Stellaris® Stepper Motor Reference Design Kit

User's Manual

Copyright © 2007–2009 Texas Instruments

Copyright

Copyright © 2007–2009 Texas Instruments, Inc. All rights reserved. Stellaris and StellarisWare are registered trademarks of Texas Instruments. ARM and Thumb are registered trademarks, and Cortex is a trademark of ARM Limited. Other names and brands may be claimed as the property of others.

Texas Instruments
108 Wild Basin, Suite 350
Austin, TX 78746
Main: +1-512-279-8800
Fax: +1-512-279-8879
http://www.luminarymicro.com

Table of Contents

Chapter 1: Stellaris® Stepper Motor Reference Design Kit Overview 9
Using the RDK 9
Features 9
Motor Technology 10
Introduction to Stepper Motors 10
Chopper Control 11
RDK Specifications 12
Electrical 12
Mechanical 12
Chapter 2: User Interfaces 13
On-board User Interface 13
Speed Mode 14
Position Mode 14
Graphical User Interface 15
File Menu 18
Configuration Window 18
Chapter 3: Hardware Description 21
Block Diagram 22
Functional Description 22
Microcontroller (Schematic Pages 1-2) 22
Output Power Stage (Schematic Page 3) 23
Control Interfaces (Schematic Page 4) 24
Software 24
Chopper Control 24
Parameter Reference 26
Serial Protocol 26
Appendix A: Parameters 27
Parameter Descriptions 27
Motor Running Configuration 28
Target Position 28
Maximum Current 28
Target Speed 28
Acceleration 28
Deceleration 29
Motor Drive Configuration 29
Winding Resistance 29
PWM Frequency 29
Fixed Rise Time 29
Drive Current 30
Holding Current 30
Control Mode 30
Decay Mode 31
Step Mode 31
Off Blanking Time 31

Appendix B: Schematics **33**
Appendix C: PCB Component Locations **39**
Appendix D: Bill of Materials (BOM) **41**

List of Tables

Table 1-1. RDK Motor Specifications 11
Table 2-1. Description of GUI Main Window Controls 16
Table 2-2. Description of Configuration Controls 19
Table 3-1. Current Monitoring Circuits 23
Table A-1. Parameter Configuration Summary 27

List of Figures

Figure 1-1. Stepper Motor 10
Figure 1-2. Stepper Speed-Torque Curve 11
Figure 2-1. On-board User Interface 13
Figure 2-2. Stepper Main GUI Window 15
Figure 2-3. Configuration Window 19
Figure 3-1. Stepper Motor Control RDK Layout 21
Figure 3-2. Block Diagram 22
Figure 3-3. Chopper Waveform Generation 25
Figure 3-4. Current Control Software Flow 25

CHAPTER 1

Stellaris® Stepper Motor Reference Design Kit Overview

Stellaris Reference Design Kits (RDKs) from Texas Instruments 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 Stepper Motor Control RDK (Stepper RDK).

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 more than a dozen operating parameters. Parameters and data transfer between the RDK control board and PC over a USB cable.
- **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 your project. 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).

Features

The Stepper RDK's primary application is driving NEMA17, NEMA23, and NEMA34 stepper motors rated at up to 80 V at 3 Amps. The Stepper RDK uses software-based chopper control in order to operate the motor at both high torque and high-step rates. The Stepper RDK has the following features:

- Advanced chopper control of bipolar stepper motors
- Flexible platform accelerates integration process
- Fast and slow decay modes
- Full-Step, Half-Step, Micro-Step, and Wave modes
- High step rates up to 10,000 steps/sec (with suitable motor)
- Programmable holding current
- Integrated USB Virtual COM port
- Bootloader for firmware upgrades over serial port
- Support for external debugger through standard 20-pin ARM header

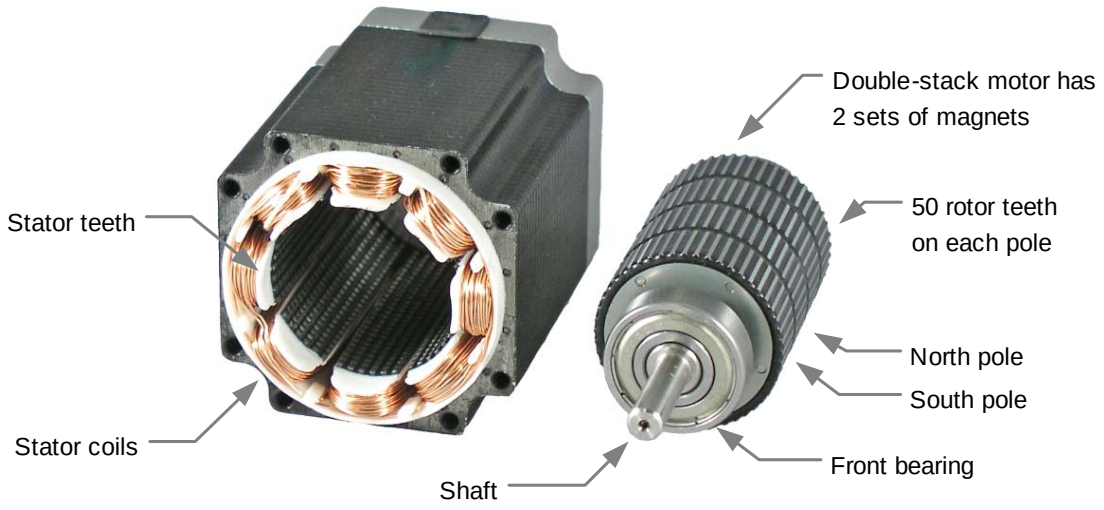
Motor Technology

Introduction to Stepper Motors

Stepper motors are synchronous DC motors which rotate in precise increments as their coils are energized. Stepper motors typically have step angles of 0.9°, 1.8°, 7.5°, or 15°. The motor in the RDK has a step angle of 1.8° for a total of 200 steps per revolution. Figure 1-1 shows a detailed photo of the NEMA23 stepper motor included in the RDK.

There are several different families of steppers motors, some with and some without permanent magnets (PM). The most common type in industrial applications is known as a hybrid stepper motor because it combines attributes from PM and non-PM motor construction.

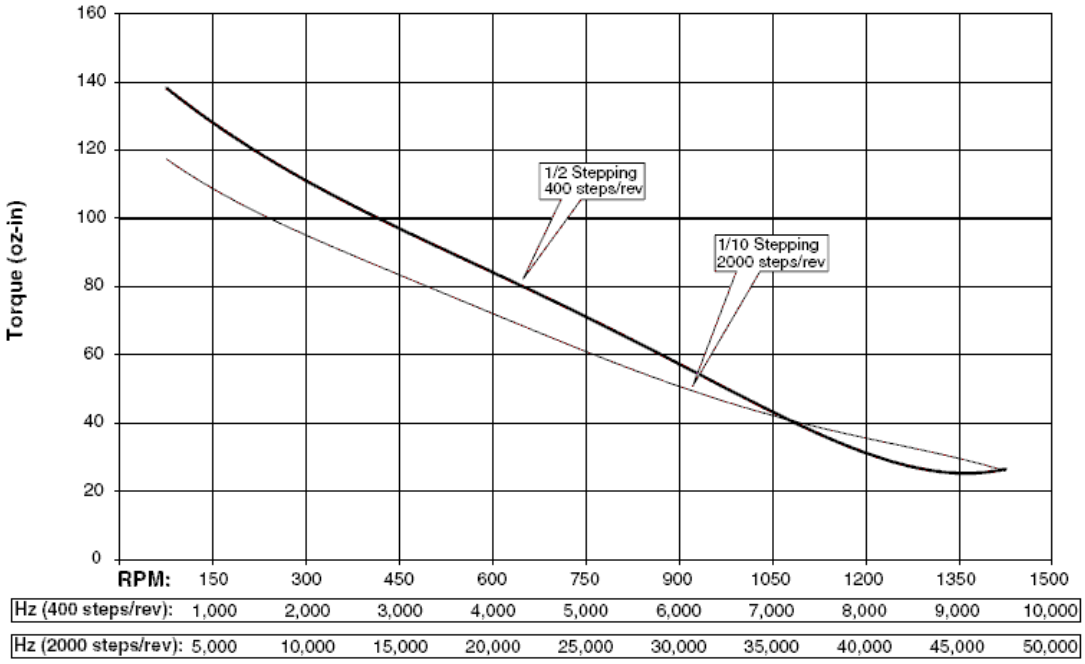
Figure 1-1. Stepper Motor



The rotor on a hybrid stepper motor typically has 200 teeth made from a suitable magnetic material and surrounding one or more powerful embedded magnets. As the stator phase is energized, the opposing pole in the next rotor tooth is attracted, resulting in a single-step.

Note that the torque curve of stepper motors is far from linear (see Figure 1-2). For each step, the motor develops peak torque when the rotor teeth are offset by one-quarter tooth pitch from the opposing pole in the energized phase. Also, overall motor torque drops considerably as motor speed increases. For this reason stepper motor torque is specified as the holding torque, or torque with no angular motion.

Figure 1-2. Stepper Speed-Torque Curve



The Stepper RDK operates bipolar stepper motors with two coils—probably the most common class of stepper motor. Bipolar refers to the fact that the stepping sequence requires coil current to flow in alternating directions. By comparison, unipolar motors require current in only one direction and are simpler to drive, but have much lower torque for the same frame size.

Stepper motors are designed for accurate open-loop positioning, and not for high efficiency. As a result, stepper motors operate at high temperatures. Current to the motor should be adjusted so that the motor case temperature never exceeds 100°C.

Chopper Control

A stepper motor can be operated at its rated DC voltage, but only low step rates are possible. This is because the current builds comparatively slowly in the stator coil.

To overcome this, chopper control uses a supply voltage much higher than the motor's rating. This allows the coil current to increase rapidly to the desired level before the control starts modulating or *chopping* the voltage to maintain that level. This allows higher step rates with more torque. A supply of 5-20 times the motor's DC voltage is commonly used.

Table 1-1. RDK Motor Specifications

Motor Frame Size	NEMA23
Holding Torque	166 oz-in (1.29 Nm)
Rated Current	2.8 A/phase
Coil Resistance	0.75Ω
Step Angle	1.8°

RDK Specifications

This reference design meets the following specifications.

Electrical

- Supported motor type: Bipolar stepper
- Motor current (rated current per coil): 3 Amps
- Motor voltage (continuous coil voltage): 1-80 V_{dc}
- Supply Voltage: 9-80 V_{dc}

Mechanical

- PCB size: 4.6" x 2.8" x 0.75” (117 mm x 71 mm x 19 mm)
- No heat sink necessary

CHAPTER 2

User Interfaces

The Stepper RDK firmware provides control of the stepper motor. It makes use of many of the features of the Stellaris microcontroller to perform the stepping function, reducing the number of external parts needed. In addition, the stepping firmware can be integrated with the user's application, eliminating the need for separate microcontrollers for the stepping and application functions.

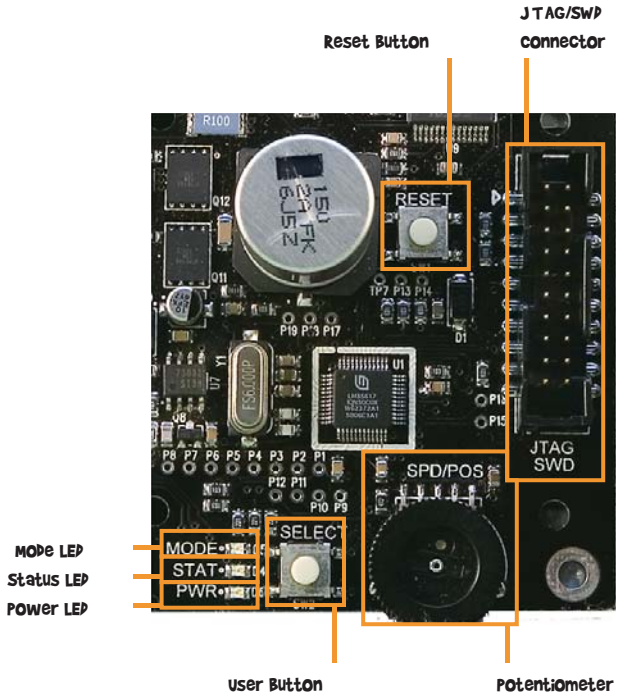
The Stepper RDK firmware generates a stepping sequence as needed to run the motor at the specified speed. It also computes acceleration and deceleration ramps to smoothly change the motor speed between stopped and target speed. It switches voltage to the control signals of the H-bridge in order to drive the correct current to the motor windings at each step in a stepping sequence.

The Stepper RDK firmware can be controlled in two ways. The simplest way is using the on-board interface, which allows the user control of the motor speed or position using controls available on the RDK board. For more complex control, a PC-hosted graphical program is available which not only allows setting of speed and position, but also a number of other parameters for tuning the motor operation (see "Graphical User Interface" on page 15).

On-board User Interface

The on-board user interface provides a way for the user to operate the stepper motor using just the controls provided on the stepper RDK board. The controls that can be used are a potentiometer, a push button, and two LEDs. See Figure 2-1 for a photo of the on-board controls.

Figure 2-1. On-board User Interface



The on-board user interface can operate in two modes: Speed mode and Position mode. In Speed mode, the motor runs continuously at a speed and direction that can be controlled by the user. In Position mode, the motor runs to a position controlled by the user. The starting mode is Speed mode.

The following on-board controls are available:

- Reset button: Restarts the stepper RDK software. The software enters Speed mode.
- User button: Switches between on-board UI modes, and starts and stops the motor. To change modes, hold down the user button for five seconds. To start and stop the motor, press and release the button. If a fault occurs (the status LED is blinking rapidly), press and hold the user button for five seconds to clear the fault. Doing this will not change modes.
- Potentiometer knob: The potentiometer is used to adjust the speed of the motor when Speed mode is used, and is used to adjust the position of the motor when Position mode is used.
- Mode LED: Informs the user which mode is selected by blinking a pattern.
- Status LED: Indicates the motor speed by blink rate. Also indicates a fault with rapid blinking.

Speed Mode

Upon entering Speed mode, the mode LED blinks one time. This is the default when the board is first powered, or after the reset button is pressed. To enter Speed mode from Position mode, press and hold the user button for five seconds, until the mode LED blinks one time.

In Speed mode, the motor runs at a speed that is controlled by the position of the potentiometer knob. Upon entering Speed mode, the motor is stopped. To start the motor running, press the user button. The motor begins running in the forward direction. Forward is designated as clockwise. Use the user button to start and stop the motor. Each time the button is pressed, the motor either starts running if it is stopped, or stops if it is already running. Each time the motor starts running, it runs in the opposite direction from the previous time.

The potentiometer knob is used to change the motor speed. The motor runs at a minimum speed of 10 steps/second when the knob is turned all the way to the left (counterclockwise), and at a maximum of about 1000 steps/second when the knob is turned all the way to the right (clockwise).

The status LED blinks at a rate that varies according to the motor speed.

Caution – Do not leave the motor running for long periods of time. If the motor is not attached to a heat sink, the case can get very hot, especially if a high drive current is used.

Position Mode

Upon entering Position mode, the mode LED blinks twice. To enter Position mode from Speed mode, press and hold the user button for five seconds, until the mode LED blinks two times.

In Position mode, the motor always runs to a position that is determined by the position of the potentiometer. When the potentiometer is moved, the motor moves to the new position. The input from the potentiometer is scaled so that the motor turns one revolution (at 200 steps/revolution) as the knob is turned from one extreme to the other. The motor turns in the same direction as the potentiometer knob.

In Position mode, the motor is enabled by default and turns as soon as the knob is turned. If the button is pressed, then the motor is disabled and does not run when the knob is turned. The motor can be re-enabled by pressing the user button again.

Graphical User Interface

The stepper motor RDK board can be controlled from a graphical user interface (GUI) program running on a PC. Using the GUI provides much greater control of the motor than the on-board interface. Use the GUI to set specific values for position, speed, acceleration, and deceleration, as well as a number of other parameters to tune the operation of the motor. The GUI program communicates with the RDK board using a virtual serial port over a USB cable.

Upon starting the GUI program, the on-board interface on the RDK board is disabled, and the knob and button have no effect.

If the program has not been used before, then a dialog box appears that lets the user select the COM port to use. Once a COM port is selected, the program remembers the selection and does not ask again. However, at any time the user can re-open the COM port dialog box by double-clicking on the COM port indicator on the main panel.

The stepper motor operation is controlled from the main window (see Figure 2-2). 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 2-2. Stepper Main GUI Window

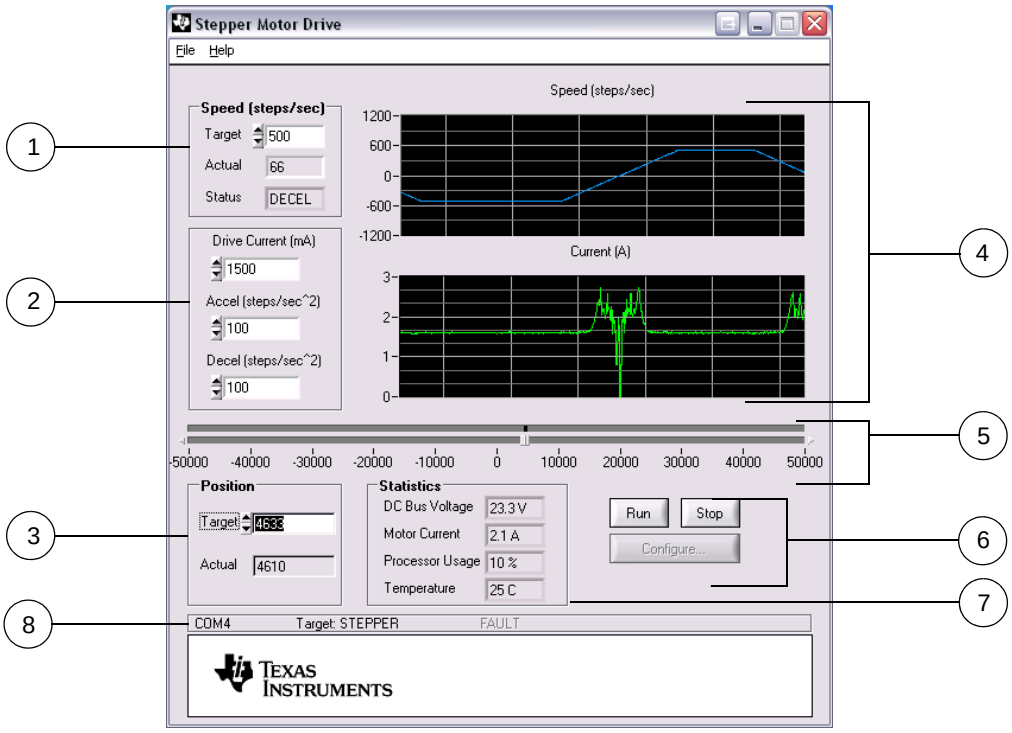


Table 2-1. Description of GUI Main Window Controls

Item No.	Name	Description
1	**Speed and Status Area**	
	Target	Sets the motor running speed in steps per second. The desired speed can be typed into the box. If the motor is already running, it changes speed to match.
	Actual	Indicates the actual motor running speed in steps per second. This value is calculated in the RDK firmware, it is not actually an independent measurement of motor speed.
	Status	Indicates if the motor is stopped, running, accelerating, or decelerating.
2	**Drive Settings Area**	
	Drive Current	Sets the value of the current that the motor control function should try to maintain in the motor winding when the winding is on during the step sequence.
	Accel	Sets the rate at which the motor accelerates to the running speed, in steps/second^2. The desired acceleration can be typed into the box. The new value is used the next time the motor needs to accelerate.
	Decel	Sets the rate at which the motor decelerates from speed to stopped, in steps/second^2. The desired deceleration can be typed into the box. The new value is used the next time the motor needs to decelerate.
3	**Position Area**	
	Target	Sets the position of the motor, in steps. The motor position can be set in two ways: first, by entering a value in the Target Position box; or by clicking on the position slider and dragging it right or left to the desired position, and then releasing it. The position control is not available until the motor has been enabled using the Run button.
	Actual	Shows the position of the motor, in steps. The position is shown both in the Actual box, and also on the slider control. There is an indicator on the upper slider that moves to show the actual motor position.
4	**Graph Area**	
	Speed Graph	This strip chart shows the speed of the motor over time. The entire graph shows 30 seconds of motor speed history. The graph is signed, showing the direction as well as the speed of the motor.
	Current Graph	This strip chart shows the current in the motor windings over time. The entire graph shows 30 seconds of winding current history. This graph shows the peak current in the windings, averaged between the two windings. The current data is only available when Chopper mode is used. If PWM mode is used, then this strip chart is grayed out.
5	**Position Slider Control**	Move the slider to adjust the motor's position. The bottom part of the slider can be dragged with the mouse to set the target position. The upper part of the slider indicates the actual position.

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

Item No.	Name	Description
6	**GUI Main Window Buttons**	
	Run button	Enables the stepper motor for running. The stepper motor must be enabled before it can be used. The motor does not move immediately when the Run button is pressed. It only moves after the position control is used to set a new position.
	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 Configuration window. The Configuration window is described in more detail in "Configuration Window" on page 18.
7	**Statistics Area**	
	DC Bus Voltage	Shows the voltage supplied to the motor, as measured by the microcontroller.
	Motor Current	Shows the peak current of the two windings, averaged together. This value is sampled when the windings are switched on. The current during the time when the windings are switched off is not measured, and that is not reflected in the measurement. The motor current is not available if PWM mode is used, and the current indicator will be grayed out.
	Processor Usage	Indicates the microcontroller CPU load by percentage. Useful for estimating the loading of different applications and motor control algorithms.
	Temperature	Indicates the internal temperature sensor of the microcontroller.
8	**Special Indicator Area**	
	COM Port	Displays the COM port number, and status. If the indicator is shown in black, and displays a number for the COM port, then the serial port is opened. If the indicator is shown in red, and displays *Err*, then no COM port is opened. The COM port selection dialog box can be opened by double clicking on the COM port indicator.
	Target	Displays the status of the target connection. If the Target is shown in black, and indicates Stepper, then the program is communicating with the RDK via the USB/serial port. 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.
	Fault	Indicates that an overcurrent fault has occurred. Otherwise, the control is not visible. To clear the fault condition, double-click on the Fault 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 are only loaded from flash if the motor is not running. If the parameters are loaded from flash, then the values shown on the main and configuration windows 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 not running. If a valid set of parameters have been saved to flash, those are 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 reads the parameters from the file (if available) and sends them to the target. The parameters are 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 causes 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 not running.
- **Update Firmware:** This menu choice can be used to load new firmware onto the RDK target board. A file chooser dialog box opens 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 not running. Once a file is chosen, the new firmware file is sent to the RDK, the RDK updates the flash with the new program, and then restarts.

NOTE: To restore the default parameters that came with your kit, from the File menu, select Load Parameters from File and load the nema23_default.ini parameter file to the target. Then select Save Parameters to Flash from the File menu to save the default parameters into flash memory.

Configuration Window

Use the Configuration window to adjust specific motor parameters. Open the Configuration window by clicking the Configure button on the main window.

In the Configuration window, change the parameters and click the OK button to send the new parameters to the target. Click the Cancel button to discard any changes.

Figure 2-3. Configuration Window

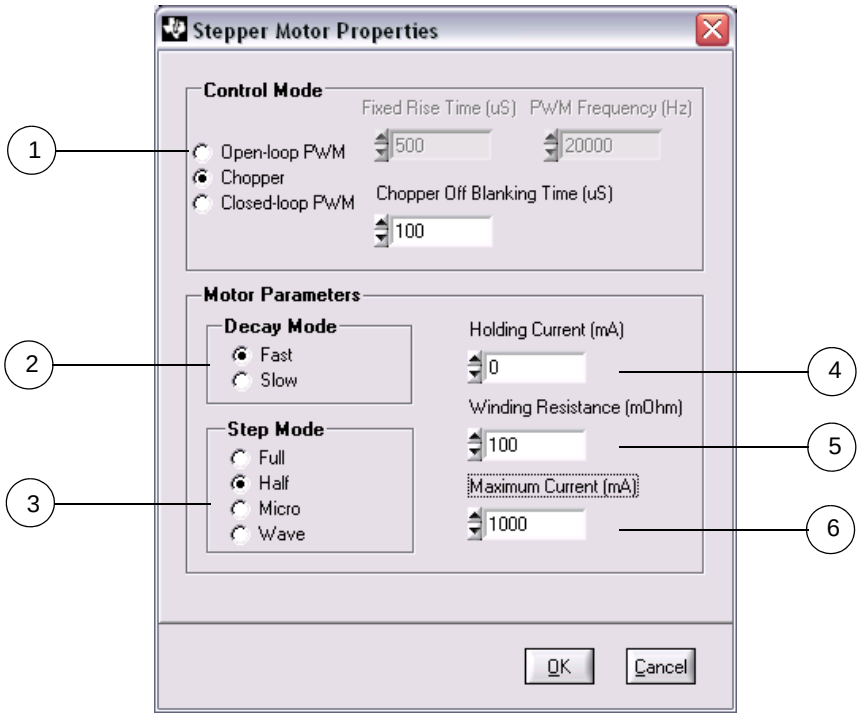


Table 2-2. Description of Configuration Controls

Item No.	Name	Description
1	**Control Mode**	
	Open-loop PWM	In Open-loop PWM control mode, the firmware sets the PWM duty cycle to a value that corresponds to the desired current. The duty cycle is calculated based on the winding resistance and the bus voltage. There is no actual measurement of the winding current. In PWM mode, the *Fixed Rise Time* parameter can also be used (see Fixed Rise Time).
	Chopper	In Chopper control mode, the microcontroller firmware monitors the current flowing in the winding, and switches the voltage to the winding on and off in order to keep the current at the desired value.
	Closed-loop PWM	In Closed-loop PWM control mode, the firmware sets the PWM duty cycle based on the measurement of the current flowing in the winding. If the current is below the desired setting, then the PWM duty cycle will be set to a large value, and is reduced as the measured current approaches the desired value.

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

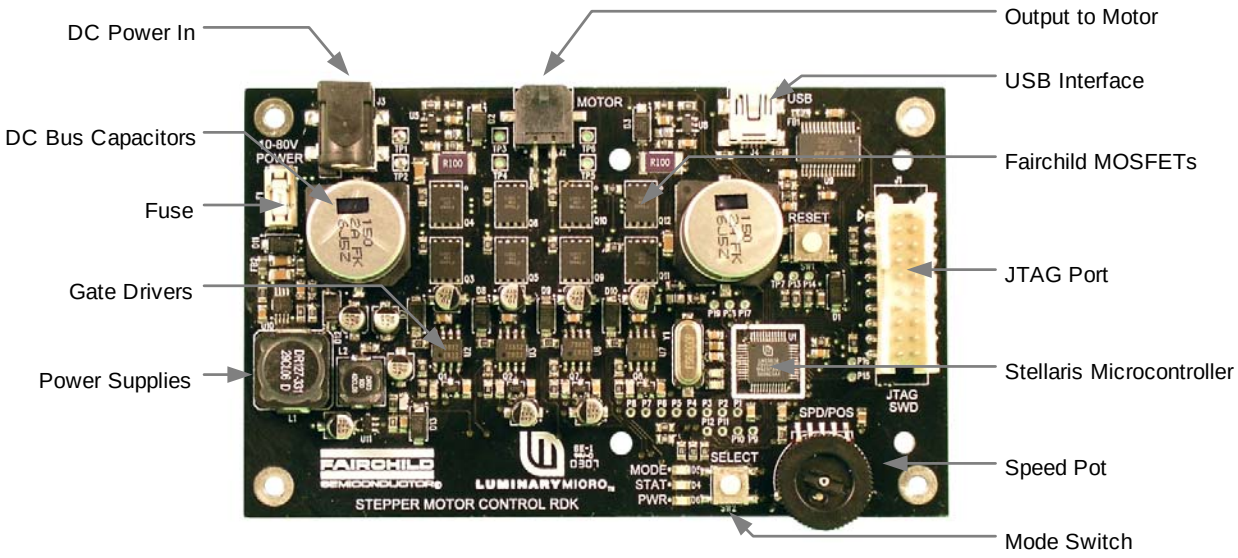
Item No.	Name	Description
1 (cont.)	Fixed Rise Time	This value is used when Open-loop PWM control mode is chosen. This value controls the amount of time that the winding is left turned on at the beginning of a step, before PWM is used to control the current in the winding. This allows the current in the winding to rapidly rise at the beginning of the step. This value is specified in microseconds. It should be adjusted with care because if the amount of time is too long, then the current in the winding may exceed the rating for the motor.
	PWM Frequency	This is the frequency used for PWM, when Open-loop or Closed-loop PWM control mode is chosen.
	Chopper Off Blanking Time	This value is used to control how long the chopper leaves the voltage off, after it turns off the winding when the drive current threshold is reached. At the end of the blanking time, the winding is turned on again and the chopper resumes measuring the winding current.
Motor Parameters		
2	**Decay Mode**	
	Slow	In Slow Decay mode, during the time that no voltage is applied to the winding, the low-side switches on the H-bridge are closed. This allows current to continue to circulate in the winding and decay slowly.
	Fast	In Fast Decay mode, during the time that no voltage is applied to the winding, all the switches are open. The current can no longer circulate and decays quickly.
3	**Step Mode**	
	Full	With full stepping, voltage is always applied to both windings, and a four-step stepping sequence is used.
	Half	With half stepping, the voltage is off during part of the stepping sequence, and an eight half-step stepping sequence is used.
	Micro	With micro stepping, the whole step is divided into 8 micro-steps. The current applied to the windings is varied sinusoidally, piecewise at each micro-step time.
	Wave	Wave stepping is the same as full stepping, except that voltage is applied to only one winding at a time.
4	Holding Current	This is the amount of current that should be applied to the windings when the motor is stopped. This increases the holding torque of the motor. Typically this value should be 0, or a fraction of the drive current.
5	Winding Resistance	This is the winding resistance of the motor that is used. This value should be entered by the user if the motor type is changed. This value is used in order to calculate the correct PWM duty cycle if PWM control mode is used.
6	Maximum Current	Sets a fault current level. If the current rises above this level, the hardware triggers a fault and places the motor in a safe configuration.

C H A P T E R 3

Hardware Description

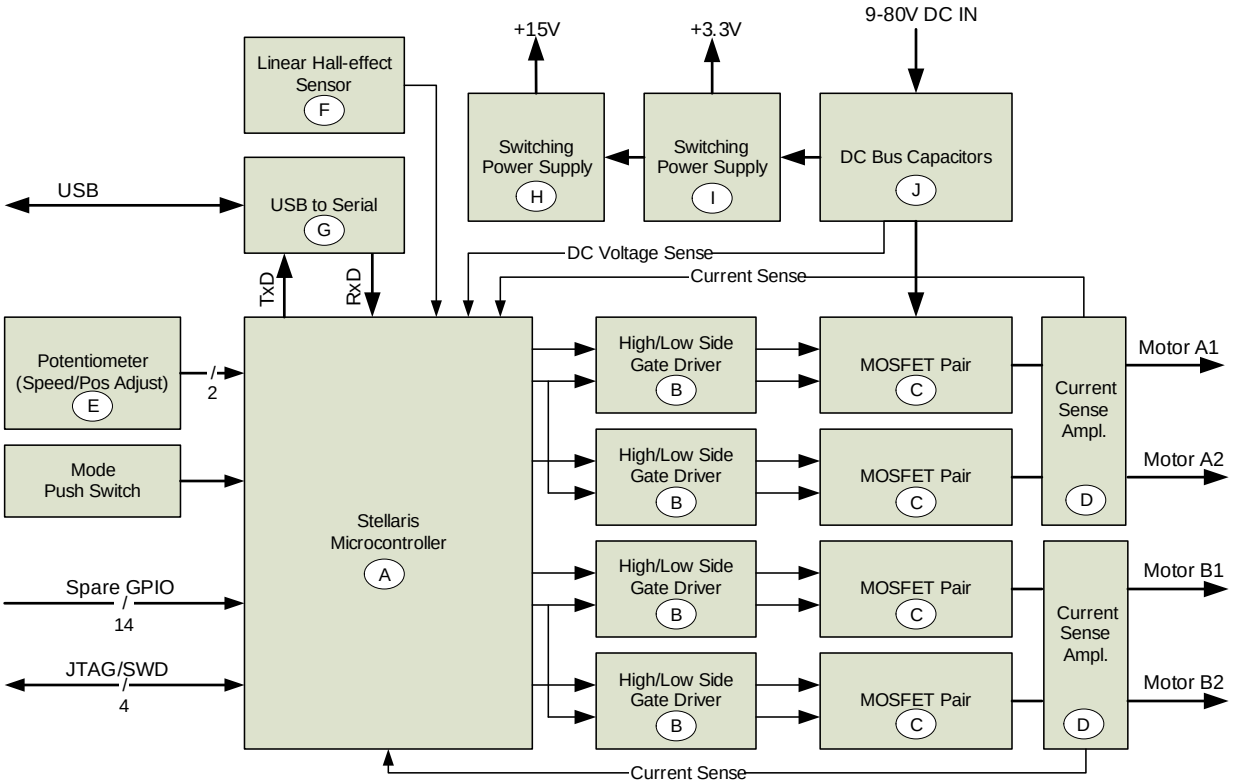
Key components in the reference design include a Stellaris LM3S617 microcontroller with an ARM Cortex-M3 core and a power stage consisting of Fairchild Semiconductor's gate drivers and MOSFETs. Other complementary components complete the design by providing protection, signal acquisition, and power supply functions. The entire circuit is built on a simple two-layer printed circuit board (see Figure 3-1). All design files are provided in the RDK CD.

Figure 3-1. Stepper Motor Control RDK Layout



Block Diagram

Figure 3-2. Block Diagram



Functional Description

Stepper motor controls normally use a dedicated controller chip to implement a chopper-based drive stage. The microcontroller, if present, is there to manage position control and send step pulses to the controller. The RDK implements all of this functionality in the Stellaris microcontroller. One of the benefits of a software implementation is that the rest of the circuit is simple and can use standard power semiconductors. This section contains a detailed description of the RDK's operation. See Appendix B, "Schematics" starting on page 33 for more details.

Microcontroller (Schematic Pages 1-2)

At the core of the Stepper Motor RDK is a Stellaris LM3S617 microcontroller. This part has a peripheral set optimized for motor control, including 6 high-speed ADC channels, a motor control PWM block, and an analog comparator.

The RDK has a 20-pin ARM JTAG port for programming and debugging. A standard debug interface can be connected to this header (J1).

Unallocated GPIO signals from the microcontroller are routed to pads labeled P1-P19. Several peripheral blocks are available for external use including SPI and UART1. The I/O pads are on a 0.1" grid to allow standard headers to be installed.

Also on this page are several LED status indicators, a simple reset circuit, and on-board user interface. The speed/position potentiometer's value is read by the microcontroller's ADC. Because the ADC's input span is 0-3 V, a resistor (R14) is used to pad the potentiometer voltage.

The microcontroller's on-chip analog comparator provides an over-current trip function. Diodes D2 and D3 gate the greater of the two motor coil currents into an R/C network which connects to the inverting comparator input. Inside the microcontroller, this level is compared to a programmable voltage reference. An interrupt will be generated in the event of an over-current condition allowing the software to quickly shut-down the power stage.

Output Power Stage (Schematic Page 3)

The power stages on schematic pages 3 and 4 are identical. One power stage is used for each of the two coils in the bipolar stepper motor.

The power stage consists primarily of a MOSFET H-bridge and associated gate drivers. The H-bridge allows the microcontroller to control the magnitude and polarity of the current in the motor. Each H-bridge has three logic control signals. PH_x1 and PH_x2 control whether the high-side or low-side switch is on. A common active-low enable signal can force all switches off.

To turn on the high-side MOSFETs, the gate voltage must be driven higher than the source. This is achieved by using a gate driver and a flying-[or bootstrap] capacitor. Using Phase A1 as an example: When the low-side MOSFET (Q4) is ON, diode D7 is forward biased and capacitors C16 and C18 charge to almost 15 V. In turn, this charge allows the high-side MOSFET (Q3) to be turned on by the high-side gate driver. As the high-side MOSFET turns on, its source voltage rises taking the negative terminal of the flying capacitor along with it. The capacitor is sized to maintain a high-side supply voltage of at least HV_{DC} + 12.5 V during the ON state. If the capacitor discharges below 11.3 V (typ), the SPM's under-voltage lock-out circuit activates to prevent the MOSFET from moving outside its safe operating area (SOA).

Two 100mΩ resistive shunts provide 100 mV/A current sensing. The resultant voltage is fed into an operation amplifier and into the comparator circuit on Page 2.

Table 3-1. Current Monitoring Circuits

	Microcontroller Comparator	**Microcontroller ADC**
Function	Software programmable current trip	Measurement of phase current amplitude
Amplifier Gain	n/a	11
Resolution	137.5 mV (1.375 A)	10 bits
Scale	100 mV/A – 0.15 V	1 bit = 2.67 mA
Trip Threshold (typ.)	Programmable reference	In software
Trip Speed (typ.)	<10 us	Software-dependent

Page 3 also shows a linear hall-effect sensor for positional feedback. This circuit is not presently populated.

Control Interfaces (Schematic Page 4)

The Stepper RDK has three power supply rails. The input power source is used directly to provide motor power and has a wide operating range. The exact supply voltage is not critical because the chopper control maintains constant motor current. Unregulated supplies can be used successfully.

The microcontroller can monitor the input voltage level using a simple V_{sense} circuit, however, this measurement is not needed for the chopper control algorithm.

A simple step-down switching regulator directly generates 3.3 V for the microcontroller. The +15 V gate driver power supply comes from a second stage boost converter, in this case a FAN5331 device from Fairchild semiconductor.

Finally, a FT232RL device provides a USB virtual COM port. The virtual COM port is a fast and reliable method of communication between the motor control board and the RDK GUI software. The protocol description can be found in the Software Reference Manual and could be used as a general purpose control method from other hosts.

Software

The Stepper Motor Control RDK software manages four primary functions:

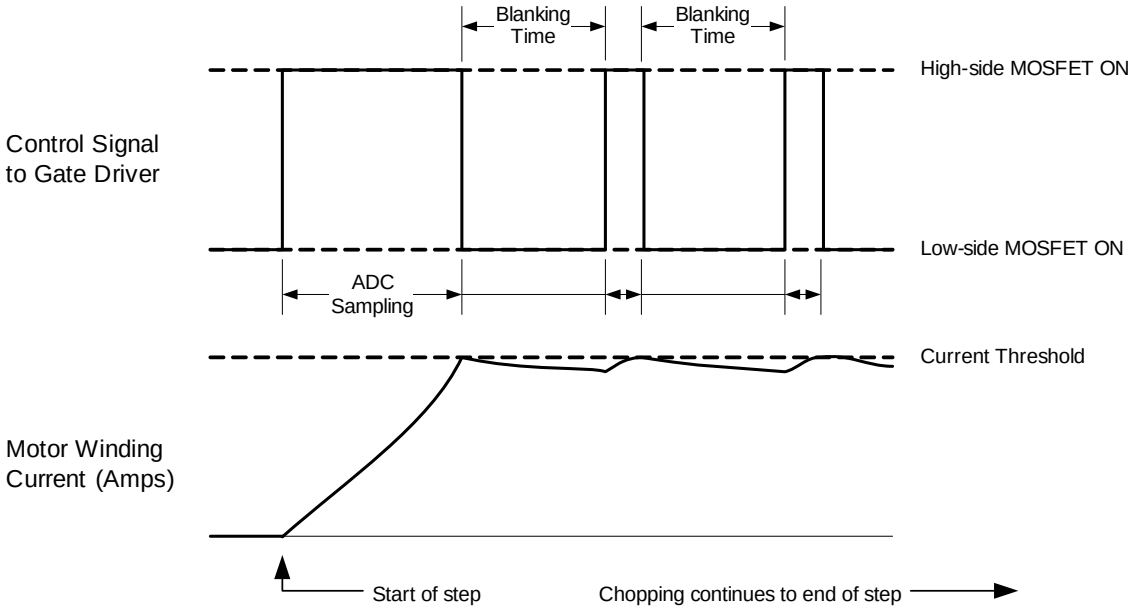
- Motor current control: Real time chopper control of motor current
- Motor step sequencing: Controlling the stepper motor's commutation sequence
- Motor velocity and position control: Calculates motor speed as it advances to a new position
- Serial communication: Command and measurement exchange with host device

The user can add software to implement additional functions that take advantage of the unused microcontroller peripherals or integrate the stepper control code with a custom application.

Chopper Control

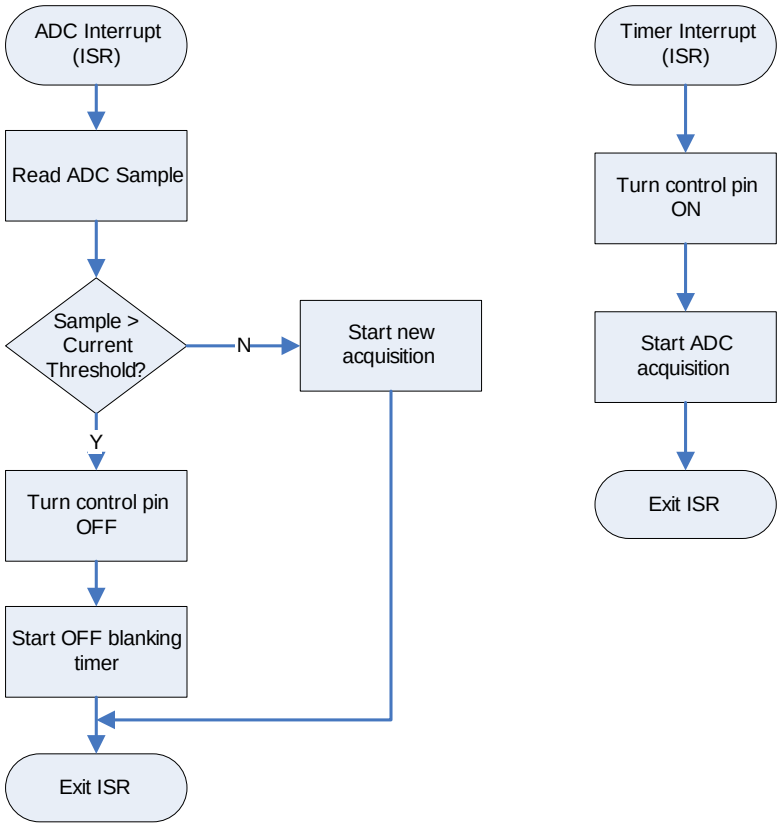
Figure 3-3 shows how the chopper waveform is generated. GPIO signals from the microcontroller turn on the MOSFET switches, causing the motor current to start to build. The rate of increase in motor current is dependent on motor characteristics, motor load, and the supply voltage. Once the ADC detects that the current has exceeded the threshold, a blanking time commences. The blanking time allows the current to collapse slightly before the cycle repeats.

Figure 3-3. Chopper Waveform Generation



A summary of the current control software is shown in Figure 3-4. This technique could be applied to other loads that benefit from a constant current control.

Figure 3-4. Current Control Software Flow



In addition to eliminating a dedicated chopper control IC, software-based chopper control makes it possible to easily change the current set-point. As an example, the RDK GUI has several parameters that change chopper control behavior for motors and loads that have differing characteristics.

Parameter Reference

See Appendix A, “Parameters,” on page 27 for a detailed description of the RDK’s parameters.

Serial Protocol

See the *Stepper Motor Control RDK Software Reference Manual* for more information.

A P P E N D I X A

Parameters

Table A-1 provides a summary of all configuration parameters. See “Parameter Descriptions” on page 27 for more information.

Table A-1. Parameter Configuration Summary

Parameter Name	ID	Units	Range	Default	See
Motor Running Configuration Parameters					
Target Position	PARAM_TARGET_POS	whole steps	-8388608–8388607	0	page 28
Maximum Current	PARAM_MAX_CURRENT	mA	1000–10000	4000	page 28
Target Speed	PARAM_TARGET_SPEED	steps/sec	10–10000	200	page 28
Acceleration	PARAM_ACCEL	steps/sec^2	100–60000	30000	page 28
Deceleration	PARAM_DECEL	steps/sec^2	100–60000	60000	page 29
Motor Drive Configuration Parameters					
Winding Resistance	PARAM_RESISTANCE	mΩ	100–5000	750	page 29
PWM Frequency	PARAM_PWM_FREQUENCY	Hz	16000–32000	20000	page 29
Fixed Rise Time	PARAM_FIXED_ON_TIME	μS	1–10000	800	page 29
Drive Current	PARAM_DRIVE_CURRENT	mA	100–3000	1500	page 30
Holding Current	PARAM_HOLDING_CURRENT	mA	0–3000	0	page 30
Control Mode	PARAM_CONTROL_MODE	choice	Chopper, Open-loop or Closed-loop PWM	Chopper	page 30
Decay Mode	PARAM_DECAY_MODE	choice	Fast or Slow	Slow	page 31
Step Mode	PARAM_STEP_MODE	choice	Full, Half, Micro, or Wave	Half	page 31
Off Blanking Time	PARAM_BLANK_OFF	μS	20–10000	100	page 31

Parameter Descriptions

This section describes parameter configuration in detail. The parameters are grouped into two areas: Motor Running Configuration parameters and Motor Drive Configuration parameters.

Motor Running Configuration

Target Position

ID	Units	Range	Default
PARAM_TARGET_POS	whole steps	-8388608–8388607	0

This parameter indicates the target position which is represented internally as a signed 24-bit number. It starts at position 0 and can run to the positive maximum or negative minimum of the range.

Maximum Current

ID	Units	Range	Default
PARAM_MAX_CURRENT	mA	1000–10000	4000

This parameter sets the trip point for a hardware comparator. If the current exceeds this value, the comparator triggers a fault and places the motor in a safe configuration.

Target Speed

ID	Units	Range	Default
PARAM_TARGET_SPEED	steps/sec	10–10000	200

This parameter sets the target speed of the motor. When moving, the motor accelerates up to this speed and remains at this speed until near the target position, at which time it decelerates to a stop. This value is in whole steps, so if Half-Stepping mode is used, then the actual stepping rate applied to the motor will be twice this value.

It may be difficult to get the stepper motor up to maximum speed if it does not have a load.

Acceleration

ID	Units	Range	Default
PARAM_ACCEL	steps/sec^2	100–60000	30000

This parameter is the rate at which the motor accelerates to reach the target speed. Larger values work better if the motor has no load, avoiding the resonant frequencies. If the motor has much load, then this value may need to be lowered.

Deceleration

ID	Units	Range	Default
PARAM_DECEL	steps/sec^2	100–60000	60000

This parameter is the rate at which the motor decelerates from the target speed to stop at the target position. Typically, the motor can decelerate faster than accelerate since the load and friction are working to help decelerate the motor.

Motor Drive Configuration

Winding Resistance

ID	Units	Range	Default
PARAM_RESISTANCE	mΩ	100–5000	750

This parameter sets the resistance of the winding. It should be obtained from the motor specification. This value is used in calculating the correct duty cycle if PWM mode is used.

PWM Frequency

ID	Units	Range	Default
PARAM_PWM_FREQUENCY	Hz	16000–32000	20000

If PWM mode is used, this parameter determines the PWM period.

Fixed Rise Time

ID	Units	Range	Default
PARAM_FIXED_ON_TIME	μS	1–10000	800

If PWM mode is used, this parameter sets the amount of time at the beginning of a step that the winding is left with full voltage applied before PWM is used to control the current. By leaving the full voltage applied to the winding, the current rises as fast as possible, allowing it to reach the drive current faster.

Caution – If making adjustments to this value, do not exceed the motor's rated current. Use lab equipment to measure the current in the winding when making adjustments to this value.

Drive Current

ID	Units	Range	Default
PARAM_DRIVE_CURRENT	mA	100–3000	1500

This parameter sets the current level in the winding when the motor is running. If the Chopper mode is used, then the chopper switches the voltage to the winding off and on in order to maintain this current level. If the PWM mode is used, then the duty cycle is calculated to maintain this current level.

This value should not necessarily be set to the rated current of the winding. For an unloaded motor, the best current setting varies with motor speed, with less current needed for running at lower speeds.

Caution – If the motor is run for long periods of time with currents approaching the rated current for the winding, the motor can become very hot. Use caution around the motor if a heat sink is not being used.

Holding Current

ID	Units	Range	Default
PARAM_HOLDING_CURRENT	mA	0–3000	0

This parameter sets the current in the winding when the motor is not running. By applying current to the winding when the motor is stopped, the holding torque of the motor can be increased. Typically, this should just be a fraction of the drive current, or zero.

Control Mode

ID	Units	Range	Default
PARAM_CONTROL_MODE	choice	Chopper, Open-loop or Closed-loop PWM	Chopper

This parameter specifies Chopper mode or PWM mode. Chopper mode monitors the winding current while the winding is on. When the current reaches the target value (Drive Current), it switches the winding off. The winding remains off for the *Off Blanking Time*. At the end of the blanking time, the winding is turned on again, and the current monitoring resumes.

In Open-loop PWM mode, the duty cycle is calculated to set the voltage applied to the winding such that the target *Drive Current* flows in the winding. However, this is for a steady state situation, and when the motor is turning, its impedance changes dynamically. This means that the PWM current control is not precise. Also, by applying less than the full bus voltage to the winding when it is turned on, it can take a long time before the drive current is reached. For this reason, the winding can be left with full voltage applied for a duration at the start of a step. This is controlled by the *Fixed Rise Time* parameter.

When using Open-loop PWM mode, current monitoring is not available.

Closed-loop PWM mode combines the features of Chopper and Open-loop PWM modes. Closed loop PWM mode uses a programmed PWM duty cycle to set the current. However, the current is also measured each time a PWM pulse is applied, and the duty cycle is adjusted to compensate for variation in the measured current compared to desired drive current.

Decay Mode

ID	Units	Range	Default
PARAM_DECAY_MODE	choice	Fast or Slow	Slow

This parameter specifies Fast Decay mode or Slow Decay mode. In Slow Decay mode, the H-bridge low-side switches are closed to remove voltage from the winding. This allows current to circulate in the winding and decay slowly. In Fast Decay mode, all the switches are opened to remove voltage from the winding, and the current decays rapidly.

For the unloaded motor, slow decay seems to work best.

Step Mode

ID	Units	Range	Default
PARAM_STEP_MODE	choice	Full, Half, Micro, or Wave	Half

This parameter specifies the stepping mode. In Full-Step mode, full positive or negative current is applied to the windings at each point in the four-step stepping cycle. In Half-Step mode, the winding current is full negative, positive, or 0 at each point in an eight half-step stepping sequence. In Micro-Step mode, the current in each winding is varied sinusoidally over a sequence of 8 microsteps per step. In Wave-Step mode, full steps are made as in Full-Step mode, except that only one winding is energized at a time.

The unloaded motor runs smoother at slower speeds using half stepping, but full stepping may be appropriate for higher speeds.

For very slow speeds, less than 200 steps per second, Micro-Step mode may be used to smooth out the motion of the motor.

Off Blanking Time

ID	Units	Range	Default
PARAM_BLANK_OFF	µS	20–10000	100

If Chopper mode is used, this parameter sets the amount of time that the winding remains off after the winding current reaches the drive current.

Caution – Great care should be taken if decreasing this value. If the off-blanking time is not long enough, the current may not drop enough between the times when the voltage is applied, and the current can continue to rise in the winding, above the rated current. Use lab equipment to observe the winding current when making adjustments to this value.

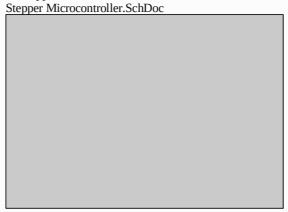
A P P E N D I X B

Schematics

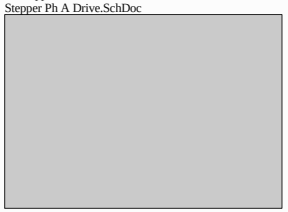
This section contains the schematics for the LM3S1968 Evaluation Board:

- Contents Page on page 34
- Microcontroller on page 35
- Driver - Coil A on page 36
- Driver - Coil B on page 37
- Power Supplies and USB on page 38

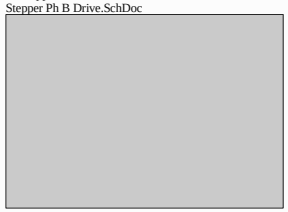
U_Stepper Microcontroller
Stepper Microcontroller.SchDoc



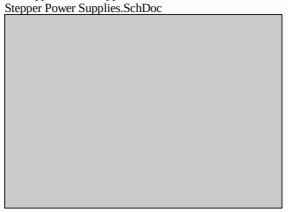
U_Stepper Ph A Drive
Stepper Ph A Drive.SchDoc



U_Stepper Ph B Drive
Stepper Ph B Drive.SchDoc



U_Stepper Power Supplies
Stepper Power Supplies.SchDoc

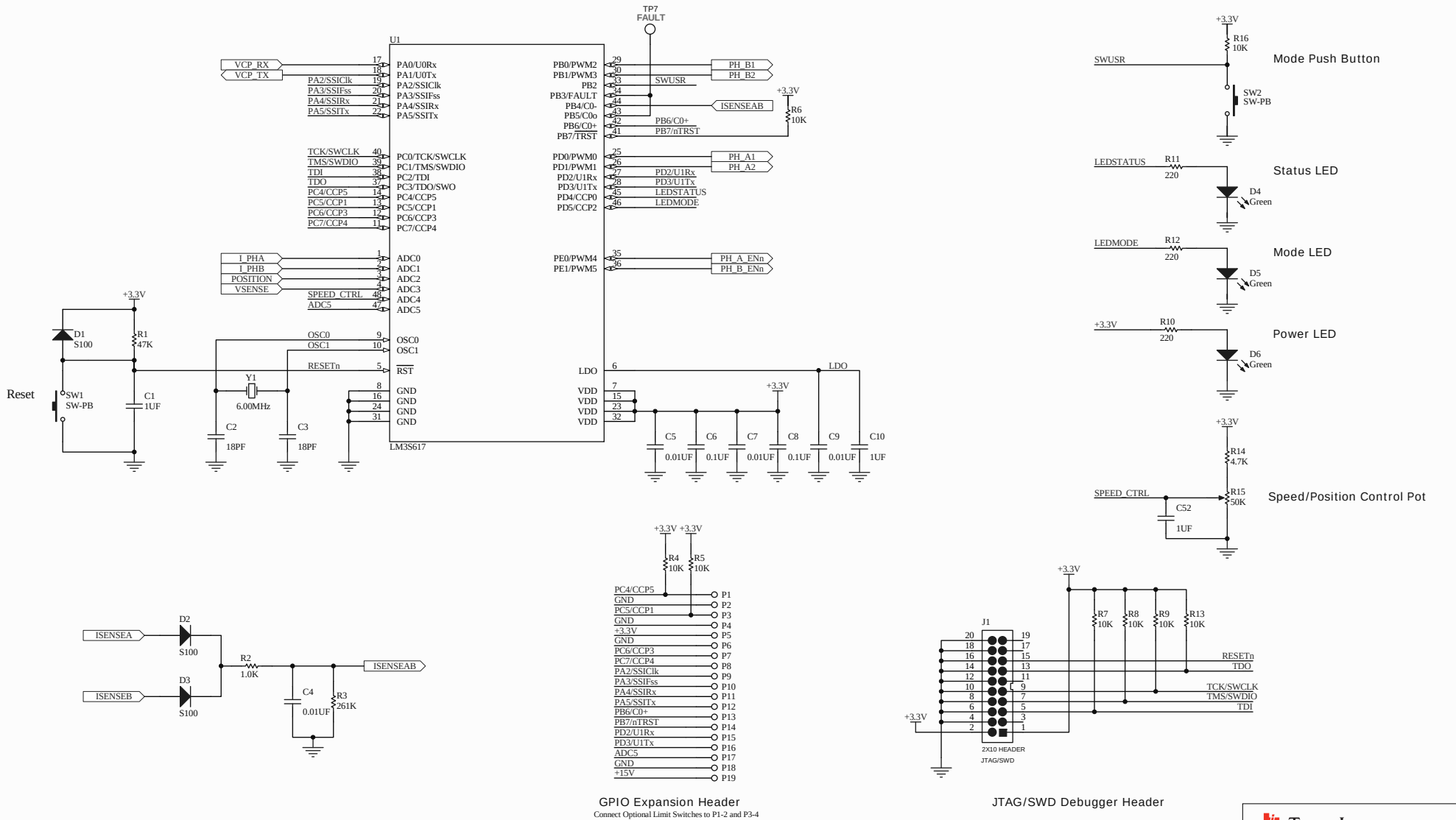


History

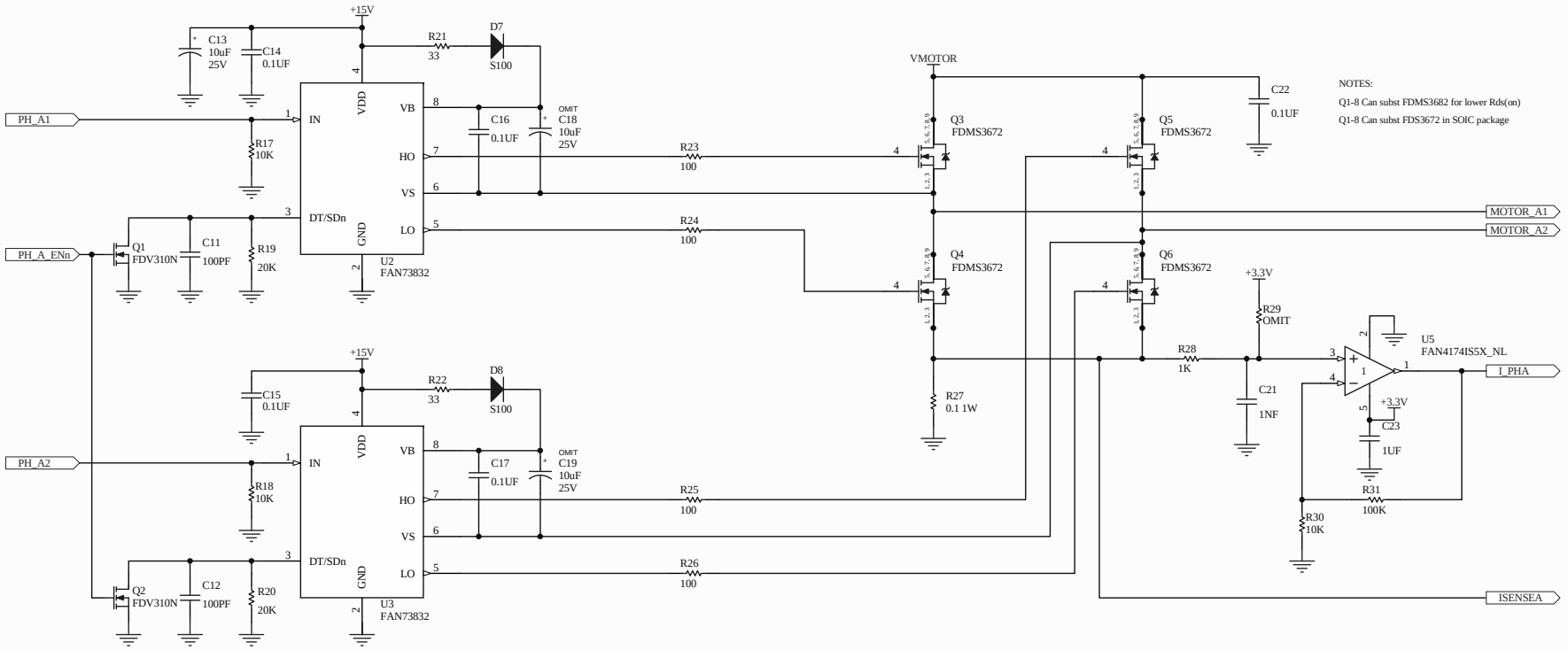
Revision	Date	Description
0	Jan 17, 07	First Full Release
0.1	Feb 07, 07	Change USB device to bus power.
A	Feb 09, 07	First Production Revision
A.1	Jul 10, 07	Change C18, C19, C31, C32 to no-populate

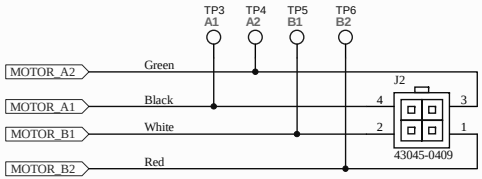
TEXAS INSTRUMENTS

Drawing Title:	Stepper Motor Reference Design Kit		
Page Title:	Contents Page		
Size: B	Document Number:		
Date: 7/10/2007	Sheet 1 of 5	Rev A.2	

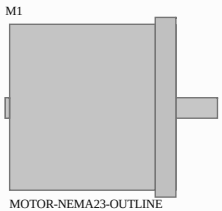


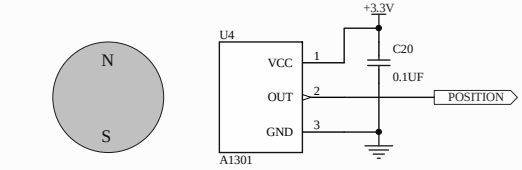
Drawing Title:	Stepper Motor Reference Design Kit
Page Title:	Microcontroller
Size: B	Document Number:
Date: 7/10/2007	Sheet 2 of 5
	Rev A.2





Stepper Motor Connections



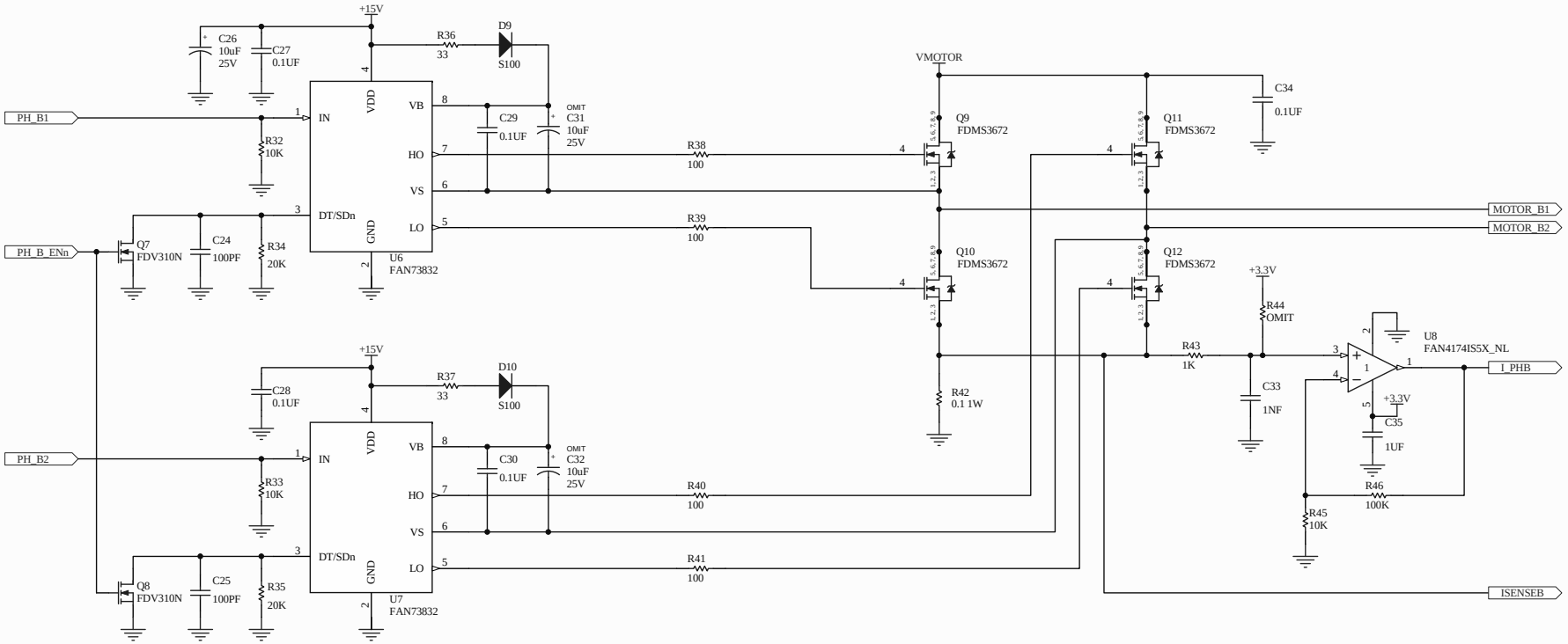


Rotating Permanent Magnet (optional)

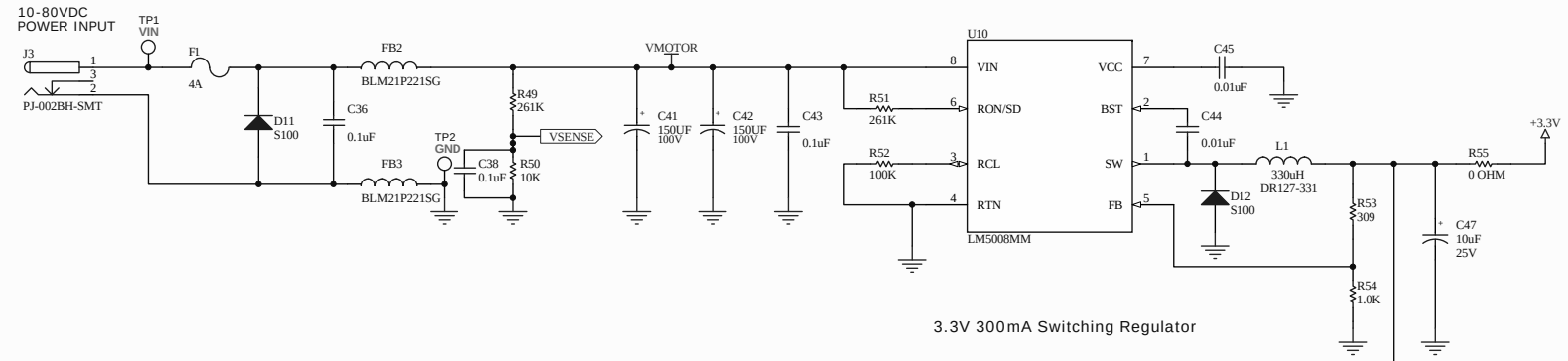
Linear Hall-Effect Position Sensor

TEXAS INSTRUMENTS

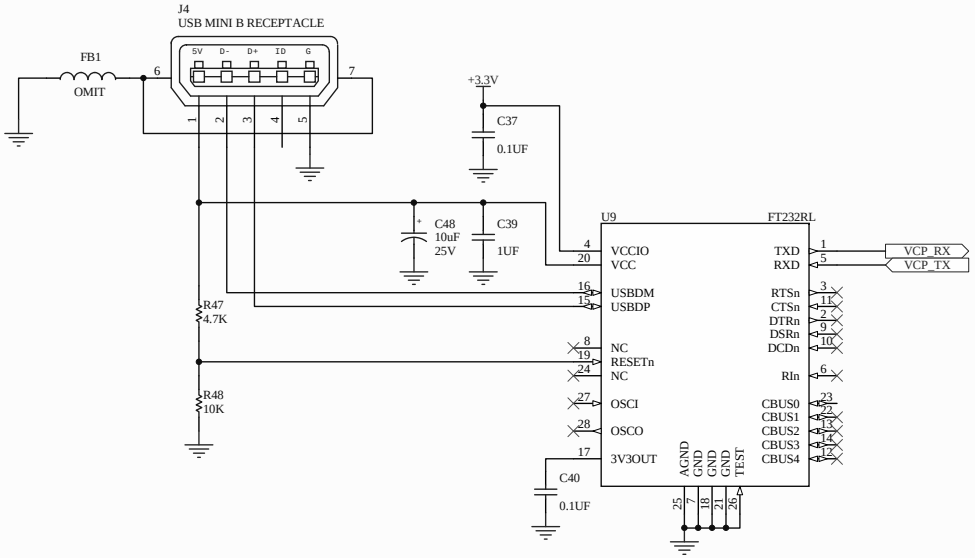
Drawing Title:	Stepper Motor Reference Design Kit
Page Title:	Driver - Coil A
Size: B	Document Number:
Date: 7/10/2007	Sheet 3 of 5 — Rev A.2



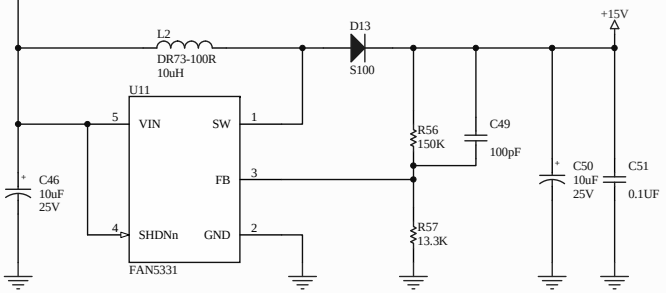
Texas Instruments	
Drawing Title:	Stepper Motor Reference Design Kit
Page Title:	Driver - Coil B
Size: B	Document Number:
Date: 7/10/2007	Sheet 4 of 5
	Rev A.2



3.3V 300mA Switching Regulator



USB Virtual COM Port



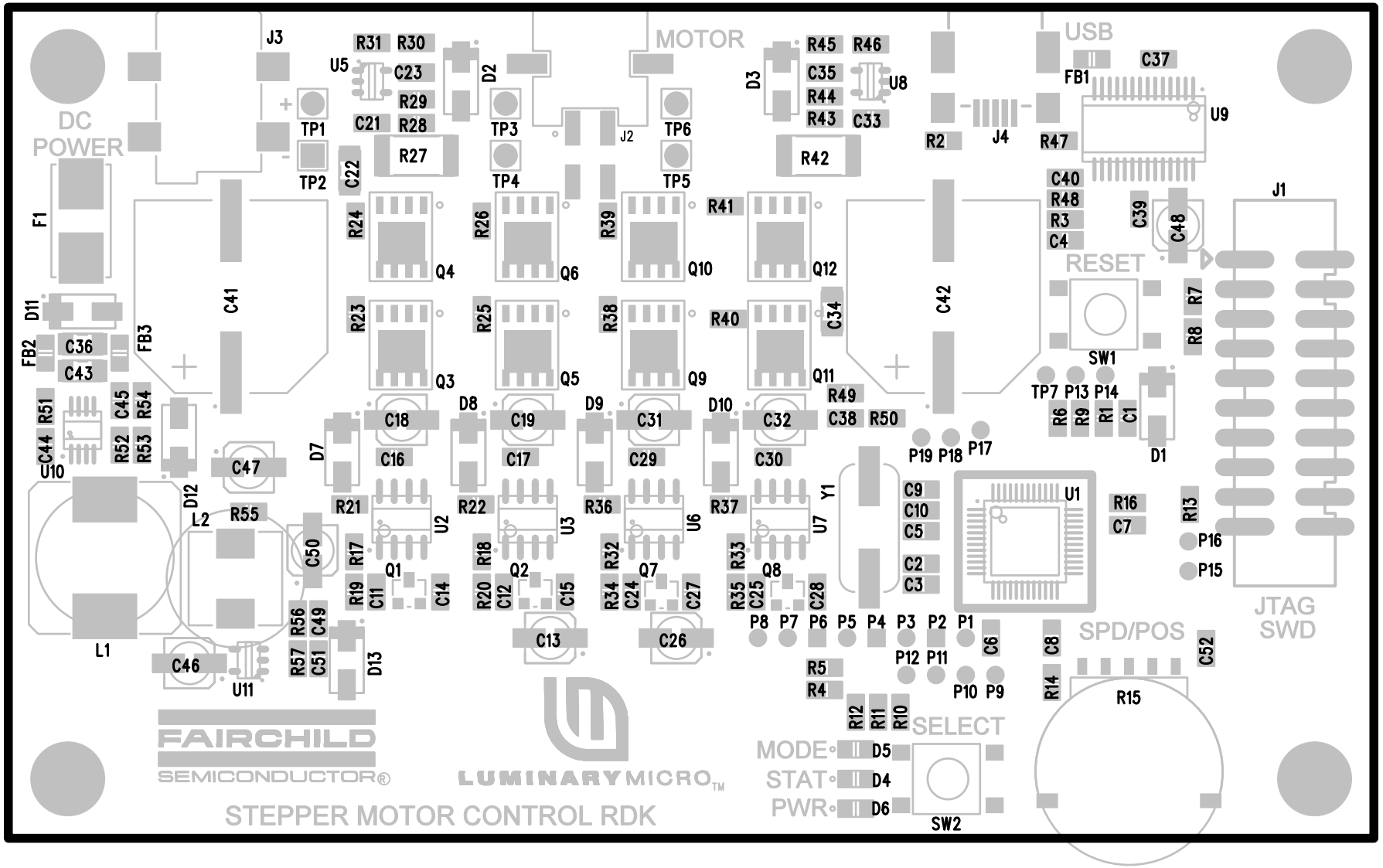
+15V 30mA Power Supply for Gate Drive

Texas Instruments	
Drawing Title:	Stepper Motor Reference Design Kit
Page Title:	Power Supplies and USB
Size: B	Document Number:
Date: 7/10/2007	Sheet 5 of 5 — Rev A.2

A P P E N D I X C

PCB Component Locations

This section shows the PCB component locations for the Stepper Motor RDK.


DC
POWER
MOTOR
USB
RESET
SW1
J1
JTAG
SWD
SPD/POS
SELECT
SW2
MODE
STAT
PWR
D5
D4
D6
FAIRCHILD
SEMICONDUCTOR®
LUMINARYMICRO™
STEPPER MOTOR CONTROL RDK
J3
J2
J4
TP1
TP2
TP3
TP4
TP5
TP6
TP7
U1
U2
U3
U4
U5
U6
U7
U8
U9
U10
U11
Y1
F1
FB1
FB2
FB3
D1
D2
D3
D4
D5
D6
D7
D8
D9
D10
D11
D12
D13
L1
L2
Q1
Q2
Q3
Q4
Q5
Q6
Q7
Q8
Q9
Q10
Q11
Q12
P1
P2
P3
P4
P5
P6
P7
P8
P9
P10
P11
P12
P13
P14
P15
P16
P17
P18
P19
R1
R2
R3
R4
R5
R6
R7
R8
R9
R10
R11
R12
R13
R14
R15
R16
R17
R18
R19
R20
R21
R22
R23
R24
R25
R26
R27
R28
R29
R30
R31
R32
R33
R34
R35
R36
R37
R38
R39
R40
R41
R42
R43
R44
R45
R46
R47
R48
R49
R50
C1
C2
C3
C4
C5
C6
C7
C8
C9
C10
C11
C12
C13
C14
C15
C16
C17
C18
C19
C21
C22
C23
C24
C25
C26
C27
C28
C29
C30
C31
C32
C33
C34
C35
C36
C37
C38
C39
C40
C41
C42
C43
C44
C45
C46
C47
C48
C49
C50
C51
C52
R51
R52
R53
R54
R55
R56
R57

A P P E N D I X D

Bill of Materials (BOM)

This section provides the BOM for the Stepper Motor RDK.

Texas Instruments
Stepper Motor Reference Design Kit
Bill Of Materials

Edison Project
Rev A Issue 3 6/10/07

Item	Ref	Qty	Part Number	Description	Mfg
1	C1, C10, C23, C35, C39, C52	6	C0805C105Z4VACTU	Capacitor 1uF 16V Y5V 0805	Kemet
2	C11, C12, C24, C25, C49	5		Capacitor 100pF 50V 10% Ceramic 0805	Kemet
3	C13, C26, C46, C47, C48, C50	6	EEE-FK1E100R	Capacitor, 10uF 25V Electro, Low Z, SMT Size B	Panasonic
4	C2, C3	2	C0805C180J5GACTU	Capacitor 18pF 50V 5% 0805 NPO	Kemet
5	C21, C33	2		Capacitor 1000pF 50V 10% Ceramic 0805	
6	C4, C5, C7, C9, C44, C45	6		Capacitor, 0.01uF 16V 10% 0805 X7R	Kemet
7	C41, C42	2	EEV-FK2A151M	Capacitor, 150uF 50V Electro, Low Z, SMT Size G	Panasonic
8	C6, C8, C14, C15, C16, C17, C27, C28, C29, C30, C37, C38, C40, C51	14	C0805C104J5RACTU	Capacitor, 0.1uF 50V 5% 0805 X7R	Kemet
9	C22, C34, C36, C43	4	C1206C104K1RACTU	Capacitor, 0.1uF 100V 10% 1206 X7R	Kemet
10	D1, D2, D3, D7, D8, D9, D10, D11, D12, D13	10	S100	Diode Schottky 100V 2A	Fairchild
11	D4, D5, D6	3	LTST-C171GKT	LED, 0805 SMT Green	LiteOn
12	F1	1	154004	Fuse, SMT in holder 4A	Littelfuse
13	FB2, FB3	2	BLM21PG221SN1D	Inductor, Chip Ferrite 2A 0805 220 Ohm@100MHz	Murata
14	J1	1	N2520-6V0C-RB-WE	Header, Low profile Shrouded 2x10way SMT	3M
15	J2	1	43045-0409	Connector, MicroFit 3mm 4pos header R/A SMT	Molex
16	J3	1	PJ-002AH-SMT	Connector, 2.1mm DC power socket SMT	CUI
17	J4	1	54819-0572	Connector, USB Mini-B SMT 5pin	Molex
18	L1	1	DR127-331-R	Inductor, 330uH Power SMT	Coiltronics
19	L2	1	DR73-100-R	Inductor, 10uH Power SMT	Coiltronics
20	Q1, Q2, Q7, Q8	4	FDV301N	Mosfet, N-Ch SOT-23	Fairchild
21	Q3, Q4, Q5, Q6, Q9, Q10, Q11, Q12	8	FDMS3672	Mosfet, Dual N-Ch 100V 5.1A SO-8	Fairchild
22	R4, R5, R6, R7, R8, R9, R13, R16, R17, R18, R30, R32, R33, R45, R48, R50	16		Resistor 10K 5% 0805	Generic
22a	R1	1		Resistor 47K 5% 0805	Generic
23	R10, R11, R12	3		Resistor 220 Ohms 5% 0805	Generic
24	R14, R47	2		Resistor 4.7K 5% 0805	Generic
25	R15	1	EVU-TUAB16B54	Trimpot, 16mm thumbwheel style SMT 50K	Panasonic
26	R19, R20, R34, R35	4		Resistor 20K 1% 0805	Generic
27	R2, R28, R43, R54	4		Resistor 1.0K 1% 0805	Generic
28	R21, R22, R36, R37	4		Resistor 33 Ohms 5% 0805	Generic
29	R23, R24, R25, R26, R38, R39, R40, R41	8		Resistor 100 Ohms 5% 0805	Generic
30	R3, R49, R51	3		Resistor 261K 1% 0805	Generic
31	R31, R46, R52	3		Resistor 100K 5% 0805	Generic
32	R57	1		Resistor 13.3K 1% 0805	Generic

33	R56	1		Resistor 150K 1% 0805	Generic
34	R53	1		Resistor 340 Ohms 1% 0805	Generic
35	R55	1		Resistor Zero Ohm 5% 0805	Generic
36	R27, R42	2	LR2512-LF-R100-F	Resistor 0.1 Ohms 2W 2512	IRC
37	SW1, SW2	2	B3S-1000	Switch, Momentary Tact SMT	Omron
38	U1	1	LM3S617-CQN25	IC, Microcontroller ARM Cortex TQFP48	Luminary
39	U10	1	LM5008MM	IC, Integrated Step-down converter	National
40	U11	1	FAN5331S	IC, Boost Converter SOT23-5	Fairchild
41	U2, U3, U6, U7	4	FAN73832M	IC, High-Low Side Gate Driver SO-8	Fairchild
42	U4	0	A1301KLHLT-T	IC, Linear Hall Effect sensor SOT-23 OMIT	Allegro
43	U5, U8	2	FAN4174IS5X_NL	IC, Low-Power, Rail-to-Rail Output, 3MHz Op Amp SOT-23	Fairchild
44	U9	1	FT232RL	USB UART Asynchronous Serial Data Transfer Chip, SSOP28 Pb-free	FTDI
45	Y1	1	FOXSDLF/060-20	Crystal, 6.00MHz HC49US SMT	Fox
46	PCB	1	SRDK-A	PCB, FR-4 4.52" x 2.80" 2-layer Gloss black solder mask	Imagineering
		150			

Non-PCB Items

47		1	450-3825	Knob, Aluminum 1.50x0.63" for 1/4" shaft	EPD
48		1	STP-MTR-23055	Stepper Motor NEMA23 166oz-in with 12" cable	SureStep
49		1	PSA15R-240P-R	Wall Adapter 24Vdc 15W with interchangeable plug adapters	Phihong
50		1	RPBAG-R	Kit of 4 plugs (USA/EU, UK, Aust)	Phihong
51		4	SJ-5018 (BLACK)	Rubber Feet Black	3M

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, modifications, enhancements, improvements, and other changes to its products and services at any time and to discontinue any product or service without notice. Customers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All products are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its hardware products to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by government requirements, testing of all parameters of each product is not necessarily performed.

TI assumes no liability for applications assistance or customer product design. Customers are responsible for their products and applications using TI components. To minimize the risks associated with customer products and applications, customers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any TI patent right, copyright, mask work right, or other TI intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information published by TI regarding third-party products or services does not constitute a license from TI to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. Reproduction of this information with alteration is an unfair and deceptive business practice. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI products or services with statements different from or beyond the parameters stated by TI for that product or service voids all express and any implied warranties for the associated TI product or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

TI products are not authorized for use in safety-critical applications (such as life support) where a failure of the TI product would reasonably be expected to cause severe personal injury or death, unless officers of the parties have executed an agreement specifically governing such use. Buyers represent that they have all necessary expertise in the safety and regulatory ramifications of their applications, and acknowledge and agree that they are solely responsible for all legal, regulatory and safety-related requirements concerning their products and any use of TI products in such safety-critical applications, notwithstanding any applications-related information or support that may be provided by TI. Further, Buyers must fully indemnify TI and its representatives against any damages arising out of the use of TI products in such safety-critical applications.

TI products are neither designed nor intended for use in military/aerospace applications or environments unless the TI products are specifically designated by TI as military-grade or "enhanced plastic." Only products designated by TI as military-grade meet military specifications. Buyers acknowledge and agree that any such use of TI products which TI has not designated as military-grade is solely at the Buyer's risk, and that they are solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI products are neither designed nor intended for use in automotive applications or environments unless the specific TI products are designated by TI as compliant with ISO/TS 16949 requirements. Buyers acknowledge and agree that, if they use any non-designated products in automotive applications, TI will not be responsible for any failure to meet such requirements.

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

Products		**Applications**	
Amplifiers	amplifier.ti.com	Audio	www.ti.com/audio
Data Converters	dataconverter.ti.com	Automotive	www.ti.com/automotive
DLP® Products	www.dlp.com	Broadband	www.ti.com/broadband
DSP	dsp.ti.com	Digital Control	www.ti.com/digitalcontrol
Clocks and Timers	www.ti.com/clocks	Medical	www.ti.com/medical
Interface	interface.ti.com	Military	www.ti.com/military
Logic	logic.ti.com	Optical Networking	www.ti.com/opticalnetwork
Power Mgmt	power.ti.com	Security	www.ti.com/security
Microcontrollers	microcontroller.ti.com	Telephony	www.ti.com/telephony
RFID	www.ti-rfid.com	Video & Imaging	www.ti.com/video
RF/IF and ZigBee® Solutions	www.ti.com/lprf	Wireless	www.ti.com/wireless

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2009, Texas Instruments Incorporated