Stellaris® Brushed DC Motor Control Reference Design Kit

User's Manual

RDK-BDC-05

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Stellaris® Brushed DC Motor Control Reference Design Kit (RDK) Overview

The RDK-BDC is a Stellaris reference design for the MDL-BDC, a Controller Area Network (CAN) based DC motor control. The MDL-BDC motor control module provides variable speed control for 12 V brushed DC motors at up to 40 A continuous current. Features include high-performance CAN networking as well as a rich set of control options and sensor interfaces, including analog and quadrature encoder interfaces.

High-frequency PWM enables the DC motor to run smoothly and quietly over a wide speed range. MDL-BDC uses highly optimized software and a powerful 32-bit Stellaris LM3S2616 microcontroller to implement open-loop speed control as well as closed-loop control of speed, position, or motor current.

The Reference Design Kit (RDK-BDC) contains an MDL-BDC motor control module as well as additional hardware and software for evaluating CAN communication. After evaluating the RDK-BDC, users may choose to either customize parts of the hardware and software design or use the MDL-BDC without modification.

See the MDL-BDC board data sheet (available for download from www.ti.com/stellaris) for complete technical specifications.

Figure 1-1. Brushed DC Motor Control Module

Feature Summary

The MDL-BDC control board provides the following features:

- Controls brushed 12 V DC motors up to 40 A continuous
- Controller Area Network (CAN) interface at 1 Mbit/s
- Industry standard servo (pulse-width modulation (PWM)) speed input interface
- Limit switch, encoder, and analog inputs
- Fully enclosed module includes fan cooling
- Flexible configuration options
- Easy to customize—full source code and design files available
- Factory source code compiles to less than 16 KB

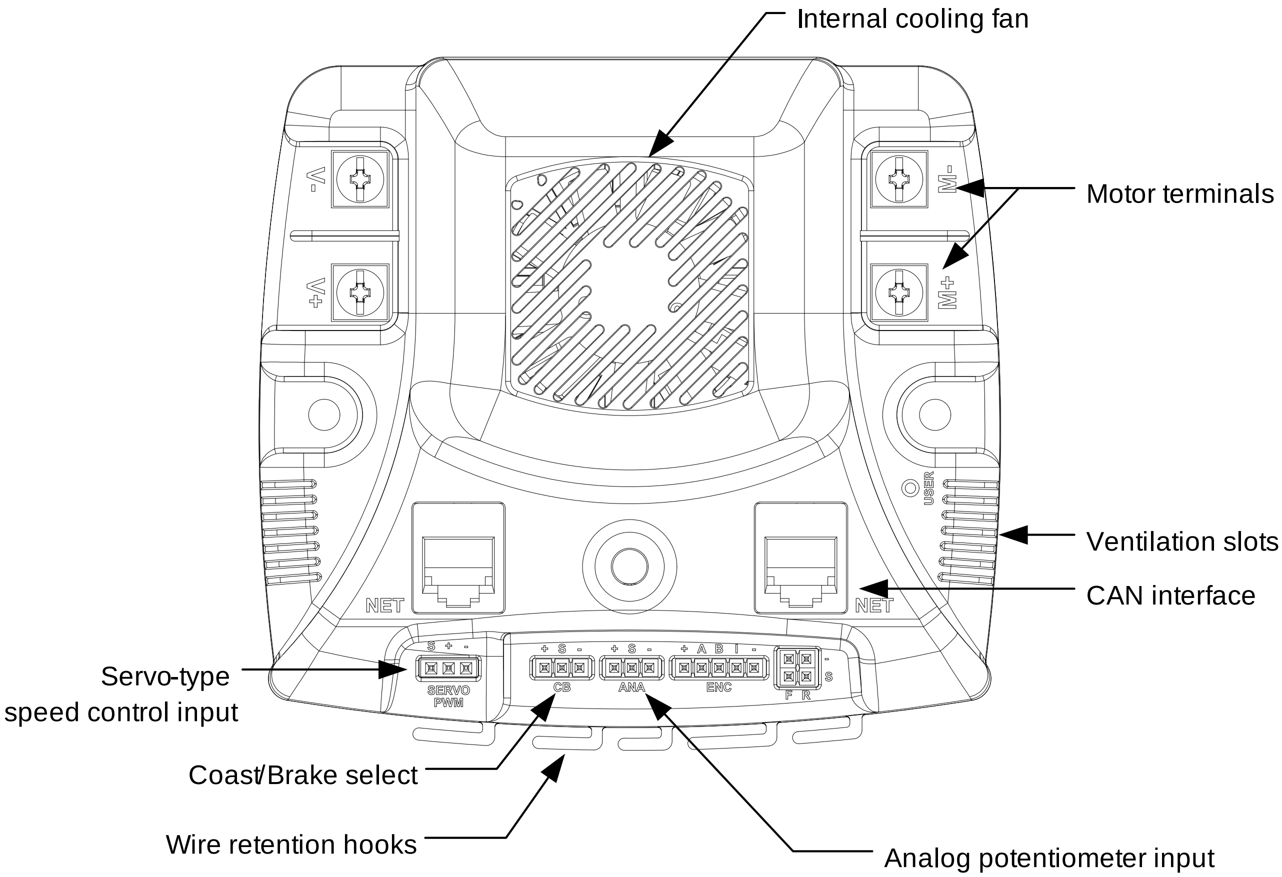
Specification Overview

Key specifications of the MDL-BDC include:

- Quiet control of brushed DC motors
  - 15 kHz PWM frequency
- Two options for Speed control
  - Industry standard R-C servo type (PWM) interface
  - Controller Area Network (CAN) interface
- CAN communication
  - Multicast shared serial bus for connecting systems in electromagnetically noisy environments
  - 1 Mbits/s bit rate
  - CAN protocol version 2.0 A/B
  - Full configurability of module options
  - Real-time monitoring of current, voltage, speed, and other parameters
- Status LED indicates Run, Direction, and Fault conditions
- Motor brake/coast selector
- Limit switch inputs for forward and reverse directions
- Quadrature encoder input
  - Index input
  - 5 V supply output to encoder
- Analog input
  - Accepts 10kΩ potentiometer or 0-3 V input
- Screw terminals for all power wiring
- Headers (0.1 inch pitch) for all control signals

For detailed specifications including electrical parameters, see the MDL-BDC data sheet.

Figure 1-2. MDL-BDC Module Key Features (top view)



Reference Design Kit Contents

The RDK-BDC contains everything needed to evaluate 12 V brushed DC motor control. The RDK-BDC includes:

- MDL-BDC motor control module
  - Suitable for motors up to 12 V 40 A
  - Uses a Stellaris LM3S2616 microcontroller
- Mabuchi RS-555PH-3255 Brushed DC Motor
  - 5000 RPM, 12 V, 3 A
- Universal input wall power supply
  - 12 V 1.25 A
  - Plug adaptors for US, UK, EU, and AUST.
- BDC CAN console
  - Convenient tool for controlling key MDL-BDC functions
  - Integrated graphics display and navigation switches
  - Firmware update feature
  - Based on EK-LM3S2965 Evaluation Kit

- CAN cable
  - Connects the console to the MDL-BDC
- CAN terminator
  - Plug-in 120-Ω terminator
- USB cable
  - Provides power and communication to the BDC CAN console
- Adapter cable for ARM JTAG/SWD fine-pitch header
  - Texas Instruments Part ADA2
- Ribbon cable for ARM JTAG/SWD
  - 20-position cable for using the BDC CAN console as a debug interface
- Reference design kit CD
  - Complete documentation, including Quickstart and user's guides
  - LM Flash Programmer utility for firmware updates
  - Complete source code, schematics, and PCB Gerber files

The source code can be modified and compiled using any of the following tools:

- Keil™ RealView® Microcontroller Development Kit (MDK-ARM)
- IAR Embedded Workbench
- Code Sourcery GCC development tools
- Code Red Technologies development tools
- Texas Instruments' Code Composer Studio™ IDE

CHAPTER 2

Using the Reference Design Kit

This chapter provides information about the RDK-BDC kit contents and on using the RDK.

Important Information

WARNING – In addition to safety risks, other factors that may damage the control hardware, the motor, and its load include improper configuration, wiring, or software. Minimize the risk of damage by following these guidelines.

- Always wear eye protection and use care when operating the motor.
- Read this guide before connecting motors other than the motor included in the RDK. DC motors may not be directly interchangeable and RDK parameter changes may be necessary before the new motor will operate correctly.
- Damage to the control board and motor can result from improper configuration, wiring, or software.

Developing with the RDK

The recommended steps for using the RDK are:

- **Follow the Quickstart Guide included on the kit CD.** The Quickstart guide will help you get the RS-555 motor up and running using the BDC CAN console in just minutes. It also contains important safety information that should be read before using the RDK.
- **Use the BDC CAN console to evaluate and optimize target motor operation.** Once the module is installed in the end application, use the BDC CAN console to configure and monitor motor operation. Using CAN, the console gives real-time access to a range of operating parameters.
- **Customize and integrate the software and/or hardware to suit an end application.** This user's manual and the *RDK-BDC Firmware Development Package User's Guide* are two important references for completing hardware and software modifications. New software can be programmed in the MDL-BDC using either the console (over CAN), or using a JTAG/SWD debug interface. The BDC console includes a JTAG/SWD debug interface feature.

Power Supply Selection

The MDL-BDC is designed primarily for use with 12 V sealed lead-acid batteries, although other power sources may be used as long as the voltage range is not exceeded.

There are two important considerations when selecting a power supply. The first is finding a supply that can supply the starting current of the motor. Even unloaded motors may have a starting current that can momentarily exceed 60 A. Many switching power supplies will shut down very quickly when starting a brushed DC motor. The power supply does not need to maintain regulation during start, but it must ensure that the supply voltage remains above the under-voltage limit.

The second consideration is how the power supply handles back-EMF and regeneration currents. During rapid deceleration of loads with high inertia, the motor acts as a generator. This current is rectified by the MDL-BDC back into the bus capacitor. As the capacitor charges, the voltage at the supply terminals may increase. It is important that the power supply can handle this momentary condition without entering a fault condition. The power supply must also present sufficiently low impedance so that the MDL-BDC's voltage rating is not exceeded. A sealed lead acid battery easily meets these requirements.

NOTE: The MDL-BDC does not have reverse polarity input protection.

Motor Selection

The MDL-BDC operates 12 V brushed DC motors. Typical motors include model BI802-001A from CIM and model RS-555PH-3255 from Mabuchi (see Table 2-1 for motor specifications). Some very small DC motors or motors in lightly loaded applications may have a limited useful speed range when controlled with PWM based voltage controls.

The MDL-BDC can also drive resistive loads with some de-rating to allow for increased ripple current inside the module. See the MDL-BDC board data sheet for full specifications.

Table 2-1. Mabuchi RS-555PH-3255 Motor Specifications

Parameter	Value	Units
At maximum efficiency		
Speed	3953	RPM
Current	1.244	A
Power	7.139	W
Torque	17.25	mMm
At maximum power		
Speed	2325	RPM
Current	3.627	A
Power	14	W
Torque	57.5	mMm
General characteristics		
No load speed	4650	RPM
No load current	0.223	A

Operating Modes

The MDL-BDC can be controlled using either the servo-style PWM Input or the CAN interface. Table 2-1 compares the capabilities of each control method.

Table 2-2. Control Method Comparison

	Control Method	
	Servo-Style PWM input	**CAN Interface**
Speed Control	Yes	Yes
Analog Position Control	No	Yes
Encoder Position Control	No	Yes
Configurable Parameters	No	Yes
Voltage, Current Measurement	No	Yes
Limit Switches	Yes	Yes
Coast/Brake Feature	Yes	Yes
Firmware Update	No	Yes

The MDL-BDC supports the simultaneous use of CAN for monitoring and the servo-style input for speed.

Servo-Style PWM Input

The MDL-BDC incorporates support for speed and direction control using the standard servo-style interface found on many radio-control receivers and robot controllers. See the MDL-BDC data sheet for specifications on the default timing of this signal.

Calibrating the PWM Input

To accommodate variation in the timing of the supplied signal, the MDL-BDC has a calibrate feature that sets new values for full-forward, full-reverse, and points in between. Calibration is typically only required in applications where the PWM source has uncertainties due to analog radio links or other variables. Direct digital sources are unlikely to require calibration.

Calibration Procedure

To calibrate the servo-style PWM input for a specific range:

1. Hold down the USER switch for five seconds (see Figure 1-2 on page 11).
2. Set the controller to send a full-forward signal.
3. Set the controller to send a full-reverse signal.
4. Set the controller to send a neutral signal.
5. Release the USER switch.

The MDL-BDC samples these signals and centers the speed range and neutral position between these limits.

If the MDL-BDC does not detect suitable servo signals during calibration, then the calibration fails. This condition is indicated by flashing the LED Red and Yellow.

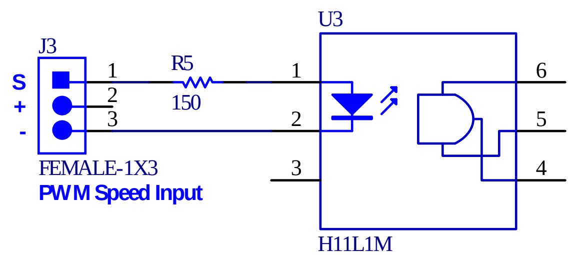
To reset the servo-style PWM input to the default factory range:

1. Disconnect the power to the MDL-BDC.
2. Hold down the USER switch with a straightened paperclip.
3. Reconnect power to the MDL-BDC
4. After 5 seconds, the LED flashes Red and Green slowly to indicate a successful calibration reset to factory settings.
5. Release the USER switch.

Electrical Interface

The servo PWM input is electrically isolated from other circuits using an optocoupler. The MDL-BDC board data sheet contains electrical specifications, including common-mode voltage limits, for the input stage.

Figure 2-1. MDL-BDC's Servo PWM Input Stage



The on-board resistor (R5) has been selected to allow a signal of only a few volts to drive the optocoupler. At 3.3 V or more it is advisable to add additional series resistance to limit the current into the LED. The PWM input stage is essentially a current-driven device, so the threshold for a logic high-level input is defined in milliamps. Some recommended values for an external resistor are listed in Table 2-3

Table 2-3. Recommended Values for External Resistor

PWM Signal Level	External Series Resistor Value
2.5 V	0 Ω (none)
3.0 V	0 Ω - 150 Ω
5.0 V	560 Ω
12 V	2.2 kΩ

CAN Communication

Controller Area Network (CAN) provides a powerful interface for controlling one or more MDL-BDC modules.The MDL-BDC has two RJ11/RJ14 sockets for daisy-chaining modules using standard cables. Each end of the CAN network should be terminated with a 120Ω resistor. The BDC CAN console has a built-in terminator.

Each MDL-BDC module on the CAN bus is accessed using an assigned ID number. The ID defaults to 1, but can be changed by sending a CAN assign ID command to the bus. Pressing the

USER switch on the MDL-BDC informs that particular module to accept the previously specified code.

The CAN protocol used by the MDL-BDC includes the following capabilities:

- Firmware update over CAN
- Read supply voltage, motor voltage, temperature, and current
- Set motor voltage or target position
- Set control mode to speed or position
- Configure parameters
- Enable features such as closed-loop speed and position control.

The CAN protocol provides a number of commands and divides them into groups based on the type of command. The commands are grouped according to broadcast messages, system level commands, motor control commands, configuration commands, and motor control status information. The interface also provides a method to extend the network protocol to other devices by defining a CAN device encoding that takes into account device type and manufacturer.

See the *RDK-BDC Software User's Guide* for complete details. The RDK-BDC includes a CAN board with an example application that demonstrates CAN control.

Default Parameters

The MDL-BDC parameters have the following default values. Parameters can be modified using CAN commands or by modifying the software source code. Parameters modified using CAN commands are volatile and must be reloaded if the power is cycled.

Table 2-4 lists the factory default configuration of the MDL-BDC.

Table 2-4. MDL-BDC Factory Default Configuration

Parameter	Default Value
Accelerate rate	Instantaneous change
Deceleration rate	Instantaneous change
Motor control mode	Open-loop speed control using voltage

For additional information on parameters, see the *RDK-BDC Firmware Development Package User’s Guide*.

Wiring

The MDL-BDC is controlled using either a servo-type PWM source or CAN commands.

Figure 2-2 on page 18 shows a typical simple wiring arrangement with power, motor, PWM control, and optional limit switch connections. Control wires should be looped through the wire retention hooks to prevent the connectors shaking loose during operation.

Figure 2-2. Basic wiring with a Servo-style speed command for open-loop motor control

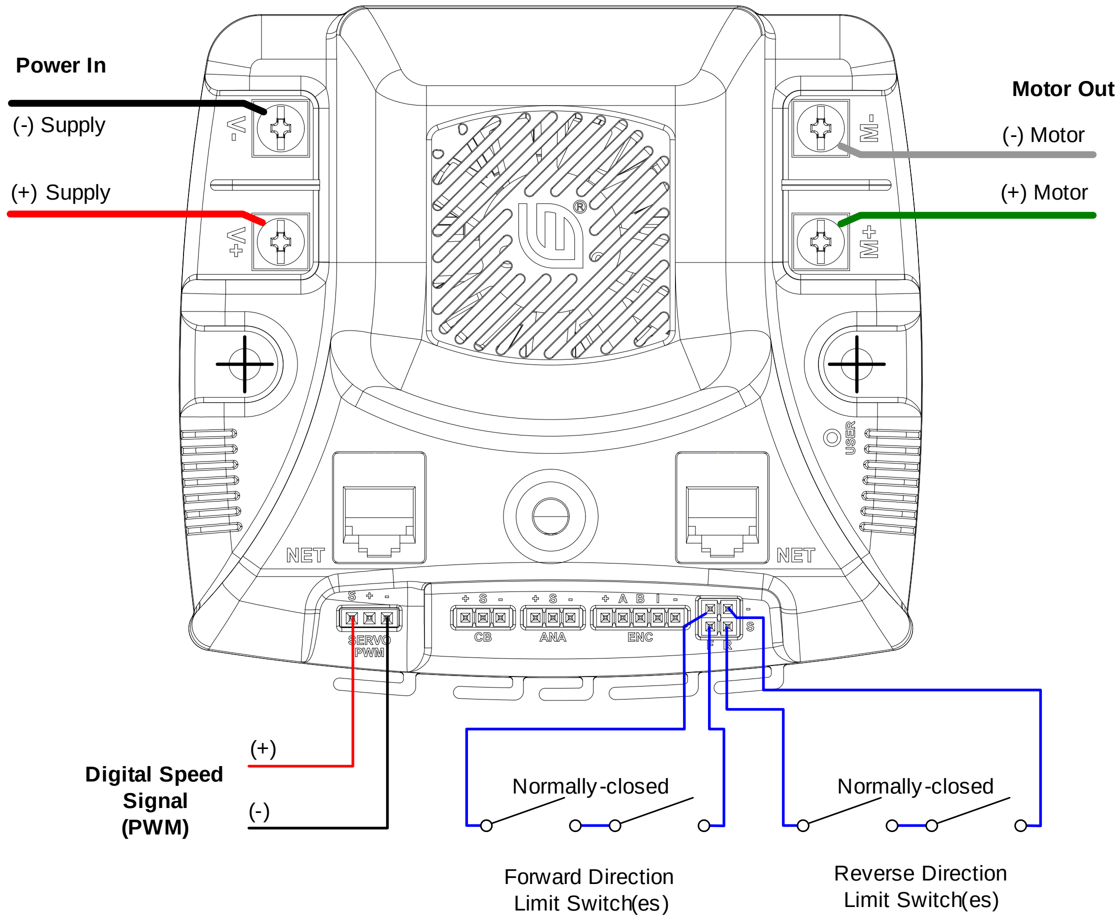
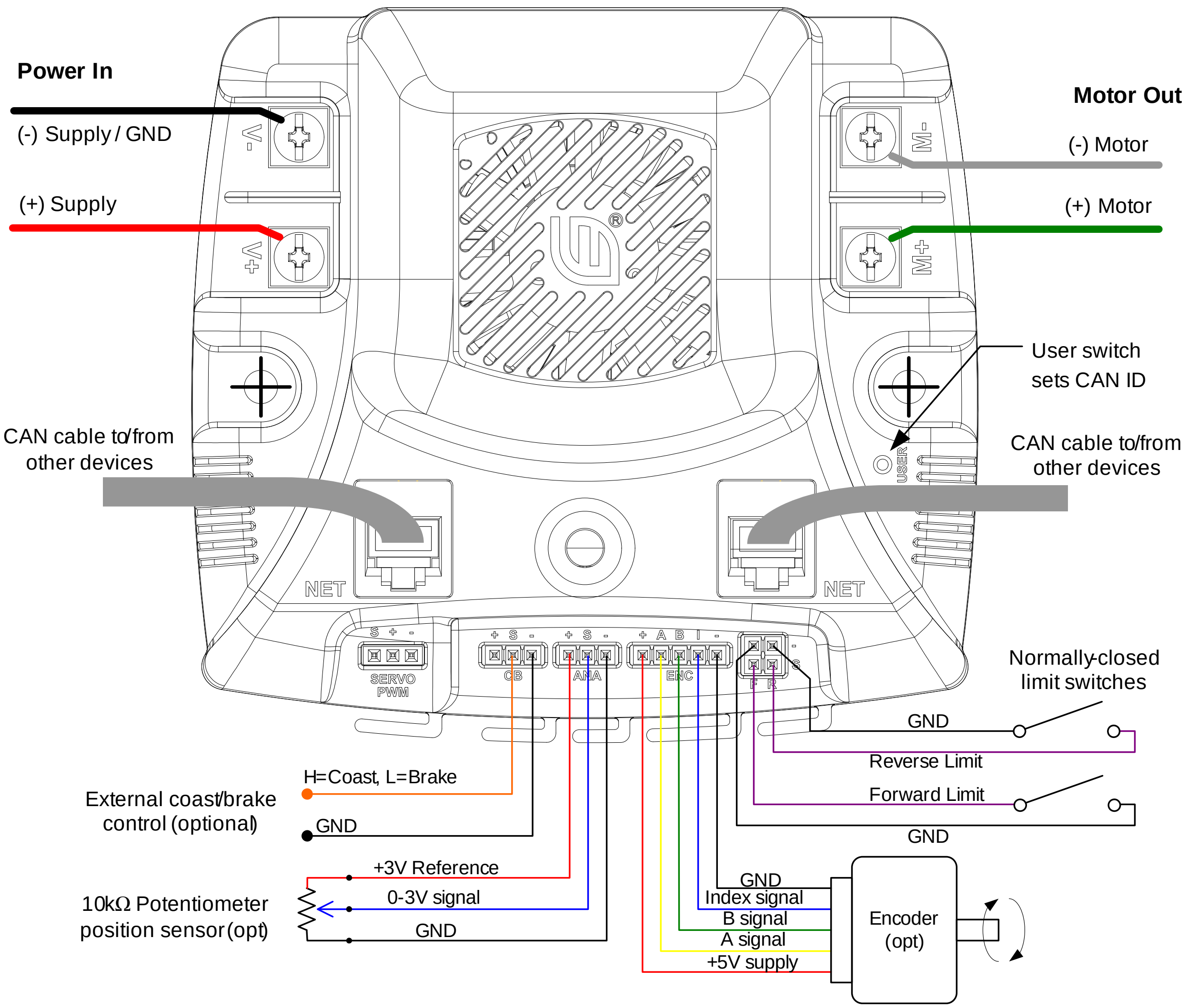


Figure 2-3 shows an advanced wiring configuration using the CAN interface. Wiring for position sensing using both a position potentiometer and a quadrature encoder is detailed. Although two sensor types are shown, the MDL-BDC software supports control and monitoring of only one sensor at a time.

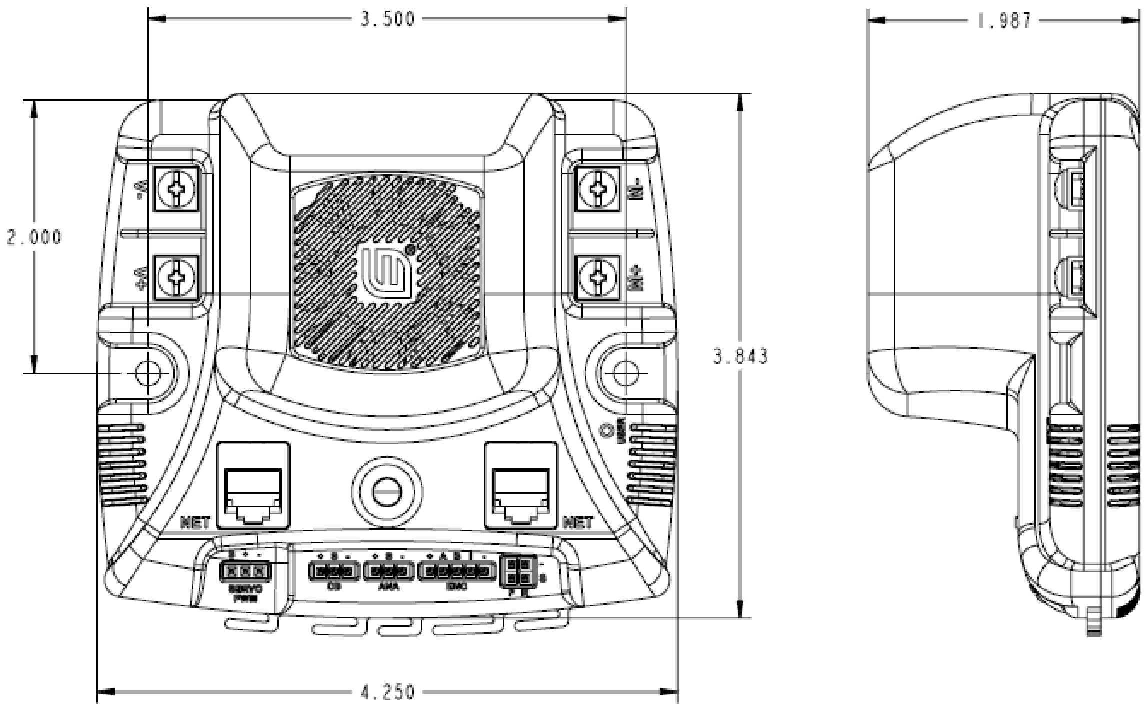
Figure 2-3. Wiring diagram showing CAN-based control for closed-loop motor control



Mechanical Drawing

Figure 2-4 shows the MDL-BDC's physical dimensions. The module has two 0.175" (4.5 mm) diameter mounting holes as indicated.

Figure 2-4. MDL-BDC Mechanical Drawing



Important: The MDL-BDC should be mounted so that the vents in the top and sides of the module are not restricted in any way. A clearance of ½ inch should be maintained around the module to aid cooling.

Status LED

Table 2-5 lists all LED status and fault codes. Fault information is prioritized, so only the highest priority fault will be indicated.

Table 2-5. Normal Operating Conditions

LED State	Module Status
Normal Operating Conditions	
Solid Yellow	Neutral (speed set to 0)
Fast Flashing Green	Forward
Fast Flashing Red	Reverse

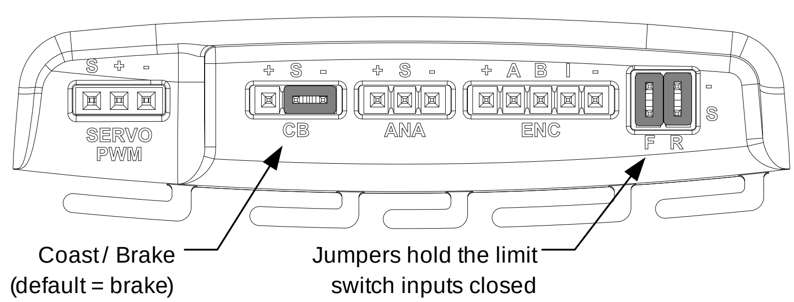
Table 2-5. Normal Operating Conditions (Continued)

LED State	Module Status
Solid Green	Full-speed forward
Solid Red	Full-speed reverse
Fault Conditions	
Slow Flashing Yellow	Loss of CAN or servo link
Slow Flashing Red	Fault
Calibration or CAN Conditions	
Flashing Red and Green	Calibration mode active
Flashing Red and Yellow	Calibration mode failure
Flashing Green and Yellow	Calibration mode success
Slow Flashing Green	CAN ID assignment mode
Fast Flashing Yellow	Current CAN ID (count flashes to determine ID)
Flashing Yellow	CAN ID invalid (that is, Set to 0) awaiting valid ID assignment

Jumper Settings

Figure 2-5 shows the factory default jumper settings.

Figure 2-5. MDL-BDC Default Jumper Settings



Fault Detection

Software and hardware in the MDL-BDC continually monitors for various fault conditions.

Fault Conditions

A slow flashing Red LED indicates a fault condition. The MDL-BDC will detect and shutdown the motor if any of the following conditions are detected.

- Power supply under-voltage
- Over temperature

- Over current
- Limit switch activated in the current direction of motion

The LED will indicate a fault state during the fault condition and for 3 seconds after the fault is cleared (except for the limit switch fault, which is cleared instantaneously).

Loss of CAN or Servo-style Speed Link

A slow flashing Yellow LED indicates that the MDL-BDC is not receiving a valid control signal. The control link error is cleared immediately when a CAN or PWM signal is restored.

C H A P T E R 3

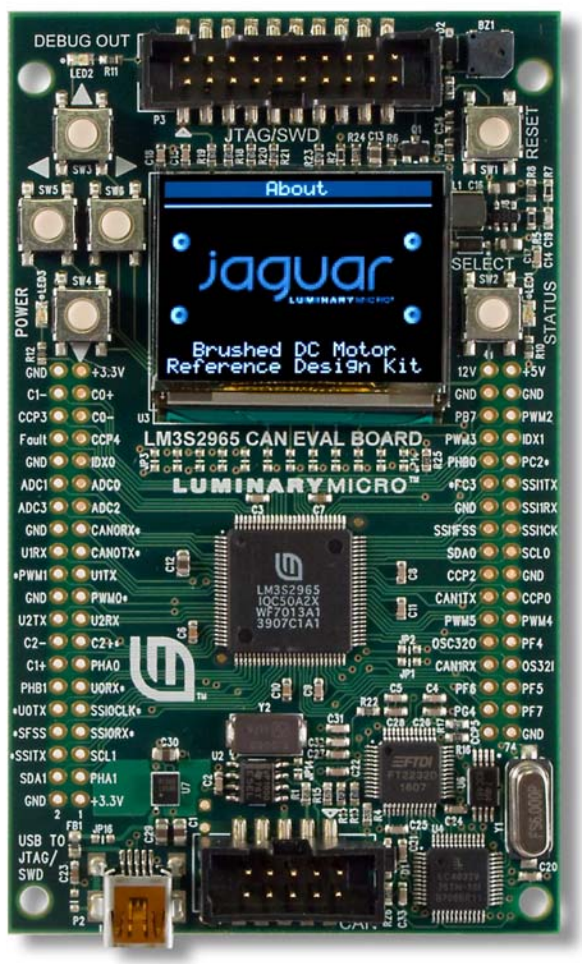
BDC Can Console

The BDC CAN console, included in the RDK-BDC, provides a convenient way to evaluate some of the capabilities of the CAN interface.

Overview

The BDC CAN console is based on the Stellaris LM3S2965 Evaluation Board. The board ships with the console application ready to run. For more information on the capabilities of this board, see the *LM3S2965 Evaluation Board User's Manual*. Note that the LM3S2110 CAN Device board is not included in the Reference Design Kit.

Figure 3-1. BDC CAN Console



The application provides a simple user interface for the brushed DC motor controller board, running on the EK-LM3S2965 board and communicating over CAN. In addition to running the motor, the motor status can be viewed, the CAN network enumerated, and the motor controller's firmware can be updated.

Using the Console

The CD included in the RDK-BDC contains a Quickstart guide that covers basic operation of the MDL-BDC and console. See this document for step-by-step instructions for connecting and using the RDK-BDC.

Cables

Table 3-1 shows several cables that are used in conjunction with the BDC CAN console and that are included in the RDK.

Table 3-1. RDK-BDC Available Cables

Cable Name	Use
CAN cable	Connects the console to the MDL-BDC
CAN terminator	Plug-in 120 Ω terminator
USB cable	Provides power and communication to BDC CAN console
ADA2 JTAG adapter	Adapts 10-pin JTAG/SWD header to 20-pin[a]
JTAG ribbon cable	20-position cable for using the BDC console as a debug interface[a]

a. These cables are only required for software debugging.

When controlling more than one MDL-BDC, modular cables (6P-4C or 6P-6C) should be used to link the modules.

Suitable cables include the Digikey H2642R-07-ND cable.

Set Up

Power for the console comes from a USB cable. The CAN cable, also included in the RDK, has a RJ-11 6P-4C connector at one end and a 10-pin socket at the other end.

Connect cables as follows:

1. Connect the CAN cable between the console CAN connector (P1) and either NET connector on the MDL-BDC.
2. Use RJ11/RJ14 modular cables to daisy-chain CAN communications to any other MDL-BDC devices. The cables should be 6-position with either 4 or 6 contacts installed. Suitable cables have plugs crimped on opposite sides of the cable and are referred to as reverse or straight cables, because pin 1 connects to pin 1.
3. The last MDL-BDC in the chain should have a CAN terminator inserted in its NET connector. The BDC CAN console has an integrated termination resistor, so it must be used as an end-point.
4. Connect the USB cable between the BDC CAN console and the USB port of a PC. The console application software will then start (see Figure 3-1 on page 23).
5. If USB drivers were not previously installed, then follow the procedure in the Quickstart guide before proceeding. USB drivers are necessary for using the console board as a firmware update and/or debugging tool.

Operation

The direction buttons (left, right, up, and down) on the left side of the BDC CAN console are used to navigate through the user interface. The select button on the right side of the console is used to select items.

The user interface is divided into several panels; the top line of the display always contains the name of the current panel. By moving the cursor to the top line and pressing select, a menu appears which allows a different panel to be displayed by pressing select again.

The BDC CAN console provides five operating modes:

- “Voltage Control Mode” on page 25
- “Current Control Mode” on page 26
- “Speed Control Mode” on page 26
- “Position Control Mode” on page 27
- “Configuration” on page 27

The mode panels in the user interface are discussed individually in more detail below. At startup, the Voltage Control mode panel is displayed first.

Voltage Control Mode

The Voltage Control mode panel allows the motor to be controlled by directly selecting the output voltage. The speed of the motor is directly proportional to the voltage applied, and applying a “negative” voltage (in other words, electronically reversing the power and ground connections) will result in the motor spinning in the opposite direction.

There are three parameters that can be adjusted on this panel; the ID, voltage, and ramp rate. The up and down buttons are used to select the parameter to be modified, and the left and right buttons are used to adjust the parameter's value. The following parameters can be adjusted:

- ID, which selects the motor controller to which commands are sent. If the ID is changed while the motor is running, the motor will be stopped.
- Voltage, which specifies the output voltage sent from the motor controller to the motor. A positive voltage will result in voltage being applied to the white output terminal and ground being applied to the green output terminal, while a negative voltage will apply voltage to the green output terminal and ground to the white output terminal.

  If the select button is pressed, changes to the output voltage will not be sent to the motor controller immediately (allowing the ramp to be used). The text color of the voltage changes from white to black to indicate that a deferred update is active. Pressing select again will send the final output voltage to the motor controller, creating a step function.
- Ramp, which specifies the rate of change of the output voltage. When set to “none”, the output voltage will change immediately. When set to a value, the output voltage is slowly changed from the current to the target value at the specified rate. This can be used to avoid browning out the power supply or to avoid over-torquing the motor on startup (for example preventing a loss of traction when a wheel is being driven).

The bottom portion of the panel provides the current motor controller status. Four fault conditions are indicated:

- Over-Current fault (C)
- Over-Temperature fault (T)

- Under-Voltage fault (V)
- Limit Switch status, Forward and Reverse

Current Control Mode

The Current Control mode panel allows the motor to be controlled by directly selecting the output current. The torque of the motor is directly proportional to the winding current, and applying a “negative” current (in other words, electronically reversing the power and ground connections) results in the motor spinning in the opposite direction.

There are five parameters that can be adjusted on this panel; the ID, current, and three control loop parameters (P, I, and D). The up and down buttons are used to select the parameter to be modified, and the left and right buttons are used to adjust the parameter's value. The following parameters can be adjusted:

- ID, which selects the motor controller to which commands are sent. If the ID is changed while the motor is running, the motor will be stopped.
- Current, which specifies the target winding current value. The output voltage of the motor controller is adjusted automatically via an internal PID control loop until the motor draws the target current value. A positive current value results in voltage being applied to the white output terminal and ground being applied to the green output terminal, while a negative current value applies voltage to the green output terminal and ground to the white output terminal.

  If the select button is pressed, changes to the current value will not be sent to the motor controller immediately and allows the operator to change the current value in one step. The text color of the current value changes from white to black to indicate that a deferred update is active. Pressing the select button again sends the final current value to the motor controller, creating a step function.
- P, the proportional value of the PID control loop.
- I, the integral value of the PID control loop.
- D, the differential value of the PID control loop.

The bottom portion of the panel provides the current motor controller and limit switch status, and have the same function as the Voltage Control Mode panel.

Speed Control Mode

The Speed Control mode panel allows the motor to be controlled by directly selecting the output shaft speed. The speed of the motor is controlled by an internal PID loop that measures the shaft speed using an attached encoder, and adjusts the voltage applied to the motor terminals. Applying a “negative” speed results in the motor spinning in the opposite direction.

There are five parameters that can be adjusted on this panel; the ID, speed, and three control loop parameters (P, I, and D). The up and down buttons are used to select the parameter to be modified, and the left and right buttons are used to adjust the parameter's value. The following parameters can be adjusted:

- ID, which selects the motor controller to which commands are sent. If the ID is changed while the motor is running, the motor will be stopped.
- Speed, which specifies the motor shaft's target angular speed value. The output voltage of the motor controller is adjusted automatically via an internal PID control loop until the motor spins at the target speed value. A positive speed value results in voltage being applied to the white output terminal and ground being applied to the green output terminal, while a negative speed value applies voltage to the green output terminal and ground to the white output terminal.

If the select button is pressed, changes to the speed value will not be sent to the motor controller immediately and allows the operator to change the speed value in one step. The text color of the speed value changes from white to black to indicate that a deferred update is active. Pressing the select button again sends the final output speed value to the motor controller, creating a step function.

- P, the proportional value of the PID control loop.
- I, the integral value of the PID control loop.
- D, the differential value of the PID control loop.

The bottom portion of the panel provides the current motor controller and limit switch status, and have the same function as the Voltage Control Mode panel.

Position Control Mode

The Position Control mode panel allows the motor to be controlled by directly selecting the output shaft angular position. The angular position of the motor is controlled by an internal PID control loop that measures the angular position using an attached potentiometer or encoder, and adjusts the voltage applied to the motor terminals. Applying a position value less than the current value results in the motor spinning in the opposite direction.

There are six parameters that can be adjusted on this panel; the ID, position, three control loop parameters (P, I, and D), and the reference (a potentiometer or encoder). The up and down buttons are used to select the parameter to be modified, and the left and right buttons are used to adjust the parameter's value. The following parameters can be adjusted:

- ID, which selects the motor controller to which commands are sent. If the ID is changed while the motor is running, the motor will be stopped.
- Position, which specifies the motor shaft's target angular position value. The output voltage of the motor controller is adjusted automatically via an internal PID control loop as measured by the reference until the motor shaft achieves the target position value.

  If the select button is pressed, changes to the position value will not be sent to the motor controller immediately and allows the operator to change the position in one step. The text color of the position value changes from white to black to indicate that a deferred update is active. Pressing select again sends the final position value to the motor controller, creating a step function.
- P, the proportional value of the PID control loop.
- I, the integral value of the PID control loop.
- D, the differential value of the PID control loop.
- Ref, specifies whether a potentiometer or an encoder is used as positional feedback. The characteristics of the potentiometer or encoder are specified on the Configuration panel.

The bottom portion of the panel provides the current motor controller and limit switch status, and have the same function as the Voltage Control Mode panel.

Configuration

The Configuration panel provides the ability for the operator to specify characteristics of the attached devices in addition to specifying some operational limits.

There are six parameters that can be adjusted on this panel: the ID, encoder lines, potentiometer turns, brake/coast override, soft limit switch characteristics, and the maximum output voltage.

- ID, selects the motor controller to which the parameters are applied.

- Encoder lines, specifies the number of encoder pulses received over one complete revolution of the encoder. The encoder lines are used for Speed and Position control modes.
- Pot turns, specifies the number of turns of the potentiometer to travel the full range. The number of potentiometer turns is used for Position control modes.
- Brake/coast, specifies whether the neutral action of the motor controller is defined by the jumper setting or is overridden by the console to brake or coast.
- Soft limit, allows the definition of a software defined positional limit, without the use of physical limit switches. If enabled, the forward and reverse limit positions and conditions may be specified.
- Max Vout, defines the maximum voltage allowed to be generated during operation. This value is used during the Current, Speed, and Position Control modes.

Device List

This panel lists the motor controllers that reside on the CAN network. All 63 possible device IDs are listed, with those that are not present shown in dark gray and those that are present in bright white. By moving the cursor to a particular ID and pressing the select button, a device ID assignment will be performed. The motor controller(s) will wait for five seconds after an assignment request for its button to be pressed, indicating that it should accept the device ID assignment. So, for example, if there are three motor controllers on a network, the following sequence can be used to give them each unique IDs:

1. Move the cursor to number 1 and press select. The LED on all three motor controllers will blink green to indicate that assignment mode is active.
2. Press the button on one of the motor controllers. It will blink its LED yellow one time to indicate that its ID is one.
3. Move the cursor to number 2 and press select.
4. Press the button on the second motor controller. It will blink its LED yellow two times to indicate that its ID is two.
5. Move the cursor to number 3 and press select.
6. Press the button on the third motor controller. It will blink its LED yellow three times to indicate that its ID is three.

Once complete, this panel will then show that there are devices at IDs 1, 2, and 3.

Firmware Update

This panel allows the firmware on the MDL-BDC to be updated over the CAN network. A firmware image for the motor controller is first stored in the flash of the console board and then used to update the motor controller. See the “Firmware Updates and Debugging” on page 29 of this document for full details on this process.

Help

This panel displays a condensed version of this application help text. Use the up and down buttons to scroll through the text.

About

This panel simply displays the startup splash screen.

C H A P T E R 4

Firmware Updates and Debugging

The MDL-BDC supports two methods for updating the firmware resident in the LM3S2616 microcontroller. The primary method uses the CAN interface and a Flash-resident boot loader for firmware transfer. During firmware development direct access and debug capability is preferable. The MDL-BDC included in the RDK has a JTAG/SWD connector installed for this purpose.

General Information

StellarisWare firmware revisions are referenced using four-digit numbers that increase with new releases, but are not necessarily contiguous (that is, numbers may be skipped).

The flash memory region between 0x0000 and 0x07FF contains a CAN boot loader. The main firmware image should be loaded at 0x0800.

Firmware Update Using CAN

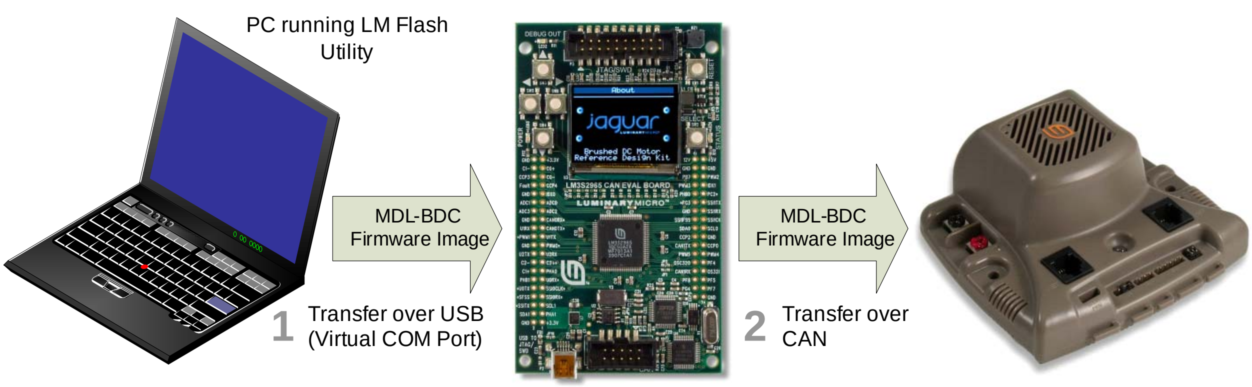
The MDL-BDC firmware can be updated over CAN using the BDC CAN console board included in the reference design kit. The capability to update the MDL-BDC firmware may also be added to any CAN Host controllers by implementing the necessary CAN protocol.

The BDC CAN console comes with a firmware image already loaded and ready for transfer to the MDL-BDC. Of course updating the firmware is a redundant process unless the firmware in the console is newer than the firmware in the module.

How to Load Firmware from a PC to the BDC CAN Console

The MDL-BDC firmware is stored in the top of flash memory in the CAN console. This image can be replaced with new software using the resident serial flash loader and the LM Flash software.

Figure 4-1. Diagram showing the two-step firmware update process



The console stores the MDL-BDC firmware image length at 0x20000 and the actual image starting at 0x20004.

Step One: Install USB Drivers for the Console

The USB driver installation is covered in the *RDK-BDC Quickstart Guide*. See that document for full details. Once the USB drivers are installed, the console appears as a Virtual Com port on your PC.

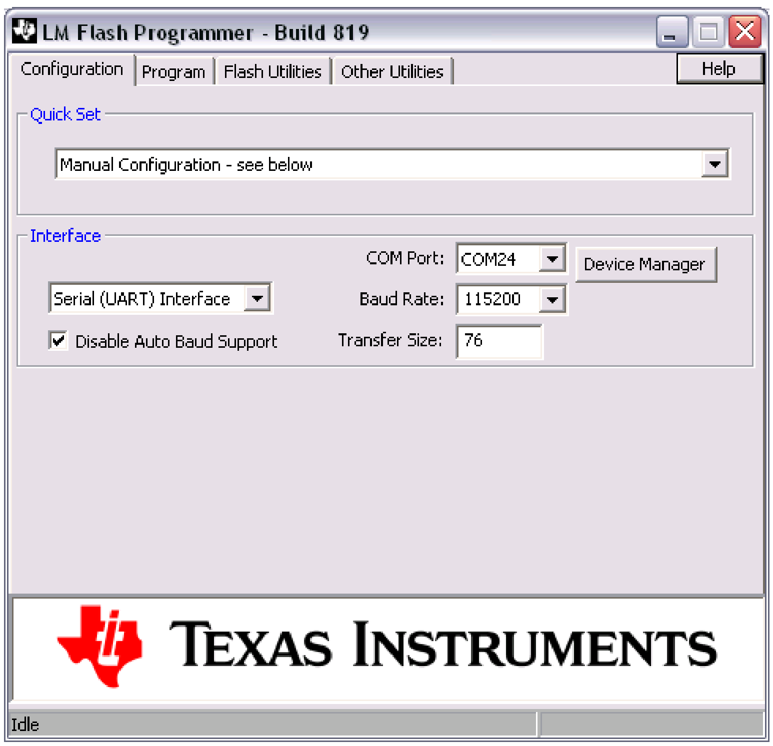
Step Two: Install LM Flash Programmer

LM Flash Programmer is a Windows GUI (or command line) application for programming Stellaris microcontrollers using a variety of interfaces. Install and run the LM Flash Programmer on a Windows PC.

Step Three: Configure LM Flash Programmer for Serial Transfer

Select the Configuration tab and from the Quick Set drop-down, select “Manual Configuration” (see Figure 4-2). Then select “Serial (UART) Interface” in the Interface drop-down menu. Next, select the COM Port assigned by Windows to the console board. This can be identified using the Windows Device Manager. Finally, verify that the baud rate is 115200 and then click the checkbox to Disable Auto Baud Support.

Figure 4-2. LM Flash Programmer Configuration

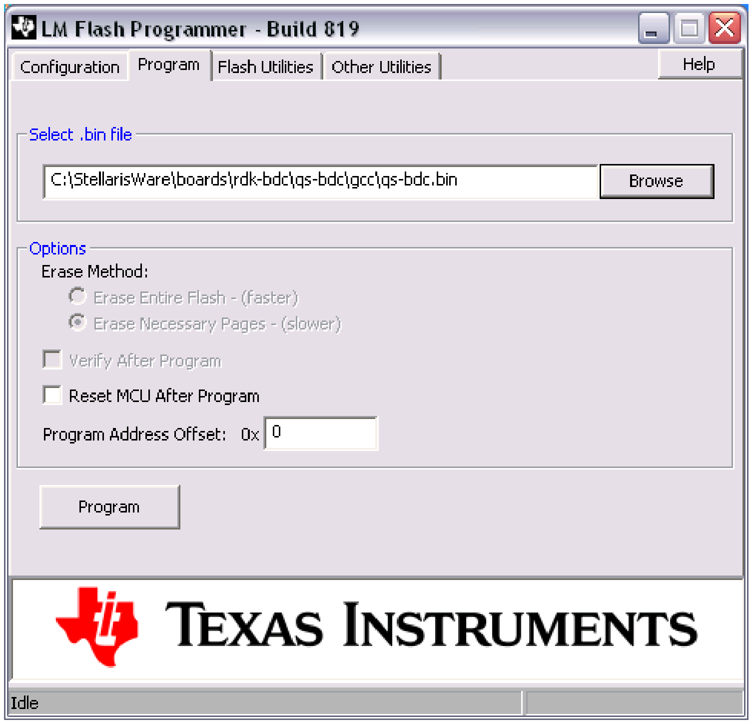


Step Four: Program the Console with the MDL-BDC firmware

Select the Program tab (see Figure 4-3). Then Browse to select the new binary file to download. The Program Address Offset is ignored by the console. Click on the Program button to start the transfer.

The BDC CAN console automatically jumps to the Firmware Update panel when the transfer is initiated. Progress bars appear on the console display and the LM Flash Programmer window.

Figure 4-3. Transfer in Progress



When programming completes, the MDL-BDC firmware is resident in the console's Flash memory. If an MDL-BDC with the currently selected CAN ID is connected, the console immediately starts a firmware update over CAN. The update over CAN may also be initiated manually. This procedure is covered in more detail in the following section called, "Firmware Update Using BDC CAN Console."

Firmware Update Using BDC CAN Console

The following steps show how to transfer the firmware image from the console into the MDL-BDC. During this operation, the USB cable is required only as a power source to the console.

Step One: Establish CAN connection

Connect the console to the MDL-BDC using the CAN cable. Follow the "Set Up" on page 24 for step-by-step instructions. Move to Step 2 once the console screen shows a valid CAN connection to the MDL-BDC.

Step Two: Navigation to the Firmware Update Panel

Press the Up navigation switch to highlight the panel Title bar. The default mode is Voltage Control Mode. Press the select switch to bring up the list of panels. Navigate to the Firmware Update title and press select again to move to that panel.

This panel allows the firmware on the MDL-BDC to be updated over the CAN network. A firmware image for the motor controller is first stored in the flash of the console board and then used to update the motor controller.

The ID of the motor controller to be updated can be selected on this panel. By using the console-resident firmware image, multiple motor controllers can be updated (one at a time) using this panel, without the need to download from a PC each time.

When not updating, the firmware version of the currently selected motor controller is displayed. If there is no motor controller on the CAN network with the current ID, the firmware version displays as “-”.

By pressing the “Select” button when the “Start” button is highlighted, the motor controller firmware update starts.

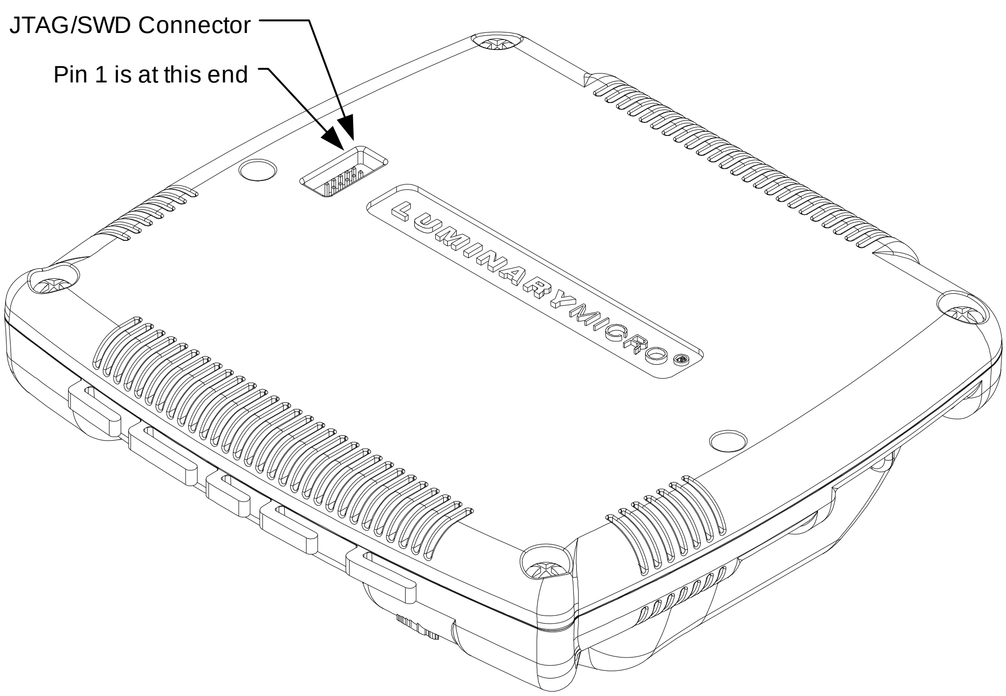
When the firmware is being transferred (either from the PC using the UART or to the motor controller using the CAN network), the ID, firmware version, and “Start” buttons will all be grayed out. A progress bar will appear below those buttons to indicate what is happening and the how far it is through the process.

The MDL-BDC automatically restarts when the firmware update is complete.

Firmware JTAG/SWD

The MDL-BDC included in the RDK-BDC has a 2x10 header installed for firmware programming and debugging using JTAG/SWD. JTAG is a four-wire interface. SWD is a high-performance two-wire interface with similar capabilities.

Figure 4-4. Locating the JTAG/SWD Connector

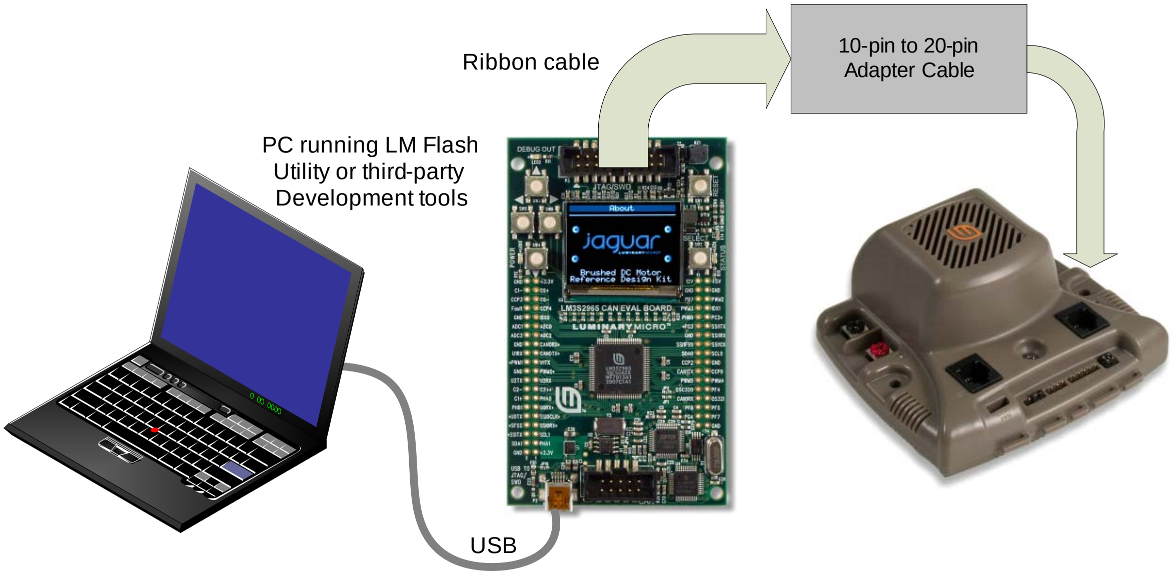


When using the JTAG/SWD cable, pay special attention to the location of pin 1 on the connector. When inserted correctly, the cable will run back across the bottom of the case. See the Chapter 5, “Hardware Description,” for additional information on the JTAG/SWD connector.

The BDC CAN console board is based on the Stellaris EK-LM3S2965 Evaluation board.

The console board can be used as a low cost In-circuit Debug Interface (ICDI) for both programming and debugging. The ICDI circuit is compatible with the LM Flash Programmer as well as leading development tools for ARM Cortex-M3. Evaluation versions for several tools are available from www.ti.com/stellaris.

Figure 4-5. Firmware debugging using JTAG/SWD



C H A P T E R 5

Hardware Description

The MDL-BDC motor control module uses a highly integrated Stellaris LM3S2616 microcontroller to handle PWM synthesis, analog sensing, and the CAN interface. Only a few additional ICs are necessary to complete the design. The entire circuit is built on a simple two-layer printed circuit board. All design files are provided on the RDK CD.

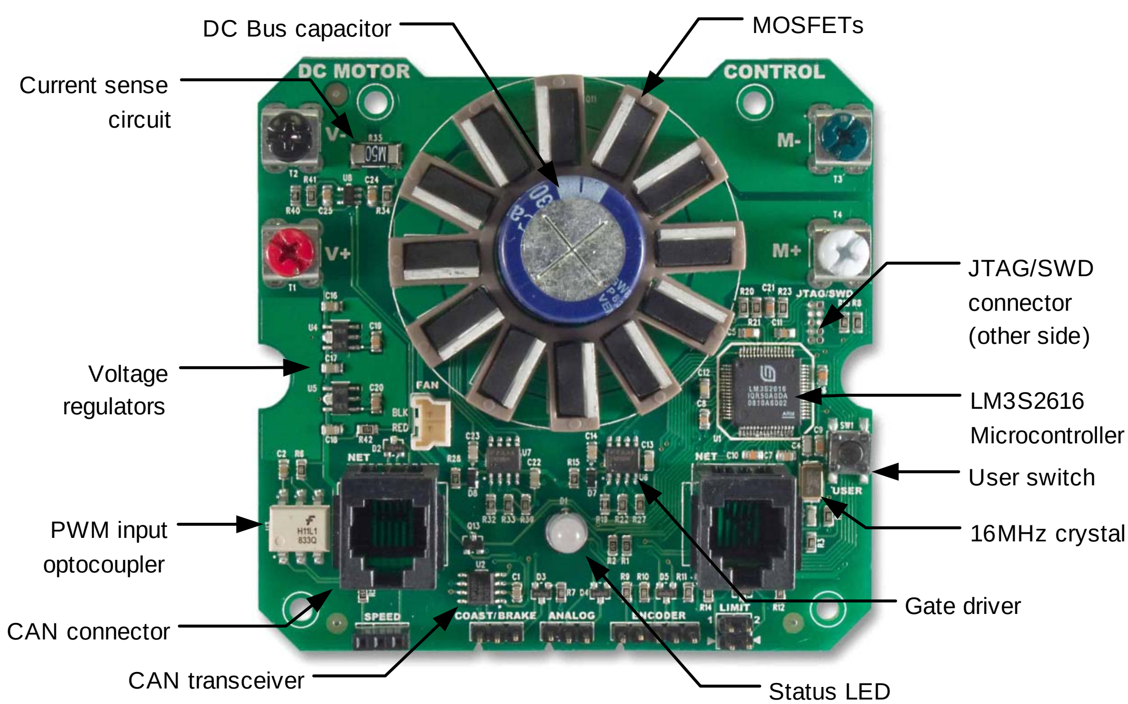
System Description

A unique aspect of the MDL-BDC design is the integrated CAN interface and low-cost, fan-cooled MOSFET array that handles high current in a small form-factor. The motor control consists of an H-bridge arrangement which is driven by fixed-frequency PWM signals.

Key Hardware Components

Figure 5-1 shows the MDL-BDC circuit board with the enclosure and cooling fan removed.

Figure 5-1. MDL-BDC Circuit Board



Schematic Description

Microcontroller, CAN, and I/O Interfaces (Page 1)

Page 1 of the schematics details the microcontroller, CAN interface, and sensor interfaces.

Microcontroller

At the core of the MDL-BDC is a Stellaris LM3S2616 microcontroller. The LM3S2616 contains a peripheral set that is optimized for networked control of motors, including 6 high-speed ADC channels, a motor control PWM block, a quadrature encoder input, as well as a CAN module.

The microcontroller's PWM module can generate two complementary PWM signal pairs that are fed to the power stage.

The LM3S2616 has an internal LDO voltage regulator that supplies 2.5 V power for internal use.

This rail requires only three capacitors for decoupling and is not connected to any other circuits.

Clocking for the LM3S2616 is facilitated by a 16 MHz crystal. Although the LM3S2616 can operate at up to 50 MHz, in order to minimize power consumption, the PLL is not enabled in this design. The 32-bit Cortex-M3 core has ample processing power to support all features including 1 Mbits/s CAN with a clock speed of 16 MHz.

Debugging

The microcontroller supports JTAG and SWD debugging as well as SWO trace capabilities. To minimize board area, the MDL-BDC uses a 0.050" pitch header footprint which matches ARM's fine-pitch definition (Figure 5-2). The connections are located on the bottom of the module, under the serial number label. The module included in the reference design kit has a header installed; however, the standard MDL-BDC (available as a separate item) does not have the header installed.

Some in-circuit debuggers provide a matching connector. Other ARM debuggers can be used with the adapter board included in the RDK.

Figure 5-2. MDL-BDC JTAG/SWD Connector

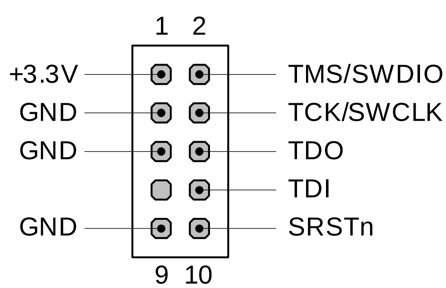
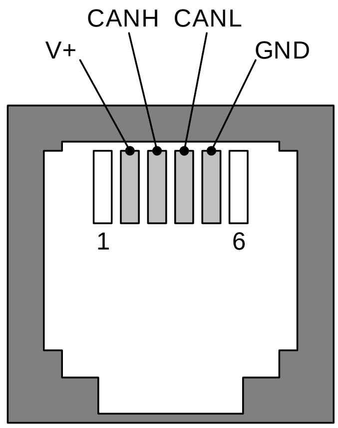


Figure 5-2 shows the pin assignments for the JTAG/SWD connector as viewed from the bottom (connector) side of the circuit board.

CAN Communication

A key feature of the LM3S2616 microcontroller is its CAN module that enables highly reliable communications at up to 1 Mbits/s. The MDL-BDC control board adds a standard CAN transceiver (U2), additional ESD protection (D2), and connectors. The pin assignments for the RJ11/RJ14 6P-4C connectors are defined in CAN in Automation (CiA DS102). Figure 5-3 shows the network connector pin assignments.

Figure 5-3. Network Connector Pin Assignments



CAN Socket Viewed from Top
(Tab down)

The V+ signal (Pin 2) is not used in the MDL-BDC, however, it is passed through to support other devices that either provide or use power from this terminal. The typical application for V+ is in providing a small amount of power to optocouplers for isolating CAN signals.

Other Interfaces

Several other interfaces are provided on 0.1" pin headers. The connections to the microcontroller are ESD-protected and in most cases have 10 kΩ pull-up resistors.

The analog input has a 0 to 3V span. In order to use a 10 kΩ potentiometer, a 1 kΩ “padding” resistor is provided on J4.1 to drop 300 mV from the 3.3 V rail when the potentiometer is connected.

Output Stage and Power Supplies (Page 2)

Page 2 of the schematics details the power supplies, gate drivers, output transistors, sensing, and fan control circuits.

Motor Output Stage

The motor output stage consists of an H-bridge with High-/Low-side gate drivers. Each leg of the H-bridge has three paralleled MOSFETs. The MOSFETs are connected in parallel to reduce Rds (on) to about 1.8 mΩ and to provide additional surface area for fan cooling. The fan blows directly on the TO-220 MOSFETs, which are arranged radially around the DC bus capacitor. A plastic ring encompasses the MOSFETs which provide mechanical support and ensures that the tabs do not touch.

The gate drivers provide up to 2 Amps of peak current to rapidly switch the gates of the MOSFETs when directed by the microcontroller's PWM module. The gate drivers are designed for high-voltage operation, but work equally well in this 12 V application. In a variation from their typical use, the PWM signal is applied to the Enable (ODn) input to modulate either the high or low side MOSFETs. A general-purpose output signal from the microcontroller controls the gate driver's PWM input which selects whether it is the high- or low-side that is being controlled by the microcontroller's PWM signal. In this configuration, dead-time, the delay between switching states on one half of an H-bridge, is only an issue when changing from forward direction to reverse direction.

Because the high-side MOSFETs are N-Channel types, a positive Vgs is required to switch them on. The gate drivers use a simple boot-strapping technique to ensure that the high-side Vgs remains above the Vgs (on) threshold. Whenever the low-side MOSFETs are on, the associated boot-strap capacitor (C24 or C23) charges to ~12 V through the resistor-diode network. Later, when the high-side MOSFETs turn on, the boot-strap capacitor maintains power to the high-side driver with respect to the Motor terminal.

One issue with the boot-strap capacitor method is that the capacitor voltage will decay to an unacceptable level unless a low-side MOSFET is periodically switched on. This state only occurs when the motor is running full-forward or full-reverse. The MDL-BDC software intermittently switches to the low-side MOSFETs for a short duration to replenish the bootstrap capacitor. The short duration has no impact on motor speed.

Power Supply

Two cascaded voltage regulators create 5 V and 3.3 V power supply rails from the 12 V input.

5 V is used only for the CAN transceiver and quadrature encoder functions. The cascaded arrangement also provides a way to spread the thermal dissipation of the linear regulators, with the 5 V taking most of the burden.

3.3 V is used by the MCU and peripheral circuitry.

Current Sensing

The current sensing circuit consists of a low-side shunt resistor (R35) and a non-inverting voltage amplifier. Due to the high current in the bridge, the shunt resistor is just 500 μΩ. Op-amp U8 amplifies the signal across R35 by a factor of 40. Because the sense resistor is in the low-side of the H-bridge, the current through it is only positive when the low-side MOSFETs are on. The software takes this into consideration when sampling the current waveform.

Resistor R43 biases the op-amp input by +10 mV to allow for negative input offset voltage. The software automatically zeroes out this small offset before the motor is started.

R42 and C25 form a low-pass filter to isolate the op-amp's power supply from the other devices on the +3.3 V power supply rail.

Voltage Sensing

A simple divider resistor network (R20/21 and R23) scales the 12 V rail down to the range of the ADC (0-3 V). Two additional dividers allow the bootstrap supplies to be monitored in software. This is an optional feature.

Fan Control

The cooling fan is self-contained and uses a small brushless DC motor. The MDL-BDC supports On/Off software control of the fan using Q13. The fan operates when the motor is running or when the temperature exceeds a certain threshold. The LM3S2616 microcontroller has an internal temperature sensor. A simple software table correlates the microcontroller temperature to overall system temperature.

C H A P T E R 6

Troubleshooting

Although the MDL-BDC is simple to use, simple errors in wiring, software ,or use can affect normal operation. This chapter provides guidance on resolving common problems.

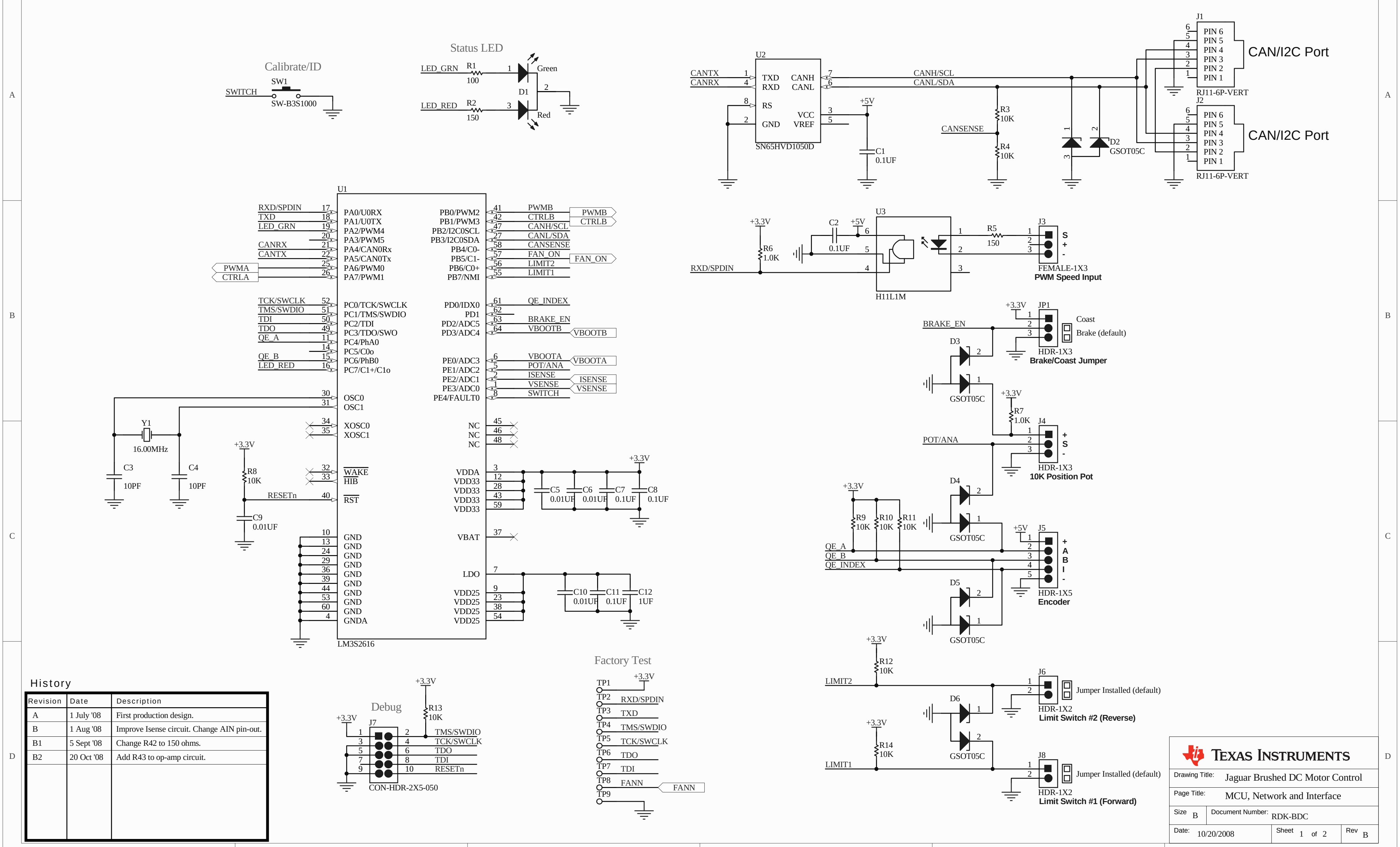
Table 6-1. Common Problems

Symptom	Diagnosis	Resolution
No LED activity (LED always off)	Power source is out of specification.	Use a volt meter to confirm that 12 V is present between the Red/Black terminals and the polarity is correct.
	Incorrect firmware (possibly containing bugs, or intended for another target).	Load new firmware into the console and re-program the MDL-BDC. It is possible in this case that the module can not be updated via the CAN interface and, therefore, must be updated using JTAG/SWD.
	No firmware loaded. Only the boot loader is resident in memory.	Load firmware into the console and re-program the MDL-BDC.
LED indicates under-voltage fault when running	The power supply is unable to maintain voltage under load.	Recharge battery or change to a power supply with a higher ampere rating.
The LED blinks erratically when motor is running	The power supply is unable to maintain voltage under load and is dropping below 6V which is resetting the MDL-BDC electronics.	Recharge battery or change to a power supply with a higher ampere rating.
Motor fails to run	Limit switches are open.	Install jumper shunts to hold limit switch inputs closed.
Motor operates in one direction only	Limit switch is open.	Check limit switch operation or insert the appropriate jumper shunt.

APPENDIX A

Schematics

This section contains the schematic diagrams for the RDK-BDC.



History

Revision	Date	Description
A	1 July '08	First production design.
B	1 Aug '08	Improve Isense circuit. Change AIN pin-out.
B1	5 Sept '08	Change R42 to 150 ohms.
B2	20 Oct '08	Add R43 to op-amp circuit.

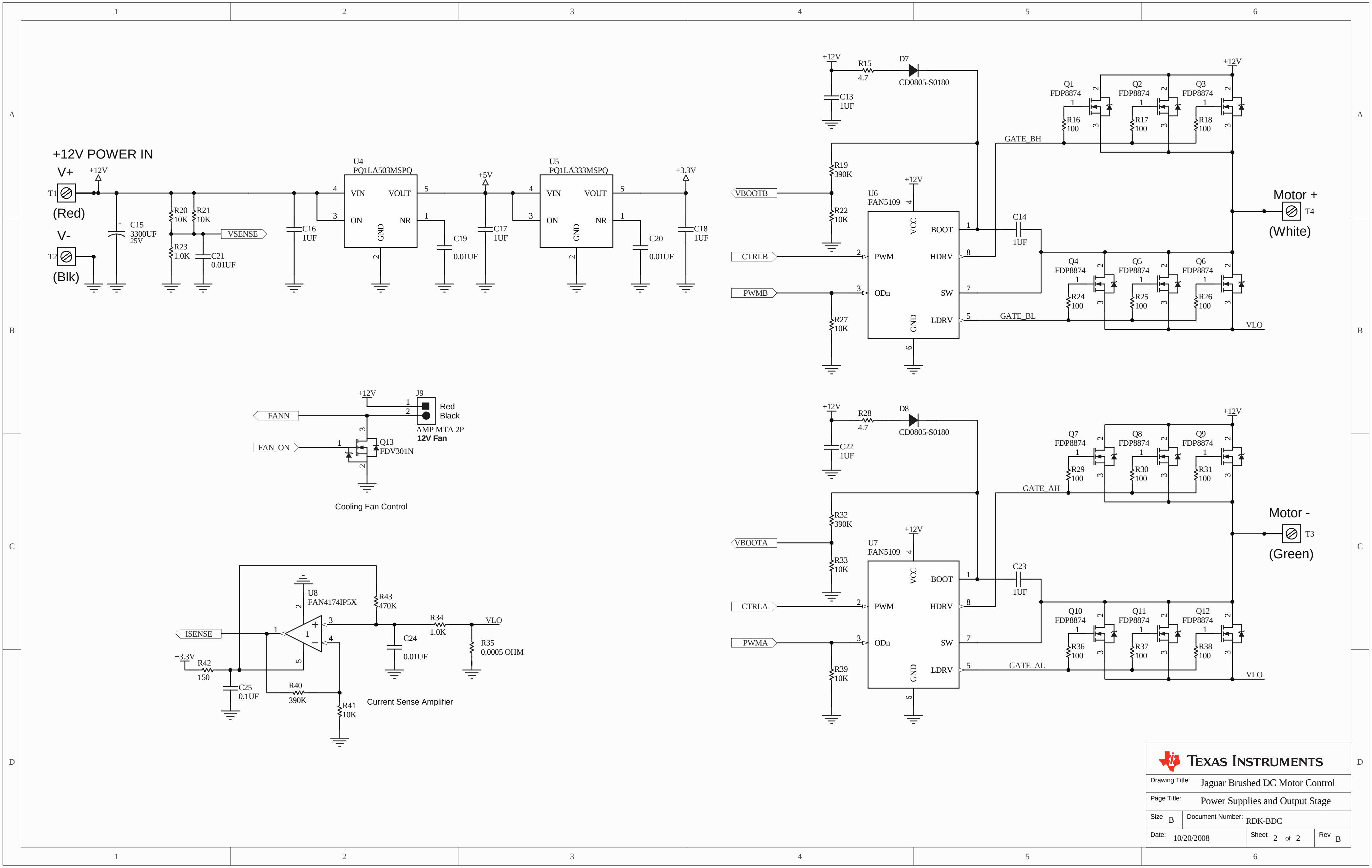
TEXAS INSTRUMENTS

Drawing Title: Jaguar Brushed DC Motor Control

Page Title: MCU, Network and Interface

Size: B | Document Number: RDK-BDC

Date: 10/20/2008 | Sheet 1 of 2 | Rev B



TEXAS INSTRUMENTS

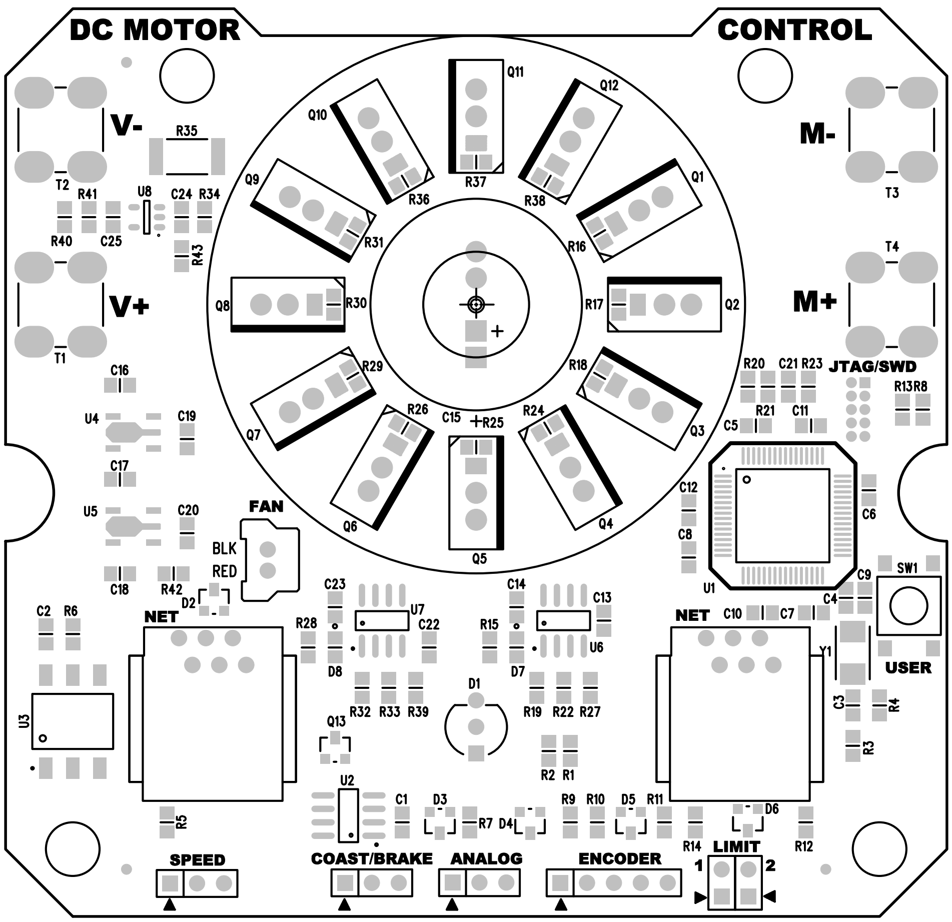
Drawing Title:	Jaguar Brushed DC Motor Control
Page Title:	Power Supplies and Output Stage
Size: B	Document Number: RDK-BDC
Date: 10/20/2008	Sheet 2 of 2 — Rev B

Board Drawing

This appendix contains details on component locations, including:

- Component placement plot for top (Figure B-1)

Figure B-1. Component Placement Plot



APPENDIX C

Bill of Materials (BOM)

Table C-1 provides the BOM for the RDK-BDC.

Table C-1. RDK-BDC Bill of Materials

Item	Ref	Qty	Part Number	Description	Mfg	Supplier	Stock No
1	C1, C2, C7, C8, C11, C25	6	C0805C104M5RACTU	Capacitor, 0.1uF 50V 20% 0805 X7R	Kemet	Mouser	80-C0805C104M5R
2	C12, C13, C14, C16, C17, C18, C22, C23	8	TMK212BJ105KG-T	Capacitor 1.0uF 25V X5R 0805	Taiyo Yuden	Digikey	587-1291-1-ND
3	C15	1	ESMG250ELL332MN20S	Capacitor, 3300uF 25V Electro 20x20mm	UCC	Digikey	565-1066-ND
4	C3, C4	2	C0805C100J5GACTU	Capacitor 10pF 50V 5% Ceramic NPO/ COG 0805	Kemet	Mouser	80-C0805C100J5G
5	C5, C6, C9, C10, C19, C20, C21, C24	8	C0805C103J5RACTU	Capacitor, 0.01uF 50V 5% 0805 X7R	Kemet	Mouser	80-C0805C103J5R
6	D1	1	WP59SRSGW/CC WP59EGW	LED, Bi-Color Red/ Grn 5mm Com Cathode	Kingbright	Digikey Mouser	754-1235-ND
7	D2, D3, D4, D5, D6	5	GSOT05C / SM05T1GOS	Diode, Dual ESD Protection Device SOT-23	Vishay	Digikey	751-1415-2-ND 754-1232-ND
8	D7, D8	2	CD1005-S0180	Diode, 80V high speed 1005 size	Bourns	Mouser	652-CD1005-S0180
9	J1, J2	2	90512-003LF 04911	Connector, RJ11 Mod-Jack 6-4 Vert Flange Blk	FCI 4ucon	Digikey 4ucon	609-1064-ND 04911
10	J3	1	PPTC031LFBN-RC 00526	Connector, Female 1x3 socket 0.1" 8.5mm gold flash	Sullins 4ucon	Digikey 4ucon	S7001-ND 00526
11	J4, JP1	2	00798	Header 1x3 0.1" 6mm contact 3mm tail gold	4ucon	4ucon	00798

Table C-1. RDK-BDC Bill of Materials (Continued)

Item	Ref	Qty	Part Number	Description	Mfg	Supplier	Stock No
12	J5	1	00806	Header 1x5 0.1" 6mm contact 3mm tail gold	4ucon	4ucon	00806
13	J6/8	1	15948	Header 2x2 0.1" 6mm contact 3mm tail gold	4ucon	4ucon	988
14	J7	0	M50-3500542	Connector, 2x5 Header 1.27mm pitch (OMIT)	Harwin	Mouser	855-M50-3500542
15	J9	1	35362-0210	Connector, 2 Pin Sherlock 2mm vert header	Molex	Arrow	35362-0250
16	JP1b, J6b, J8b	3	151-8000 05734	Jumper Shunt 0.1"gold	Kobiconn 4ucon	Mouser 4ucon	151-8000 05734
17	Q1, Q2, Q3, Q4, Q5, Q6, Q7, Q8, Q9, Q10, Q11, Q12	12	FDP8874	Mosfet N-Channel V 30V 114A TO-220	Fairchild	Arrow	FDP8874
18	Q13	1	FDV301N	Mosfet N Channel SOT-23	Fairchild	Arrow	FDV301NTR-ND
19	R1, R16, R17, R18, R24, R25, R26, R29, R30, R31, R36, R37, R38	13		Resistor, 100 ohms 5% 0805	Panasonic	Digikey	P100ATR-ND
20	R15, R28	2		Resistor, 4.7 Ohms 5% 0603	Panasonic	Digikey	P4.7ATR-ND
21	R2, R5, R42	3		Resistor, 150 ohms 5% 0805	Panasonic	Digikey	P150ATR-ND
22	R6, R7, R23, R34	4		Resistor 1.0K 1% 0805	Panasonic	Digikey	P1.00KCTR-ND

Table C-1. RDK-BDC Bill of Materials (Continued)

Item	Ref	Qty	Part Number	Description	Mfg	Supplier	Stock No
23	R3, R4, R8, R9, R10, R11, R12, R13, R14, R20, R21, R22, R27, R33, R39, R41	16		Resistor, 10.0K 1% 0805	Panasonic	Digikey	P10.0KCTR-ND
24	R35	1		Resistor 0.0005 Ohms 2W 1% 2512	Stackpole	Digikey	CSNL20.00051%RTR-ND
25	R19, R32, R40	3		Resistor 390K 1% 0805	Vishay	Digikey	541-390KCRTR-ND
26	R43	1		Resistor 470K 1% 0805	Panasonic	Digikey	P470KCTR-ND
27	SW1	1	B3S-1000P	Switch, Momentary Tact 160gmf 6mm	Omron	Arrow / Future	SW415-ND
28	T1	1	7701-2	Terminal, Screw Vertical 15A Red Screw	Keystone	Bisco	7701-2
29	T2	1	7701-3	Terminal, Screw Vertical 15A Black Screw	Keystone	Bisco	7701-3
30	T4	1	7701-4	Terminal, Screw Vertical 15A White Screw	Keystone	Bisco	7701-4
31	T3	1	7701-6	Terminal, Screw Vertical 15A Green Screw	Keystone	Bisco	7701-6
32	U1	1	LM3S2616	IC, Microcontroller Stellaris Cortex-M3 64-TQFP	TI	TI	LM3S2616
33	U2	1	SN65HVD1050D	IC, CAN Transceiver SO-8	TI	Arrow / Digikey	296-19416-5-ND
34	U3	1	H11L1SR2VM H11L1SR2M	IC, Optocoupler Schmitt Trigger SMD-8	Fairchild	Arrow	H11L1SR2VM H11L1SR2M
35	U4	1	PQ1LA503MSPQ	IC, Voltage regulator 5.0V 500mA SOT89-5	Sharp	Mouser	852-PQ1LA503MSPQ

Table C-1. RDK-BDC Bill of Materials (Continued)

Item	Ref	Qty	Part Number	Description	Mfg	Supplier	Stock No
36	U5	1	PQ1LA333MSPQ	IC, Voltage regulator 3.3V 500mA SOT89-5	Sharp	Mouser	852-PQ1LA333MSPQ
37	U6, U7	2	FAN5109BMX	IC, Half-Bridge Gate Driver SO-8	Fairchild	Arrow	FAN5109BMX
38	U8	1	FAN4174IS5X_NL	IC, Op-amp Rail-to-Rail SOT-23	Fairchild	Arrow	FAN4174IS5X
39	Y1	1	NX5032GA-16.000000MHZ	Crystal, 16.00MHz 5.0x3.2mm SMT	NDK	Digikey	644-1037-2-ND
40	Z	1	8902	LED standoff, plastic 0.16" for LED D1	Keystone	Mouser	534-8902
41	Z	1	BD-BDC-B2	PCB, FR-406 2-layer 3.375"x3.500" 2-oz finished	Advanced	Advanced	BD-BDC-B2
		116					

Final Assembly							
Item	**Ref**	**Qty**	**Part Number**	**Description**	**Mfg**	**Supplier**	**Stock No**
F1		1	412-FH KDE1204PFV2.11.MS.A.GN	Fan 12VDC 40x40x10mm 7CFM w/ 2" lead w/ Molex Sherlock connector	EBM / Sunon	EBM Direct / Digikey	412-FH 259-1351-ND
F2		1	LM-0608-01	Enclosure, ABS plastic 3 pieces	Cypress	Cypress	LM-0608-01
F3		4	90380A110	Screw, #4 x 0.500" plastite (for fan)	McMaster	McMaster	90380A110
F4		4	90380A108	Screw, #4 x 0.375" plastite (for enclosure)	McMaster	McMaster	90380A108

IMPORTANT NOTICE

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

Products		**Applications**	
Amplifiers	amplifier.ti.com	Audio	www.ti.com/audio
Data Converters	dataconverter.ti.com	Automotive	www.ti.com/automotive
DLP® Products	www.dlp.com	Broadband	www.ti.com/broadband
DSP	dsp.ti.com	Digital Control	www.ti.com/digitalcontrol
Clocks and Timers	www.ti.com/clocks	Medical	www.ti.com/medical
Interface	interface.ti.com	Military	www.ti.com/military
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