Stellaris® Brushless DC (BLDC) Motor Control Reference Design Kit with Ethernet and CAN

User's Manual

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CHAPTER 1

Overview

The Brushless DC Motor Control Reference Design Kit (RDK-BLDC) is a four-quadrant motor control for three-phase brushless DC motors rated at up to 36 V. Key features of the RDK include complete CAN and Ethernet communications interfaces, a powerful 32-bit Stellaris microcontroller, and embedded software to optimally control a wide range of motors in diverse applications.

Stellaris Reference design kits (RDKs) accelerate product development by providing ready-to-run hardware, a typical motor, and comprehensive documentation including hardware design files. Designers without prior motor control experience can successfully implement a sophisticated motor control system using the RDK-BLDC.

Integrated 10/100 Ethernet connects the RDK-BLDC to an array of network options—from dedicated industrial networks to worldwide control and monitoring over the internet.

Reference Design Kit Contents

The BLDC Motor Control Reference Design Kit contains everything needed to evaluate BLDC motor control. The RDK includes:

- Motor control circuit board
  - Suitable for motors up to 36V 15A
  - Uses a Stellaris LM3S8971 microcontroller
- Brushless DC Motor
  - See Table 3-2 on page 38 for motor specifications
- Universal Input Wall power supply
  - 24 V 15 W
  - Plug adaptors for US, UK, EU and AUST.
- Retractable Ethernet cable
  - 10/100baseT
- Debug adapter
  - Adapts 10-pin fine-pitch ARM JTAG connector to std. 20-pin connector
- Reference Design Kit CD
  - Complete documentation, including Quick-start and User's Guides
  - Graphical User Interface (GUI) installer
  - 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

Important Information

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. Brushless 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. We recommend using a current-limited power supply during development. Remove power immediately if current exceeds the motor's current (Ampere) or power (Watt) rating.

Using the RDK

The recommended steps for using the RDK are:

- **Follow the Quickstart Guide included in the kit.** The Quickstart guide will help you get the motor up and running in minutes. It also contains important safety information that should be read before using the RDK.
- **Use the RDK GUI software to evaluate and optimize motor performance.** The RDK GUI gives real-time access to over 37 operating parameters. Parameters and data transfer between the motor control and PC over an Ethernet cable. Once configured, the board can be used as a standard motor control module. The configuration can then be duplicated on other control boards.
- **Customize and integrate the hardware and software to suit an end application.** This user's manual and the *Software Reference Manual* are two important references for completing hardware and software modifications. Software can be programmed in the motor control board using either the RDK GUI software or using a JTAG debug interface (available from leading development tools vendors).
- **Customize the firmware.** Using the parameters determined from the GUI and `qs-bldc` firmware, the `basic-bldc` firmware can be customized and used as a starting point for the end application.

Features

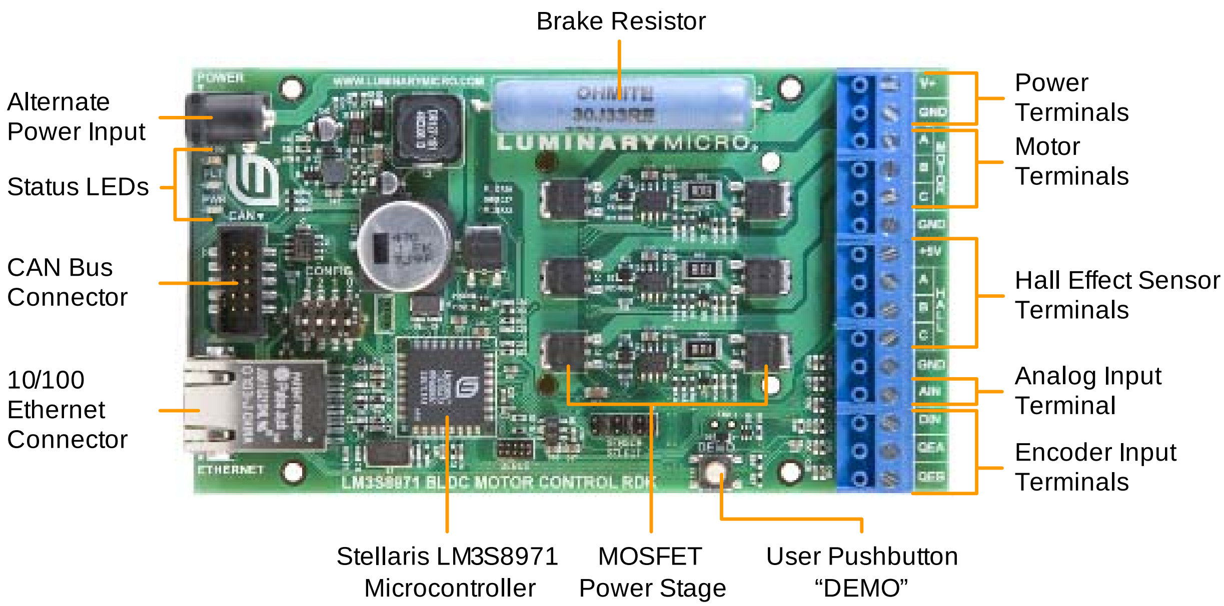
- Advanced motor control for three-phase brushless DC motors
- Four quadrant operation
- Hall Effect, Quadrature, and Sensorless operation modes
- Flexible RDK platform accelerates integration process
- On-board braking circuit
- Incremental quadrature encoder input
- Analog and digital control inputs
- Test mode push-button

- Status LEDs indicate Power, Run, and Fault conditions
- Optional power-managed fan for forced-air cooling
- Screw terminals for all power and signal wiring
- JTAG/SWD port for software debugging

Communications Features

- Integrated 10/100 Ethernet
  - Auto MDI/MDIX
  - Traffic and Link indicator LEDs
- CAN bus
  - Supports up to 1 Mbps
  - DIP switches for setting CAN address
  - On-board selectable CAN terminator
- Serial port (optional)
  - Header provides TXD and RXD signals
  - CMOS signal levels
  - 115.2 kbaud, 8 bit, no parity,1 stop bit operation (115.2 kbaud,8,N,1)

Figure 1-1. RDK-BLDC Board



Motor Technology

This section provides an introduction to the operation of brushless DC motors. Understanding motor fundamentals will be helpful when modifying operational parameters using the GUI.

Applications

Brushless DC motors are electronically commutated, permanent-magnet motors, offering efficient operation, good torque characteristics, and long life. They find homes in diverse applications ranging from CPU cooling in personal computers to automotive, mobility, and automation systems.

Main Components

The stator (or stationary part of the motor) consists of a frame and copper wire windings (see Figure 1-2). In a brushless DC motor the rotor (or rotating part of the motor) is a shaft with one or more permanent magnets. The rotor may be located inside or outside the stator. Internal rotors use magnets with one or more pairs of poles (north and south). External rotors often have radial-mounted magnets which allow a higher number of poles and proportionally greater torque.

Figure 1-2. BLDC Motor Rotor and Hall-Effect Sensor Assembly

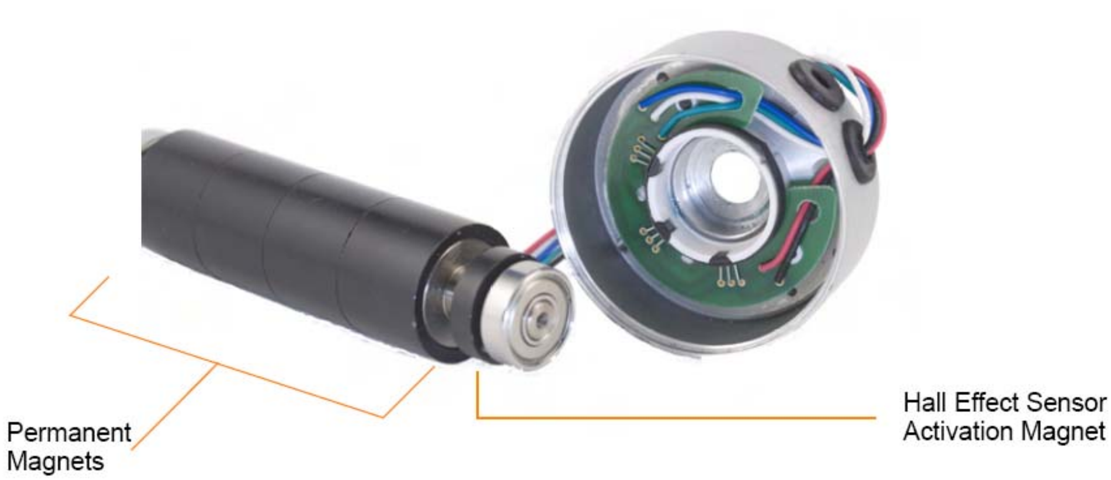
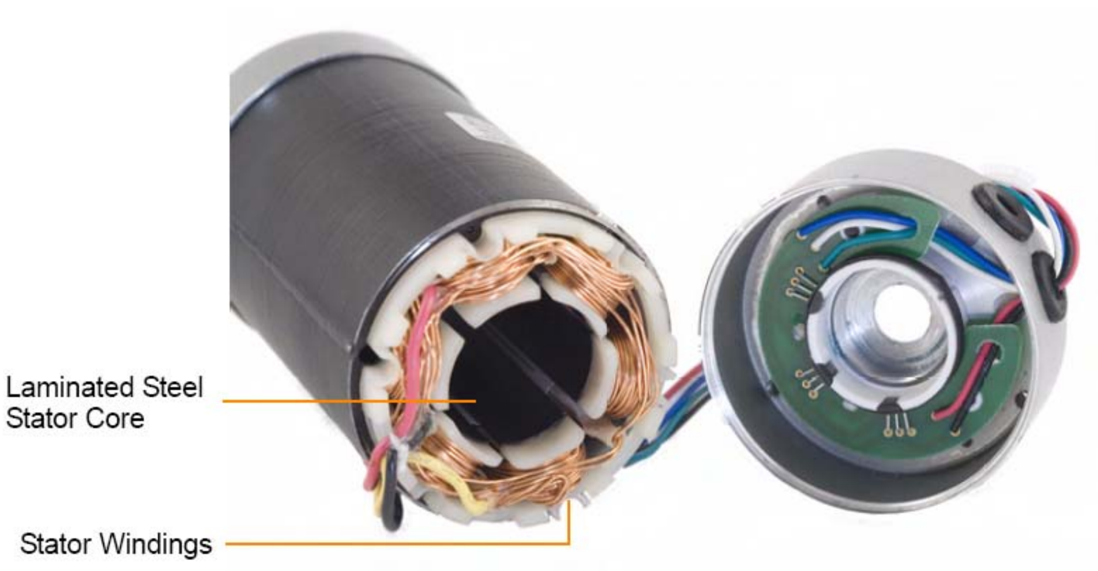


Figure 1-3. BLDC Motor Stator



Most brushless DC (BLDC) motors have three phases. A three-phase brushless DC motor (BLDC motor) has three windings, which are each distributed in two or more slots in the stator. The windings may be connected in either a wye “Y” (Figure 1-4) or delta (Figure 1-5) configuration. Wye “Y” connections are more common, but from an electrical drive perspective the two are identical. The electrical connection points are commonly referred to as phases.

Commutation

The motor is driven by applying a positive voltage potential to one phase and a negative potential to another. This results in current flowing into the motor through one winding and out of the motor through the other. By properly sequencing the current through the phases, the motor turns. A BLDC motor is a synchronous machine so, when driven correctly, the rotational speed of the motor has a direct relationship to the rate of sequencing. In order to maintain synchronicity over a speed/ torque range, the rotor position should be monitored.

There are several options for feedback systems, including Hall Effect sensors and optical encoders.

Figure 1-4. Wye “Y” Winding Configuration

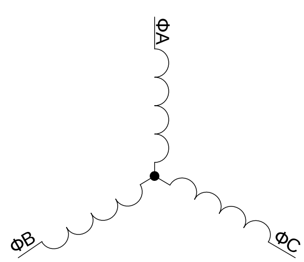
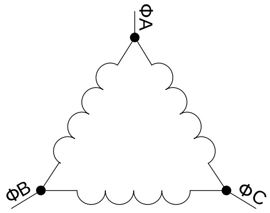


Figure 1-5. Delta Winding Configuration



In its simplest form, the BLDC motor commutation sequence has six steps. The phase states are listed in Table 1-1. The phase state column shows the relative potential on motor phase connections.

Table 1-1. BLDC Motor Commutation Sequence Phase States

	State Number	Phase State
Forward ↓ / Reverse ↑	State 1	B+A-
	State 2	C+A-
	State 3	C+B-
	State 4	A+B-
	State 5	A+C-
	State 6	B+C-

Position Sensing

In order to commutate the brushless DC motor, the microcontroller needs to know the rotor position. The RDK supports two common methods of position sensing as shown in Table 1-2.

Table 1-2. Comparison of Brushless DC Motor Position Sensing Methods

	Hall-Effect Sensor	Sensorless (Back-EMF)
Type	Directly senses rotor field	Indirectly senses rotor field
Mounting	In or on motor	N/A
Speed Range	All speeds	Medium to high
Applications	Constant and variable torque	Best suited to variable torque
Motor ‘shakes’ at start-up	No	Sometimes
Cost	Medium	Very low
Reliability	Medium	High

Hall-effect sensors are usually required for constant torque type applications. They allow the BLDC control board to maintain precise positioning over a wide speed range with varying loads.

Hall-effect sensors may be arranged for 60° or 120° angles. Figure 1-6 and Figure 1-7 show the relationship between sensors and commutation for both configurations.

Figure 1-6. Six Step Commutation for 120° Hall Sensors

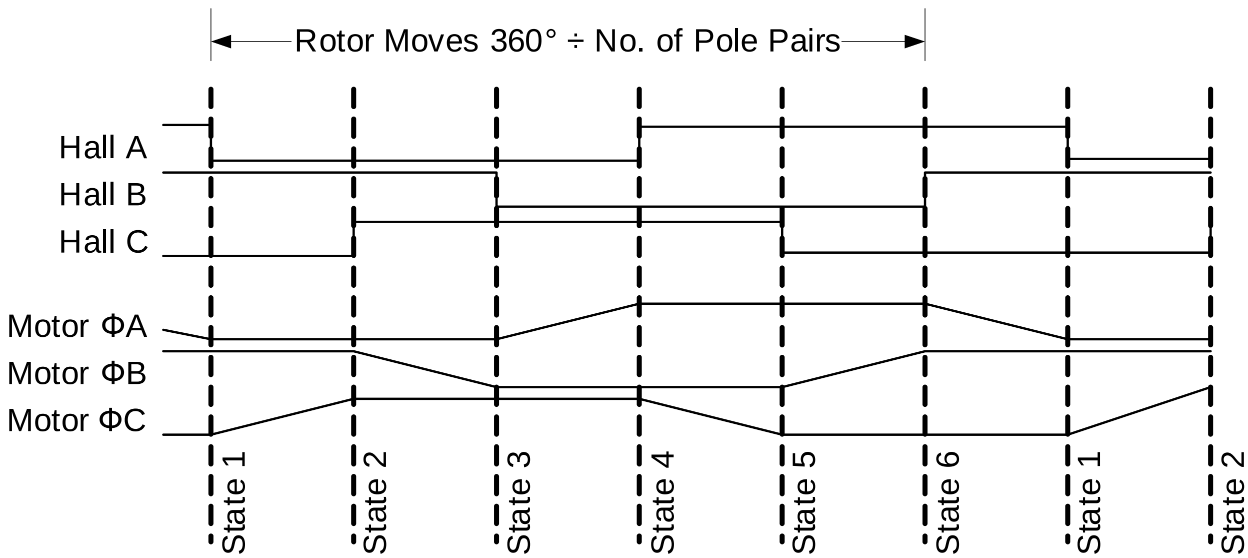
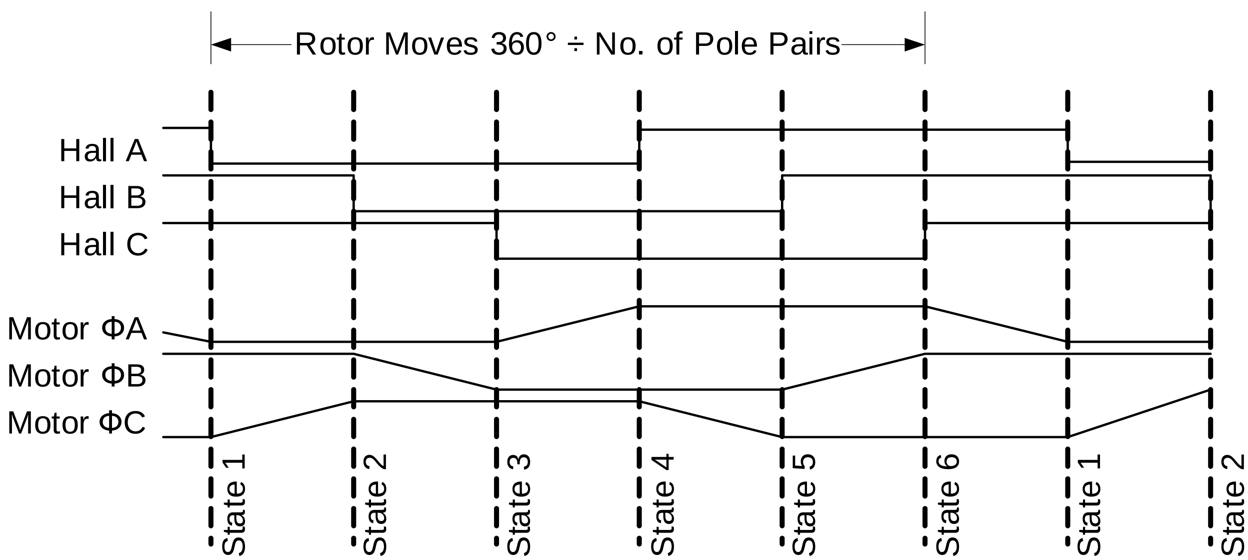


Figure 1-7. Six Step Commutation for 60° Hall Sensors



Hall-effect sensors used in brushless DC motors usually have digital or, more specifically, open-drain outputs. A few motor manufacturers have an option to install analog-output Hall-effect sensors which provide a voltage level proportional to the field strength. When sampled with an ADC, analog Hall-effect sensors allow precise position measurement beyond the 60° resolution offered by digital sensors. This is an advantage in servo type applications where precise positioning is required. The RDK control board supports analog Hall-effect sensors.

Back-EMF sensing detects motor position without using sensors by monitoring the voltage potential on the non-active phase. In Figure 1-6 and Figure 1-7, the inactive phase is indicated by a rising or falling sloped line. For State 1, the non-active phase is Phase C. The sloped line is an approximation of the voltage induced in that winding. This is known as Back Electromotive Force or back-EMF. Typically, voltage comparators are used to detect zero-crossings in the back-EMF signals. The Stellaris design eliminates the comparator circuitry by using the microcontroller's internal ADC module for adaptive determination of zero crossing events.

RDK Specifications

The following information summarizes the RDK control board specifications. For detailed electrical specifications, refer to the BLDC RDK data sheet.

- Power supply range: 12-36 V DC
- Motor voltage range: 12-36 V DC
- Motor current range: 0-14 A
- Speed Range: 1-60,000 RPM

C H A P T E R 2

Graphical User Interface

This section describes the graphical user interface (GUI) in detail. The GUI runs on a Windows PC and communicates with the RDK control board using Ethernet. The Quickstart guide explains how to install the GUI and connect to the RDK.

Main GUI Window

Motor operation is controlled from the main window (see Figure 2-1). The main window provides user controls for controlling the motor, as well as several indicators to provide status of the motor operation. Most parameters can only be modified when the motor is stopped, and are not selectable while the motor is running. Table 2-1 describes the controls in detail.

Figure 2-1. BLDC Motor Control Main GUI Window

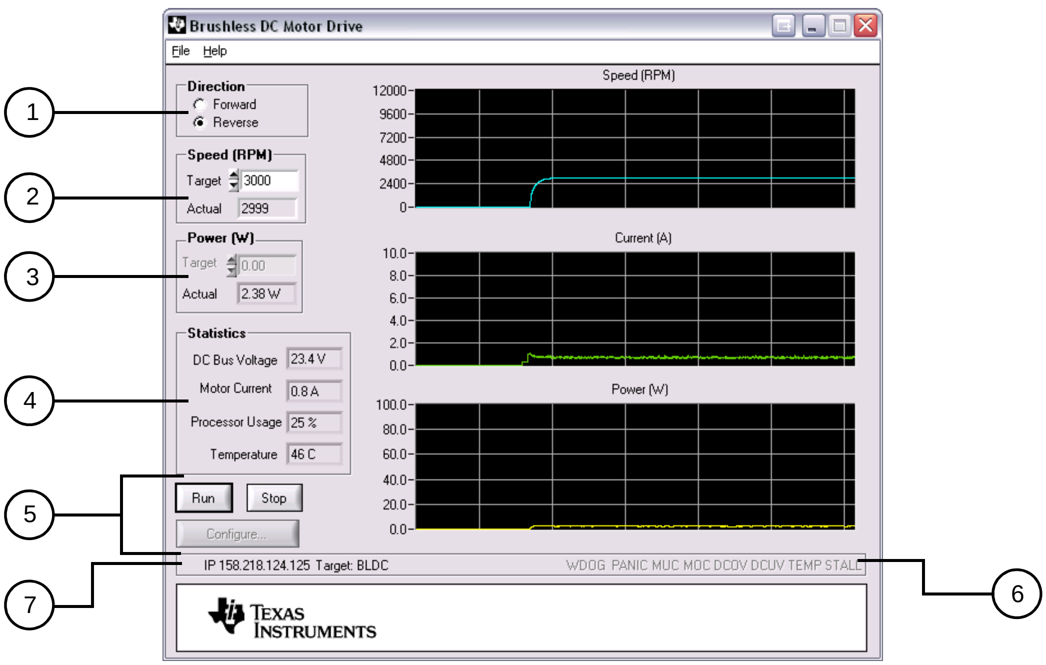


Table 2-1. Description of GUI Main Window Controls

Item No.	Name	Description
1	**Direction Area**	
	Forward	Configures the motor to run in the forward direction.
	Reverse	Configures the motor to run in the reverse direction.

Table 2-1. Description of GUI Main Window Controls (Continued)

Item No.	Name	Description
2	**Speed (rpm) Area**	
	Target Speed (rpm)	Displays the target motor speed in revolutions per minute (rpm). This value can be changed by the user.
	Actual Speed (rpm)	Displays the actual motor speed in revolutions per minute (rpm). This value cannot be changed by the user.
3	**Power (W) Area**	
	Target Power (W)	Displays the target motor power in watts (W). This value can be changed by the user.
	Actual Power (W)	Displays the actual motor power in watts. This value cannot be changed by the user.
4	**Statistics Area**	
	DC Bus Voltage	Indicates the average DC bus voltage.
	Motor Current	Indicates the motor current as measured by the RDK control board.
	Processor Usage	Indicates the microcontroller CPU load by percentage. Useful for estimating the loading of different applications and motor control algorithms.
	Temperature	Indicates the ambient temperature near the microcontroller using the internal temperature sensor.
5	**GUI Main Window Buttons**	
	Run button	Starts the motor. The motor runs using the current configuration until the Stop button is clicked or a fault condition is detected.
	Stop button	Stops the motor. If the motor is running, the motor decelerates to a stop. Once the Stop button has been clicked, the Run button must be clicked before the motor will operate again.
	Configure button	Opens the Parameter Configuration window. The Parameter Configuration window is described in more detail in “Parameter Configuration Window” on page 23.

Table 2-1. Description of GUI Main Window Controls (Continued)

Item No.	Name	Description
6	**Indicator Area**	
	Watchdog (WDOG)	Indicates that the watchdog timer has expired without the motor drive software updating the PWM outputs. This could be an indication of a stalled motor. The motor drive outputs are shutdown.
	Panic	Indicates that control has received a request to immediately shut down without a controlled motor ramp down.
	Motor Under Current Fault (MUC)	Indicates that the motor was drawing less current than the under-current limit and the motor has been stopped. This feature is useful for detecting an open circuit in the motor. Some motors have internal thermal cut-outs, that can be detected with the MUC indicator.
	Motor Over Current Fault (MOC)	Indicates that the motor was drawing more current than the over-current limit and the motor has been stopped. This may indicated a motor stall condition.
	DC Over Voltage Fault (DCOV)	Indicates that the high-voltage DC supply rail is too high. This can occur if the motor is slowed down too quickly.
	DC Under Voltage Fault (DCUV)	Indicates that the high-voltage DC supply rail is too low.
	Over Temperature Fault (TEMP)	The ambient air temperature near the microcontroller has exceeded the limit and the motor has been stopped.
	Motor Stall (STALL)	While in the run mode, the motor speed was detected to be at zero for greater than 1.5s and has been shut down.
7	**Special Indicator Area**	
	IP Address	Displays the IP address of the target, and status. If the indicator displays in black, and shows an IP address, then the network connection is opened. If the indicator displays in red, then there is no connection. The network connection selection dialog box can be opened by double-clicking on the IP address indicator.
	Target	Displays the status of the target connection. If the "Target" is shown in black, and indicates "BLDC," then the program is communicating with the RDK via the network. If the indicator is shown in red, then there was a problem communicating with the target. Communication with the target can be restarted by double clicking on the Target indicator.

File Menu

The File menu can be used to help manage the parameters. The following menu items are available:

- **Load Parameters from Flash:** The adjustable parameters that control the motor operation may be stored in flash memory in the RDK microcontroller. This menu choice commands the target to copy the parameters that were found in flash into the active memory. The parameters will only be loaded from flash if the motor is stopped. If the parameters are loaded from flash, then the values shown on the main and configuration windows will change to reflect the new parameter values.

- **Save Parameters to Flash:** Saves the adjustable motor parameters to the RDK microcontroller's flash memory. The parameters are only saved when the motor is stopped. If a valid set of parameters have been saved to flash, those will be loaded whenever the target is powered or reset.
- **Load Parameters from File:** The adjustable motor parameters can be loaded from a file that was previously saved. This menu choice will read the parameters from the file (if available) and send them to the target. The parameters will only be loaded if the motor is stopped.
- **Save Parameters to File:** The adjustable motor parameters can be saved to a file. Selecting this menu choice will cause all of the parameters to be read from the RDK board, and stored to a file. The parameters can only be stored to a file if the motor is stopped.
- **Update Firmware:** This menu choice can be used to load new firmware onto the RDK target board. A file chooser dialog box will open to allow the user to select the firmware binary file to load to the target. This menu choice can only be used if the motor is stopped. Once a file is chosen, the new firmware file will be sent to the RDK, the RDK will update the flash with the new program, and then restart.

NOTE: To restore the default parameters that came with your kit, from the File menu, select Load Parameters from File and load the selni.ini parameter file to the target. Then select Save Parameters to Flash from the File menu to save the default parameters into flash memory.

Target Selection Window

The Target Selection window is used to select the BLDC motor board to use for connection over the network. This window appears if you used the program and no target was previously selected, or if you double-click on the IP address indicator on the lower left part of the main window.

The Target Selection Window shows all of the motor boards that are on the local network.

Figure 2-2. Target Selection Window

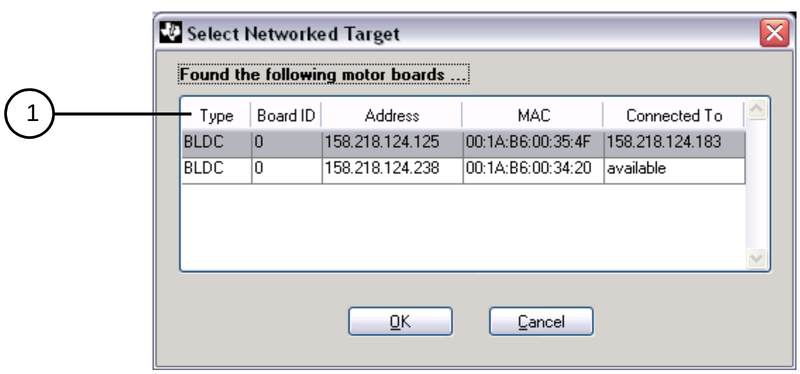


Table 2-2. Description of Target Selection Window Controls

Item No.	Name	Description
1	**Available Motor Board Display**	
	Types	Displays the type of motor board and should indicate “BLDC.”
	Board ID	Displays the position of the DIP-switches on the motor board. The use of these switches is up to the user. The board IDs can be unique, but it is not necessary.
	Address	Displays shows the IP address of the motor board.
	MAC	Displays the MAC address of the motor board. This can be used to uniquely identify a motor board.
	Connected To	Displays the IP address of a host machine that the motor board is connected to. If the motor board is not connected to a host machine, then this field will show “available.” Generally, you should only try to connect to a board that is available, though nothing prevents you from taking over the connection of a board that is already connected.

Select one of the motor boards from the displayed list and click the OK button. If you decide not to connect to any of the boards, click the Cancel button.

Parameter Configuration Window

The Parameter Configuration window is used to allow adjustment of certain system parameters. The window contains four tabs: PWM Configuration, Motor Configuration, Drive Configuration, and DC Bus Configuration. Open the Parameter Configuration window by clicking the Configure button on the main window and then clicking the tab you want to configure. The left and right arrows to the right of the tabs can be used to scroll to the tabs that are not visible.

Change the parameters and click the OK button to send the new parameters to the target. Click the Cancel button to discard any changes.

PWM Configuration

In the Parameter Configuration window, click the PWM Configuration tab to display parameters for configuring the PWM output (see Figure 2-4). Table 2-4 describes the controls in detail.

Figure 2-3. PWM Configuration Window

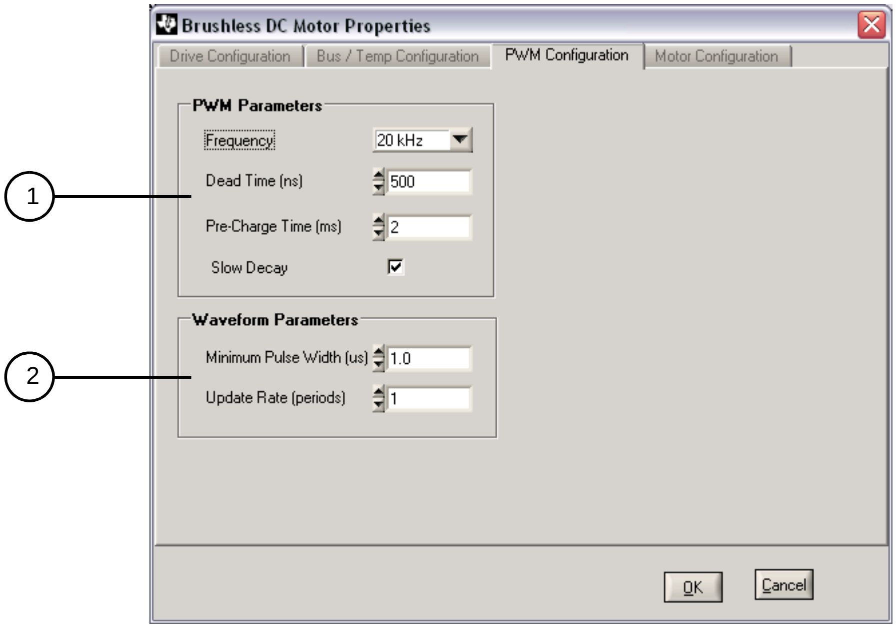


Table 2-3. Description of PWM Configuration Controls

Item No.	Name	Description
1	**PWM Parameters**	
	Frequency	Sets the frequency of the PWM waveforms produced by the microcontroller. Higher frequencies will produce less audible noise in the motor but result in higher processor usage and greater power-stage switching losses.
	Dead Time	The amount of time between the activation of the high and low side switches on a motor phase. This is used to prevent a short-circuit or shoot-through condition.
	Pre-Charge Time	The amount of time to pre-charge the high-side gate drivers before starting the motor drive.
	Slow Decay	When selected, this indicates that the PWM is being driven in slow-decay mode. When not selected, PWM in operating in fast-decay mode.

Table 2-3. Description of PWM Configuration Controls (Continued)

Item No.	Name	Description
2	**Waveform Parameters**	
	Minimum Pulse Width	The width of the smallest pulse (positive or negative) that should be produced by the motor drive. This prevents pulses that are too short to perform any useful work (but that still incur switching losses).
	Update Rate	The number of PWM periods between updates to the output waveforms. Updating the output waveform more frequently results in better quality waveforms (and less harmonic distortion) at the cost of higher processor usage.

Motor Configuration

In the Parameter Configuration window, click the Motor Configuration tab to display parameters for configuring the motor (see Figure 2-4). Table 2-4 describes the controls in detail.

Figure 2-4. Motor Configuration Window

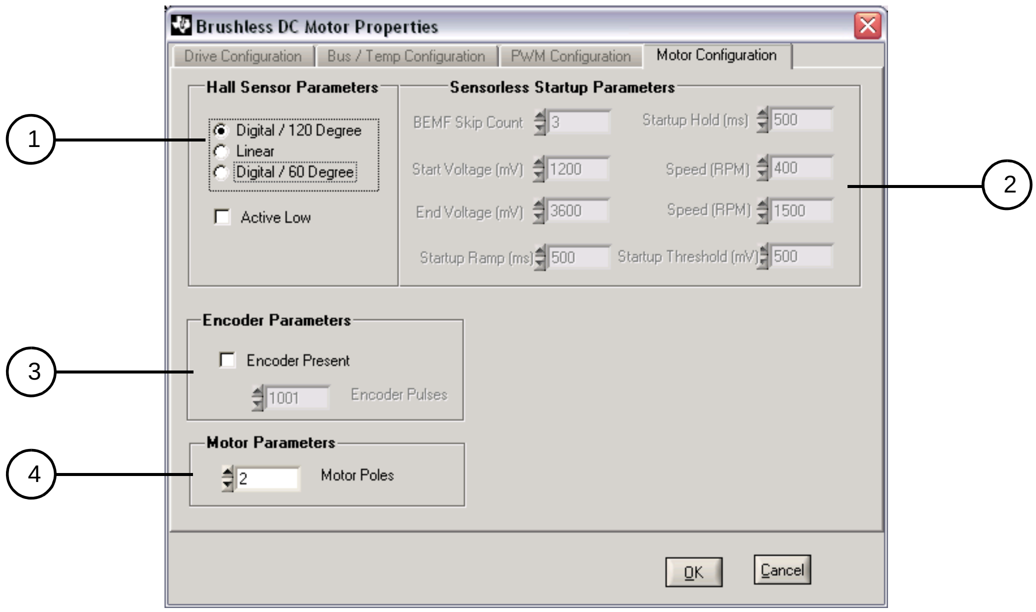


Table 2-4. Description of Motor Configuration Controls

Item No.	Name	Description
1	**Hall Sensor Parameters (J9 jumpers must be configured for Hall Sensor operation)**	
	Digital / 120 Degree	Indicates that digital Hall sensors with 120-degree spacing are in use.
	Linear	Indicates that linear Hall sensors are in use.
	Digital / 60 Degree	Indicates that digital Hall sensors with 60 degree spacing are in use.
	Active Low	Indicates that the Hall sensor input is Active Low (inverted). If the box is not checked, the Hall sensor input is interpreted as Active High.

Table 2-4. Description of Motor Configuration Controls (Continued)

Item No.	Name	Description
2	**Sensorless Parameters (J9 jumpers must be configured for Sensorless operation)**	
	BEMF Skip Count	Sets the number of PWM periods to skip after a commutation event occurs before starting to look for the next Zero-Crossing event. This number must be customized for the motor and load.
	Startup Hold	Sets the number of milliseconds to hold the motor in the initial startup mode during sensorless operation. For high-inertia loads, this number may need to be increased to allow the motor position to stabilize before ramping up the motor speed.
	Start Voltage	Sets the initial voltage for the motor during open-loop sensorless startup.
	Start Speed	Sets the initial speed for the motor drive during open-loop sensorless startup.
	End Voltage	Sets the final voltage for the motor drive during open-loop sensorless startup.
	End Speed	Sets the final speed for the motor drive during open-loop sensorless startup.
	Startup Ramp	Sets the duration, in milliseconds) for the transition from start to end during open-loop sensorless startup.
	Startup Threshold	Sets the Back EMF threshold voltage used to disable startup in sensorless mode.
3	**Encoder Parameters**	
	Encoder Present	Indicates that the motor is equipped with a position encoder.
	Encoder Pulses	Sets the number of pulses per revolution of the position encoder. This control is not available if the Encoder Present checkbox is not checked.
4	**Motor Parameters**	
	Motor Poles	Sets the number of poles for the motor. This is used by the motor for speed calculations.

Drive Configuration

In the Parameter Configuration window, click the Drive Configuration tab to display parameters for configuring the drive (see Figure 2-5). Table 2-5 describes the controls in detail.

Figure 2-5. Drive Configuration Window

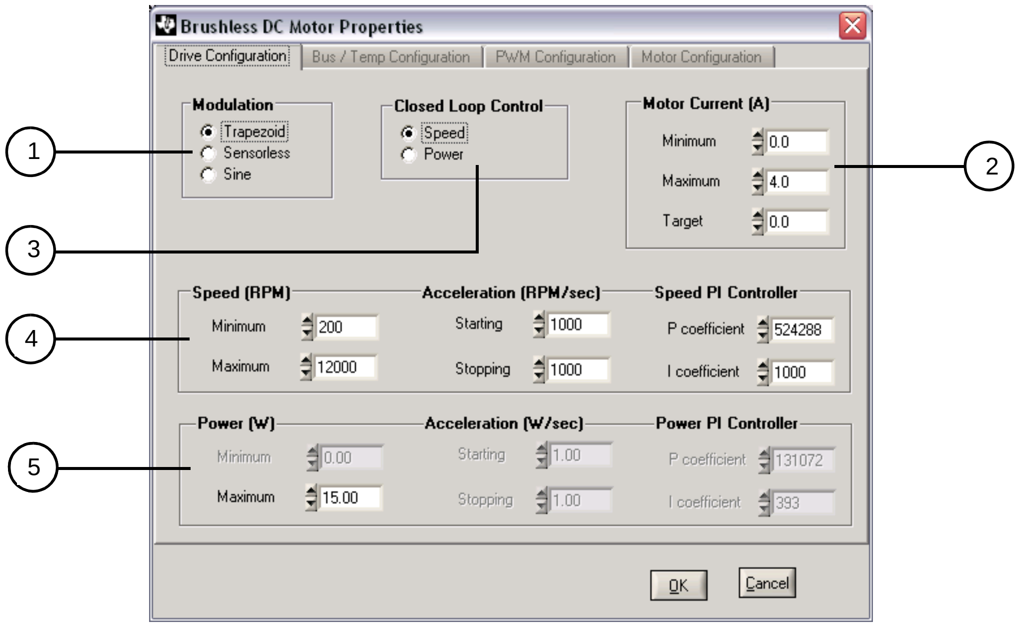


Table 2-5. Description of Drive Configuration Controls

Item No.	Name	Description
1	**Modulation**	
	Trapezoid	Selects sensored, trapezoid modulation.
	Sensorless	Selects sensorless, trapezoid modulation.
	Sine	Selects sinusoid modulation.
2	**Motor Current**	
	Minimum/Maximum	Sets the limits for motor over and under current.
	Target	Sets the limit for motor operational current. If zero, then this parameter is not used.
3	**Closed Loop control**	
	Speed/Power	Selects speed or power as the control variable in the closed-loop operation of the motor.
4	**Speed**	
	Minimum/Maximum	Sets the limits for motor speed.
	Starting/Stopping	Sets the acceleration and deceleration rates. Reducing these values increases the time the motor takes to change speeds.
	P/I Coefficients	Defines the response characteristic of the closed-loop speed controller. Normally, these parameters can be left at factory-default settings.

Table 2-5. Description of Drive Configuration Controls (Continued)

Item No.	Name	Description
5	**Power**	
	Minimum/Maximum	Sets the limits for motor power.
	Starting/Stopping	Sets the acceleration and deceleration rates. Reducing these values increases the time the motor takes to change power.
	P/I Coefficients	Defines the response characteristic of the closed-loop power controller. Normally, these parameters can be left at factory default settings.

DC Bus Configuration

In the Parameter Configuration window, click the DC Bus Configuration tab to display parameters for configuring the DC bus (see Figure 2-6). Table 2-6 describes the controls in detail.

Figure 2-6. DC Bus Configuration Window

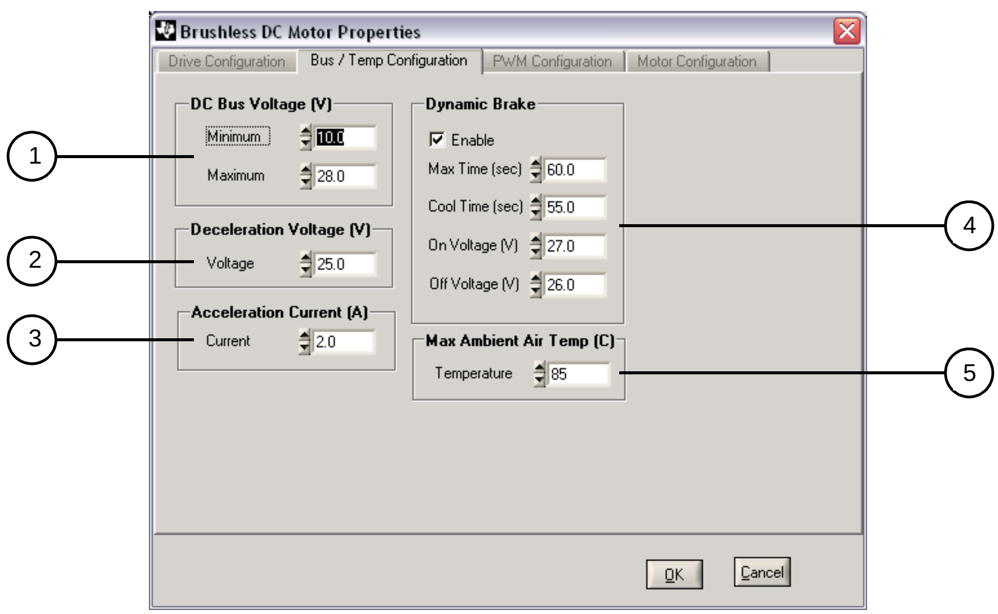


Table 2-6. Description of DC Bus Configuration Controls

Item No.	Name	Description
1	**DC Bus Voltage (V)**	
	Minimum	Sets the minimum DC bus voltage before a fault is signaled.
	Maximum	Sets the maximum DC bus voltage before a fault is signaled.

Table 2-6. Description of DC Bus Configuration Controls (Continued)

Item No.	Name	Description
2	**Deceleration Voltage (V)**	
	Voltage	The DC bus voltage at which the deceleration rate is scaled back in an effort to control increases in the DC bus voltage.
3	**Acceleration Current (A)**	
	Current	The motor current at which the acceleration rate is scaled back in an effort to control power surges.
4	**Dynamic Brake**	
	Enable	Turns dynamic braking on. Dynamic braking actively dissipates energy from the motor as it brakes. These settings control the braking levels and dynamic characteristics.
	Max Time (sec)	The maximum amount of time the dynamic brake can be applied before it is forced off to prevent overheating.
	Cool Time (sec)	The time at which the dynamic brake can be reapplied after reaching the Maximum time. The brake is allowed to cool for the delta of Max Time and Cool Time.
	On Voltage (V)	The dynamic brake is applied when the DC bus voltage exceeds this value.
	Off Voltage (V)	Once applied, the dynamic brake is disengaged when the DC bus voltage drops below this level.
5	**Max Ambient Air Temp (C)**	
	Temperature	Trip point for over temperature trip.

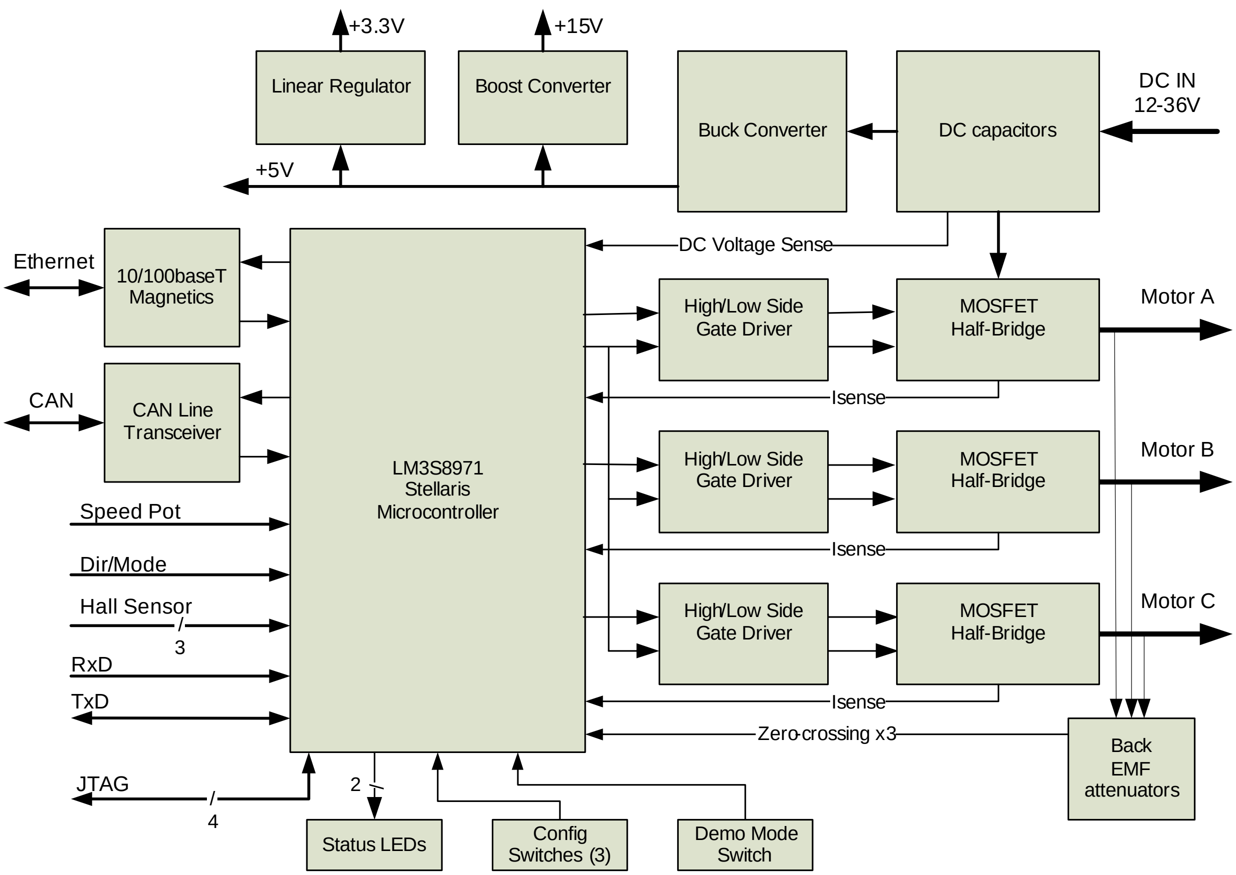
Hardware Description

The BLDC motor control design uses the highly integrated Stellaris LM3S8971 microcontroller to handle all PWM synthesis, position, and analog sensing as well as Ethernet and CAN networking. 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 feature of the control's design is the ability to integrate CAN and Ethernet into a low-cost motor control design. Most sections of the design use commodity parts available from several vendors.

Block Diagram



Functional Description

This section describes the motor control's hardware design in detail.

Microcontroller and Networking (Schematic Page 1)

Page 1 of the schematics details the microcontroller, communications, and debug interfaces.

Microcontroller

At the core of the Brushless DC Motor RDK is a Stellaris LM3S8971 microcontroller. The LM3S8971 contains a peripheral set that is optimized for networked control of brushless DC motor control, including 8 high-speed ADC channels, a motor control PWM block, quadrature encoder inputs, as well as CAN and Ethernet modules.

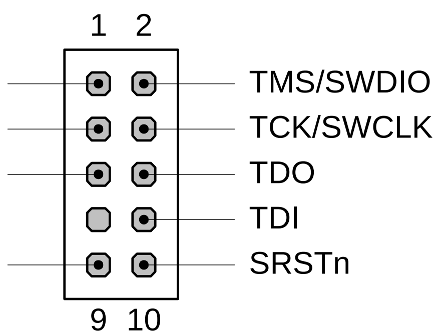
The Stellaris microcontroller directly manages the sequencing of the motor phases and the current in those phases. The microcontroller's PWM module generates three complementary PWM signal pairs that are fed to the power stage.

The LM3S8971 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.

Debugging

The microcontroller supports JTAG and SWD debugging as well as SWO trace capabilities. To minimize board area, the RDK uses a 0.050" pitch header which matches ARM's fine-pitch definition (Figure 3-1). Some in-circuit debuggers provide a matching connector. Other ARM debuggers can be used with the adaptor board included in the RDK.

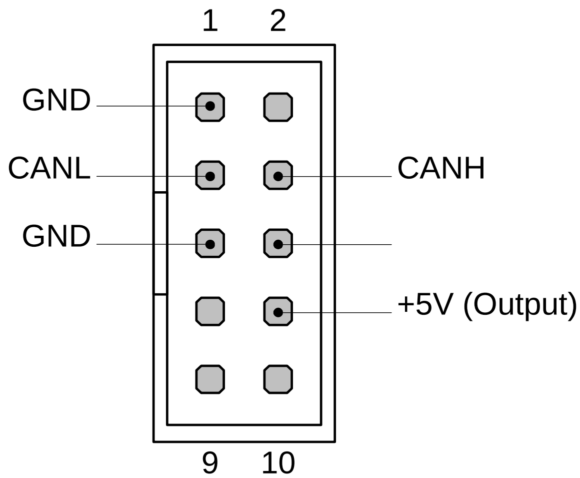
Figure 3-1. Debug Connector Pinout



CAN Communication

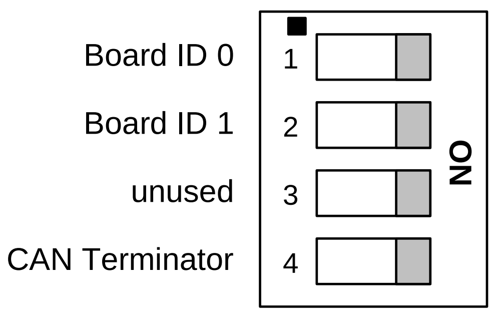
A key feature of the LM3S8971 is its CAN module that enables highly reliable communications at up to 1 Mbits/s. The RDK control board includes a standard CAN transceiver and a 10-pin CAN connector whose signal assignments follow a commonly used CAN standard. A simple adaptor (not included in the kit) can be used to allow the use of standard DB-9 CAN cables (as specified by CAN in Automation CiA DS102).

Figure 3-2. CAN Header Pinout



An on-board 120-ohm resistor provides bus termination. If more than two CAN devices are on a network, then remove the termination resistor for all devices except the two end-points. To remove the terminator, move the DIP switch (“T”) to the Off position.

Figure 3-3. DIP Switch Assignments



The RDK Ethernet protocol allows the GUI to access multiple control boards over the network. The Board ID switches assign an ID number from 0 to 3 to the board. The GUI searches for RDK boards, and then provides a list of Board IDs. The user can select a board to monitor and configure from that list.

Output Power Stage (Schematic Page 2)

The power output stage uses six N-channel MOSFETs arranged in three half-bridges to drive the motor phases.

Power Amplifier

N-channel MOSFETs require a positive gate voltage (Vgs) to turn on. Fairchild FAN7382 high-voltage drivers are used to control the high- and low-side gates in each half-bridge. The bootstrap power supply system used by the gate drivers allows the MOSFET gate to reach almost Vmotor+15 V to optimize Rds(on) and improve efficiency.

The microcontroller provides the power stage with three pairs of complementary PWM signals. A guard-band between high-side and low-side MOSFET on-states, called dead-time, ensures that "shoot-through" conduction can not occur. The duration of the dead-time is controlled by the PWM block inside the microcontroller and can be set in software. The default dead-time is 500 ns.

Current Sensing

Three 18mΩ resistive shunts provide 18 mV/A current sensing for each leg of the H-bridge. Independent current sense circuits are not required for 6-step BLDC motor operation but are a benefit for sine-controlled permanent magnet motors and field-oriented control (FOC) control algorithms.

Each current sense circuit uses an op-amp for voltage gain. Both positive and negative current measurement is accommodated by biasing the input of the op-amp to 300 mV. The result is a voltage signal into the microcontroller's ADC of 68.15 mV/A, centered at 1.13 V. The ADC's span is 0 to 3 V, so measurements from -16.5 A to +27.4 A are possible.

Because the current sense resistors are located in the H-bridge leg, rather than in series with the coil, differences in the current waveform must be considered. PWM switching of high- and low-side MOSFETs means the actual motor current can be measured using the sense resistor only within a certain window. The microcontroller's PWM module triggers the ADC sequencer to accommodate this window and provide a valid motor current measurement.

Power, Sensor, and Control Terminals (Schematic Page 3)

Schematic page 3 shows the power and control signal terminal block and associated circuitry.

Terminal Connections

Apart from CAN and Ethernet, all connections to the brushless DC motor control board can be made using a 15-position screw terminal block (see Table 3-1).

Table 3-1. Terminal Block Descriptions

Terminal	Function	Description
1	V+	12-36 V Positive DC supply input
2	GND	Ground for DC supply input
3	Motor A	Connection to motor A phase
4	Motor B	Connection to motor B phase
5	Motor C	Connection to motor C phase
6	GND	Signal ground
7	+5 V	5 Volt supply to Hall-effect sensors, and so on
8	Hall A	Hall-effect sensor input
9	Hall B	Hall-effect sensor input
10	Hall C	Hall-effect sensor input
11	GND	Signal ground
12	AIN	0-5 V analog input
13	DIN	Digital input quadrature encoder index pulse
14	QEB	Quadrature encoder input

Table 3-1. Terminal Block Descriptions (Continued)

Terminal	Function	Description
15	QEA	Quadrature encoder input

For operation above 2 Amps, a power supply should be connected directly to the terminal block rather than the DC power jack.

Sensor Option Jumpers

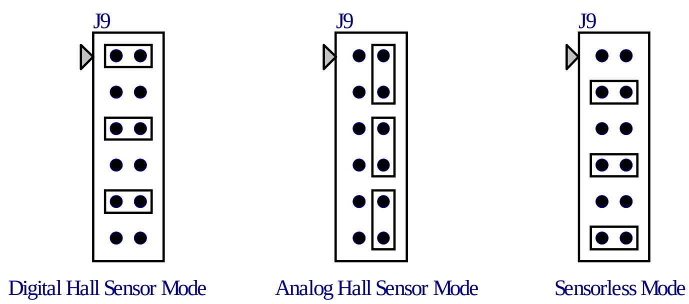
The control board supports three different motor position sensor modes:

- Digital Hall-effect sensors
- Analog Hall-effect sensors
- Sensorless operation

Refer to “Motor Technology” on page 13 of this manual for a practical comparison of the features and benefits of each mode.

For each mode, the jumpers on the control board must match the GUI configuration. The factory default setting enables digital Hall-effect sensor mode, as this is most commonly used.

Figure 3-4. Jumper Selections for Each Sensor Mode



In digital Hall-effect sensor mode, the hall terminals are monitored by general-purpose input pins on the microcontroller. Edge transitions on GPIOs trigger interrupts. The jumper positions apply a 6.81 KΩ pull-up resistor to each channel. These are necessary because the microcontroller's internal pull-up resistors are too high in value for fast transitions with long, capacitive Hall-effect sensor cables.

In analog Hall-effect sensor mode, the jumpers route the hall inputs to three ADC channels, using the 6.81 KΩ resistors as attenuators to bring the 5 V span to a 3 V span that is compatible with the ADC conversion range. One ADC bit represents 4.93 mV.

Finally, Sensorless mode uses the same three ADC channels to measure the back-EMF potential of each of the motor phases. For each of the 6 commutation steps, only the non-driven phase contains useful positioning information. A 40:1 attenuator brings the motor voltage safely within the range of the ADC. One ADC bit represents 117.3 mV.

Power Supplies and Control (Schematic Page 4)

The RDK has four main power supply rails.

Main DC Rail and Brake Circuit

The motor voltage comes directly from the DC input supply. For optimal performance, the power supply should be the same as the motor's rated voltage. In practice, the control's PWM voltage control will allow higher-voltage supplies to be used.

When rapid deceleration occurs, particularly of loads with high inertia, the motor will act as a generator. Regenerative currents are rectified by the MOSFETs and the energy returns to the main DC rail. As the capacitors on the DC rail charge, the voltage rises. The brake circuit allows excess power to be dissipated if the DC power rail exceeds a certain limit. For a 36 V supply, the brake might activate at 42 V. The DC rail must never exceed 55 V or the RDK will be permanently damaged.

Some applications will require braking circuits that exceed the capabilities of the on-board brake. A brake resistor with greater power dissipation may be used. Ensure that the rating of MOSFET Q1 is not exceeded.

In addition, some power supplies will not tolerate a voltage higher than their nominal output. Even with a brake, permanent damage can be caused by excessive regeneration. This should be a consideration when selecting a power supply for an end application.

3.3 V, 5 V, and 15 V Supply Rails

Housekeeping power comes from two cascaded switching regulators which first generate 5.0 V, then 15 V, for the MOSFET gate drivers. A separate low-dropout (LDO) regulator supplies low-noise 3.3 V power to the microcontroller.

Fan Cooling

The power MOSFETs have a low ON resistance and do not require a heatsink when driving most BLDC motors. In high ambient temperature applications or when driving large motors, the RDK has provisions for forced air cooling. In order to avoid bulky and expensive aluminum heatsinks, the RDK may use a small fan to cool the power stage MOSFETs and the braking resistor. To save energy and extend its lifetime, the fan only operates when the microcontroller estimates that power dissipation in the devices exceeds their free-air capabilities.

A fan is not included in the RDK, but most 50x50mm 5 V fans rated at ≤0.8 W may be used. The recommended fan is Sunon P/No KDE0505PFV2. The fan mounts above the MOSFET stage using 0.5" nylon standoffs. Two adjacent pads provide power to the fan.

Software

The software running on the Stellaris microcontroller is responsible for generating motor drive waveforms, making real-time voltage and current measurements, and managing networking protocols. The software is written entirely in C. The RDK CD includes the full source code.

There are two versions of firmware included on the RDK CD. The `qs-bldc` firmware is what comes preloaded on the board. This is the quickstart firmware. This software is configured to work with the Ethernet bootloader and the BLDC GUI to ease firmware upgrade, along with storage and retrieval of motor drive parameters.

A second firmware application, `basic-bldc`, is also included. This is a stripped-down version for the `qs-bldc` with all serial communications disabled, non-volatile parameter storage removed, and only a single user interface (push-button) enabled. This application can serve as a starting point for reduced footprint firmware targeted for a custom motor-drive board.

For the latest version of the software, visit www.ti.com/stellaris.

Other Functions

During operation, the motor drive continuously monitors DC bus voltage, motor current, and microcontroller ambient temperature.

Several steps are taken to manage the DC bus voltage; if the motor drive is decelerating and the DC bus voltage exceeds a parameter value (due to regeneration), the rate of deceleration is temporarily decreased. If the DC bus voltage exceeds another parameter value, a dynamic brake is applied to reduce the DC bus voltage.

There are several fault conditions that result in power to the motor being turned off as a safety measure:

- DC bus voltage gets too high (from excessive regeneration)
- DC bus voltage gets too low (usually from a loss of input power)
- Motor current gets too high
- Motor current gets too low
- Motor speed drops to zero while running
- Microcontroller ambient temperature gets too high

The fault condition must be manually cleared before the motor drive will operate again.

Motor Control Parameters

The brushless DC motor control software has an extensive set of parameters which it stores in on-chip Flash memory. The parameters define both high-level operation (for example, acceleration rate) and low-level operation (for example, modulation algorithm). Because they are stored in flash rather than hard-coded, the RDK GUI program provides a visual method for monitoring and adjusting control parameters over Ethernet.

Parameter Reference

See Appendix A, “Parameters and Real-Time Data Items,” on page 41 for a detailed description of the RDK's parameters.

Implementation Considerations

This section provides information on items to consider when integrating the brushless DC motor control board in an end application.

Motor Selection

The RDK is able to control a wide range of brushless DC motors because the GUI allows a large degree of parameter flexibility. The key parameters to consider when matching a motor to the RDK include:

- Motor voltage – must be less than the control board's rated voltage
- Motor current – must be less than the control board's rated current
- Sensor type – must be compatible with one of the three RDK modes
- Commutation sequence – some motors are non-standard and may require motor or sensor wiring that is not straight-through (that is, A-A, B-B, and so on).

The RDK has been tested with a range of motors (see Table 3-2).

Table 3-2. Test Motor Comparison

Manufacturer	Model Number	Voltage (E)	Output Power (Pmax)	Speed (Snl)	Torque (Tc)	Notes
Beijing Precision Motor	BL3056-24-060	24 V	60 W	10800 RPM	0.227 Nm	Parameters defined in BL3056-24.ini[a]
Pittman	N2341S001	12 V		7197 RPM	0.110 Nm	Requires hall sensor signal remapping
Anaheim Automation	BLWR235S-36V-4000	36 V	180 W	4000 RPM	1.3 Nm	
Anaheim Automation	BLZ362-36V-3500	36 V	500 W	4100 RPM	1.4 Nm	
Anaheim Automation	BLWR110S-15-8000	15 V	6 W	8000 RPM	0.021 Nm	Parameters defined in BlWR110S-15.ini[a]
Anaheim Automation	BLWR111S-24-10000	24 V	15 W	10000 RPM	0.042 Nm	Parameters defined in BLWR111S-24.ini[a]

a. One of these motors is included in the RDK-BLDC Reference Design Kit.

Mechanical and Thermal

The control board should be mounted in an orientation that provides maximum free-air cooling. In restricted spaces, including enclosures without ventilation, de-rating of the drive will be necessary to keep the MOSFET case temperature safely below 125°C.

When mounting the control board, ensure that screws and spacers do not short out traces, components, or copper areas on the PCB. Nylon hardware is recommended for mounting the cooling fan.

Protocols

See the *RDK-BLDC Firmware Development Package User's Guide* for more information on CAN and Ethernet protocols used in the RDK.

Troubleshooting

The RDK is carefully designed to be up and running in just minutes. When connecting other motors, power sources, or cables, the following list may help resolve problems.

Table 3-3. Troubleshooting

Problem	Possible Resolution
• Motor does not operate • Motor does not operate smoothly • Clicking noise can be heard • Motor runs in one direction but not the other	• Check motor power wiring. • Check Hall-effect sensor wiring. • Confirm Hall-effect sensor commutation sequence is correct. It may be necessary to move Hall-effect sensor connections. • In sinusoid mode, reduce motor acceleration.

Table 3-3. Troubleshooting (Continued)

Problem	Possible Resolution
• GUI motor speed does not match actual motor speed	• The motor has more (or less poles). Change the GUI setting to match the motor.
• Motor stalls or is very hot	• Confirm Hall-effect sensor commutation sequence is correct. It may be necessary to move Hall-effect sensor connections. • Check that voltage and current settings match the motor's ratings. • In sinusoid mode, reduce motor acceleration.
• Motor begins to accelerate, then stops abruptly	• Power supply may be inadequate for motor power rating, causing the DC bus to sag momentarily.

A P P E N D I X A

Parameters and Real-Time Data Items

This section provides detailed information for parameters and real-time data items (see “Real-Time Data Items” on page 59).

Parameters

Table A-1 provides a summary of all configuration parameters. See “Parameter Descriptions” on page 43 for more information.

NOTE: Default values are for the BL3056-24 motor. Default values for other motor types may be different.

Table A-1. Parameter Configuration Summary

ID	Units	Range	Default[a]	See
PARAM_ACCEL	RPM/second	1 to 50000	600	page 45
PARAM_ACCEL_CURRENT	milliamperes	0 to 50000	5000	page 49
PARAM_ACCEL_POWER	watts/second	1 to 50	0	page 47
PARAM_BRAKE_COOL_TIME	milliseconds	0 to 60000	55000	page 49
PARAM_BRAKE_OFF_VOLTAGE	millivolts	1000 to 40000	37000	page 50
PARAM_BRAKE_ON_VOLTAGE	millivolts	1000 to 40000	38000	page 50
PARAM_CONTROL_MODE	choice	0 to 1	0	page 44
PARAM_CURRENT_SPEED	RPM	0 to 60000	0	page 43
PARAM_DECAY_MODE	Boolean	0 to 1	1	page 54
PARAM_DECEL	RPM/second	1 to 50000	600	page 46
PARAM_DECEL_POWER	watts/second	1 to 50	0	page 43
PARAM_DECEL_VOLTAGE	millivolts	0 to 50000	35000	page 50
PARAM_DIRECTION	Boolean	0 to 1	0	page 43
PARAM_ENCODER_PRESENT	Boolean	0 to 1	10	page 54
PARAM_ETH_TCP_TIMEOUT	seconds	0 to 4294967295	10	page 57
PARAM_FAULT_STATUS	flags	n/a	0	page 57
PARAM_FIRMWARE_VERSION	number	0 to 65335	varies	page 58
PARAM_MAX_BRAKE_TIME	milliseconds	0 to 60000	60000	page 51
PARAM_MAX_BUS_VOLTAGE	millivolts	1000 to 40000	40000	page 51
PARAM_MAX_CURRENT	milliampere	0 to 15000	10000	page 44
PARAM_MAX_POWER	watts	0 to 360	0	page 48

Table A-1. Parameter Configuration Summary (Continued)

ID	Units	Range	Default[a]	See
PARAM_MAX_SPEED	RPM	0 to 60000	20000	page 46
PARAM_MAX_TEMPERATURE	degrees Celsius	0 to 85	85	page 58
PARAM_MIN_BUS_VOLTAGE	millivolts	1000 to 40000	10000	page 51
PARAM_MIN_CURRENT	milliampere	0 to 15000	0	page 45
PARAM_MIN_POWER	watts	0 to 360	0	page 48
PARAM_MIN_SPEED	RPM	0 to 60000	200	page 46
PARAM_MODULATION	choice	0 to 2	0	page 45
PARAM_MOTOR_STATUS	enumeration	n/a	0	page 59
PARAM_NUM_LINES	count	0 to 65535	71000	page 54
PARAM_NUM_POLES	count	2 to 254	2	page 55
PARAM_POWER_I	choice	0 to 1	0	page 48
PARAM_POWER_P	choice	0 to 1	0	page 49
PARAM_PRECHARGE_TIME	milliseconds	0 to 255	2	page 52
PARAM_PWM_DEAD_TIME	20 nanoseconds	0 to 255	25	page 52
PARAM_PWM_FREQUENCY	choice	0 to 7	3	page 53
PARAM_PWM_MIN_PULSE	1/10th of a microsecond	0 to 250	50	page 53
PARAM_PWM_UPDATE	PWM periods	0 to 255	0	page 53
PARAM_SENSOR_POLARITY	Boolean	0 to 1	0	page 55
PARAM_SENSOR_TYPE	choice	0 to 2	0	page 55
PARAM_SPEED_I	16.16 fixed-point signed integer	-2,147,483,648 to 2,147,483,647	1000	page 47
PARAM_SPEED_P	16.16 fixed-point signed integer	-2,147,483,648 to 2,147,483,647	524288	page 47
PARAM_STARTUP_COUNT	milliseconds	1 to 65535	1000	page 55
PARAM_BEMF_SKIP_COUNT	count	0 to 255	3	page 56
PARAM_STARTUP_ENDSP	rpm	0 to 60000	1000	page 56
PARAM_STARTUP_ENDV	millivolts	1 to 50000	3600	page 44
PARAM_STARTUP_RAMP	milliseconds	1 to 65535	500	page 56
PARAM_STARTUP_STARTSP	rpm	0 to 60000	400	page 44
PARAM_STARTUP_STARTV	millivolts	1 to 50000	1200	page 57
PARAM_STARTUP_THRESH	millivolts	1 to 50000	500	page 57

Table A-1. Parameter Configuration Summary (Continued)

ID	Units	Range	Default[a]	See
PARAM_TARGET_CURRENT	milliampere	0 to 15000	0	page 45
PARAM_TARGET_POWER	watts	0 to 360	0	page 44
PARAM_TARGET_SPEED	RPM	0 to 60000	varies	page 44
PARAM_USE_DYNAM_BRAKE	Boolean	0 to 1	1	page 52
PARAM_USE_ONBOARD_UI	Boolean	0 to 1	1	page 59

a. Default values are for the BL3056-24 motor. Default values for other motor types may be different.

Parameter Descriptions

This section describes parameter configuration in detail. The parameters are grouped into the following areas:

- Run-time control
- Motor drive
- Motor drive speed
- Motor drive power
- DC bus/temp configuration
- PWM configuration
- General motor configuration
- Sensorless motor configuration
- Informational

Run-Time Control Parameters

Current Drive Speed

ID	Units	Range	Default
PARAM_CURRENT_SPEED	RPM	0 to 60000	0

This parameter is a read-only value that provides the current speed of the motor drive. This is the same value that is provided using the *Current Rotor Speed* real-time data item.

Motor Drive Direction

ID	Units	Range	Default
PARAM_DIRECTION	Boolean	0 to 1	0

This parameter specifies the direction of rotation for the motor drive. Since the motor drive has no knowledge of the connection of the windings to the drive, it can not be said that one particular value means clockwise rotation and the other means counter-clockwise rotation. Changing the value of this parameter reverses the direction of rotation. In sensorless mode, changing this value while running may result in a STALL fault. If this occurs, simply clear the fault condition and restart the motor.

Target Drive Power

ID	Units	Range	Default
PARAM_TARGET_POWER	watts	0 to 360	0

This parameter is a read-only value that provides the target power of the motor drive.

Target Drive Speed

ID	Units	Range	Default
PARAM_TARGET_SPEED	RPM	0 to 60000	varies

This parameter specifies the target speed of the motor drive. This is the frequency of the rotor. Note that the target frequency should not exceed the maximum drive frequency speed; if it does, then the motor drive will never be able to achieve the target rotor speed (since the output speed can never exceed the maximum drive speed).

This parameter value must lie between the *Minimum Drive Speed* and the *Maximum Drive Speed*.

Motor Drive Parameters

Control Mode

ID	Units	Range	Default
PARAM_CONTROL_MODE	choice	0 to 1	0

This parameter defines the control variable used in the PI loop for motor control. A value of 0 (default) indicates that speed is the control variable. A value of 1 indicates that power is the control variable.

Maximum Motor Current

ID	Units	Range	Default
PARAM_MAX_CURRENT	milliampere	0 to 15000	10000

This parameter specifies the maximum current that should be consumed by the motor while operating. If the measured motor current is greater than this value, an over-current fault will be triggered and the motor drive will immediately shut down. If this value is zero, the maximum motor current check is disabled.

Minimum Motor Current

ID	Units	Range	Default
PARAM_MIN_CURRENT	milliampere	0 to 15000	0

This parameter specifies the minimum current that should be consumed by the motor while operating. If the measured motor current is less than this value, an under-current fault will be triggered and the motor drive will immediately shut down. If this value is zero, the minimum motor current check is disabled.

Modulation Type

ID	Units	Range	Default
PARAM_MODULATION	choice	0 to 2	0

This parameter selects the modulation type to be used to drive the motor. A value of 0 indicates that trapezoid modulation will be used, a value of 1 indicates that sensorless modulation will be used, and a value of 2 indicates that sine wave modulation will be used.

The value of this parameter can not be changed while the motor drive is running. Most Brushless DC motors are not designed/optimized to support Sine wave modulation. Results will vary from motor to motor when using Sine Wave mode.

Target Motor Current

ID	Units	Range	Default
PARAM_TARGET_CURRENT	milliampere	0 to 15000	0

This parameter specifies the target current that should be consumed by the motor while operating. If the measured motor current is greater than this value, the motor drive will be reduced in speed/ current until the measured value is below the parameter value. If this value is zero, the target current check is disabled.

Motor Drive Speed Parameters

Acceleration Rate

ID	Units	Range	Default
PARAM_ACCEL	RPM/second	1 to 50000	1000

This parameter is the rate at which the output speed increases when it is less than the target speed. This is the maximum rate of acceleration that is allowed, though lower acceleration rates can be utilized.

Deceleration Rate

ID	Units	Range	Default
PARAM_DECEL	RPM/second	1 to 50000	1000

This parameter is the rate at which the output speed decreases when it is greater than the target speed. If the DC bus voltage exceeds the value of the *DC Bus Deceleration Voltage* parameter, the value of this parameter will be temporarily scaled back to slow the rise in the DC bus voltage. If the DC bus voltage is below the *DC Bus Deceleration Voltage* parameter and this parameter was previously scaled back, it will be slewed back to the parameter value at a rate of 15RPM/sec every millisecond. This is the maximum rate of deceleration that is allowed, though lower deceleration rates can be utilized.

Setting this parameter value too high may result in DC bus voltage increases that can not be handled by deceleration rate scaling and dynamic braking. In this case, a DC bus over-voltage fault will occur.

Maximum Drive Speed

ID	Units	Range	Default
PARAM_MAX_SPEED	RPM	0 to 60000	20000

This parameter specifies the maximum speed at which the motor drive will operate. The output speed will never exceed this speed.

The maximum drive frequency should never be set higher than the maximum speed that the motor can handle; setting this parameter higher could result in permanent damage to the motor (mechanical failure from excessive speed, melted winding insulation from excessive heating, and so on).

Minimum Drive Speed

ID	Units	Range	Default
PARAM_MIN_SPEED	RPM	0 to 60000	200

This parameter specifies the minimum speed at which the motor drive will operate. When running, the output frequency will not go below this speed. When stopping or reversing direction, this minimum speed is ignored and the output frequency will slew all the way down to 0.

The minimum drive speed should never be set lower than the slowest drive frequency that will turn the motor; setting this parameter lower will result in effort being expended for no gain (the motor simply will not spin).

Speed Controller I Coefficient

ID	Units	Range	Default
PARAM_SPEED_I	16.16 fixed-point signed integer	-2,147,483,648 to 2,147,483,647	1000

This parameter is the I coefficient of the PI controller used to adjust the speed of the motor drive while in Closed-Loop mode. The I coefficient adjusts the output frequency based on the integral of all past errors in the sampled rotor speed (known as the integral term). In 16.16 fixed point notation, 65536 corresponds to 1.0 (that is, the integral term is equal to the integrator value).

Larger values of the I coefficient result in a decrease in the rise time of the output in response to a step input, an increase in the overshoot, and an elimination of the steady state error. Smaller values do the opposite (though the steady state error will always be eliminated by non-zero I coefficients). For effective operation of the PI controller, the *Frequency Controller P Coefficient* should also be set.

Speed Controller P Coefficient

ID	Units	Range	Default
PARAM_SPEED_P	16.16 fixed-point signed integer	-2,147,483,648 to 2,147,483,647	524288

This parameter is the P coefficient of the PI controller used to adjust the speed of the motor drive while in Closed-Loop mode. The P coefficient adjusts the output frequency based on the error in the most recently sampled rotor speed (known as the proportional term). In 16.16 fixed point notation, 65536 corresponds to 1.0 (that is, the proportional term is equal to the error).

Larger values of the P coefficient result in a decrease in the rise time of the output in response to a step input, an increase in the overshoot, and a decrease in the steady state error. Smaller values do the opposite. For effective operation of the PI controller, the *Frequency Controller I Coefficient* should also be set.

Motor Drive Power Parameters

Acceleration Power

ID	Units	Range	Default
PARAM_ACCEL_POWER	watts/second	1 to 50	0

This parameter is a read-only value that provides the acceleration power speed of the motor drive.

Deceleration Power

ID	Units	Range	Default
PARAM_DECEL_POWER	watts/second	1 to 50	0

This parameter is a read-only value that provides the deceleration power speed of the motor drive.

Maximum Power

ID	Units	Range	Default
PARAM_MAX_POWER	watts	0 to 360	0

This parameters specifies the maximum power at which the motor drive will operate. When running, the motor will not go above this power.

Minimum Power

ID	Units	Range	Default
PARAM_MIN_POWER	watts	0 to 360	0

This parameters specifies the minimum power at which the motor drive will operate. When running, the motor will not go below this power.

Power Controller I Coefficient

ID	Units	Range	Default
PARAM_POWER_I	16.16 fixed-point signed integer	-2,147,483,648 to 2,147,483,647	1000

This parameter is the I coefficient of the PI controller used to adjust the power of the motor drive while in Closed-Loop mode. The I coefficient adjusts the output frequency based on the integral of all past errors in the sampled rotor speed (known as the integral term). In 16.16 fixed point notation, 65536 corresponds to 1.0 (that is, the integral term is equal to the integrator value).

Larger values of the I coefficient result in a decrease in the rise time of the output in response to a step input, an increase in the overshoot, and an elimination of the steady state error. Smaller values do the opposite (though the steady state error will always be eliminated by non-zero I coefficients). For effective operation of the PI controller, the *Frequency Controller P Coefficient* should also be set.

Power Controller P Coefficient

ID	Units	Range	Default
PARAM_POWER_P	16.16 fixed-point signed integer	-2,147,483,648 to 2,147,483,647	524288

This parameter is the P coefficient of the PI controller used to adjust the power of the motor drive while in Closed-Loop mode. The P coefficient adjusts the output frequency based on the error in the most recently sampled rotor speed (known as the proportional term). In 16.16 fixed point notation, 65536 corresponds to 1.0 (that is, the proportional term is equal to the error).

Larger values of the P coefficient result in a decrease in the rise time of the output in response to a step input, an increase in the overshoot, and a decrease in the steady state error. Smaller values do the opposite. For effective operation of the PI controller, the *Frequency Controller I Coefficient* should also be set.

DC Bus/Temp Configuration Parameters

Acceleration Current

ID	Units	Range	Default
PARAM_ACCEL_CURRENT	milliampere	0 to 10000	5000

This parameter specifies the motor current at which the acceleration rate is reduced. The acceleration rate is decreased proportional to the amount by which the motor current exceeds the value of this parameter. Therefore, this acts more aggressively as the motor current gets higher.

To avoid bouncing the motor current and therefore, the acceleration rate, a reduced acceleration rate is slowly increased by 15 rpm every millisecond when the motor current is below the value of this parameter.

Setting the value of this parameter too low will result in the motor accelerating slower than it could or should. Setting the value of this parameter too high will result in the ineffective control of the motor current. Setting the value of this parameter at or above the value of the *Maximum Motor Current* parameter will effectively disable this feature.

Dynamic Brake Cooling Time

ID	Units	Range	Default
PARAM_BRAKE_COOL_TIME	milliseconds	0 to 60000	55000

This parameter specifies the value the dynamic brake counter must reach in order to re-enable the power resistor if it has been forced off. See the description of the *Maximum Dynamic Braking Time* parameter for details.

The value of this parameter must be less than the value of the *Maximum Dynamic Braking Time* parameter, though this is not enforced by the firmware.

Dynamic Brake Disengage Voltage

ID	Units	Range	Default
PARAM_BRAKE_OFF_VOLTAGE	millivolts	1000 to 40000	37000

This parameter specifies the DC bus voltage at which the braking resistor is disabled.

If this value is too low, the braking resistor may never turn off once enabled; if it is too high, the braking resistor may not stay on for very long or it may cycle on and off very quickly. The value of this parameter must be less than the value of the *Dynamic Brake Engage Voltage* parameter, though this is not enforced by the firmware.

Dynamic Brake Engage Voltage

ID	Units	Range	Default
PARAM_BRAKE_ON_VOLTAGE	millivolts	1000 to 40000	38000

This parameter specifies the DC bus voltage at which the braking resistor is enabled. The braking resistor converts voltage on the DC bus into heat in an attempt to reduce the voltage level on the DC bus.

If this value is too low, the braking resistor could be turned on all the time. If it is too high, the braking resistor may never be turned on (or it may turn on immediately before an over-voltage fault). The value of this parameter must be greater than the value of the *Dynamic Brake Disengage Voltage* parameter, though this is not enforced by the firmware.

DC Bus Deceleration Voltage

ID	Units	Range	Default
PARAM_DECEL_VOLTAGE	millivolts	1000 to 40000	35000

This parameter specifies the DC bus voltage at which the deceleration rate is reduced. A slower deceleration will result in a smaller increase in the DC bus voltage. The deceleration rate is decreased proportional to the amount by which the DC bus voltage exceeds the value of this parameter, with the deceleration reduced to 15 RPM/sec when the DC bus voltage is 64 V above this parameter. Therefore, this acts more aggressively as the DC bus voltage gets higher.

To avoid bouncing the DC bus voltage and therefore, the deceleration rate, a reduced deceleration rate is slowly increased by 15 rpm every millisecond when the DC bus voltage is below the value of this parameter.

Setting the value of this parameter too low (that is, below the normal DC bus voltage) will result in the motor decelerating slower than it could or should. Setting the value of this parameter too high will result in the ineffective control of the DC bus voltage. Setting the value of this parameter at or above the value of the *Maximum DC Bus Voltage* parameter will effectively disable this feature.

Maximum Dynamic Braking Time

ID	Units	Range	Default
PARAM_MAX_BRAKE_TIME	milliseconds	0 to 60000	60000

This parameter specifies the maximum amount of accumulated time that the dynamic brake can be on. Turning on the power resistor causes it to generate heat; turning it off causes that heat to dissipate. A counter increases when the power resistor is on and decreases when it is off. If the counter reaches the value of this parameter, the power resistor is turned off regardless of the DC bus voltage to prevent overheating of the power resistor. Once forced off, the counter must decrease to the value of the *Dynamic Brake Cooling Time* parameter before it can be turned on again (giving it time to cool down before being used again).

If the value of this parameter is too small, the motor drive will not be able to make effective use of the power resistor to control the DC bus voltage. If the value of this parameter is too large, the power resistor may overheat, resulting in permanent damage.

The value of this parameter must be larger than the value of the *Dynamic Brake Cooling Time* parameter, though this is not enforced by the firmware.

Maximum DC Bus Voltage

ID	Units	Range	Default
PARAM_MAX_BUS_VOLTAGE	millivolts	1000 to 40000	40000

This parameter specifies the maximum DC bus voltage that should be present on the motor drive. If the DC bus voltage goes above this value, an over-voltage fault will be triggered and the motor drive will immediately shut down.

Caution – When the motor is being decelerated it acts like a generator, increasing the DC bus voltage. If the motor is decelerated too quickly, the DC bus voltage will rise too high. Left unhandled, the elevated DC bus voltage could cause permanent damage to components on the motor drive board (such as the DC bus capacitors, which are rated for 100 volts).

Minimum DC Bus Voltage

ID	Units	Range	Default
PARAM_MIN_BUS_VOLTAGE	millivolts	1000 to 40000	10000

This parameter specifies the minimum DC bus voltage that should be present on the motor drive. If the DC bus voltage drops below this value, an under-voltage fault will be triggered and the motor drive will immediately shut down.

This will typically only occur when the mains input to the board is disconnected (or the mains power goes out).

Dynamic Braking Enable

ID	Units	Range	Default
PARAM_USE_DYNAM_BRAKE	Boolean	0 to 1	1

This parameter specifies whether dynamic braking should be used; a value of 1 enables dynamic braking and a value of 0 disables it.

Dynamic braking is the use of a power resistor to control the increase in the DC bus voltage caused by decelerating a Brushless DC motor. By using dynamic braking, the motor can be decelerated at a faster rate since the added DC bus voltage rise is counteracted by the power resistor.

PWM Configuration Parameters

High-side Gate Driver Precharge Time

ID	Units	Range	Default
PARAM_PRECHARGE_TIME	milliseconds	0 to 255	2

This parameter specifies the amount of time to precharge the high-side gate driver before starting to drive waveforms to the inverter bridge. The high-side gate drivers have a charge pump that generates the voltage required to drive the high-side gates; this charge pump only operates when there is switching on the corresponding low-side gate. The high-side gate drivers are precharged by driving 50% duty cycle PWM signals to only the low-side gate drivers for the specified time period.

Setting this value too low results in trying to drive PWM signal to the high-side gate drivers before they can turn on the high-side gates. This results in PWM signals that do not make it to the motor. This is a brief phenomenon, and it is typically harmless to bypass the precharge step. Setting this value too high simply results in an increased delay before the motor starts spinning.

PWM Dead Time

ID	Units	Range	Default
PARAM_PWM_DEAD_TIME	20 nanoseconds	25 to 255	100

This parameter specifies the amount of time to delay between turning off one gate on a phase and turning on the other gate. The dead time is required since the turn on and turn off times of the gates do not always match, and the times for the high-side and low-side gates do not always match. This time delay prevents shoot-through current that would occur if both gates were on at the same time (which is a short between the DC bus and ground).

While the dead time prevents damage to the motor and motor drive, it also introduces harmonic distortion into the drive waveforms.

The dead time required by the smart power module on the RDK-ACIM board is 2 uS; this parameter can not be decreased. It can be increased in order to evaluate the performance of the motor with a larger dead time (before building a custom board with a different inverter that required a longer dead time).

PWM Frequency

ID	Units	Range	Default
PARAM_PWM_FREQUENCY	choice	0 to 7	3

This parameter selects the frequency of the PWM signals used to drive the inverter bridge. The PWM frequency can be 8 KHz (parameter value 0), 12.5 KHz (parameter value 1), 16 KHz (parameter value 2), 20 KHz (parameter value 3), 25 KHz (parameter value 4), 40 KHz (parameter value 5), 50 KHz (parameter value 6), or 80 KHz (parameter value 7).

Higher PWM frequencies produce less audible noise in the motor windings (though there may be little or no PWM frequency-induced audible noise in the windings of high quality motors). Higher PWM frequencies also cause higher processor usage due to an increased interrupt rate.

Support for 80 KHz PWM frequency is included but not recommended for use with the `qs-bldc` firmware. This configuration has only been tested with the basic-bldc firmware configured for a single pole-pair motor.

Minimum PWM Pulse Width

ID	Units	Range	Default
PARAM_PWM_MIN_PULSE	1/10th of a microsecond	0 to 250	50

This parameter provides the width of the smallest PWM pulse that will be generated by the motor drive. If the motor drive attempts to produce a PWM pulse that is shorter than this value, it will lengthen the PWM pulse to this value.

Small PWM pulses are removed since they do no useful work. By the time the gate has turned on and is starting to let current flow, it is turned off again by the short pulse. In order to avoid switching that performs no useful work, the pulse is lengthened.

Lengthening PWM pulses results in the introduction of harmonic distortion in the output waveforms.

Waveform Update Rate

ID	Units	Range	Default
PARAM_PWM_UPDATE	PWM periods	0 to 255	0

This parameter specifies the number of PWM periods that occur between recomputations of the output waveforms. The parameter value is the number of periods minus 1; for example, a parameter value of 4 means that the waveform is recomputed every 5 PWM periods.

Smaller update rates mean more frequent recomputation of the output waveform. This results in higher quality waveforms (with less harmonic distortion) at the cost of increased processor usage.

There is an indirection relationship between this parameter, the *PWM Frequency* parameter, and the *Maximum Drive Speed* parameter. The *PWM Frequency* combined with the *Waveform Update Rate* determines the *Maximum Drive Speed* that can be produced by the motor drive without aliasing in the output waveforms. The following equation must be true:

(PWM Frequency / 4) ≥ ((PARAM_MAX_SPEED / 60) * (PARAM_NUM_POLES + 1) * 6)

What this means is that there must be at least four PWM periods for every commutation of the motor. This relation is not enforced by the firmware.

Decay Mode

ID	Units	Range	Default
PARAM_DECAY_MODE	choice	0 to 1	1

This parameter specifies the decay mode used in trapezoid modulation. For a value of 0, fast decay mode is used. For a value off 1, slow decay mode is used.

Slow decay mode enables PWM only on the high side of the active phase, while fast decay mode enables PWM on both high and low side switches. For example, when driving phase A high and B low, in fast decay, both phase A high and B low would be driven with a PWM signal. In slow decay, only phase A high would be driven with PWM. Phase B low would be asserted high.

General Motor Configuration Parameters

Encoder Present

ID	Units	Range	Default
PARAM_ENCODER_PRESENT	Boolean	0 to 1	0

This parameter indicates the presence of an encoder on the rotor shaft.

A parameter value of 1 indicates that an encoder is present. When an encoder is present, the *Number of Encoder Lines* parameter indicates the number of lines in the encoder.

Number of Encoder Lines

ID	Units	Range	Default
PARAM_NUM_LINES	count	0 to 65535	1000

This parameter specifies the number of lines in the encoder, minus 1 (since it is not possible to have a zero line encoder). A line corresponds to a rising edge and a falling edge produced by the encoder. This information is used to convert edges from the encoder into the rotor frequency.

Number of Poles

ID	Units	Range	Default
PARAM_NUM_POLES	count	2 to 254	2[a]

a. Default values are for the BL3056-24 motor. Default values for other motor types may be different.

This parameter specifies the number of poles in the motor. This parameter will always be an even number, and has a minimum value of 2 (since it not possible to have a zero pole motor or a motor with an odd number of poles).

This information is obtained from the motor being used, either from the name plate on the motor or from the data sheet for the motor. The default value is for the BL3056-24 motor. Other motors may have different values.

Sensor Polarity

ID	Units	Range	Default
PARAM_SENSOR_POLARITY	Choice	0 to 1	0

This parameter specifies the polarity of the Hall sensor connected to the motor.

A parameter value of 0 indicates that the Hall sensor inputs are active high. A parameter value of 1 indicates that the Hall sensor inputs are active low.

Sensor Type

ID	Units	Range	Default
PARAM_SENSOR_TYPE	Choice	0 to 2	0

This parameter specifies the type of Hall sensor connected to the motor.

A parameter value of 0 indicates that digital Hall sensors are connected to the motor with 120-degree spacing. A parameter value of 1 indicates that Linear/Analog Hall sensors are connected to the motor. A value of 2 indicates that digital Hall sensors are connected to the motor with 60-degree spacing.

Sensorless Motor Configuration Parameters

Sensorless Hold Time

ID	Units	Range	Default
PARAM_STARTUP_COUNT	milliseconds	1 to 65535	1000

This parameter specifies the amount of time, in milliseconds, to hold the motor position in the initial startup state. Larger inertia loads may require a longer hold time to allow the motor shaft to stabilize before starting the open-loop startup sequence in sensorless mode.

Sensorless BEMF Skip Count

ID	Units	Range	Default
PARAM_BEMF_SKIP_COUNT	count	0 to 255	3

This parameter specifies the number of PWM periods that should be skipped after a commutation before looking for a zero-crossing event.

Sensorless Ending Speed

ID	Units	Range	Default
PARAM_STARTUP_ENDSP	rpm	0 to 60000	1000

When starting up the motor in sensorless mode, this is the open-loop speed at which the motor will be driven at the end of the process.

Sensorless Ending Voltage

ID	Units	Range	Default
PARAM_STARTUP_ENDV	millivolts	1 to 50000	3600

When starting up the motor in sensorless mode, this is the voltage (translated to a PWM duty cycle based on the measured DC Bus Voltage) that is applied to the motor at the end of the process.

Sensorless Ramp Time

ID	Units	Range	Default
PARAM_STARTUP_RAMP	milliseconds	1 to 65535	500

When starting up the motor, this is the amount of time that will be used to ramp both the voltage and speed from their starting values to the ending values. At the end of this time, it is assumed that the motor will be spinning with sufficient speed to generate levels of back EMF voltage that can be detected and used in the closed-loop operation.

Sensorless Starting Speed

ID	Units	Range	Default
PARAM_STARTUP_STARTSP	rpm	0 to 60000	400

When starting up the motor in sensorless mode, this is the open-loop speed at which the motor will be driven at the beginning of the process.

Sensorless Starting Voltage

ID	Units	Range	Default
PARAM_STARTUP_STARTV	millivolts	1 to 50000	1200

When starting to spin the motor in sensorless mode, this is the voltage (translated to a PWM duty cycle based on the measured DC Bus Voltage) that is applied to the motor at the beginning of the process.

Sensorless Threshold Voltage

ID	Units	Range	Default
PARAM_STARTUP_THRESH	millivolts	1 to 50000	500

When attempting to startup the motor, this is the Back EMF voltage threshold below which the motor drive software will not attempt to start the motor. If the voltage is above this value, it is assumed that the motor shaft is still spinning and must be allowed to spin down before attempting a restart.

Informational Parameters

Ethernet TCP Timeout

ID	Units	Range	Default
PARAM_ETH_TCP_TIMEOUT	seconds	0 to 4294967295	10

This parameter specifies the length of time (in seconds) before a TCP connection to the motor drive will timeout when there is no activity on the link. The default value is 10s. A value of 0 is used to disable the timeout function.

Motor Drive Fault Status

ID	Units	Range	Default
PARAM_FAULT_STATUS	flags	n/a	0

This parameter is a read-only value that provides the current status of faults in the motor drive. This value is a bit field, with each bit indicating a different fault condition as follows:

Bit	Fault Condition
0	An emergency stop was requested.
1	The DC bus voltage dropped too low.
2	The DC bus voltage rose too high.
3	The motor current dropped too low.

Bit	Fault Condition
4	The motor current rose too high.
5	The watchdog timer rest the motor.
6	The ambient temperature rose too high.
7	The motor stalled.

These fault conditions are sticky; any fault condition that has occurred will be indicated. A write of any value to this parameter clears all fault conditions.

The motor drive will not operate while a fault condition is indicated in this parameter.

Firmware Version

ID	Units	Range	Default
PARAM_FIRMWARE_VERSION	number	0 to 65535	varies

This read-only parameter provides the version number of the firmware. Changing the value of this parameter in the source code makes it difficult for Stellaris support personnel to determine the firmware in use when trying to provide assistance; this parameter should only be changed after careful consideration.

Maximum Ambient Temperature

ID	Units	Range	Default
PARAM_MAX_TEMPERATURE	degrees Celsius	0 to 85	85

This parameter specifies the maximum ambient temperature that is allowed. If the ambient temperature exceeds this value, an over-temperature fault will be triggered and the motor drive will immediately shut down.

The ambient temperature is an approximation of the ambient temperature on the top of the microcontroller’s package (which is relatively removed from the heat sink and the smart power module which generates a majority of the heat). The junction temperature of the microcontroller is measured with the ADC and the on-chip temperature sensor and used to approximate the ambient temperature as determined by lab characterization of the transfer function.

Motor Drive Status

ID	Units	Range	Default
PARAM_MOTOR_STATUS	enumeration	n/a	0

This parameter is a read-only value that provides the current operating status of the motor drive. The value will be one of the following:

Value	Meaning
0	The motor drive is stopped.
1	The motor drive is running.
2	The motor drive is accelerating.
3	The motor drive is decelerating.

On-board User Interface Enable

ID	Units	Range	Default
PARAM_USE_ONBOARD_UI	Boolean	0 to 1	1

This parameter determines whether the on-board user interface elements can be used to control the motor drive. If the value of this parameter is 1, the on-board user interface will control the motor drive; if 0 they will not.

The motor drive can always be operated over the Ethernet interface.

The on-board user interface is disabled by the BLDC GUI upon startup and re-enabled on exit.

Real-Time Data Items

Table A-2 provides a summary of all real-time data items. See “Real-Time Data Items Descriptions” on page 60 for more information.

Table A-2. Real-Time Data Items

ID	Units	Range	Default	See
DATA_BUS_VOLTAGE	millivolts	0 to 40000	varies	page 61
DATA_FAULT_STATUS	flags	n/a	varies	page 60
DATA_MOTOR_CURRENT	milliampere	-32768 to 32767	varies	page 61
DATA_MOTOR_STATUS	enumeration	n/a	varies	page 60
DATA_PHASE_A_CURRENT	milliampere	-32768 to 32767	varies	page 61
DATA_PHASE_B_CURRENT	milliampere	-32768 to 32767	varies	page 61
DATA_PHASE_C_CURRENT	milliampere	-32768 to 32767	varies	page 61

Table A-2. Real-Time Data Items (Continued)

ID	Units	Range	Default	See
DATA_PROCESSOR_USAGE	%	0 to 100	varies	page 60
DATA_ROTOR_SPEED	RPM	0 to 60000	varies	page 60
DATA_TEMPERATURE	degrees Celsius	0 to 85	varies	page 62

Real-Time Data Items Descriptions

This section describes the real-time data items in detail. The data items are grouped into two areas: motor speed and measurement.

Drive Status Parameters

Motor Drive Status

ID	Units	Range
DATA_MOTOR_STATUS	enumeration	n/a

This real-time data item provides the current status of the motor drive. This is the same data in the same format as the *Motor Drive Status* parameter.

Motor Drive Fault Status

ID	Units	Range
DATA_FAULT_STATUS	flags	n/a

This real-time data item provides the current fault status of the motor drive. This is the same data in the same format as the *Motor Drive Fault Status* parameter.

Processor Usage

ID	Units	Range
DATA_PROCESSOR_USAGE	%	0 to 100

This real-time data item provides the percentage of the processor being used.

Motor Speed Parameters

Current Rotor Speed

ID	Units	Range
DATA_ROTOR_SPEED	RPM	0 to 60000

This real-time data item provides the current speed of the motor’s rotor.

Measurement Parameters

DC Bus Voltage

ID	Units	Range
DATA_BUS_VOLTAGE	millivolts	0 to 40000

This real-time data item provides the DC bus voltage. The DC bus under-voltage and over-voltage faults trigger based on the value of this real-time data item, and the dynamic braking and reduced deceleration controls operated based on this value as well.

Motor Phase A Current

ID	Units	Range
DATA_PHASE_A_CURRENT	milliampere	-32768 to 32767

This real-time data item provides the current for the A phase of the motor.

Motor Phase B Current

ID	Units	Range
DATA_PHASE_B_CURRENT	milliampere	-32768 to 32767

This real-time data item provides the current for the B phase of the motor.

Motor Phase C Current

ID	Units	Range
DATA_PHASE_C_CURRENT	milliampere	-32768 to 32767

This real-time data item provides the current for the C phase of the motor.

Motor Current

ID	Units	Range
DATA_MOTOR_CURRENT	milliampere	-32768 to 32767

This real-time data item provides the current for the entire motor.

Ambient Temperature

ID	Units	Range
DATA_TEMPERATURE	degrees Celsius	0 to 85

This real-time data item provides the ambient temperature on the top of the microcontroller's package, as inferred by measuring the microcontroller's junction temperature. The over-temperature fault triggers based on the value of this real-time data item.

Motor Power

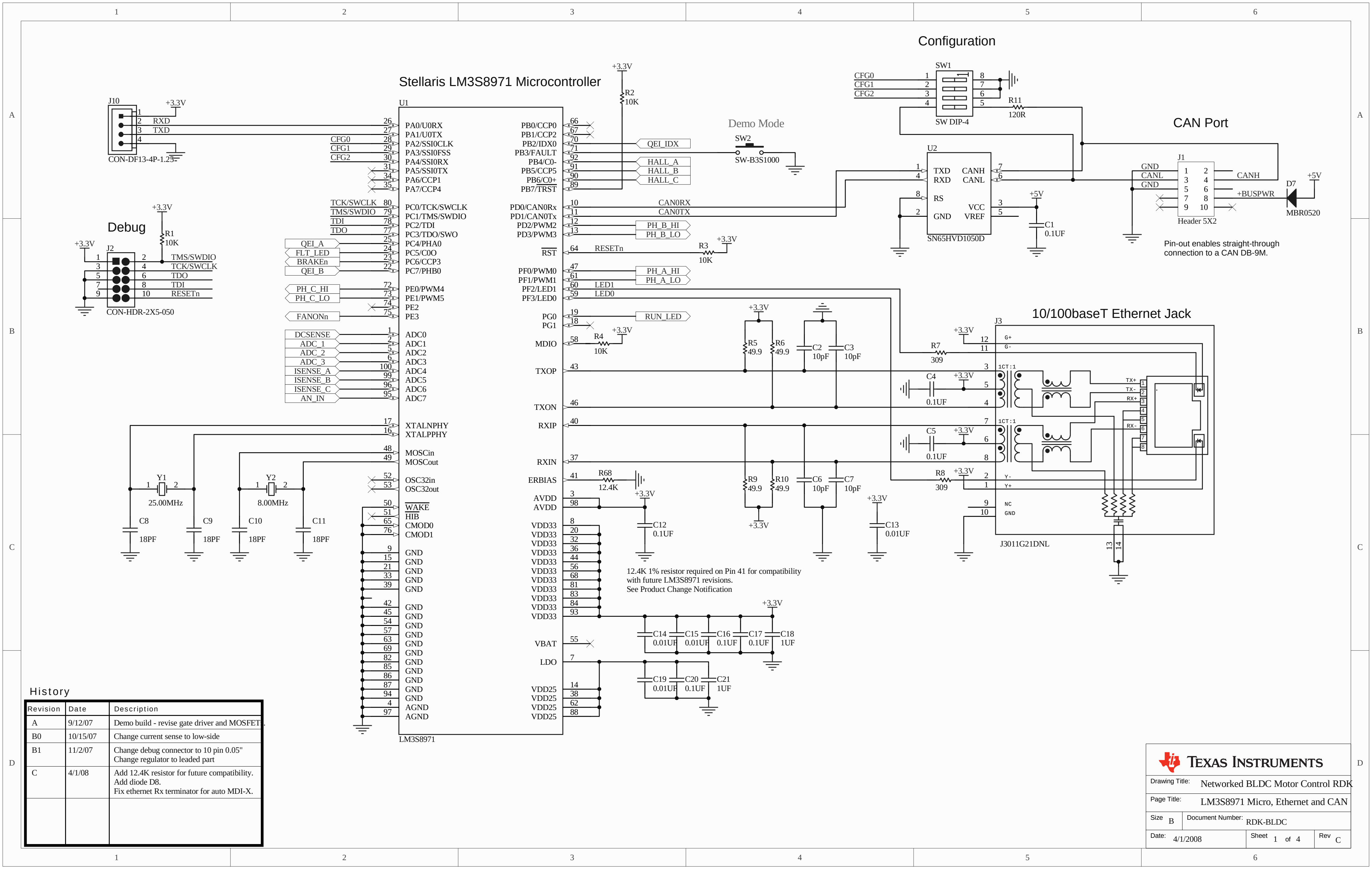
ID	Units	Range
DATA_MOTOR_POWER	milliwatts	0 to 360000

This real-time data provides the motor operating power. This power is calculated as the bus voltage times the measured motor current times the duty cycle of the PWM output wave form.

APPENDIX B

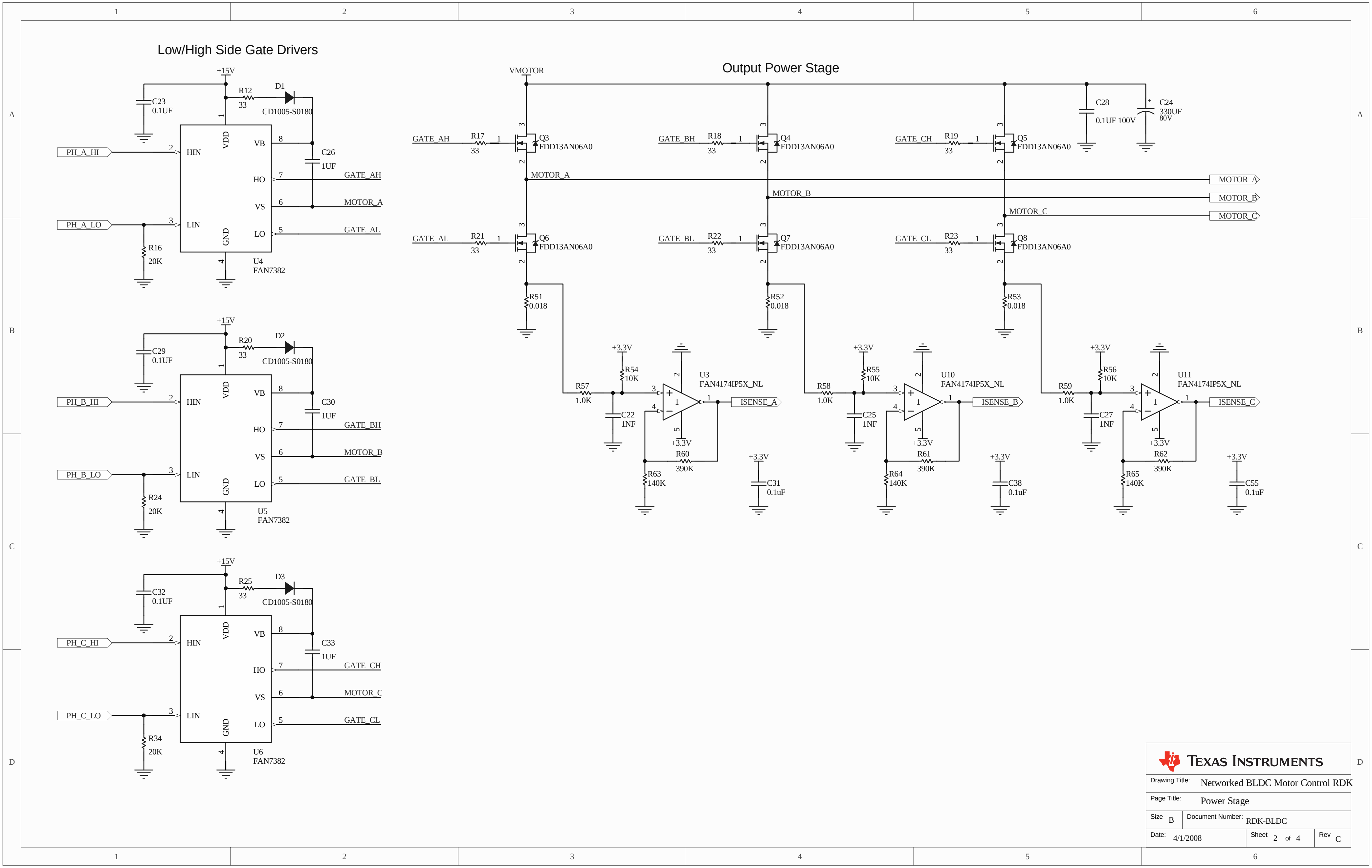
Schematics

This section contains the schematics for the BLDC Motor Control Board:

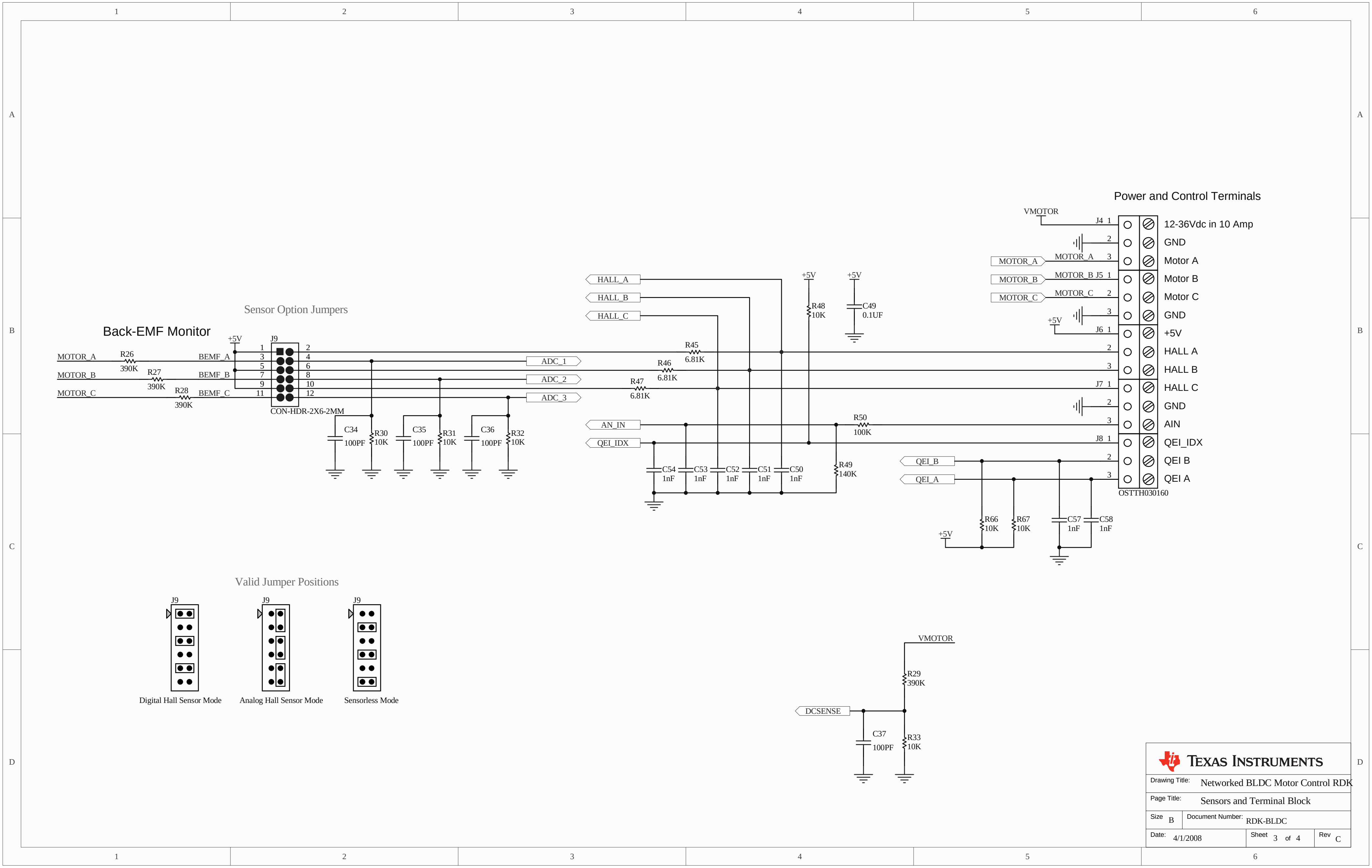


History

Revision	Date	Description
A	9/12/07	Demo build - revise gate driver and MOSFET.
B0	10/15/07	Change current sense to low-side
B1	11/2/07	Change debug connector to 10 pin 0.05" Change regulator to leaded part
C	4/1/08	Add 12.4K resistor for future compatibility. Add diode D8. Fix ethernet Rx terminator for auto MDI-X.



Texas Instruments
Drawing Title: Networked BLDC Motor Control RDK
Page Title: Power Stage
Size B | Document Number: RDK-BLDC
Date: 4/1/2008 | Sheet 2 of 4 | Rev C


Power and Control Terminals
VMOTOR
J4
12-36Vdc in 10 Amp
GND
Motor A
Motor B
Motor C
GND
+5V
HALL A
HALL B
HALL C
GND
AIN
QEI_IDX
QEI B
QEI A
MOTOR_A
MOTOR_B
MOTOR_C
J5
J6
J7
J8
OSTTH030160
HALL_A
HALL_B
HALL_C
+5V
R48
10K
C49
0.1UF
Sensor Option Jumpers
Back-EMF Monitor
R26
390K
R27
390K
R28
390K
BEMF_A
BEMF_B
BEMF_C
J9
CON-HDR-2X6-2MM
ADC_1
ADC_2
ADC_3
R45
6.81K
R46
6.81K
R47
6.81K
C34
100PF
R30
10K
C35
100PF
R31
10K
C36
100PF
R32
10K
AN_IN
QEI_IDX
R50
100K
C54
1nF
C53
1nF
C52
1nF
C51
1nF
C50
1nF
R49
140K
QEI_B
QEI_A
R66
10K
R67
10K
C57
1nF
C58
1nF
Valid Jumper Positions
Digital Hall Sensor Mode
Analog Hall Sensor Mode
Sensorless Mode
R29
390K
DCSENSE
C37
100PF
R33
10K
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Drawing Title: Networked BLDC Motor Control RDK
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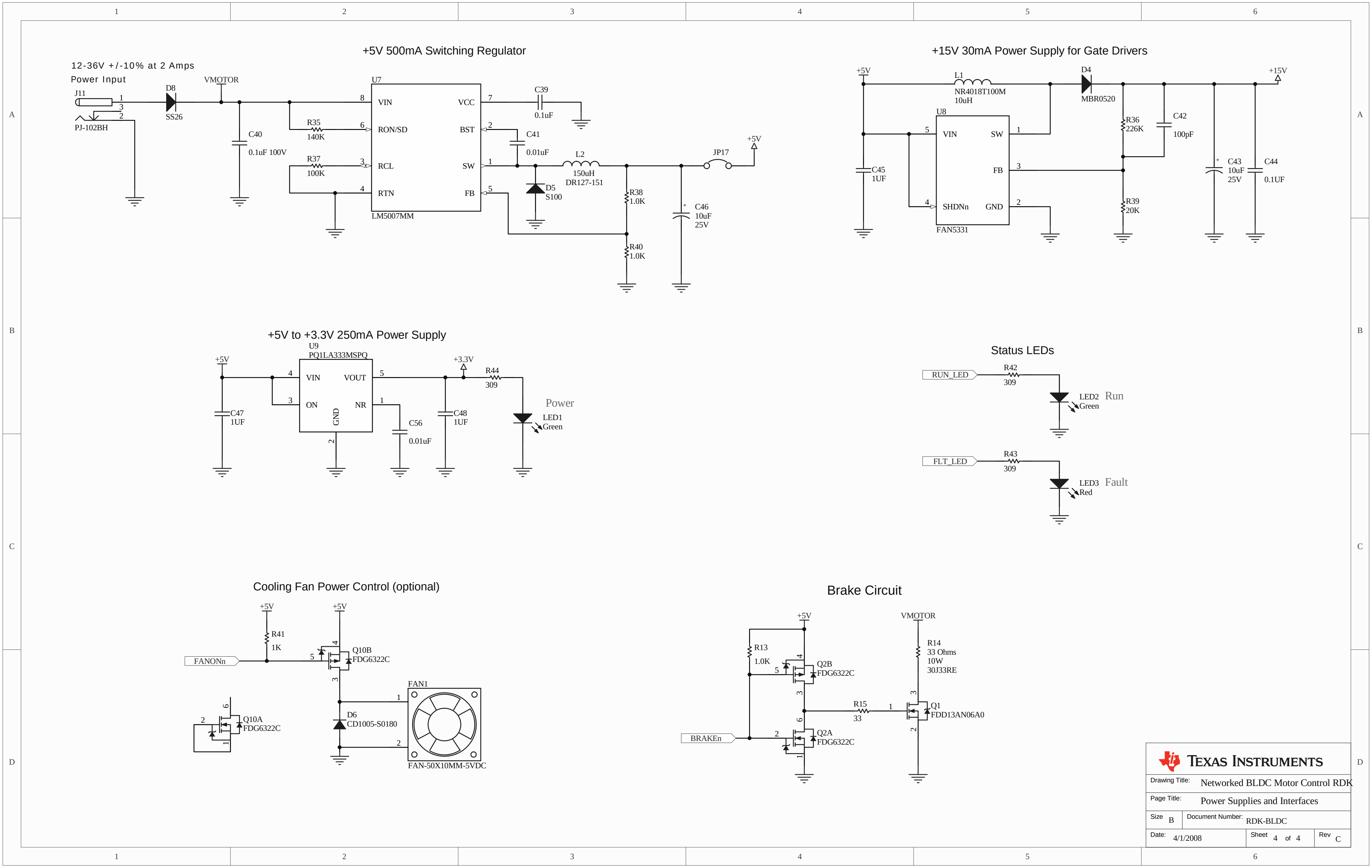
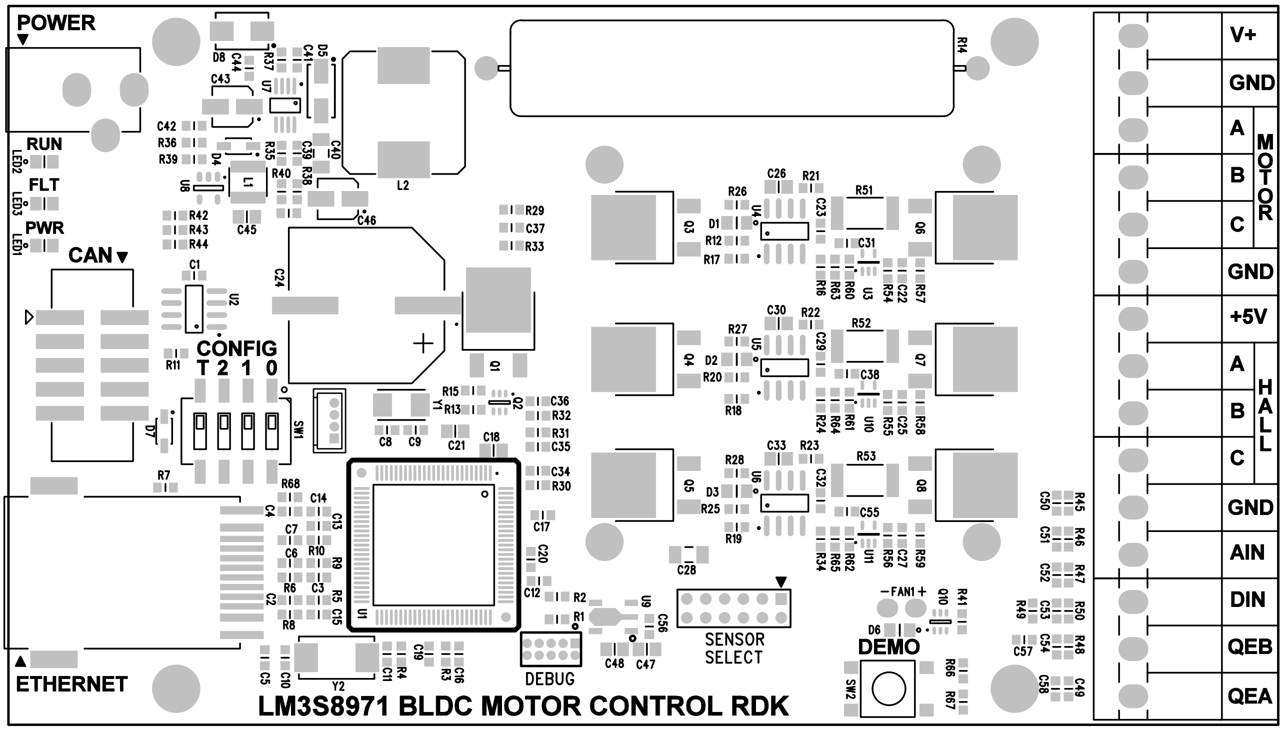

+5V 500mA Switching Regulator
12-36V +/-10% at 2 Amps
Power Input
J11
PJ-102BH
D8
SS26
VMOTOR
C40
0.1uF 100V
R35
140K
R37
100K
U7
VIN
RON/SD
RCL
RTN
VCC
BST
SW
FB
LM5007MM
C39
0.1uF
C41
0.01uF
L2
150uH
DR127-151
D5
S100
R38
1.0K
R40
1.0K
JP17
+5V
C46
10uF
25V
+15V 30mA Power Supply for Gate Drivers
+5V
L1
NR4018T100M
10uH
D4
MBR0520
+15V
U8
VIN
SW
FB
SHDNn
GND
FAN5331
C45
1UF
R36
226K
C42
100pF
R39
20K
C43
10uF
25V
C44
0.1UF
+5V to +3.3V 250mA Power Supply
U9
PQ1LA333MSPQ
+5V
VIN
ON
GND
VOUT
NR
C47
1UF
C56
0.01uF
C48
1UF
+3.3V
R44
309
Power
LED1
Green
Status LEDs
RUN_LED
R42
309
LED2
Green
Run
FLT_LED
R43
309
LED3
Red
Fault
Cooling Fan Power Control (optional)
+5V
R41
1K
FANONn
Q10B
FDG6322C
Q10A
FDG6322C
D6
CD1005-S0180
FAN1
FAN-50X10MM-5VDC
Brake Circuit
+5V
VMOTOR
R13
1.0K
Q2B
FDG6322C
Q2A
FDG6322C
BRAKEn
R15
33
R14
33 Ohms
10W
30J33RE
Q1
FDD13AN06A0
TEXAS INSTRUMENTS
Drawing Title: Networked BLDC Motor Control RDK
Page Title: Power Supplies and Interfaces
Size B
Document Number: RDK-BLDC
Rev C
Date: 4/1/2008
Sheet 4 of 4

PCB Component Locations

This section shows the PCB component locations for the BLDC RDK.



A P P E N D I X D

Bill of Materials (BOM)

This section provides the BOM for the BLDC RDK.

Item	Ref	Qty	Part Number	Description	Mfg	Supplier	Stock No
1	C1, C4, C5, C12, C16, C17, C20, C23, C29, C31, C32, C38, C39, C44, C49, C55	16	PCC2398CT-ND	Capacitor, 0.1uF 50V 10% 0603 X7R	Panasonic	Digikey	PCC2398CT-ND
2	C13, C14, C15, C19, C41, C56	6	C0603C103J5RACTU	Capacitor, 0.01uF 50V 5% 0603 X7R	Kemet	Mouser	80-C0603C103J5R
3	C18, C21, C26, C30, C33, C45, C47, C48	8	TMK212BJ105KG-T	Capacitor 1.0uF 25V X5R 0805	Taiyo Yuden	Digikey	587-1291-1-ND
4	C2, C3, C6, C7	4	C0603C100J5GACTU	Capacitor 10pF 50V 5% Ceramic NPO/COG 0603	Kemet	Mouser	80-C0603C100J5G
5	C22, C25, C27, C50, C51, C52, C53, C54, C57, C58	10	C0603C102K5RACTU	Capacitor 1nF 50V 10% X7R 0603	Kemet	Mouser	80-C0603C102K5R
6	C24	1	EEV-FK1J471M	Capacitor, 470uF 63V Electro, Low Z, SMT Size J16	Panasonic	Digikey	PCE3485TR-ND
7	C28, C40	2	C1206C104K1RACTU	Capacitor, 0.1uF 100V 10% 1206 X7R	Kemet	Mouser	80-C1206C104K1
8	C34, C35, C36, C37, C42	5	C0603C101K5GACTU	Capacitor 100pF 50V 10% 0603 COG	Kemet	Mouser	80-C0603C101K5G
9	C43, C46	2	EEE-FK1E100R	Capacitor, 10uF 25V Electro, Low Z, SMT Size B	Panasonic	Digikey	PCE3795TR-ND
10	C8, C9, C10, C11	4	C0603C180J5GACTU	Capacitor 18pF 50V 5% Ceramic NPO/COG 0603	Kemet	Mouser	80-C0603C180J5G
11	D1, D2, D3, D6	4	CD1005-S0180	Diode, 80V high speed 1005 size	Bourns	Mouser	652-CD1005-S0180
12	D4, D7	2	MBR0520L	Diode, Schottky 500mA 20V SOD123	Fairchild	Arrow/Mouser	MBR0520L
13	D5	1	S100	Diode Schottky 100V 2A	Fairchild	Mouser	512-S100
14	J1	1	N2510-6V0C-RB-WE AWHW10A-0202-T-R	Connector, 10 way dual LP shrouded header vert SMT	4ucon /3M/ Assmann	4Ucon / Digikey	03585 / MSH10KCT-ND / HLN10H-ND
15	J2	1	M50-3500542	Connector, 2x5 Header 1.27mm pitch	Harwin	Mouser	855-M50-3500542
16	J3	1	J3011G21DNL	Connector, RJ45 with 10/100 magnetics, shielded SMT	Pulse	Arrow	J3011G21DNL
17	J4a, J5a, J6a, J7a, J8a	5	OSTTH030160	Terminal Block 3 pos 5mm pluggable	OST	Digikey	ED2656-ND
18	J10	1	PJ-102AH	Connector, 2.1mm DC power socket high-current	CUI	Digikey	CP-102AH-ND
19	J4-8b	1	EDSTL130/15	Pin Header 15 pos Tin 5mm	OST	Digikey	ED1673-ND
20	J9a	1	M22-2520605 PRPN062PAEN-RC	Header, 12 pin (2x6), 2mm pitch	Harwin Sullins	Mouser Digikey	855-M22-2520605 S5801-06-ND
21	J9b	3	M22-1900005	Jumper Shunt 2mm gold	Harwin	Mouser	855-M22-1900005
22	L1	1	NR4018T100M	Inductor 10uH 1A 4x4mm	Taiyo Yuden	Digikey	587-1664-2-ND
23	L2	1	DR127-151-R	Inductor, 150uH Power SMT	Coiltronics	Digikey	
24	LED1, LED2	2	LTST-C171GKT	LED, 0805 SMT Green	LiteOn	Mouser / Arrow	LTST-C171GKT
25	LED3	1	LTST-C171EKT	LED, 0805 SMT Red	LiteOn	Mouser / Arrow	LTST-C171EKT
26	Q1, Q3, Q4, Q5, Q6, Q7, Q8	7	FDD13AN06A0	Mosfet N-Channel 60V 50A DPAK	Fairchild	Mouser	512-FDD13AN06A0
27	Q2, Q10	2	FDG6322C	Mosfet P-N Channel Complementary Pair 25V SC70-6	Fairchild	Digikey	FDG6322CTR-ND
28	R1, R2, R3, R4, R30, R31, R32, R33, R48, R54, R55, R56, R66, R67	14	P10.0KHCT-ND	Resistor, 10K 1% 0603	Panasonic	Digikey	P10.0KHCT-ND
29	R45, R46, R47	3	P6.81KHCT-ND	Resistor 6.81K 1% 0603	Panasonic	Digikey	P6.81KHCT-ND
30	R11	1	P120GCT-ND	Resistor, 120 ohms 5% 0603	Panasonic	Digikey	P120GCT-ND
31	R12, R15, R17, R18, R19, R20, R21, R22, R23, R25	10	P33GCT-ND	Resistor, 33 ohms 5% 0603	Panasonic	Digikey	P33GCT-ND
32	R13, R38, R40, R41, R57, R58, R59	7	P1.00KHCT-ND	Resistor 1.0K 1% 0603	Panasonic	Digikey	P1.00KHCT-ND
33	R14	1	30J33RE	Resistor 33 ohms 10W Wirewound	Ohmite	Mouser	588-30J33RE
34	R16, R24, R34, R39	4	P20.0KHCT-ND	Resistor 20.0K 1% 0603	Panasonic	Digikey	P20.0KHCT-ND
35	R26, R27, R28, R29, R60, R61, R62	6	CRCW0603390KFKEA	Resistor 390K 1% 0603	Vishay	Digikey	541-390KHCT-ND
36	R35, R49, R63, R64, R65	5	P140KHCT-ND	Resistor 140K 1% 0603	Panasonic	Digikey	P140KHCT-ND
37	R36	1	P226KHCT-ND	Resistor 226K 1% 0603	Panasonic	Digikey	P226KHCT-ND
38	R37, R50	2	P100KHCT-ND	Resistor 100K 1% 0603			P100KHCT-ND
39	R5, R6, R9, R10	4	P49.9HCT-ND	Resistor 49.9 Ohms 1% 0603	Panasonic	Digikey	P49.9HCT-ND
40	R51, R52, R53	3	LRF2512LF-01-R018-FT	Resistor 0.018 Ohms 2W 1% 2512	IRC	TTI	LRF2512LF-01-R018-FT
41	R7, R8, R42, R43, R44	5		Resistor 309 Ohms 0603			
42	SW1	1	219-4MST	Switch, DIP 4 position SMT Medium actuator	CTS	Digikey	CT2194MST-ND
43	SW2	1	B3S-1000P	Switch, Momentary Tact 160gmf 6mm	Omron	Arrow / Future	SW415-ND
44	U1	1	LM3S8971	IC, Microcontroller ARM Cortex TQFP-100	Texas Inst	Texas Inst	LM3S8971
45	U2	1	SN65HVD1050D	IC, CAN Transceiver SO-8	TI	Arrow / Digikey	296-19416-5-ND
46	U3, 10, U11	3	FAN4174IP5X_NL	IC, Op-amp Rail-to-Rail SC70-5	Fairchild	Mouser	512-FAN4174IP5X
47	U4, U5, U6	3	FAN7382MX	IC, High-Low Side Gate Driver SO-8	Fairchild	Mouser	512-FAN7382MX
48	U7	1	LM5007MM	IC, Integrated Step-down converter	National	Digikey	LM5007MMCT-ND
49	U8	1	FAN5331SX	IC, Boost Converter SOT23-5	Fairchild	Mouser	512-FAN5331SX
50	U9	1	PQ1LA333MSPQ	IC, Voltage regulator 3.3V 500mA SOT89-5	Sharp	Mouser	852-PQ1LA333MSPQ
51	Y1	1	NX5032GA-25.000000MHZ	Crystal, 25.00MHz 5.0x3.2mm SMT	NDK	Digikey	644-1041-2-ND
52	Y2	1	NX8045GB-8.000000MHZ	Crystal, 8.00MHz 8.0x4.5mm SMT	NDK	Digikey	644-1018-2-ND
53	Z1	4	SJ-5306 CLEAR	Rubber feet - hemisphere clear .15x.375	3M	Mouser	517-SJ-5306CL
54	Z2	1	RDK-LM3S8971-B1	PCB, FR-4 4-layer Rev B1	Advanced	Advanced	RDK-LM3S8971-B