TI Designs

High-Voltage Stepper Reference Design Using DRV8711

TEXAS INSTRUMENTS

Description

The TIDA-01227 reference design is a 15-V to 70-V stepper motor controller for bipolar applications. The design uses the following parts from Texas Instrument: DRV8711 bipolar stepper motor, controller gate driver; CSD19538Q3A 100-V, N-Channel NexFET™ power MOSFETs; CSD17483F4 30-V, N-Channel FemtoFET™ MOSFET; MSP430G2553 MCU; LM5107 100-V, 1.4-A peak, half-bridge gate driver; and LM5017 12-V buck converter. The focus of this design is to demonstrate the use of the DRV8711 stepper motor controller to control stepper motors at voltages higher than 60 V. The DRV8711 operates at 12 V while using additional circuitry to convert to high-voltage control signals.

Resources

TIDA-01227	Design Folder
DRV8711	Product Folder
LM5107	Product Folder
LM5017	Product Folder
CSD19538Q3A	Product Folder
CSD17483F4T	Product Folder
MSP430™ LaunchPad™ Value-Line Development Kit	Tool Folder

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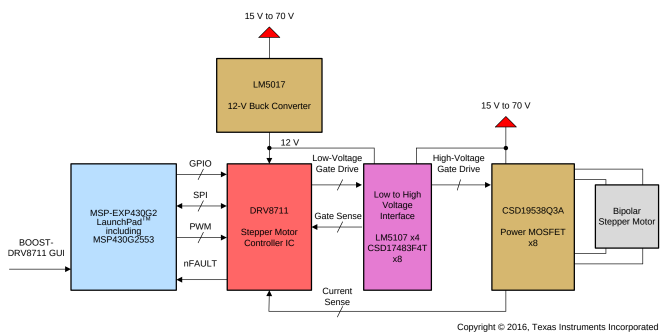
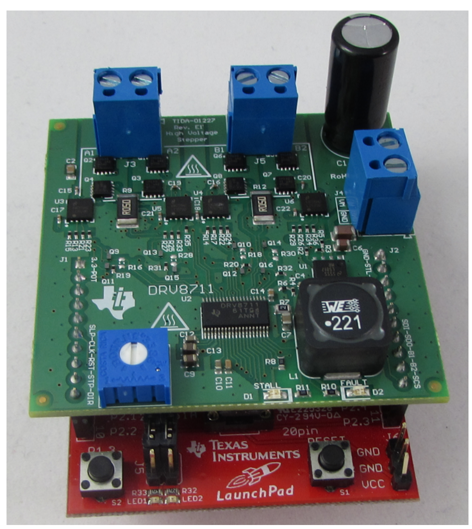
Features

- 15-V to 70-V Input Voltage Range
- 2-A RMS, 3-A Peak Output Current Capability
- Designed to Use LaunchPad™ and Boost-DRV8711 Software
- Board Size: 2.3 in × 2.25 in
- Onboard 12-V, 0.6-A Buck Converter
- Wide Array of System Protection Features Including DRV8711 Overtemperature and Supply Undervoltage Protection

Applications

- High-Speed Printers
- High-Speed Industrial Steppers





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1 System Overview

1.1 System Description

The TIDA-01227 design configures the DRV8711 device to control a bipolar stepper motor at voltages above the absolute maximum voltage of the DRV8711. This configuration is possible by adding an interface between the DRV8711 controller and the CSD19538Q3A field-effect transistors (FETs). The interface converts lower-voltage signals to higher-voltage signals controlling the full-bridges. This configuration can be used in applications that require high-speed operation. Higher voltage allows the current to change at a faster rate, which increases the motor speed. A high-speed printer is an example of a typical application.

The reference design is composed of three main sections: the MCU, the power stage, and the power conversion sections.

The first section is the MCU, which decodes the commands from the graphical user interface (GUI) and sends the appropriate signals to the DRV8711 controller.

The second section is the power stage, which consists of the DRV8711 gate driver, the LM5107 half-bridge drivers, and the power MOSFETs. The LM5107 acts as an interface between the DRV8711 gate driver and the power MOSFETs. The power stage amplifies the control signals from the MCU to the motor and regulates the current in the windings based on the settings in the configuration registers.

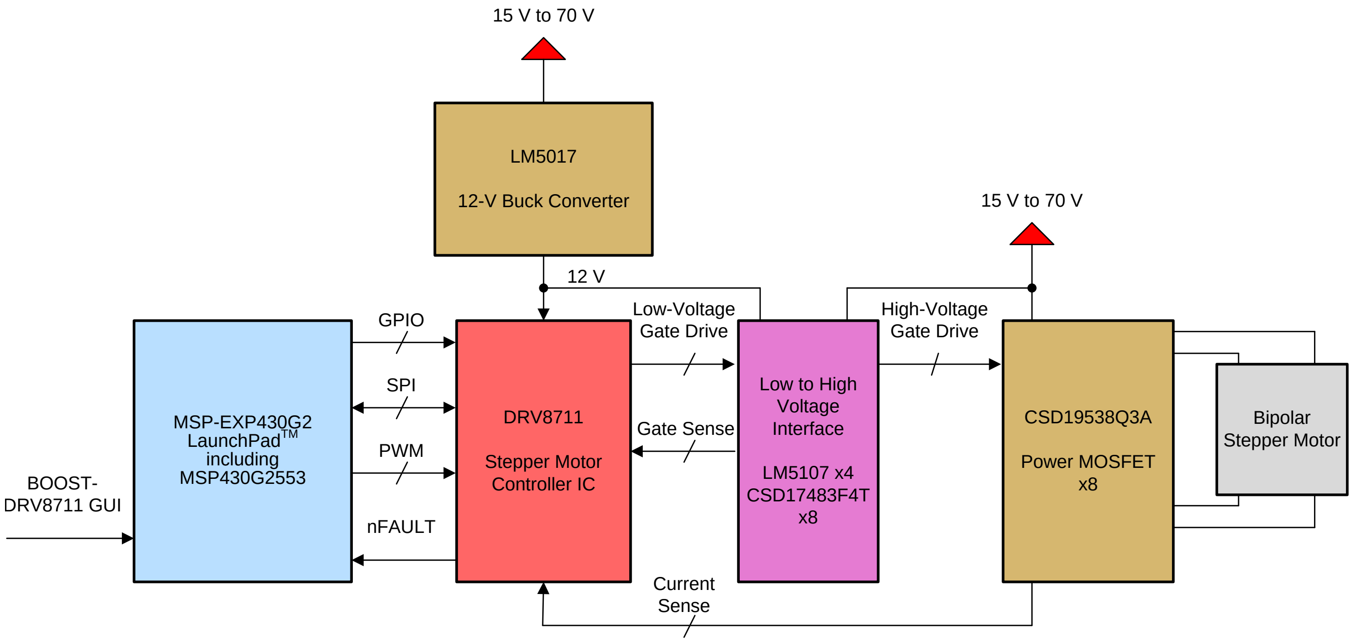
The third section is the power conversion section, which supplies power to the MOSFETs from the main power input. Power to the DRV8711 is supplied through a switching buck converter.

1.2 Key System Specifications

Table 1. Key System Specifications

PARAMETER	SPECIFICATIONS	DETAILS
Voltage operation above absolute maximum of DRV8711	System configured for 70-V operation; absolute maximum of the DRV8711 is 60 V, recommended maximum is 52 V	Section 2.1
Interface between DRV8711 and high-voltage FETs	Interface converts DRV8711 outputs from 0 V to 10/22 V into 0-V to 3.3-V inputs at the LM5107	Section 2.1
12-V buck regulator	Converts > 15 V to 12 V to provide power to the DRV8711 and LM5107 bootstrap capacitors	Section 2.1

1.3 Block Diagram



1.4 Highlighted Products

1.4.1 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. Figure 1 shows the functional block diagram of the DRV8711 device.

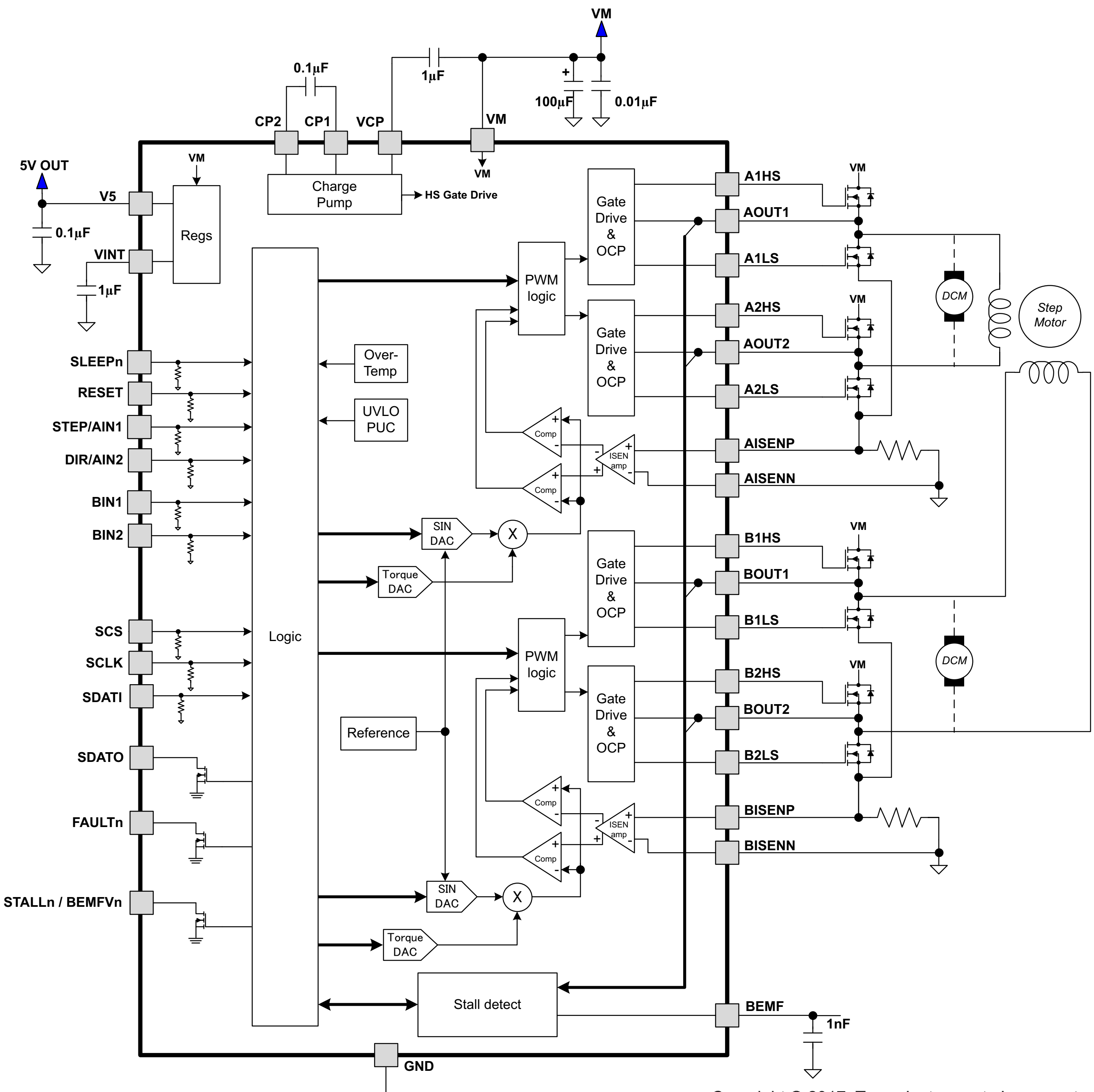


Figure 1. DRV8711 Functional Block Diagram

An ultra-smooth motion profile can be achieved using adaptive blanking time, adjustable decay times, and various current decay modes, including an auto-mixed decay mode. When microstepping, motor stall can be reported with an optional back-electromotive force (back-EMF) output.

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

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.

1.4.2 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 reduced instruction set computing (RISC) CPU, 16-bit registers, and constant generators that contribute to maximum code efficiency. The digitally-controlled oscillator (DCO) allows wakeup from low-power modes to active mode in less than 1 µs.

Figure 2 shows the MSP430G2553 functional block diagram.

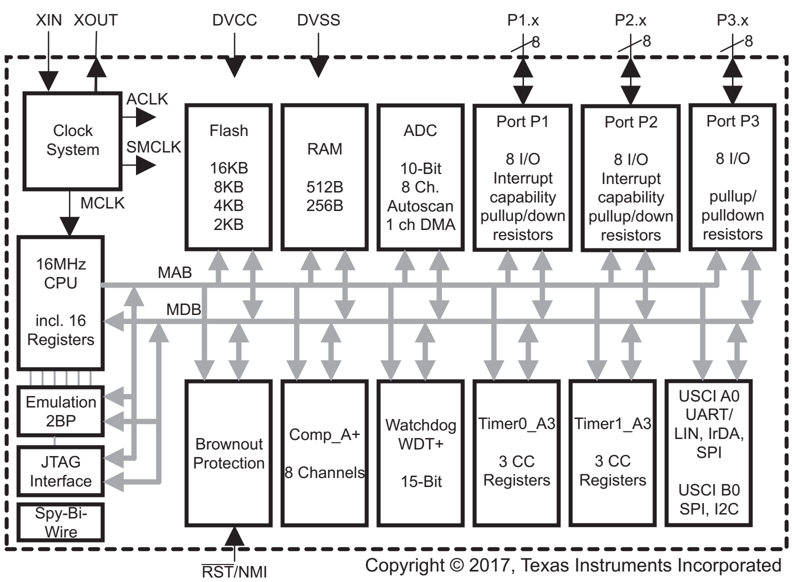


Figure 2. MSP430G2553 Functional Block Diagram

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 ADC.

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.

1.4.3 LM5107

The LM5107 is designed to drive both the high-side and the low-side N-channel FETs in a synchronous buck or a half-bridge configuration. The outputs are independently controlled with transistor-transistor logic (TTL) input thresholds. The floating high-side driver is capable of working with supply voltages up to 100 V. An integrated high-voltage diode is provided to charge the high-side gate drive bootstrap capacitor. A robust level shifter operates at high speed while consuming low power and providing clean level transitions from the control logic to the high-side gate driver. Undervoltage lockout is provided on both the low-side and the high-side power rails.

Figure 3 shows the LM5107 functional block diagram.

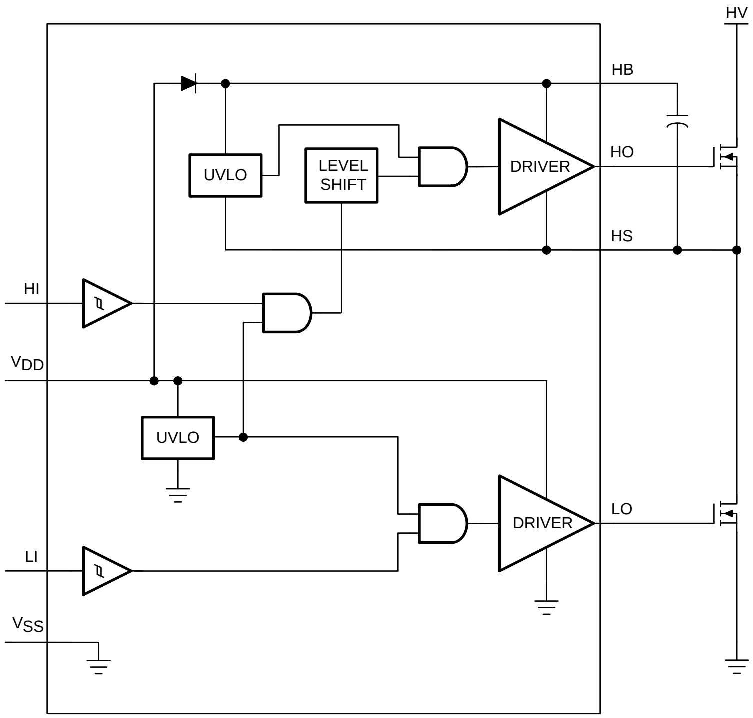


Figure 3. LM5107 Functional Block Diagram

1.4.4 LM5017

The LM5017 step-down switching regulator features all the functions required to implement a low-cost, efficient, buck converter capable of supplying up to 0.6 A to the load. This high-voltage regulator contains a 100-V N-channel buck and synchronous switches, is easy to implement, and is provided in thermally-enhanced HSOP PowerPAD-8 and WSON-8 packages. The regulator operation is based on a constant on-time control scheme using an on-time inversely proportional to V_{IN}. This control scheme does not require loop compensation. The current limit is implemented with a forced off-time inversely proportional to V_{OUT}. This scheme ensures short-circuit protection while providing minimum foldback.

The LM5017 can be applied in numerous applications to efficiently downregulate higher voltages. This regulator is well-suited for 48-V telecom and automotive power bus ranges.

Figure 4 shows the LM5017 functional block diagram.

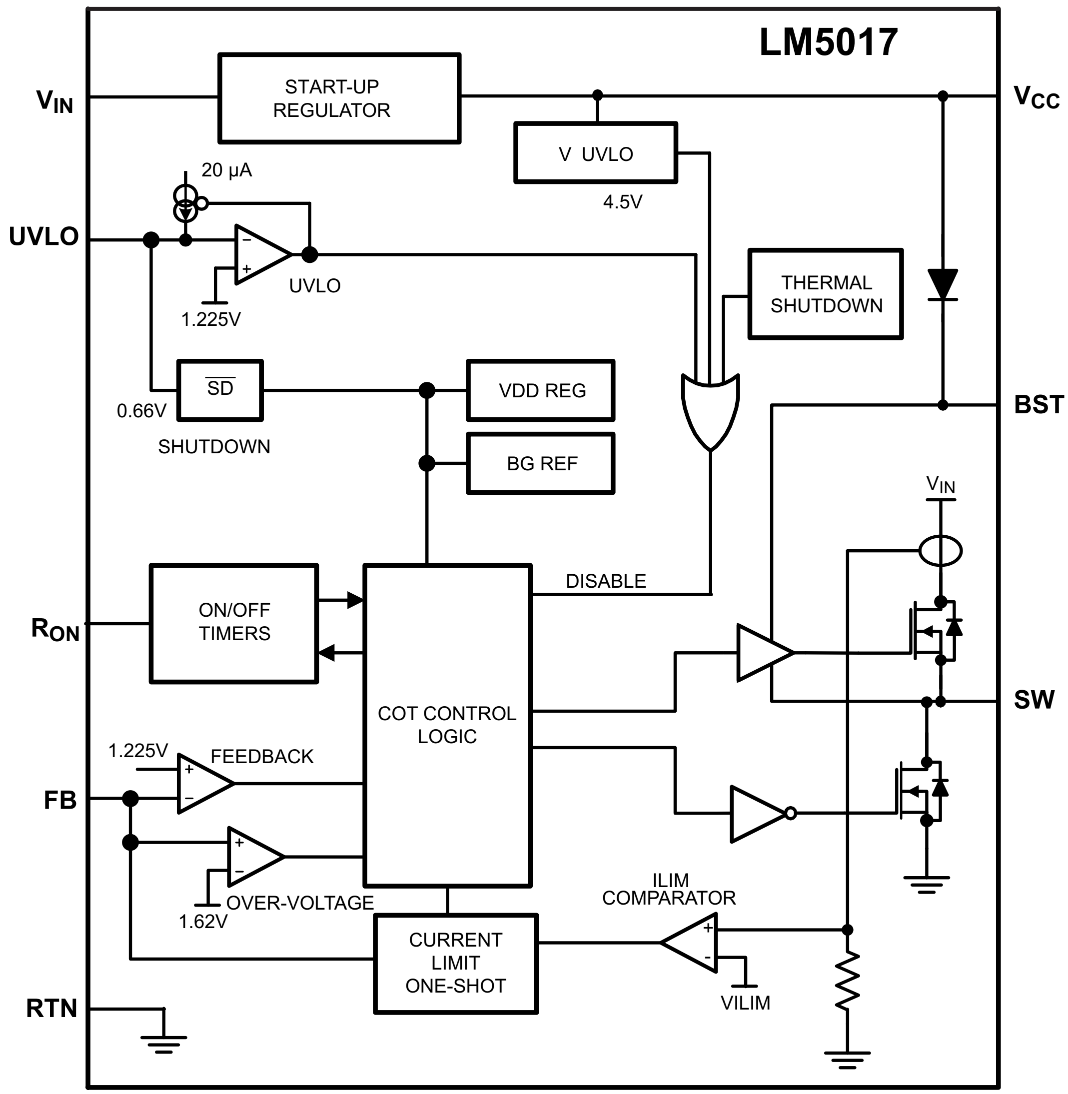


Figure 4. LM5017 Functional Block Diagram

1.4.5 CSD17483F4T

This 200-mΩ, 30-V N-Channel FemtoFET™ MOSFET technology is designed and optimized to minimize the footprint in many handheld and mobile applications. This technology is capable of replacing standard small-signal MOSFETs while providing at least a 60% reduction in footprint size.

Figure 5 shows the top view of the CSD17483F4T MOSFET.

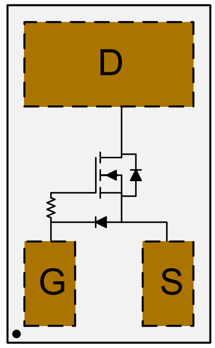


Figure 5. CSD17438F4 Top View

1.4.6 CSD19538Q3A

This 100-V, 49-mΩ, SON 3.3-mm × 3.3-mm NexFET™ power MOSFET is designed to minimize conduction losses and reduce board footprint in Power-over-Ethernet (PoE) applications.

Figure 6 shows the top view of the CSD19538Q3A MOSFET.

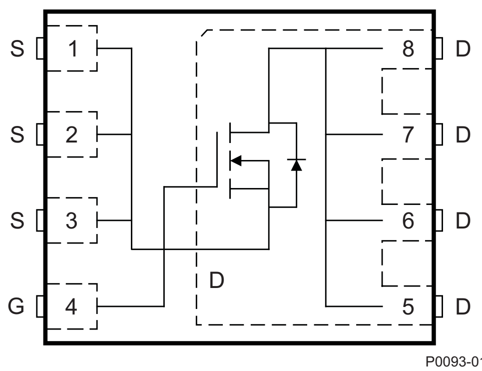


Figure 6. CSD19538Q3A Top View

2 System Design Theory

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

2.1 Hardware Design Theory

TIDA-01227 is designed to spin stepper motors at high rates of speed. In some applications, this action can only be achieved by increasing the system voltage used to regulate the current. As the motor speed increases and the back-electromotive force of the motor increases, the rate of change in current is limited. By increasing the system voltage, the rate of change in current can be increased and the speed of the motor can be increased.

This design has been tested to 70 V with 2-A current full-scale. With different components, the design can be extended to higher voltages. Although not added for this reference design, consider placing a thermal circuit near the FETs to monitor the operating temperature of the FETs.

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

Figure 7 shows the schematic for the DRV8711 block.

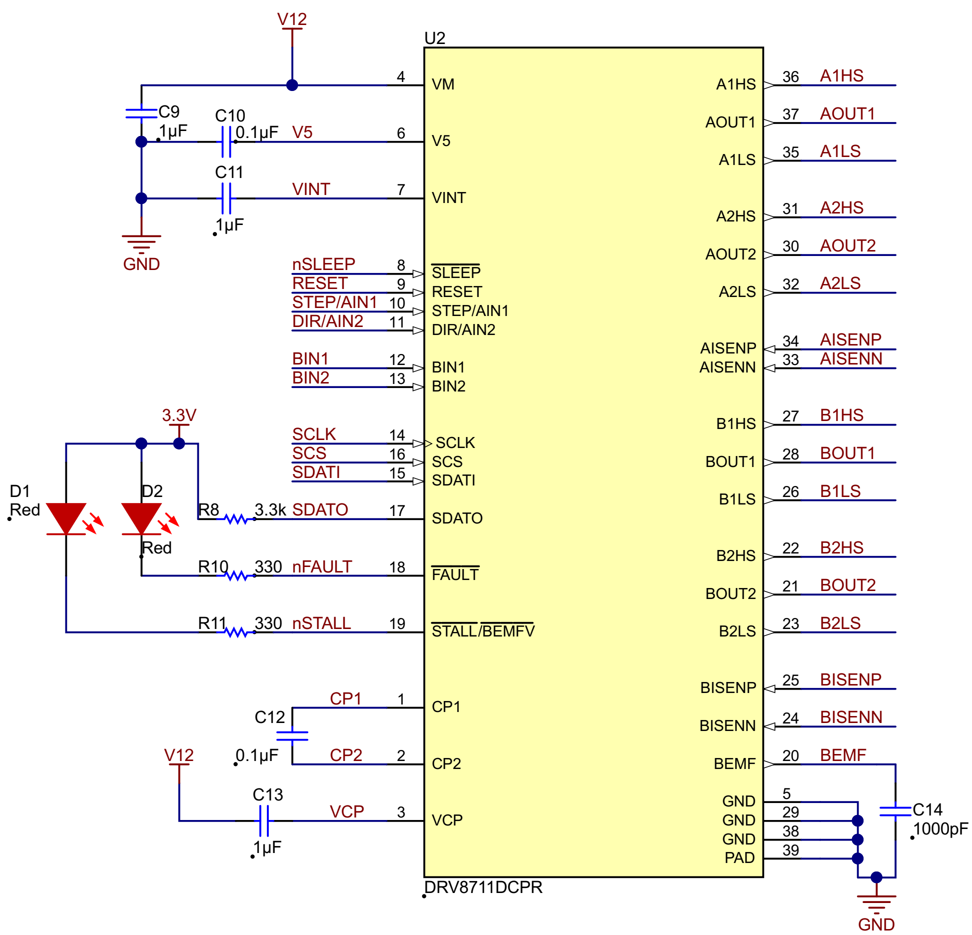


Figure 7. DRV8711 Block

The DRV8711 stepper motor controller sends the commands to the LM5107 device through a voltage divider. The ALSx and BLSx output pins of the DRV8711 device toggle from 0 V to 10 V. These signals are then divided to 0 V to 3.3 V using a 3:1 attenuation network. The AHSx and BHSx output pins toggle from 0 V to 22 V and are divided down to 0 V to 3.3 V with a 7:1 attenuation network. The integrated-microstepping indexer 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 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.

Four CSD19538Q3A N-channel power MOSFETs are used to control the current in each winding of a bipolar stepper. These FETs are turned ON and OFF by the LM5107 device using the commands at the inputs. The circuit shown in Figure 8 is one full-bridge and controls the current direction and magnitude in each motor.

Bridge

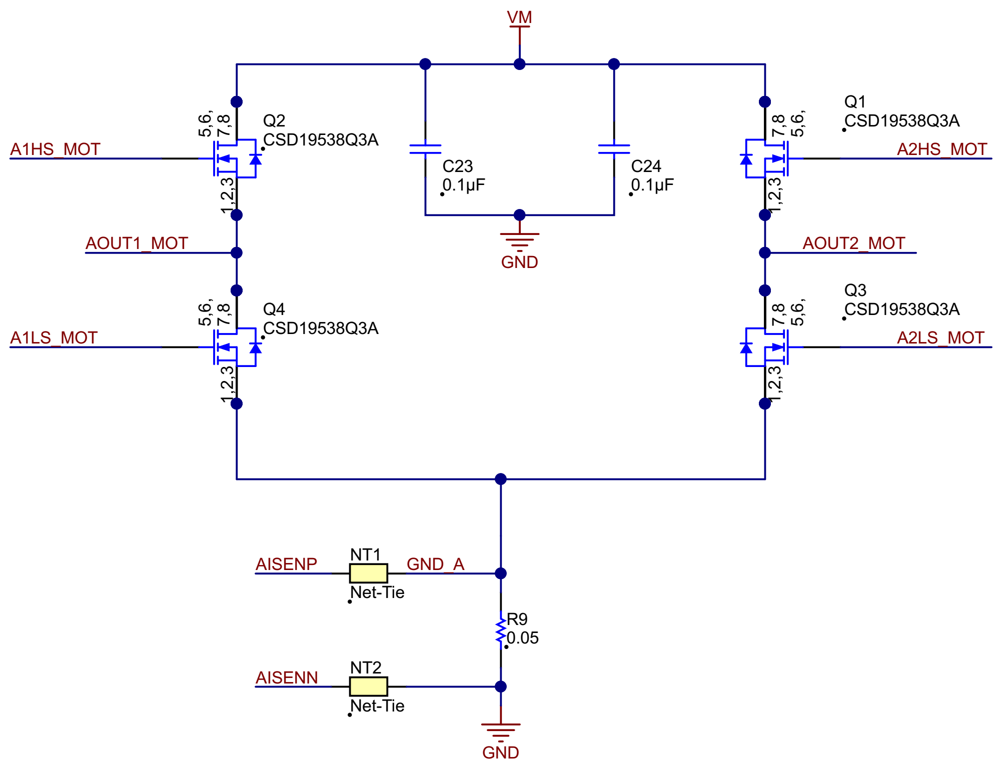


Figure 8. Single Full-Bridge

The DRV8711 device controls the FETs using a resistor divider network to create the necessary signals to the LM5107 device. The CSD17483F4T FETs are used to create a 12-V or 0-V signal at xOUT1 and xOUT2. These signals are used to disable the overcurrent and predriver faults of the DRV8711 device.

The Net-Tie shown in Figure 9 is placed in the circuit to allow evaluation of a current-limiting resistor. If required, the Net-Tie can be cut and a resistor can be placed between the two CSD17483F4T FETs. This method can be used if the timing of the high-side and low-side FETs create a shoot-through condition.

To improve the efficiency of the design, the timing can be adjusted using the configuration registers of the DRV8711 gate drivers. Changing the Idrive and Tdrive has little effect on the power FETs, but changing the dead time does have an effect.

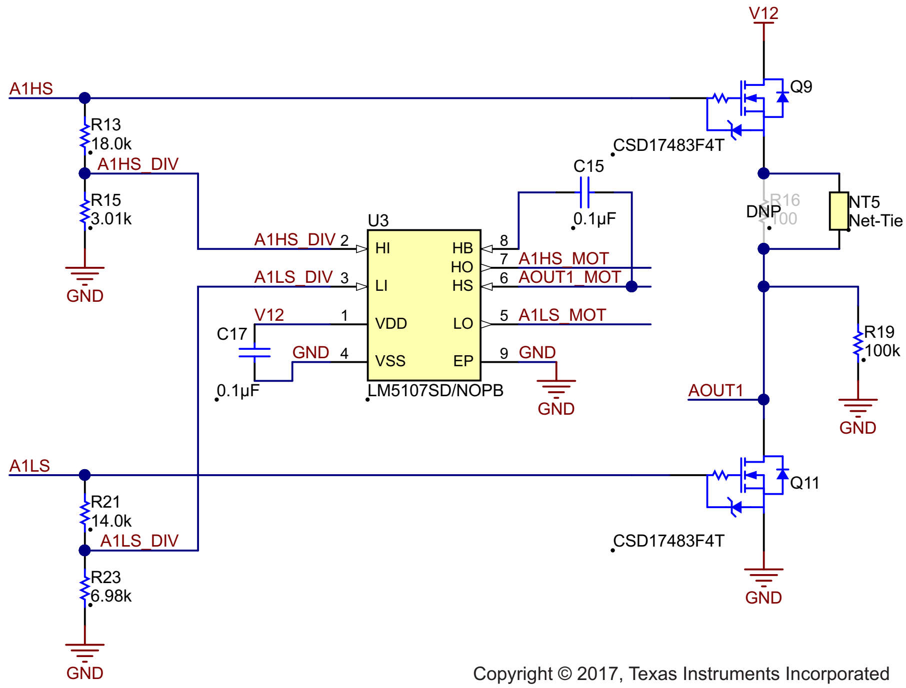


Figure 9. Interface from DRV8711 to High-Voltage FETs

The LM5017 device is used to create a 12-V supply (see Figure 10). This device is a regulated buck converter that takes the VM input voltage and steps the input voltage down to 12 V to provide power to the DRV8711 and the LM5107 devices. The DRV8711 device is set to operate at 12 V, providing a 12-V gate-to-source voltage (Vgs) on the low-side outputs and approximately 22 V on the high-side outputs.

The voltages of the outputs are then divided down to create a 0-V to 3-V input to the LM5107 device.

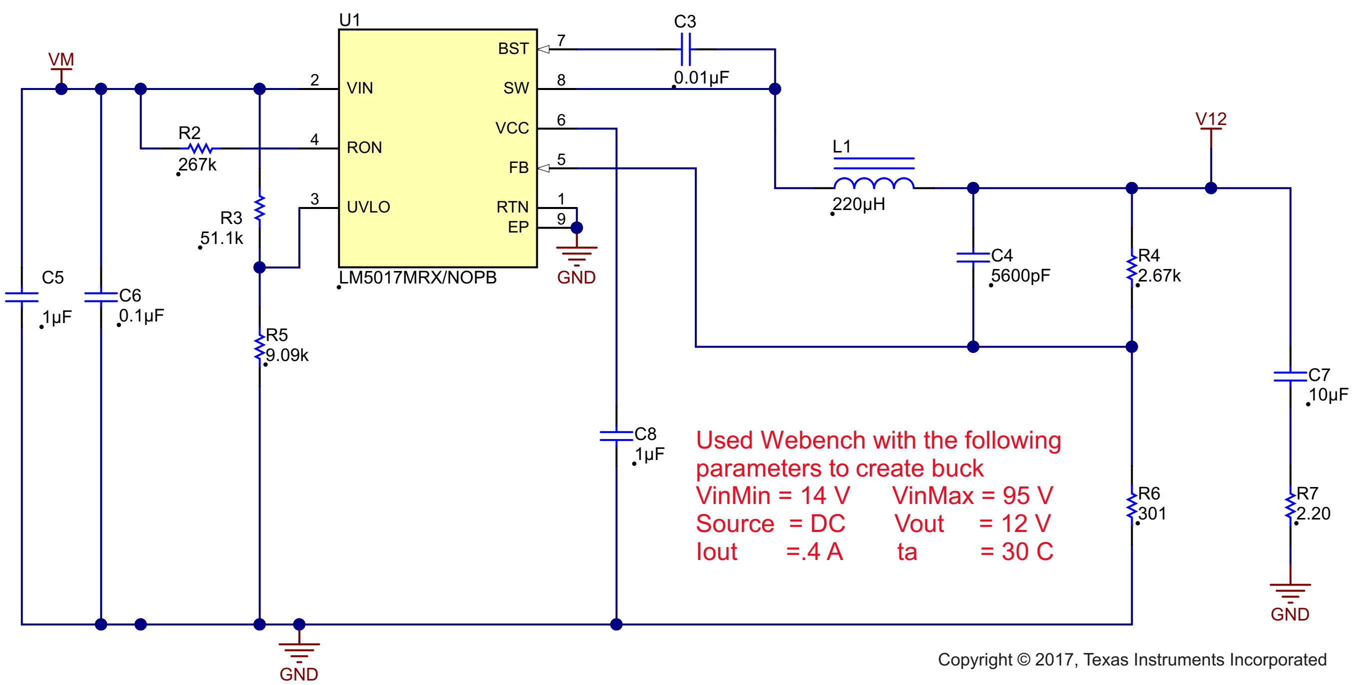


Figure 10. 12-V Regulator Block

The power supply is connected directly to the board and filtered with a 100-µF bulk electrolytic capacitor (see Figure 11).

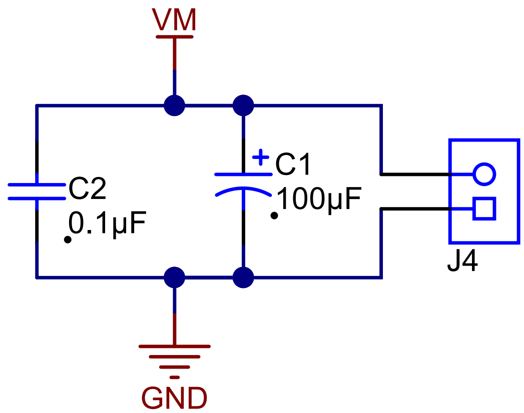


Figure 11. Power Connections

2.2 Software 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 *Configuring the LaunchPad*, *Introduction*, *Setting up the BOOST-DRV8711 Firmware*, and *Setting up the BOOST-DRV8711 GUI* sections of the *BOOST-DRV8711 User's Guide* [1]. Refer to this *BOOST-DRV8711 User's Guide* [1] for instructions on loading the firmware into the LaunchPad. When loaded, refer to the user's guide for instructions on how to install and open the GUI.

After the GUI is open, use the instructions in Section 3 to control the stepper. The GUI sets the decay mode, max current, gate drive timing, microstep mode, and other key parameters to operate the stepper motor.

3 Getting Started Hardware and Software

3.1 Hardware

To operate TIDA-01227, a LaunchPad must be connected to the board. The LaunchPad requires the BOOST-DRV8711 firmware to be loaded. The BOOST-DRV8711 GUI can be used to control the motor. The specified power must be > 15 V and < 70 V and the motor must be connected.

The circuit has been tested to 70 V and with 2-A full-scale current.

3.2 Connections

The TIDA-01227 reference design can be powered from a 15-V to 70-V power supply. The supply is connected to the printed-circuit board (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 through connectors J1 and J2.

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

3.3 Procedure

Refer to the following steps 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 to mirror the specifications in Figure 12 and Figure 13.

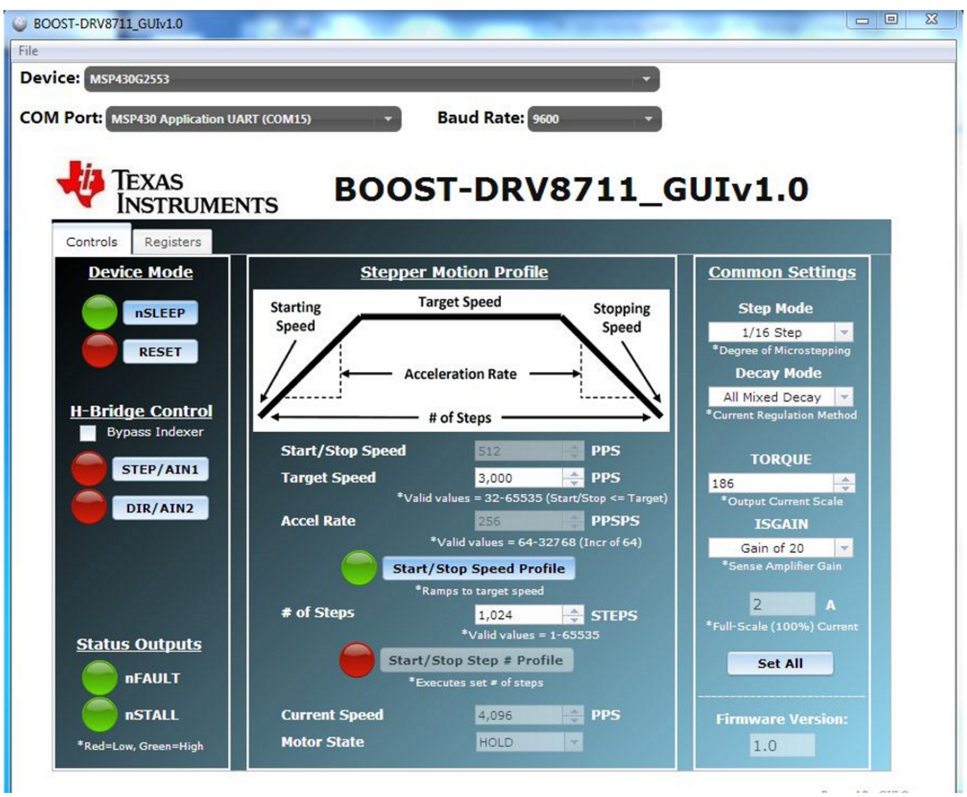


Figure 12. GUI Front Panel Settings

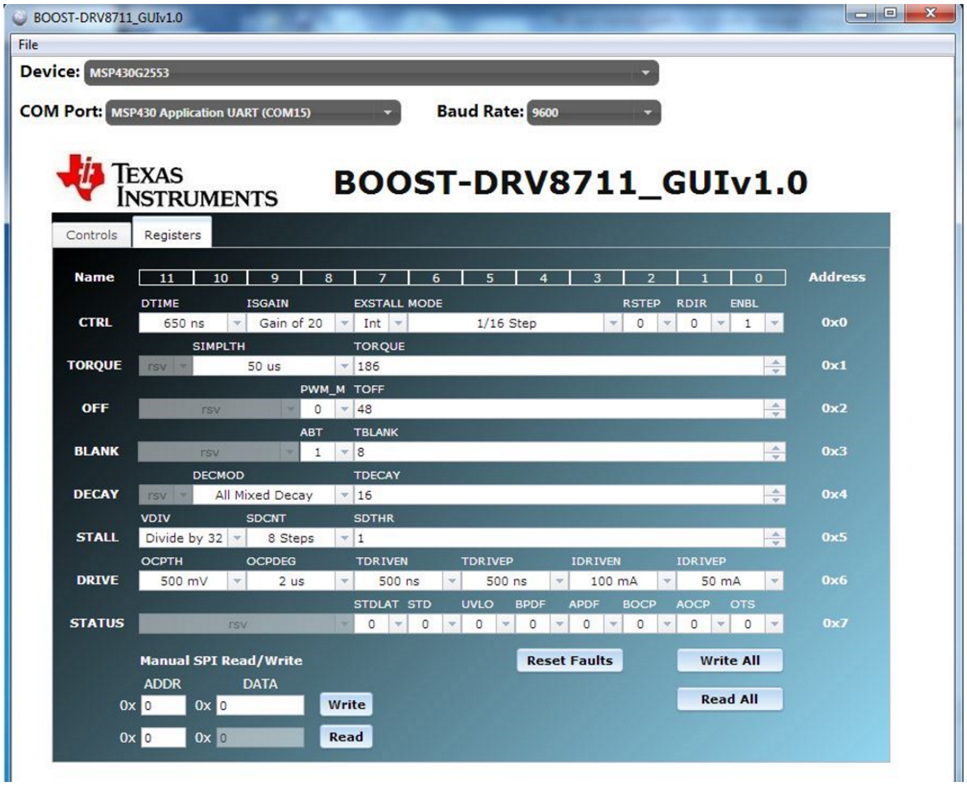


Figure 13. GUI Register Settings

3.4 Software

TIDA-01227 uses the BOOST-DRV8711 GUI to control the bipolar stepper motor. The firmware and GUI, along with installation instructions, is located in the BOOST-DRV8711 tool folder.

4 Testing and Results

The following equipment was used during the testing of the reference design (see Figure 14):

- DC power supply Chroma 620012P-100-50
- Multimeter Tektronix DMM 4040
- Oscilloscope Tektronix DPO 7054

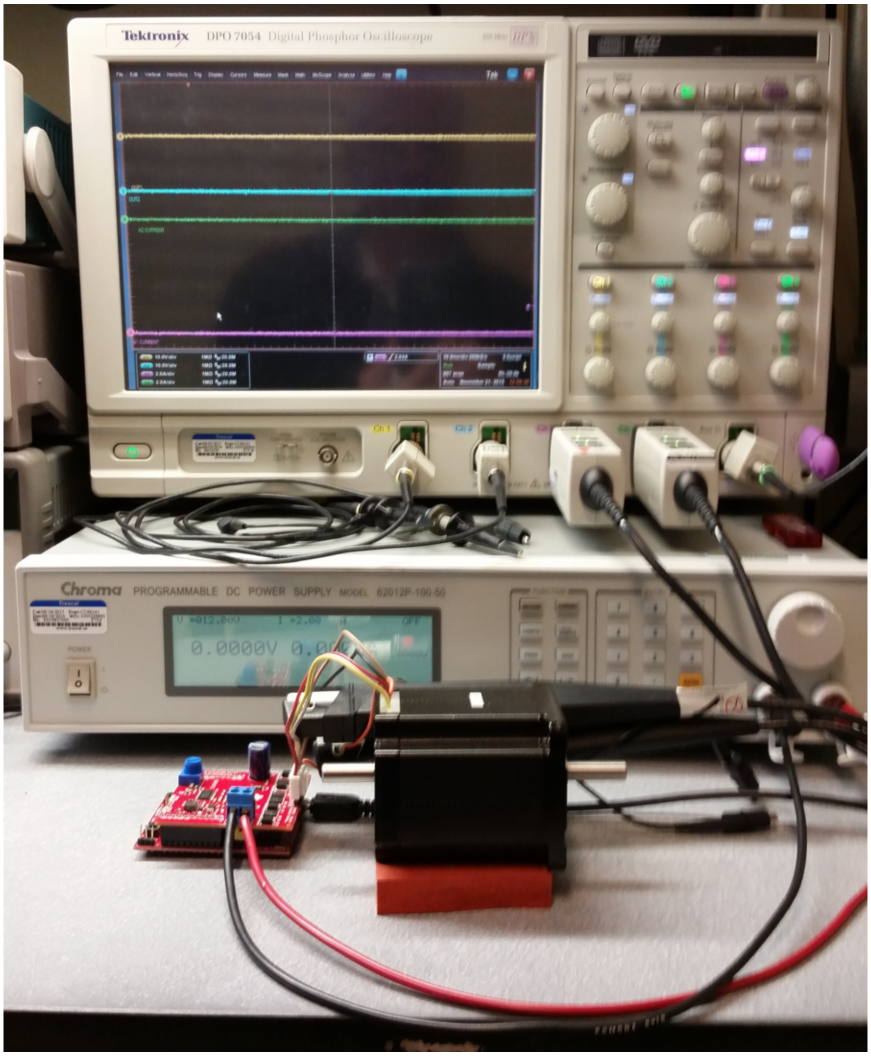


Figure 14. Bench Setup

Data was collected at 24 V and 48 V to highlight the difference in current available at higher voltages (see Figure 15). The motor is being operated at 40k steps per seconds, 1/32 microsteps, and 2-A full-scale current.

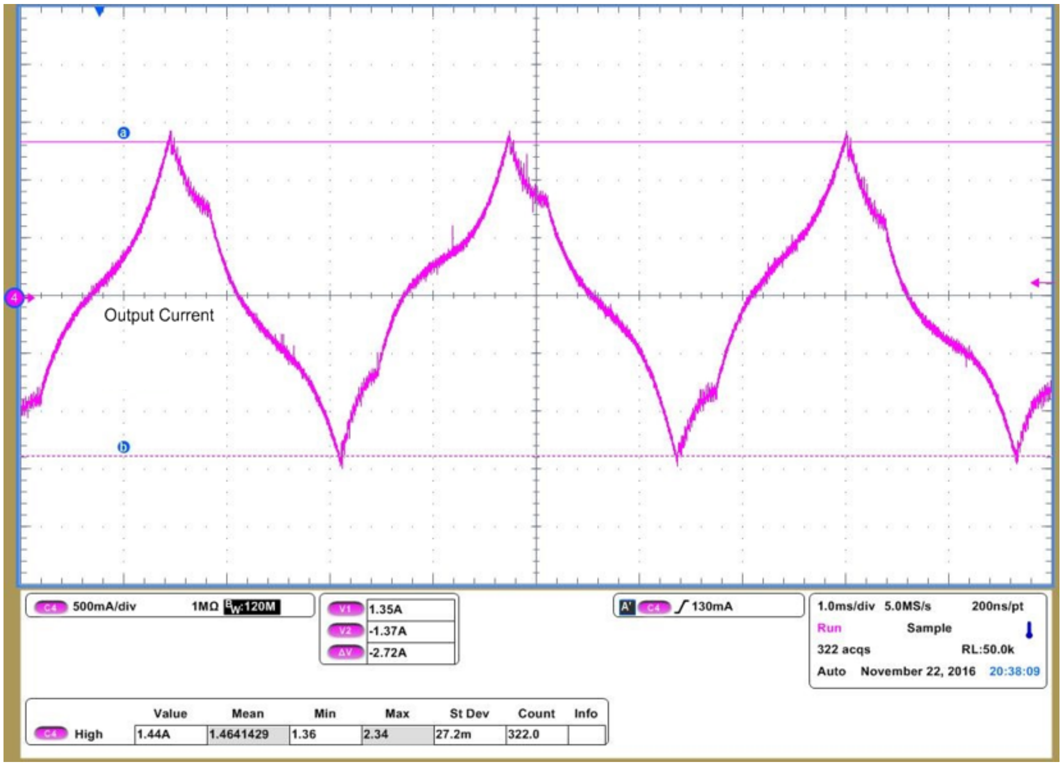


Figure 15. 40k PPS, 24 V, 2-A Full-Scale, 1/32 Microstep Mode

At 24V, the normal current sine wave has collapsed and the current is no longer able to reach the full-scale target of 2 A (see Figure 16). The current only reaches 1.35 A.

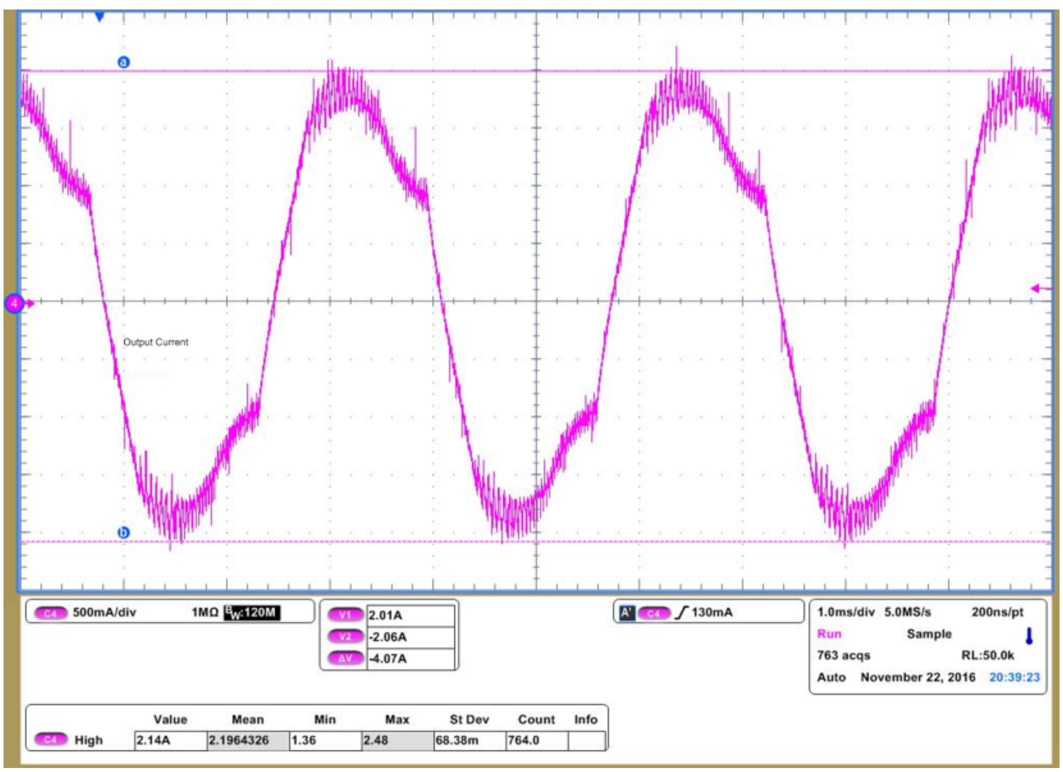


Figure 16. 40k PPS, 48 V, 2-A Full-Scale, 1/32 Microstep Mode

At 48 V the sine wave has degraded, but current is able to reach the full-scale target of 2 A.

The following data in Figure 17 through Figure 26 was collected from 30 V to 70 V in 10-V increments. The stepper was operated in 1/8 microstep mode and the step input was toggled at 1k steps per second.

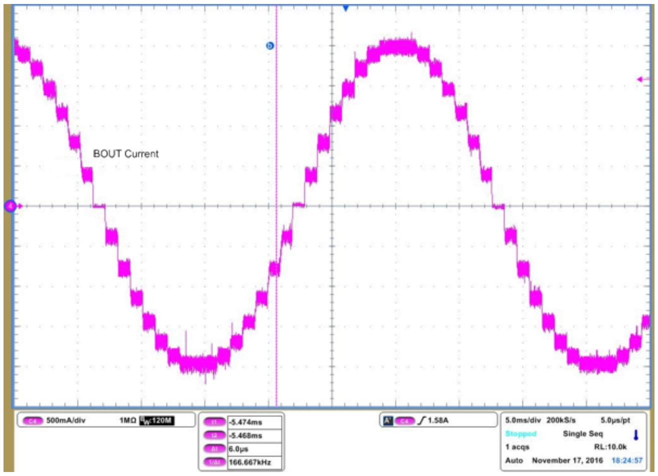


Figure 17. 30 V, 1k PPS 1/8 Microstep Mode Current

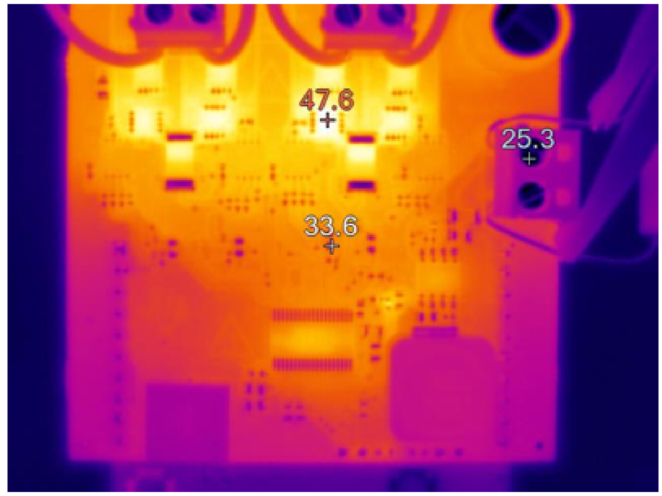


Figure 18. 30 V, 1k PPS 1/8 Microstep Mode Thermal Image

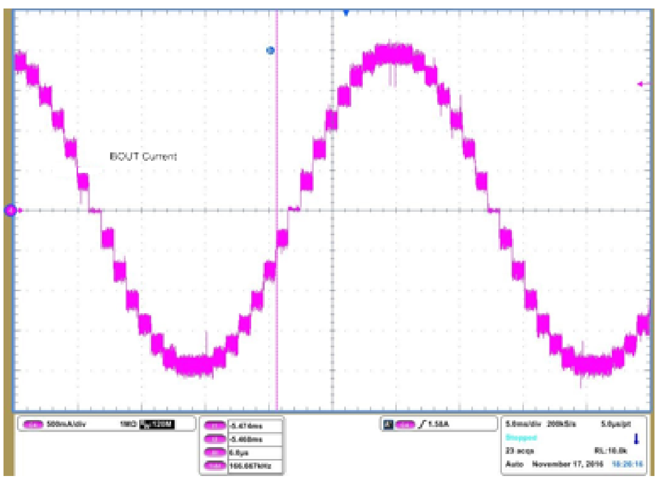


Figure 19. 40 V, 1k PPS 1/8 Microstep Mode Current

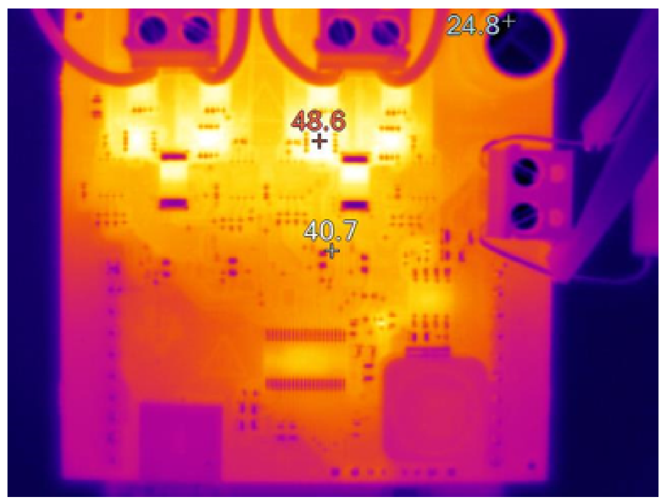


Figure 20. 40 V, 1k PPS 1/8 Microstep Mode Thermal Image

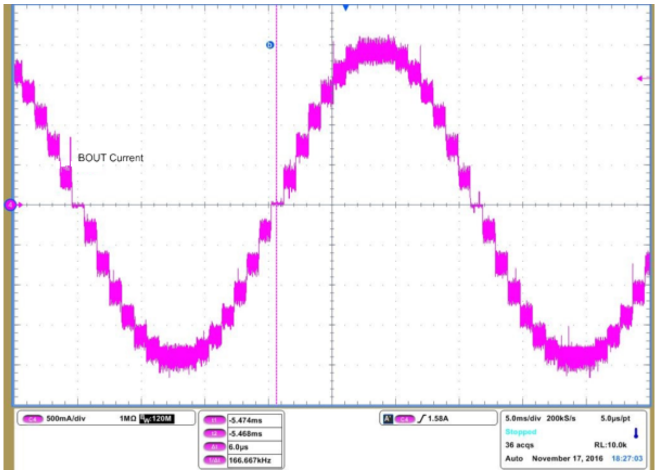


Figure 21. 50 V, 1k PPS 1/8 Microstep Mode Current

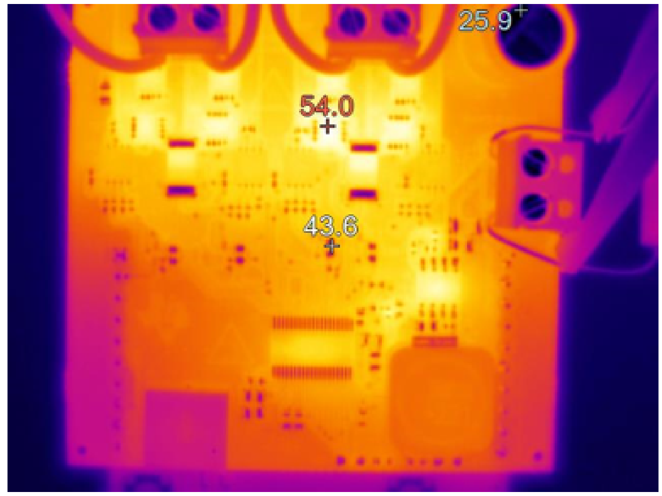


Figure 22. 50 V, 1k PPS 1/8 Microstep Mode Thermal Image

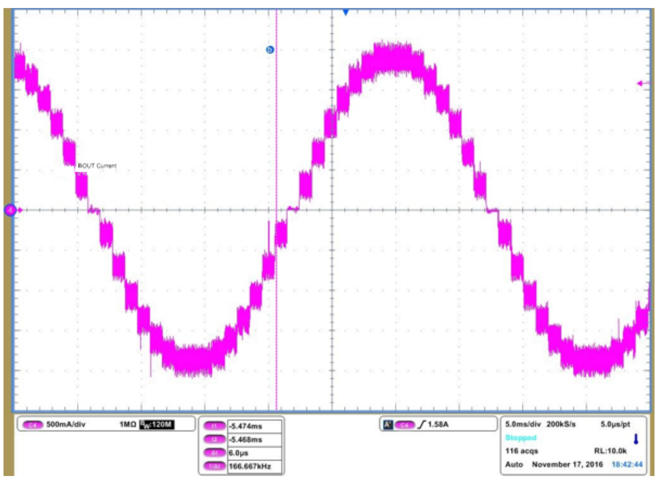


Figure 23. 6 0V, 1k PPS 1/8 Microstep Mode Current

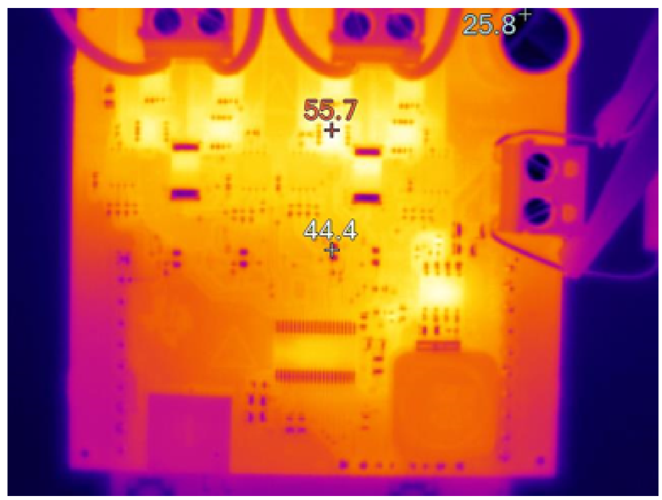


Figure 24. 60 V, 1k PPS 1/8 Microstep Mode Thermal Image

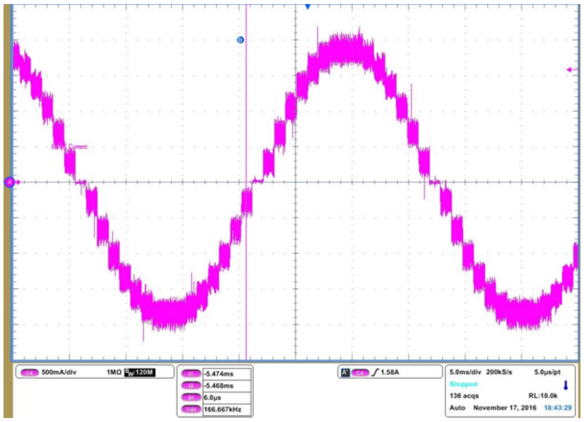


Figure 25. 70 V, 1k PPS 1/8 Microstep Mode Current

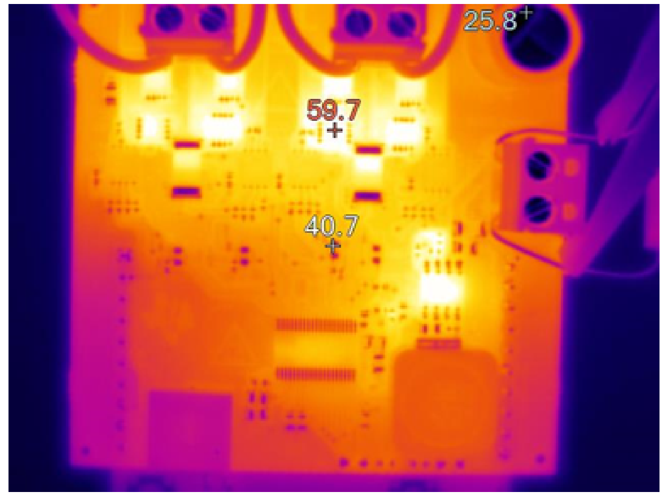


Figure 26. 70 V, 1k PPS 1/8 Microstep Mode Thermal Image

5 Design Files

5.1 Schematics

To download the schematics, see the design files at TIDA-01227.

5.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-01227.

5.3 PCB Layout Recommendations

5.3.1 Layout Prints

To download the layer plots, see the design files at TIDA-01227.

5.4 Altium Project

To download the Altium project files, see the design files at TIDA-01227.

5.5 Gerber Files

To download the Gerber files, see the design files at TIDA-01227.

5.6 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-01227.

6 Software Files

To download the software files, see the design files at TIDA-01227.

7 Related Documentation

1. Texas Instruments, *DRV8711EVM User's Guide*, DRV8711EVM User's Guide (SLVA637)
2. Texas Instruments, *DRV8711 Decay Mode Setting Optimization*, DRV8711 Application Report (SLVA637)
3. Texas Instruments, *DRV8711 Quick Spin and Tuning Guide*, DRV8711 Application Report (SLVA632)

7.1 Trademarks

8 Terminology

MCU— Microcontroller

NetTie— Schematic element that allows two net names to be connected. In the layout, the NetTie is a piece of metal.

PPS— Pulses per second applied at the STEP input of the DRV8711

9 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.

Revision History A

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Original (January 2017) to A Revision	Page
• Changed "ALSx and BLS output pins" to "ALSx and BLSx output pins"	10