

TI Designs

Unipolar Stepper Motor Driver using a Bipolar Stepper Motor Controller Reference Design



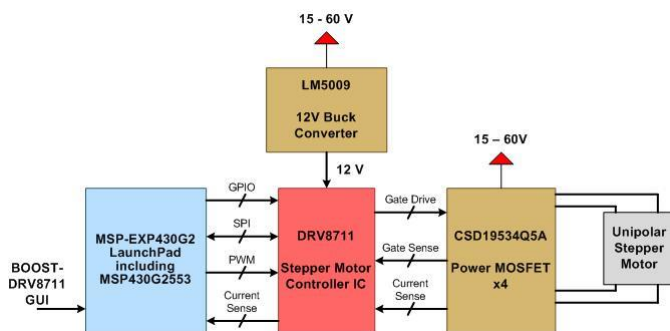
Design Overview

The TIDA-00872 reference design is a 15 to 60 V stepper motor controller for unipolar stepper applications. It uses the Texas Instrument's DRV8711 Bipolar Stepper Motor Controller gate driver, CSD19534Q5A 100V, N-Channel NexFET Power MOSFET s, CSD17483F4 30V, N-Channel FemtoFET™ MOSFET, MSP430G2553 MCU, and LM5009 12 V buck converter. This design is focused on demonstrating a unique configuration of the DRV8711.

Design Resources

TIDA-00872	Design Folder
DRV8711	Product Folder
MSP430G2553	Product Folder
LM5009	Product Folder
CSD19534Q5A	Product Folder
CSD17483F4	Product Folder
MSP430 LaunchPad Value Line	Tool Folder

Block Diagram



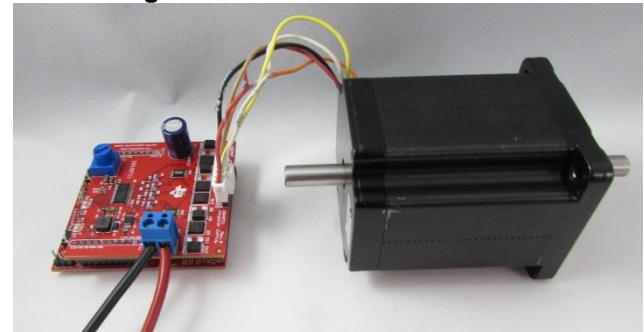
Design Features

- 15 to 60 V input voltage range
- 3.5 A RMS, 5 A peak output current capability
- Designed to use Launchpad and Boost-DRV8711 software
- Board size is 2.3 inches by 2.25 inches
- Onboard 12V, 0.15 A buck converter
- Wide array of system protection features including MOSFET V_{DS} overcurrent and supply undervoltage protection

Featured Applications

- Cash and Currency Machines
- Industrial Steppers

Board Image



1 System Description

TIDA-00872 configures the DRV8711 to control a unipolar stepper motor. This is possible using slow decay, and using the high side gate control to control the low side FETs. This type of motor control can be used for currency counter and cash machines, where a unipolar stepper motor application is desired.

The motor controller is composed of two main components. The first component is the MCU, which decodes the commands from the GUI, and sends the appropriate signals to the DRV8711 controller. The second component is the power stage which consists of the DRV8711 gate driver and power MOSFETs. The power stage amplifies the control signals from the MCU to the motor, and regulates the current in the windings using slow decay.

Power is supplied to the power MOSFETs from the main power input. Power to the DRV8711 is supplied through a switching buck converter.

1.1 DRV8711 Stepper Motor Controller

The DRV8711 stepper motor controller controls the external N-channel power MOSFETs. The MOSFETs are connected in a unique arrangement to allow the DRV8711 to control a unipolar stepper. The configuration requires some of the protection features to be disabled.

Each output of the DRV8711 controls a CSD17438F4 FemtoFET. These FETs are configured to provide the proper V_{gs} to the CSD19543Q5A FETs when the high side is enabled, and to provide the proper voltage at the xOUT pins for correct operation.

The stall detection feature is also disabled for this application. Stalls will be indicated, but the information is not valid.

1.2 MSP430G2553 Microcontroller

The MSP430G2553 is the brain of the system. It provides the signals required to enable the DRV8711, select the settings required via the SPI interface, and to control the current and direction. Once the DRV8711 registers have been initialized, the MSP430G2553 sends the command to move the stepper.

The MCU430G255, a value line microcontroller, has a SPI interface to configure the DRV8711 and an internal timer used to provide the step input. The step input begins at a low step per second rate and accelerates to the final speed using an acceleration profile set by the GUI.

LM5009MM/NOPB Step-Down Buck Converter

The LM5009MM/NOPB provides an efficient, regulated 12 V power supply from the higher VM voltage. This 12V is used to power the DRV8711, and to provide the proper gate voltages to the CSD19534Q5A NexFET™ N-Channel Power MOSFET.

A minimum load of approximately 4mA is used to minimize discontinuous conduction mode. This prevents the 12V required by the DRV8711 from dropping when an increase of current is required.

1.3 CSD19534Q5A NexFET™ N-Channel Power MOSFET

The motor controller uses four CSD19534Q5A to control the current of the unipolar stepper motor. This power MOSFET is an ultra-low $R_{DS(on)}$ device designed to minimize losses in power conversion, switching applications. It comes in a compact, 8 pin SON 5 x 6 mm package with an $R_{DS(on)}$ of 12.6 m Ω at a V_{GS} of 10 V to minimize board space required and limit thermal dissipation.

Product Summary

$T_A = 25^\circ\text{C}$		TYPICAL VALUE		UNIT
V_{DS}	Drain-to-Source Voltage	100		V
Q_g	Gate Charge Total (10 V)	17		nC
Q_{gd}	Gate Charge Gate to Drain	3.2		nC
$R_{DS(on)}$	Drain-to-Source On Resistance	$V_{GS} = 6\text{ V}$	14.1	m Ω
		$V_{GS} = 10\text{ V}$	12.6	m Ω
$V_{GS(th)}$	Threshold Voltage	2.8		V

Figure 1: CSD19534Q5A Summary

2 Block Diagram

Shown below is the block diagram of the system.

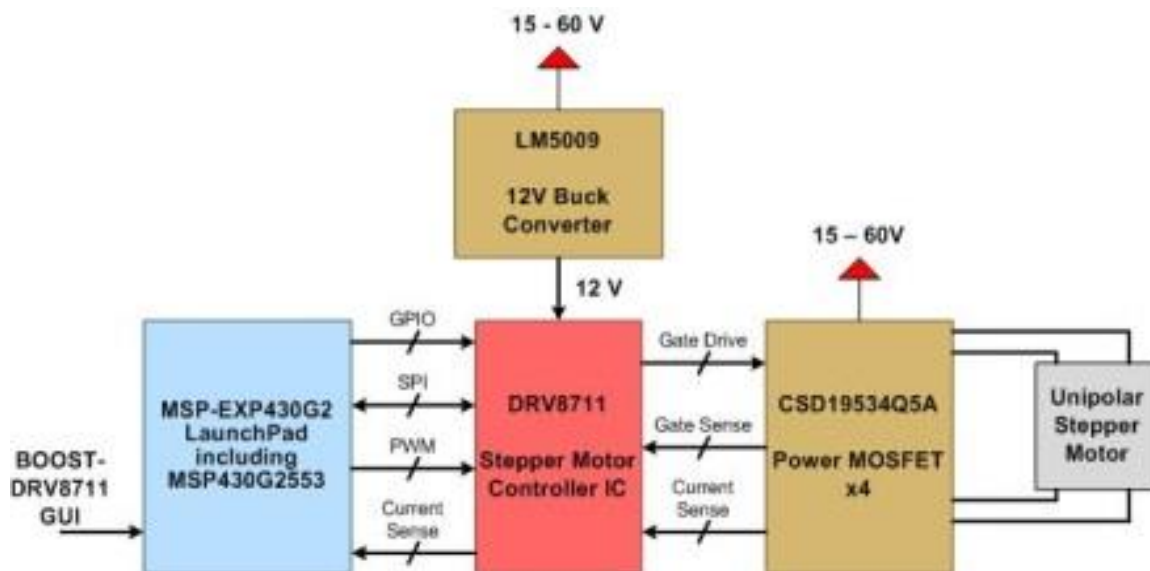


Figure 2: TIDA-00872 Block Diagram

2.1 Highlighted Products

The critical devices to this design are outlined below.

- [DRV8711](#): Stepper Motor Controller IC
- [MSP430G2553](#): Mixed Signal Microcontroller

2.1.1 DRV8711

The DRV8711 device is a stepper motor controller that uses external N-channel MOSFETs to drive a bipolar stepper motor or two brushed DC motors. A microstepping indexer is integrated, which is capable of step modes from full step to 1/256-step.

An ultra-smooth motion profile can be achieved using adaptive blanking time and various current decay modes, including an auto-mixed decay mode. Motor stall is reported with an optional back-EMF output.

A simple step/direction or PWM interface allows easy interfacing to controller circuits. A SPI serial interface is used to program the device operation. Output current (torque), step mode, decay mode, and stall detection functions are all programmable through a SPI serial interface.

Internal shutdown functions are provided for overcurrent protection, short-circuit protection, undervoltage lockout, and overtemperature. Fault conditions are indicated through a FAULTn pin, and each fault condition is reported through a dedicated bit through SPI.

A block diagram for the DRV8711 is shown below.

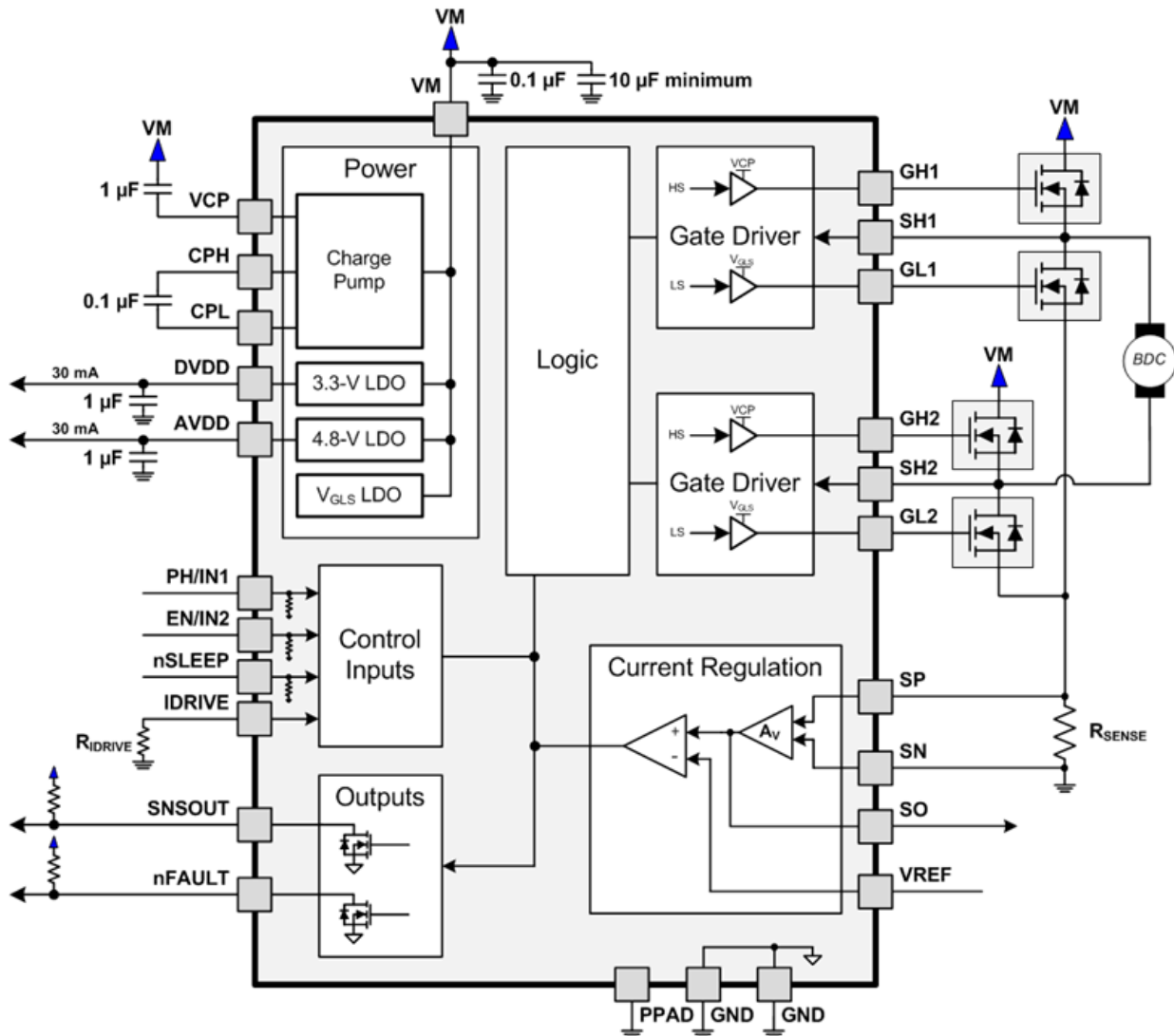


Figure 3: DRV8711 Block Diagram

2.1.2 MSP430G2553

The Texas Instruments MSP430 family of ultra-low-power microcontrollers consists of several devices featuring different sets of peripherals targeted for various applications. The architecture, combined with five low-power modes, is optimized to achieve extended battery life in portable measurement applications. The device features a powerful 16-bit RISC CPU, 16-bit registers, and constant generators that contribute to maximum code efficiency. The digitally controlled oscillator (DCO) allows wake-up from low-power modes to active mode in less than 1 μ s.

The MSP430G2x13 and MSP430G2x53 series are ultra-low-power mixed signal microcontrollers with built-in 16-bit timers, up to 24 I/O capacitive-touch enabled pins, a versatile analog comparator, and built-in communication capability using the universal serial communication interface. In addition the MSP430G2x53 family members have a 10-bit analog-to-digital (A/D) converter.

Typical applications include low-cost sensor systems that capture analog signals, convert them to digital values, and then process the data for display or for transmission to a host system.

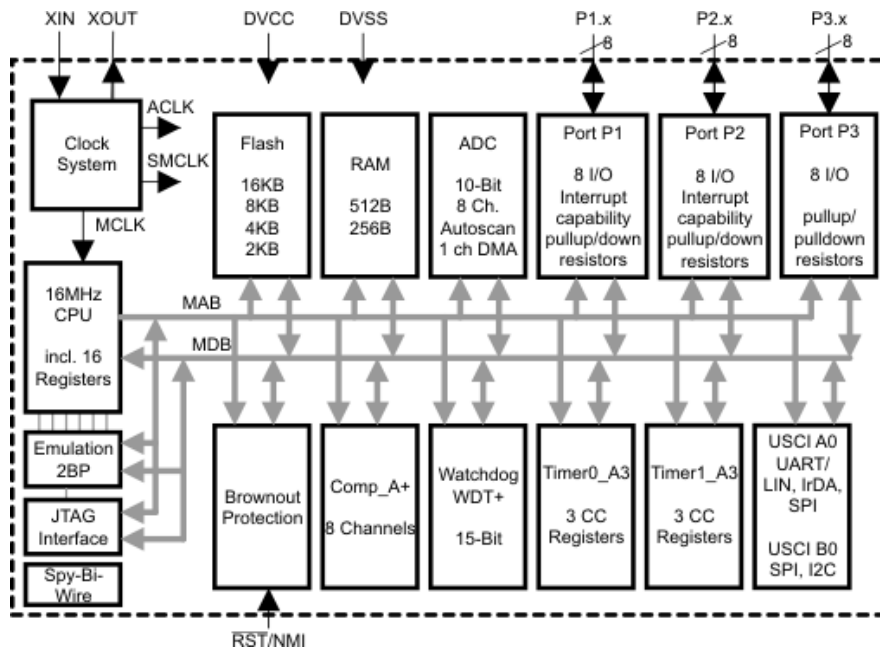


Figure 4: MSP430G2553 Block Diagram

3 System Design Theory

The 15 to 60 V, 3 A, Unipolar Stepper Controller Reference Design demonstrates operation of a bipolar stepper control in a unipolar environment. To achieve this operation, some of the protection features have been disabled.

Overcurrent protection (OCP) and predriver fault are monitoring the translation femtoFETs instead of the low side FET.

Thermal shutdown (TSD) protection works as designed. Undervoltage lockout (UVLO) is now monitoring the 12V buck instead of VM

The DRV8711 stepper motor controller receives control and speed commands from the BOOST-DRV8711 GUI via a MSP430G2 LaunchPad. The commands are received via USB and converted into DRV8711 settings.

Section 3.1 describes the hardware design theory and section 3.2 will describe the software theory of the reference design.

3.1 Hardware System Design Theory

The MSP430G2 LaunchPad, containing a MSP430G2553, has been configured to act as the interface between the BOOST-DRV8711 GUI and the DRV8711. The 3.3 V power supply is supplied from the computer via the USB connector.

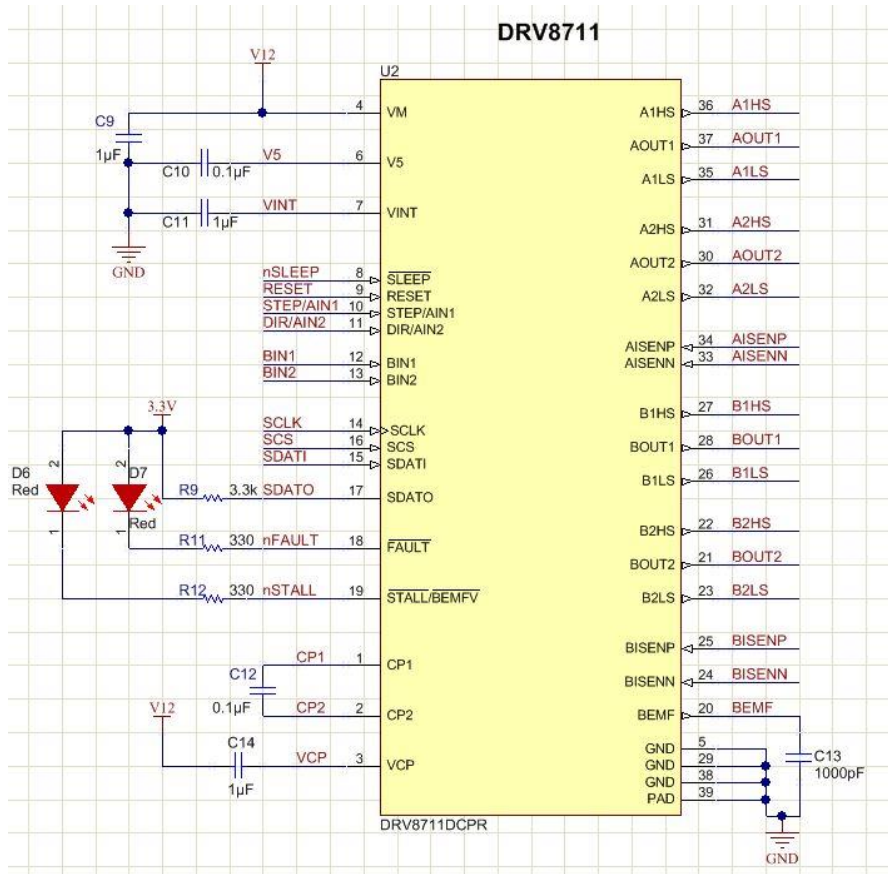


Figure 5: DRV8711 Block

The DRV8711 is a stepper motor controller that uses external N-channel MOSFETs to drive a bipolar stepper motor or two brushed DC motors. A microstepping indexer is integrated, which is capable of step modes from full step to 1/256-step.

The internal current shunt amplifiers are referenced to the internal reference voltage, and adjusted using the TORQUE setting, gain, and indexer table. The OUTx pins then control the low side power FETs to regulate the current. The STEP and DIR pins control the indexer table. As the STEP pin transitions from a logic low to high, the indexer changes to the next state. The nSLEEP pin is used to wake the device from its low power sleep mode.

The DRV8711 provides configurations for managing the MOSFET slew rate and switching performance along with protection features such as automatic switching handshaking, overcurrent, undervoltage, and overtemperature protection.

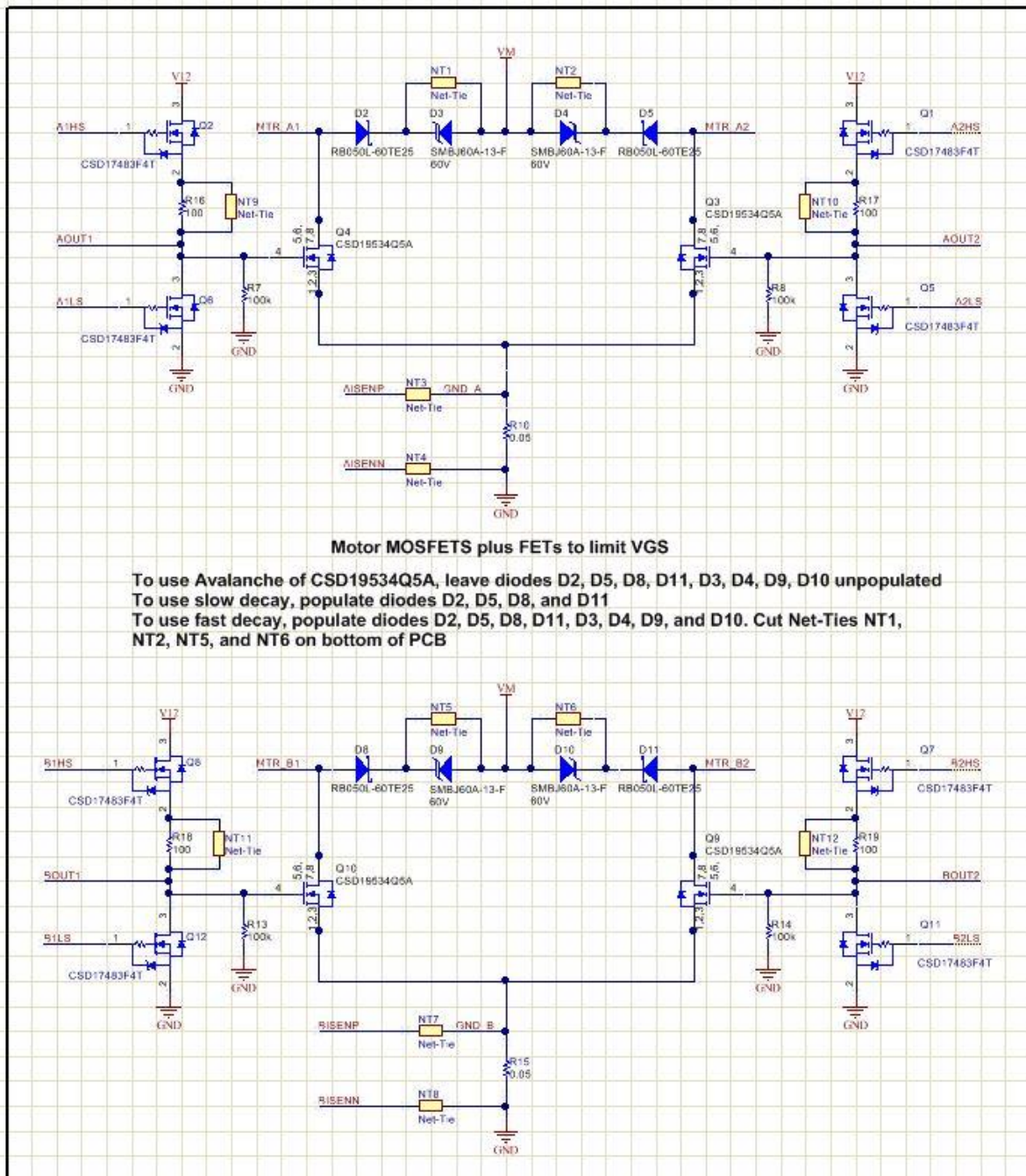


Figure 6: Power FETs Block

Four CSD19534Q5A N-channel power MOSFETs are used to control the current of unipolar stepper. The DRV8711 controls the low side FETs using two CSD17483 femtoFETs. When driving current into the low side FETs, the HS output controls the low side FET and provide the proper voltage to the xOUTn pin.

The DRV8711 is set for slow decay for this application. Slow decay uses the high side output and opposite low side output to drive current into the motor winding. When the desired current level is reached, both high side outputs are turned off and both low side outputs are turned on. This turns off both low side power FETs.

When entering current regulation mode, the power FETs avalanche for a brief period (~1us) as the current decreases. The power FETs block allows the driver to control the current in each of the stepper motor windings.

Any combination of fast or mixed decay cannot be used in this configuration. When fast or mixed decay is activated, the opposite low side FET turns on, eventually causing the current direction to change.

To improve the efficiency the design, the MOSFET are driven with the configurable DRV8711 gate drivers. This allows for minimal conduction and switching losses. To understand more about motor gate drivers and MOSFETs see this [app note](#).

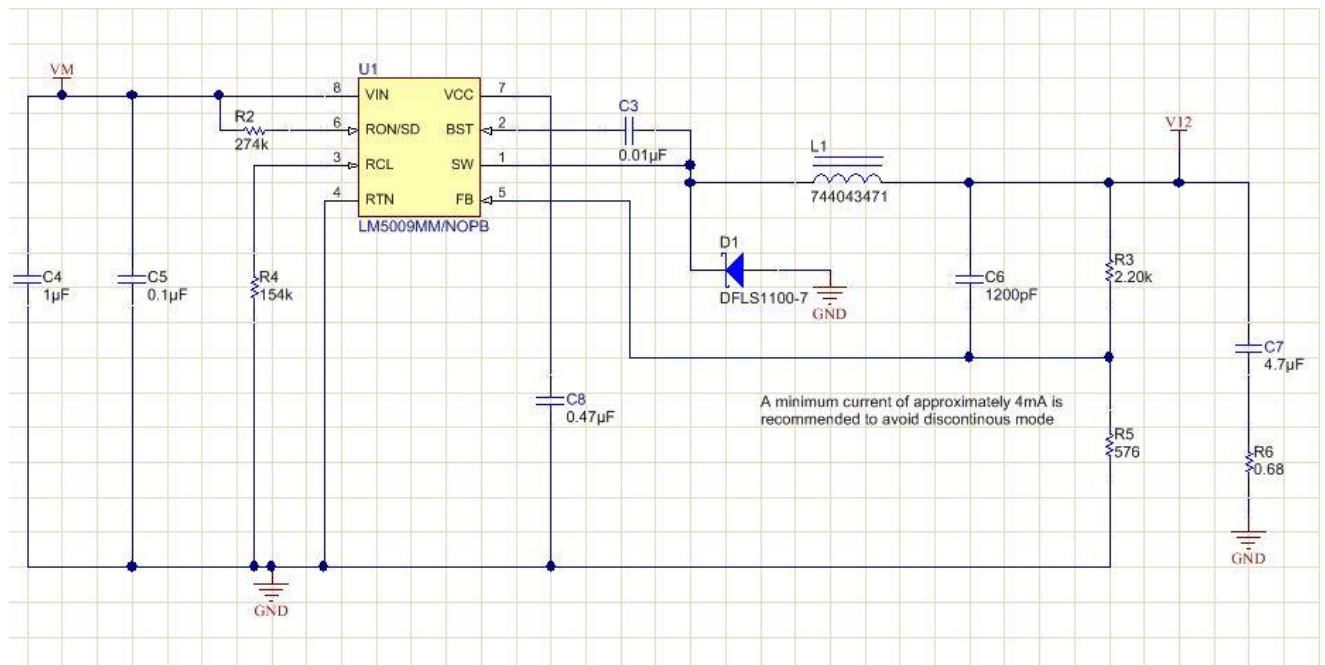


Figure 7: 12 V Regulator Block

The LM5009 is used to create a 12V supply. It is a regulated buck converter that takes the VM input voltage and steps it down to 12 V to provide power to the DRV8711. The DRV8711 is set to operate at 12V; providing 12V gate to source voltage (V_{gs}) on the low side FETs.

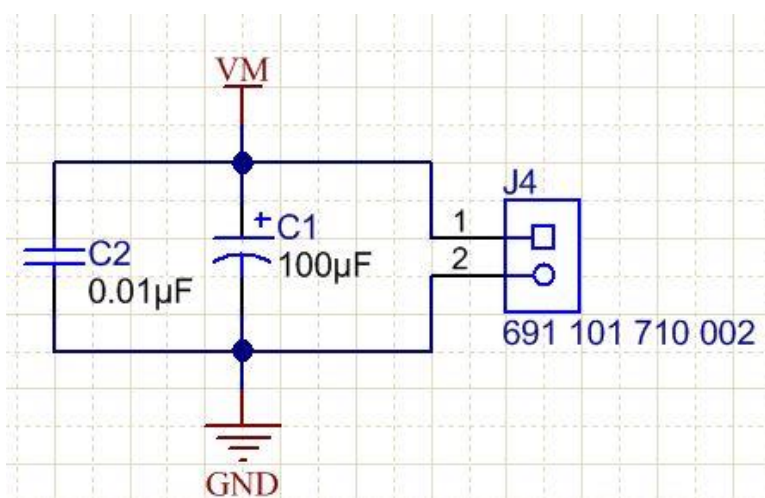


Figure 8: Power Input Block

The power supply is connected directly to the board and filtered with a 100 μF bulk electrolytic capacitor.

3.2 Software System Design Theory

The motor controller uses the BOOST-DRV8711 GUI and firmware. This code can be loaded and control the stepper when configured as shown in the document.

Refer to the [BOOST-DRV8711 User's Guide](#) for instructions on loading the firmware into the LaunchPad. Once loaded, refer to the user guide for instructions on how to install and open the GUI.

After the GUI is open, use the instructions below to control the stepper. The GUI will set the decay mode, max current, gate drive timing, microstep mode, and other key parameters to operate the stepper motor.

4 Getting Started Hardware

4.1 Connections

The TIDA-00872 reference design can be powered from a 15V to 60V power supply. The supply is connected to the PCB through the VM and GND connections on the J4 connector. The motor is connected to the PCB through the J3 connector. The PCB is connected to the LaunchPad via connectors J1 and J2.

The speed, microstep mode, chopping current, and other key parameters are controlled by the GUI.

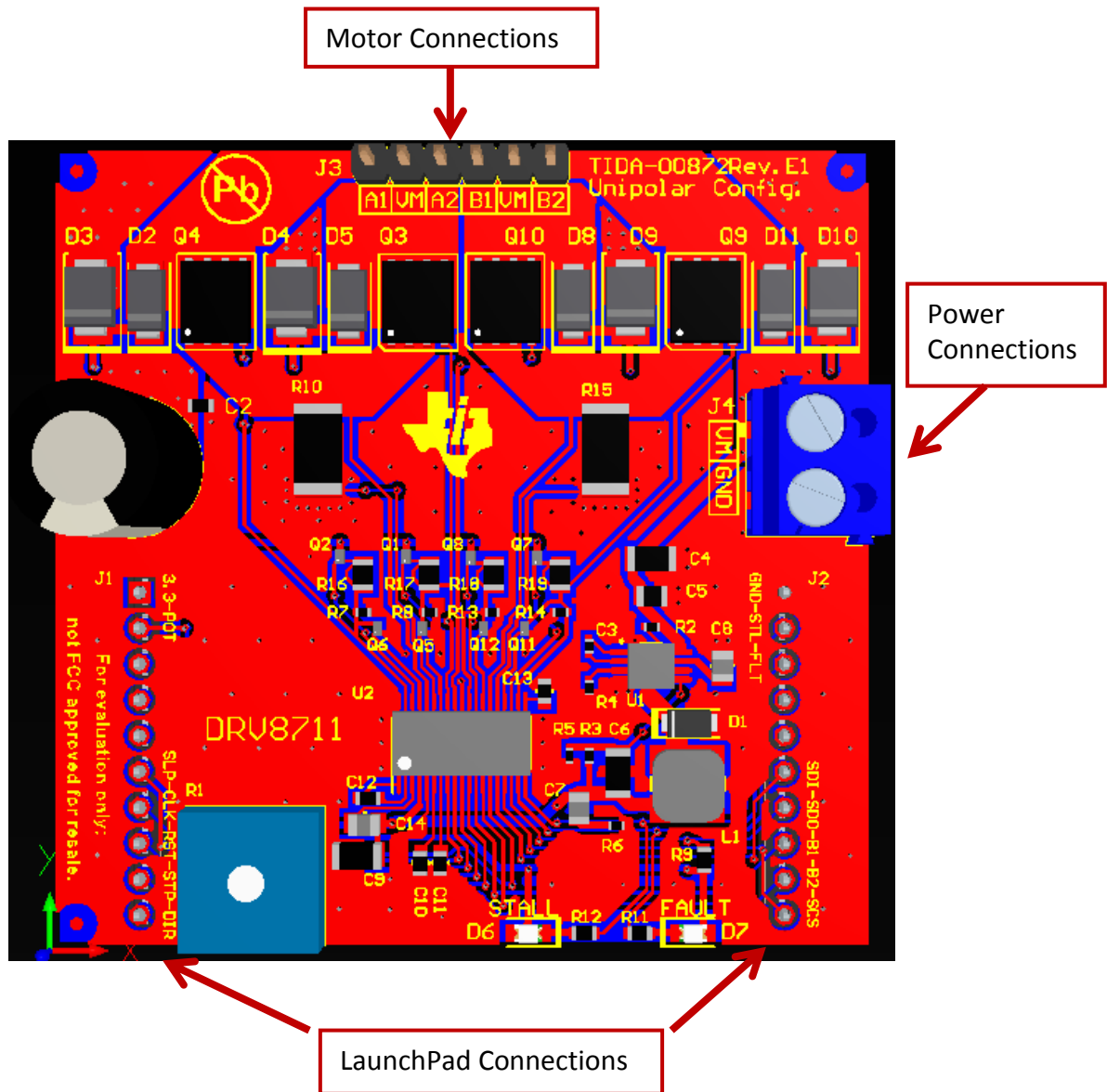


Figure 9: Connections

For this design, a Moons Stepper motor with the following parameters was used.

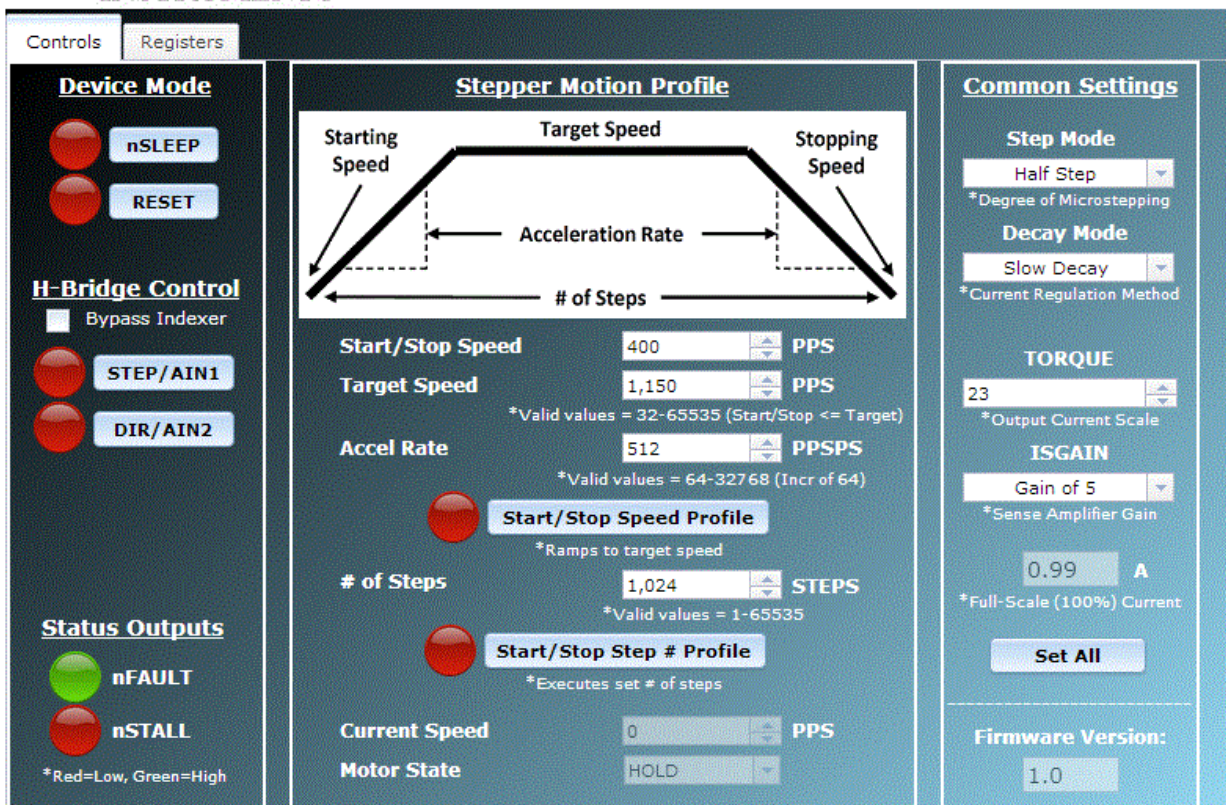
Voltage	36V nominal
Current	2.9A
Resistance	3.0 Ohms
Inductance	1.5 mH @ 10kHz

The PCB is configured to use the avalanche of the CSD19534Q5A NexFETs.

4.2 Procedure

Refer to the steps below to get started with the reference design hardware.

1. Connect the power supply to the design through the J4 connector.
2. Connect the motor to the design through the J3 connector.
3. Program the LaunchPad with the BOOST-DRV8711 firmware.
4. Attach the LaunchPad, enable the power supply, and open the GUI.
5. Set the GUI controls as shown below.



The screenshot displays the GUI for the BOOST-DRV8711 stepper driver, divided into three main sections: Device Mode, Stepper Motion Profile, and Common Settings.

Device Mode: Includes buttons for nSLEEP, RESET, STEP/AIN1, and DIR/AIN2. A Bypass Indexer checkbox is present. Status outputs nFAULT (green) and nSTALL (red) are shown, with a note: *Red=Low, Green=High.

Stepper Motion Profile: Features a trapezoidal speed profile graph with labels for Starting Speed, Target Speed, Stopping Speed, Acceleration Rate, and # of Steps. Below the graph are input fields:

- Start/Stop Speed: 400 PPS
- Target Speed: 1,150 PPS (*Valid values = 32-65535 (Start/Stop <= Target))
- Accel Rate: 512 PPS (*Valid values = 64-32768 (Incr of 64))
- # of Steps: 1,024 STEPS (*Valid values = 1-65535)

 Two red buttons are visible: Start/Stop Speed Profile (*Ramps to target speed) and Start/Stop Step # Profile (*Executes set # of steps). At the bottom, Current Speed is 0 PPS and Motor State is HOLD.

Common Settings: Includes:

- Step Mode: Half Step (*Degree of Microstepping)
- Decay Mode: Slow Decay (*Current Regulation Method)
- TORQUE: 23 (*Output Current Scale)
- ISGAIN: Gain of 5 (*Sense Amplifier Gain)
- Current: 0.99 A (*Full-Scale (100%) Current)

 A Set All button and Firmware Version (1.0) are also present.



Name	11	10	9	8	7	6	5	4	3	2	1	0	Address						
CTRL	DTIME		ISGAIN		EXSTALL		MODE		RSTEP	RDIR	ENBL		0x0						
	850 ns		Gain of 5		Int		Half Step		0	0	1								
TORQUE	SIMPLTH				TORQUE								0x1						
	rsv				100 us				69										
OFF	rsv		PWM_M		TOFF								0x2						
	rsv		0		12														
BLANK	rsv		ABT		TBLANK								0x3						
	rsv		0		8														
DECAY	DECMOD				TDECAY								0x4						
	rsv				Slow Decay				8										
STALL	VDIV		SDCNT		SDTHR								0x5						
	Divide by 32		1 Step		64														
DRIVE	OCPH		OCPDEG		TDRIVEN		TDRIVEP		IDRIVEN		IDRIVEP		0x6						
	500 mV		4 us		500 ns		500 ns		300 mA		150 mA								
STATUS	rsv		STDLAT		STD		UVLO		BPDF		APDF		BOCP		AOCP		OTS		0x7
	rsv		1		1		0		0		0		0		0		0		

Manual SPI Read/Write
 ADDR: 0x 0 DATA: 0x 0 **Write**
 0x 0 0x 0 **Read**

Reset Faults **Write All**
Read All

6. Start the motor as described in the BOOST-DRV8711 User Guide.
7. Experiment with the settings if desired.

5 Getting Started Firmware

TIDA-00872 uses the BOOST-DRV8711 GUI to control the unipolar stepper motor. The firmware and GUI, along with installation instructions is located in the BOOST-DRV8711 tool folder.

6 Test Setup

Equipment	Name
DC Power Supply	Chroma 620012P-100-50
Multimeter	Tektronix DMM 4040
Oscilloscope	Tektronix DPO 7054

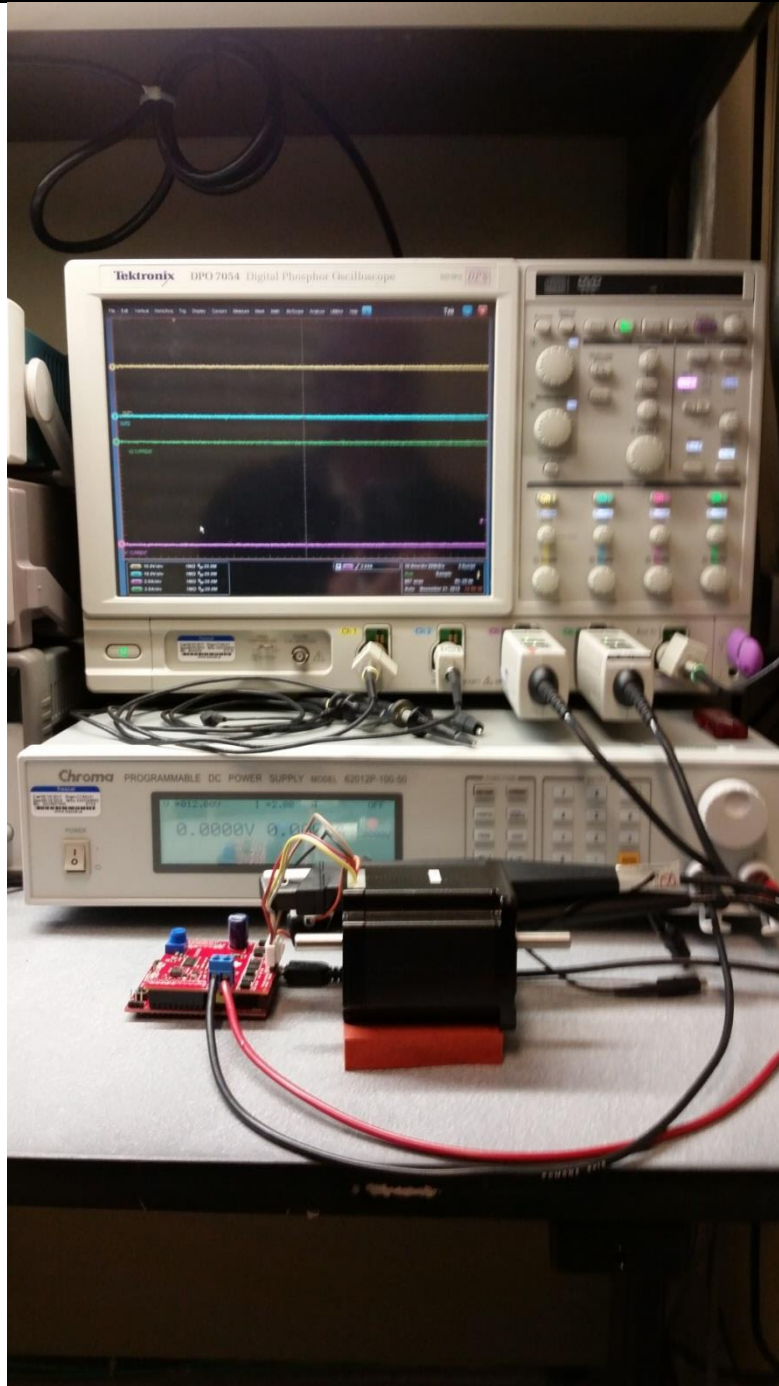


Figure 10: Test Setup

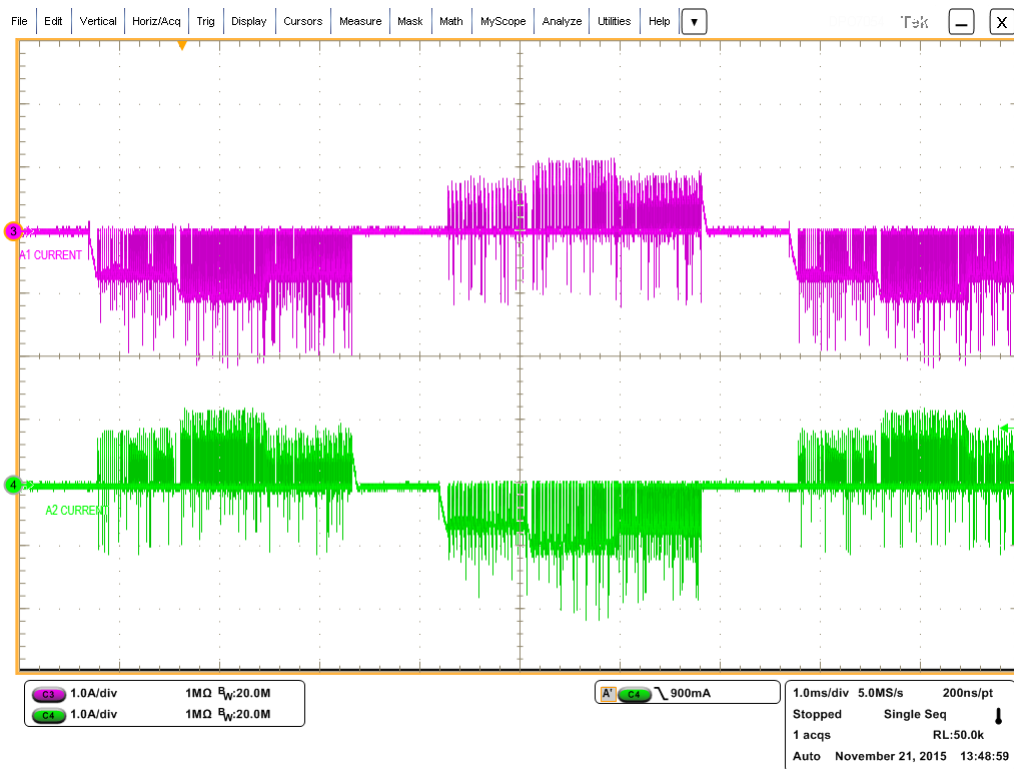
7 Test Data

7.1 Functional Tests

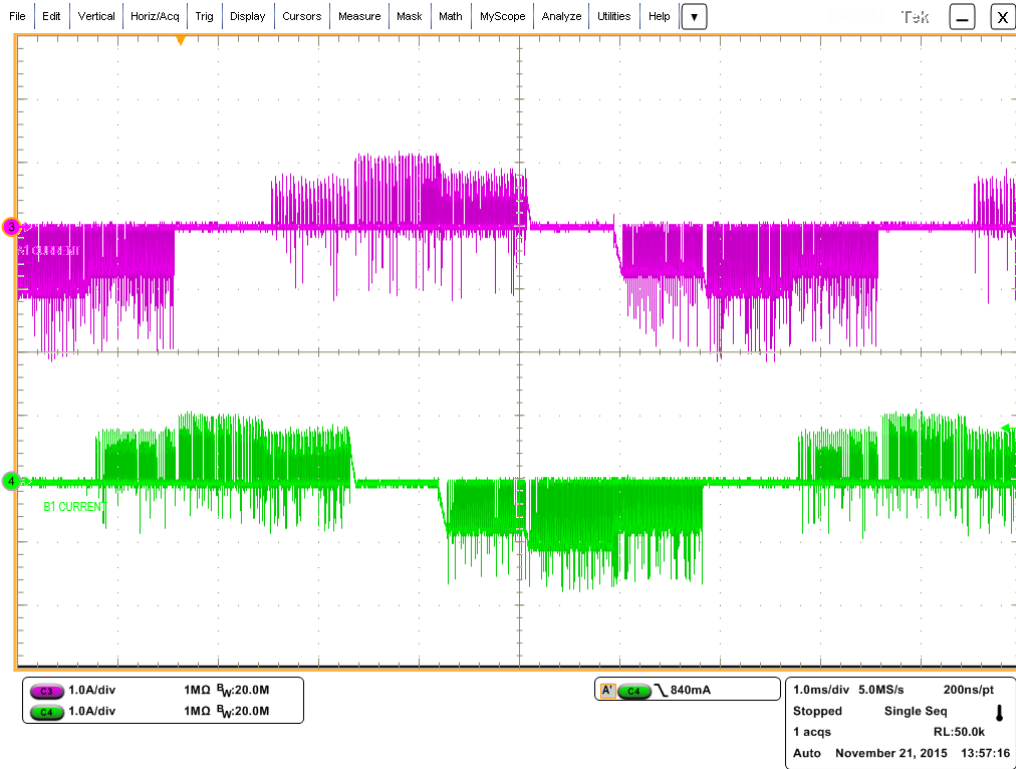
7.1.1 Winding Current

The current in the stepper motor was captured when running at 1150 steps per second in half step mode. VM voltage was 36V, and the current was capture at 1A, 2A, and 3A.

Current at 1A in A1 and A2:



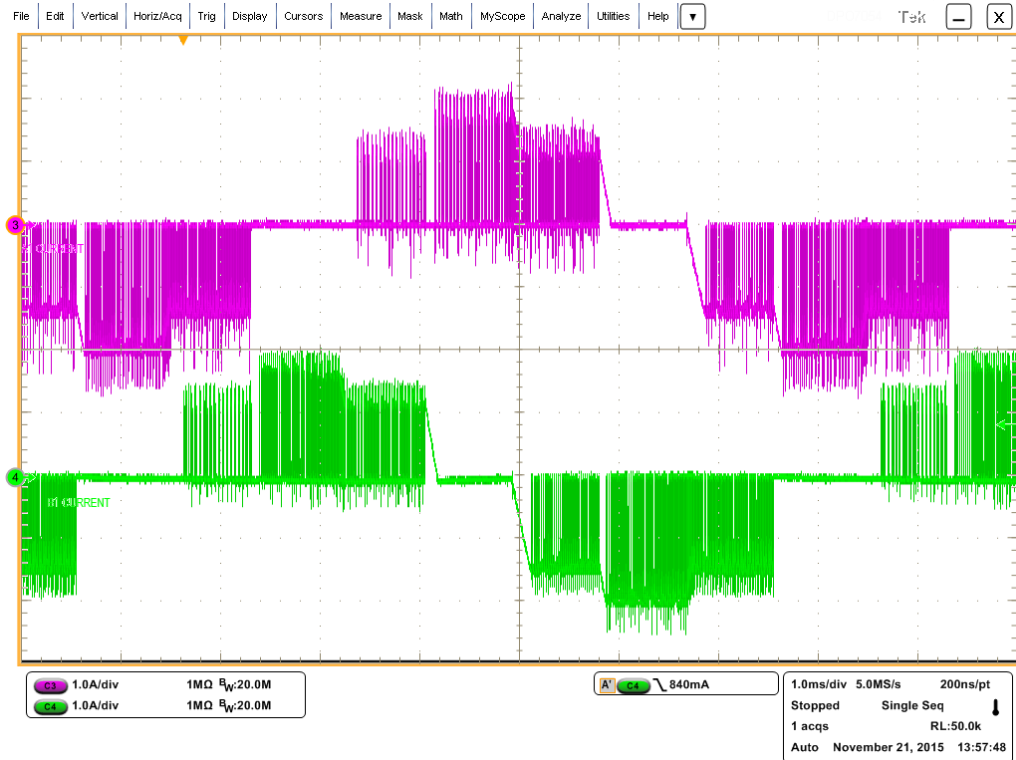
Current at 1A in A1 and B1:



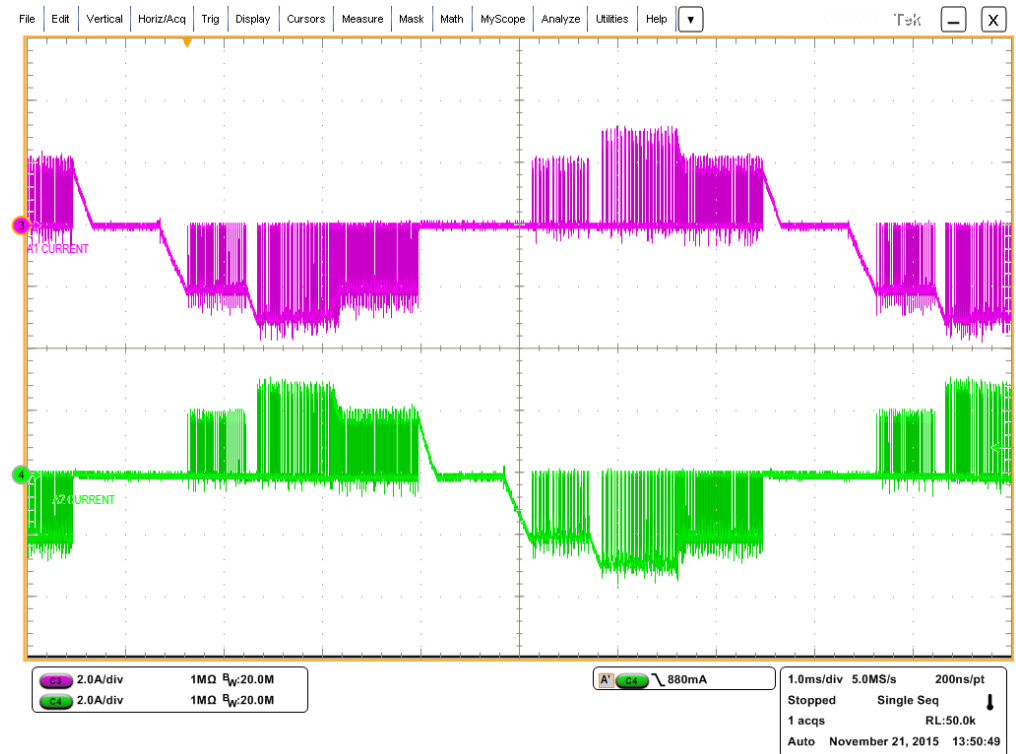
Current at 2A in A1 and A2.



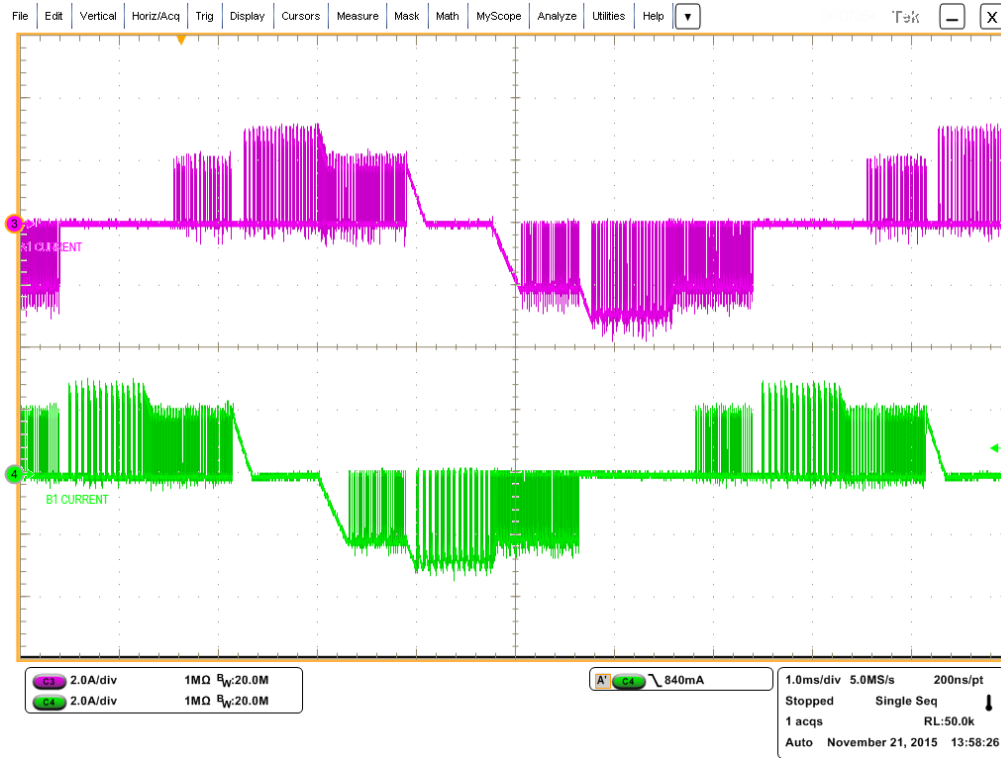
Current at 2A in A1 and B1.



Current at 3A in A1 and A2.



Current at 3A in A1 and B1.

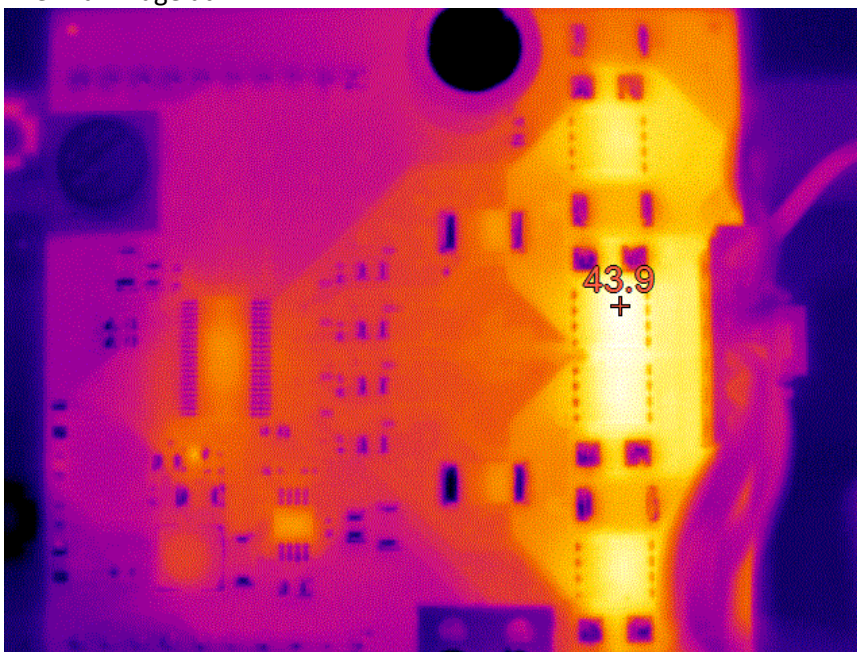


7.1.2 Board Temperature

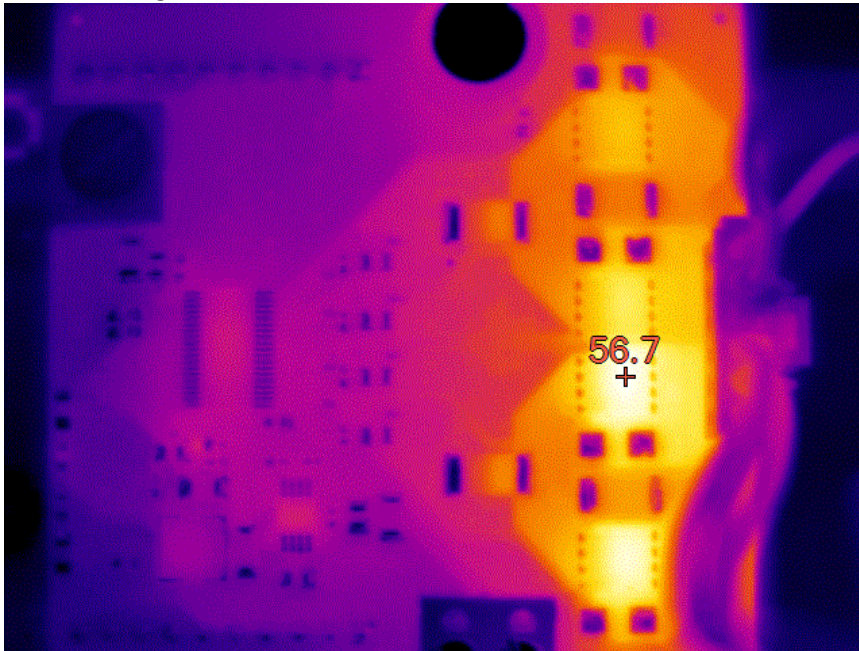
Thermal images of the PCB were captured with currents of 1A, 2A, and 3A in the windings. The maximum temperature is highlighted.

VM is 36V. The motor is spinning at 1150 steps per second at ½ microstep. The DRV8711 settings are those shown in the GUI images.

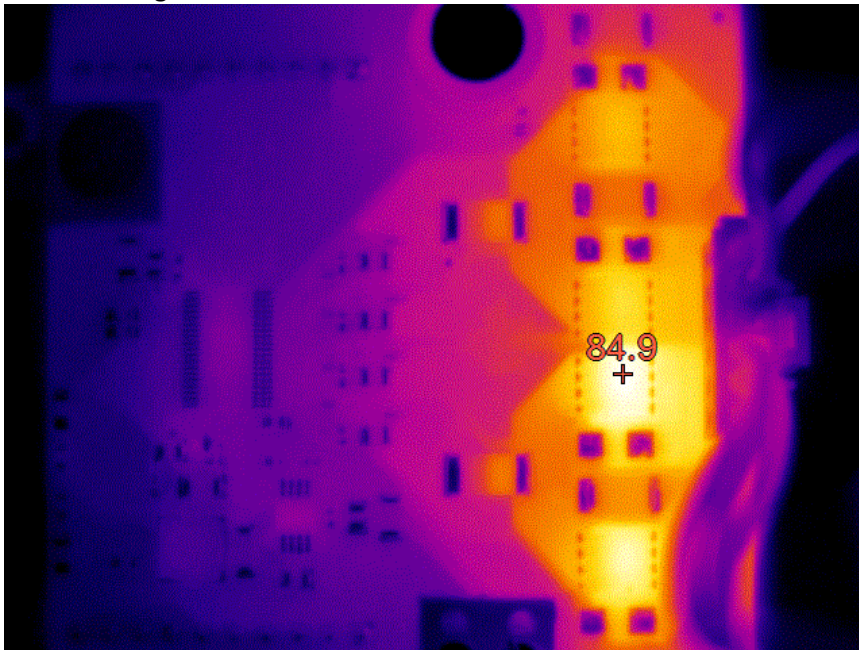
Thermal image at 1A:



Thermal image at 2A:



Thermal image at 3A:



8 Design Files

The complete design files can be downloaded at the reference design home page at [TIDA-00872](#).

9 Software Files

The BOOST-DRV8711 software files were used for this reference design. The files can be downloaded at [TIDA-00872](#).

10 References

1. <http://www.ti.com/lsds/ti/analog/motordrivers/overview.page>
2. Texas Instruments E2E Community, <http://e2e.ti.com/>
3. Texas Instruments MSP430G2553 MCU, <http://www.ti.com/product/msp430g2553>
4. Texas Instruments DRV8711 Stepper Motor Gate Driver, <http://www.ti.com/product/drv8711>
5. Texas Instruments 9.5-95V Wide Vin, 150mA Constant On-Time Non-Synchronous Buck Regulator <http://www.ti.com/product/lm5009>
6. Texas Instruments CSD19534Q5A 100V, N-Channel NexFET Power MOSFET, <http://www.ti.com/product/CSD19534Q5A>
7. Texas Instruments CSD17483F4 30V, N-Channel FemtoFET™ MOSFET, <http://www.ti.com/product/CSD17483F4>
8. Texas Instruments Code Composer Studio Integrated Development Environment, <http://www.ti.com/tool/ccstudio>
9. MSP430 LaunchPad Value Line Development Kit, <http://www.ti.com/tool/msp-exp430g2>
10. BOOST-DRV8711, <http://www.ti.com/tool/boost-drv8711>

11 About the Author

Rick Duncan is an Applications Engineer for Texas Instrument's motor drive business, where he is responsible for supporting TI's motor drive portfolio. Rick graduated from Louisiana State University with a Bachelor's of Science in Electrical Engineering.

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