johanson Technology
1	SH1	EMI Shielding	24x17.5x3.05mm	1020059A	Mekoprint
1	ANT1	Ceramic antenna		2450AT43B100	Johanson Technology

A.4 MIB data

Table 8-2. MIB data.

Attribute class	Attribute	Offset/ bytes [:bit]	Value	Remarks
mib_revision	N/A	0x00	1	
mac_ieee_address	N/A	0x01	board-specific	little endian
board	board_name	0x09	U231T-B	Board type according to Atmel naming rules
	board_version	0x11	1	Board revision
	plm_key	0x13	A09-1495/01	reference to manufacturing system
	board_serial	0x1E	board-specific	Board serial number
	board_id	0x28	0	ID returned by the Xplain ID command
features	power_class	0x2A:0	1	defines board power consumption
	rf_connector	0x2A:2	0	whether board has external RF connector available
	rf_onboard_ant	0x2A:3	1	whether board has onboard antenna(s) available
	rf_ant_rangeinfo	0x2A:4	0	whether the antenna is limited in frequency range
	rf_ant_diversity	0x2A:5	0	whether board supports antenna diversity
	rf_lna	0x2A:6	0	true: receive path contains a LNA, rx power readings require recalculation
	rf_lna_bypass	0x2A:7	0	whether software has to take care of additional LNA-Bypass functions
	rf_pa	0x2B:0	0	whether board supports the transceiver PA control feature
	rf_pa_bypass	0x2B:1	0	whether software has to take care of additional PA-Bypass functions
	rf_trx_acc_reset	0x2B:2	0	whether transceiver reset has to be activated to access the 'mib' memory
antenna options	ant_gain	0x2C	0	Measured gain of the RF path
	ant_range1_start	0x2D	240	Antenna Frequency Range(s)
	ant_range1_stop	0x2E	250	
	ant_range2_start	0x2F		
	ant_range2_stop	0x30		
	ant_range3_start	0x31		
	ant_range3_stop	0x32		
frontend	tx_pwr_default	0x33	3	Safe, conservative default power setting, not violating any regulatory rules.
	pa_gain	0x34	0	Gain of a PA in line with the TX path without considering saturation effects.

Attribute class	Attribute	Offset/ bytes [:bit]	Value	Remarks
	pa_bypass_gain	0x35	0	Attenuation of a PA bypass in line with the RF path
	lna_gain	0x36	0	Gain of a LNA in line with the RX path
	lna_bypass_gain	0x37	0	Attenuation of a PA bypass in line with the RF path
calibration	cal_16mhz	0x38	board-specific	calibration value for onboard transceiver clock
crc		0x39	board-specific	CRC-16, little endian

- Notes:
- Gains are given as like $\pm 127 \times 1\text{dBi}$; for example 4 = 4dBi.
 - Frequency ranges are given in f/10; for example 240 = 2400MHz.

Appendix B. Radio certification

The RF231USB-RD has received regulatory approvals for modular devices in the United States and European countries.

B.1 United States (FCC)

Compliance Statement (Part 15.19)

The device complies with Part 15 of the FCC rules. To fulfill FCC Certification requirements, an Original Equipment Manufacturer (OEM) must comply with the following regulations:

- The modular transmitter must be labeled with its own FCC ID number, and, if the FCC ID is not visible when the module is installed inside another device, the outside of the device into which the module is installed must also display a label referring to the enclosed module
- This exterior label can use wording such as the following. Any similar wording that expresses the same meaning may be used

Contains FCC-ID: XVV-ARM323E00

This device complies with Part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) this device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

Note: The RF231USB-RD fulfills a Permissive Change Class 1 regarding to FCC Section 2.1043. The internal / external antenna(s) used for this mobile transmitter must provide a separation distance of at least 20cm from all persons and must not be co-located or operate in conjunction with any other antenna or transmitter.

Installers must be provided with antenna installation instructions and transmitter operating conditions for satisfying RF exposure compliance. This device is approved as a mobile device with respect to RF exposure compliance, and may only be marketed to OEM installers.

B.2 Europe (ETSI)

If the device is incorporated into a product, the manufacturer must ensure compliance of the final product to the European harmonized EMC and low-voltage/safety standards. A Declaration of Conformity must be issued for each of these standards and kept on file as described in Annex II of the R&TTE Directive.

The manufacturer must maintain a copy of the device documentation and ensure the final product does not exceed the specified power ratings, and/or installation requirements as specified in the user manual. If any of these specifications are exceeded in the final product, a submission must be made to a notified body for compliance testing to all required standards. The "CE" marking must be affixed to a visible location on the OEM product. The CE mark shall consist of the initials "CE" taking the following form:

- If the CE marking is reduced or enlarged, the proportions given in the above graduated drawing must be respected
- The CE marking must have a height of at least 5mm except where this is not possible on account of the nature of the apparatus
- The CE marking must be affixed visibly, legibly, and indelibly

More detailed information about CE marking requirements you can find at "DIRECTIVE 1999/5/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL" on 9 March 1999 at section 12.

Appendix C. References

- [1] AT91SAM ARM-based Flash MCU, SAM3S Series, preliminary datasheet, doc. no. 6500; Atmel Corporation. Downloadable from: <http://www.atmel.com/images/doc6500.pdf>.
- [2] AT86RF231; Low Power, 2.4GHz Transceiver for ZigBee, IEEE 802.15.4, 6LoWPAN, RF4CE, SP100, WirelessHART and ISM Applications; Datasheet; Rev. 8111B-MCU Wireless-02/09; Atmel Corporation. Downloadable from: <http://www.atmel.com/images/doc8111.pdf>
- [3] IEEE Std 802.15.4-2006: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (LR-WPANs).
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Appendix D. Revision history RF231USB PCBA

Version	Description
A09-1495/01	Initial revision

Appendix E. EVALUATION BOARD/KIT IMPORTANT NOTICE

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