Design Guide: TIDA-010251

18-V, 600-W BLDC Motor Inverter Reference Design

Description

This design guide demonstrates a 600-W power stage for driving a three-phase brushless DC motor in cordless tools operating from a 5-cell Li-ion battery with a voltage up to 21 V. The design is a 60-mm × 60-mm compact drive, bringing 33-A_{RMS} continuous current at 20-kHz switching frequency. A heat sink is not used, only natural convection, and the design uses sensor-based trapezoidal control. The design shows MOSFET operation within the safe operating area using enhanced protections including MOSFET overcurrent and shoot-through protection using VDS monitoring, switching voltage spike optimization with slew rate control and overtemperature protection

Resources

TIDA-010251	Design Folder
MSPM0G1507	Product Folder
DRV8328	Product Folder
CSD18510Q5B	Product Folder
TMP61	Product Folder

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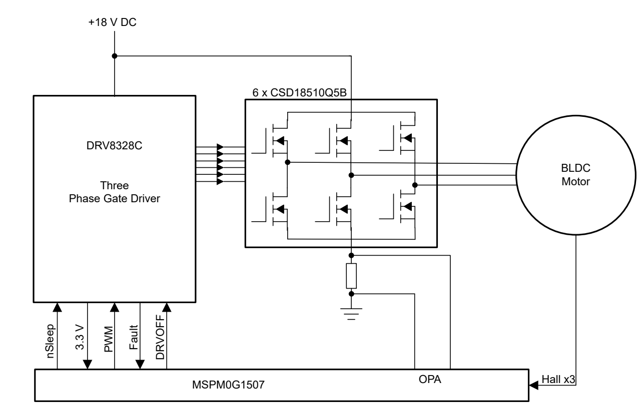
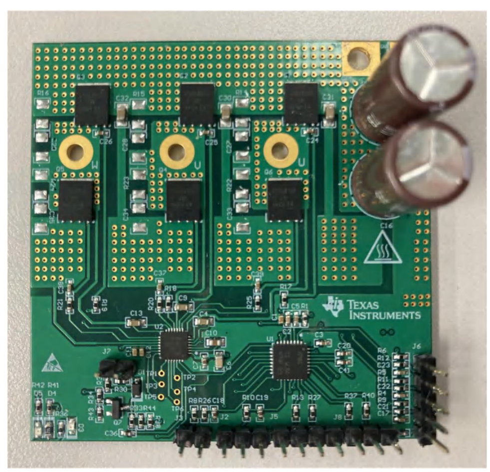
Features

- 600-W drive for brushless DC (BLDC) motor supporting sensor-based trapezoidal control
- Designed to operate from 5 V to 21 V
- Supports up to 33-A_{RMS} continuous winding current
- PCB form factor of 60 mm × 60 mm
- High efficiency at 18 V, 600 W for 20-kHz unipolar trapezoidal control
- Operating ambient temperature: –20°C to +55°C

Applications

- Cordless handheld garden tool
- Cordless power tools
- Cordless vacuum cleaner
- Lawn mower





1 System Description

Power tools are used in various industrial and household applications such as drilling, grinding, cutting, polishing, driving fasteners, and so forth. The most common types of power tools use electric motors while some use internal combustion engines, steam engines, or compressed air. Power tools can be either corded or cordless (battery powered). Corded power tools use the mains power (the grid power) to power up the AC or DC motors.

Cordless tools use battery power to drive DC motors. Most cordless tools use lithium-ion batteries, the most advanced in the industry offering high energy density, low weight, and greater life. Power tools are available in different power levels and battery voltage levels. Power tools such as cordless chainsaws and circular saws and different garden tools like cordless wood and branch cutters require a very high torque and need a very high peak current.

Cordless tools use brushed or brushless DC (BLDC) motors. The BLDC motors are more efficient and have less maintenance, low noise, and longer life. Power tools have requirements on form factor, efficiency, peak current, reliability, and thermal performance. Therefore, high-efficient power stages with a compact size are required to drive the power tool motor. The small form factor of the power stage enables flexible mounting, better PCB layout performance, and low-cost design. High efficiency provides maximum battery duration and reduces cooling efforts. The high-efficiency requirement in turn demands switching devices with a low drain-to-source resistance ($R_{DS(on)}$). The power stage must also make sure protections like motor stall or any high current prevention are available.

This reference design uses the CSD18510Q5B MOSFET featuring a very low $R_{DS(on)}$ of 0.79-mΩ in a SON5 × 6 SMD package. The DRV8328C three-phase gate driver is used to drive the three-phase MOSFET bridge, which can operate from 4.5 V to 60 V and support programmable gate current with a maximum setting of 2-A sink and 1-A source. The DRV8328C includes low dropout (LDO), which helps to provide power for the MCU. The TPM61 temperature sensor is used to sense the FET temperature. The MSPM0G1506 microcontroller is used to implement the control algorithm.

1.1 Key System Specifications

PARAMETER	SPECIFICATIONS
Input Voltage	18-V DC (5-V minimum to 21-V maximum) – 5-cell Li-Ion
Rated Output Power	600 W
RMS Current	33 A
Control Method	Sensor-based trapezoid
Inverter Switching frequency	20 kHz
Feedback signals	DC bus voltage, Hall sensor, low-side DC bus current
Board specification	60 mm × 60 mm, 4-layer, 2-oz copper
Operating ambient	–20°C to 55°C

WARNING

TI intends this reference design to be operated in a lab environment only and does not consider the board to be a finished product for general consumer use.

TI Intends this reference design to be used only by qualified engineers and technicians familiar with the risks associated with handling high-voltage electrical and mechanical components, systems, and subsystems.

Hot surface! Contact can cause burns. **Do not touch!** Some components can reach high temperatures > 55°C when the board is powered on. Do not touch the board at any point during operation or immediately after operating, because high temperatures can be present.

CAUTION

Do not leave the design powered when unattended.

2 System Overview

Figure 2-1 shows the reference design block diagram.

The entire system is represented in the blocks in the following list:

- 3-phase motor inverter stage
- MCU controller
- Motor phase current sensing
- UART serial communication

2.1 Block Diagram

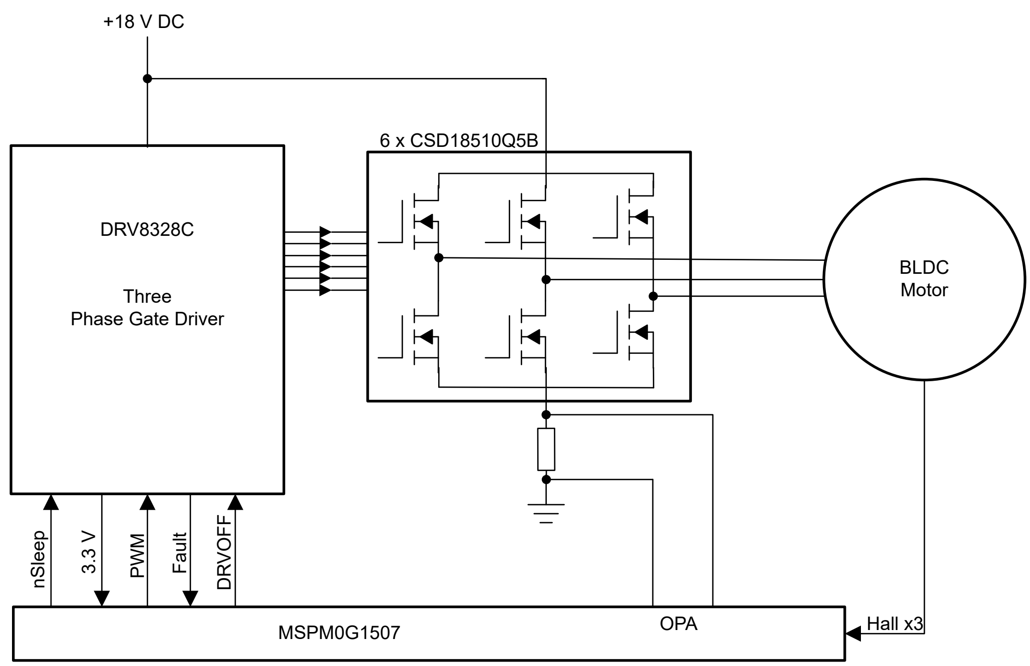


Figure 2-1. TIDA-010251 Block Diagram

2.2 Design Considerations

The reference design has the following sub-blocks:

- Three-phase power stage including gate drivers and FETs
- Motor position sensor (three Hall latches) interface for sensored trapezoidal control
- DC bus low-side current sensing for torque control and software current limit provided by the MCU
- MOSFET temperature sensing using onboard temperature sensor
- Host controller to implement the necessary motor control algorithms, sensing, and protections

2.3 Highlighted Products

The following highlighted products are used in this reference design. Key features for selecting the devices for this reference design are revealed in the following sections. Find more details of the highlighted devices in the respective product data sheet.

2.3.1 DRV8328C

The key requirements in selecting the gate driver are:

- Sufficient source and sink current to reduce the switching losses
- Sufficiently high gate-drive voltage to make sure the MOSFET conducts at the minimum $R_{DS(on)}$
- High level of overcurrent and other protections to enable a reliable system operation under worst-case conditions like motor stall, short circuit, and so forth

The DRV8328 family of devices is an integrated gate driver for three-phase applications. The devices provide three half-bridge gate drivers, each capable of driving high-side and low-side N-channel power MOSFETs. The device generates the correct gate-drive voltages using an internal charge pump and enhances the high-side MOSFETs using a bootstrap circuit. A trickle charge pump is included to support 100% duty cycle. The gate-drive architecture supports peak gate-drive currents up to 1-A source and 2-A sink. The device has an integrated accurate 3.3-V LDO that can be used to power an external controller. The DRV8328 can operate from a single power supply and supports a wide input supply range of 4.5 V to 60 V.

2.3.2 MSPM0G1507

MSPM0G150x microcontrollers (MCUs) are part of the highly-integrated, ultra-low-power 32-bit MCU mixed signal processor (MSP) family based on the enhanced Arm® Cortex®-M0+ 32-bit core platform operating at up to 80-MHz frequency. These cost-optimized MCUs offer high-performance analog peripheral integration, support extended temperature ranges from –40°C to 125°C, and operate with supply voltages ranging from 1.62 V to 3.6 V.

The MSPM0G150x devices provide up to 128KB embedded Flash program memory with built-in error correction code (ECC) and up to 32KB SRAM with a hardware parity option. The devices also incorporate a memory protection unit, 7-channel DMA, math accelerator, and a variety of high-performance analog peripherals such as two 12-bit 4-MSPS ADCs, configurable internal shared voltage reference, one 12-bit 1-MSPS DAC, three high-speed comparators with built-in reference DACs, two zero-drift, zero-crossover op amps with programmable gain, and one general-purpose amplifier. These integrated analog peripherals and processing capabilities can greatly reduce form factor and allow the MSPM0G150x series to be a great option for implementing the motor control algorithm with Hall-effect position sensor measurement and for performing low-side current sensing.

2.3.3 CSD18510Q5B

The key requirements in selecting the MOSFET include:

- High efficiency (MOSFET with low losses under operating condition)
- Small size to reduce the form factor of the design
- Low $R_{DS(on)}$
- High peak current capability

The reference design uses six CSD18510Q5B MOSFETs to implement the three phase inverter, thus meeting requirements. The MOSFET is rated up to 40 V, having an $R_{DS(on)}$ of 0.79-mΩ in a SON 5-mm × 6-mm NexFET™ power MOSFET that has been designed to minimize losses in power-conversion applications.

2.3.4 TMP61

The TMP61 is a positive temperature coefficient (PTC) linear silicon thermistor. The device behaves as a temperature-dependent resistor, and can be configured in a variety of ways to monitor temperature based on the system-level requirements. The TMP61 has a nominal resistance at 25°C of 10 kΩ with ±1% maximum tolerance, a maximum operating voltage of 5.5 V, and maximum supply current of 400 µA. The benefits of this device include no extra linearity circuitry, minimized calibration, less resistance toleration variation, larger sensitivity at high temperatures, and simplified conversion methods to save time and memory in the processor. This device can be used in a variety of applications to monitor temperature close to a heat source with the very small DEC package option compatible with the typical 0402 footprint.

3 System Design Theory

The three-phase BLDC motor needs a three-phase electronic drive to energize the motor, based on the rotor position. The electronic drive consists of:

- Power stage with a three-phase inverter having the required power capability
- MCU to implement the motor control algorithm
- Position sensor for accurate motor current commutation
- Gate driver for driving the three-phase inverter
- Power supply to power the MCU

For more details about BLDC trapezoidal control, see the *Trapezoidal Control of BLDC Motors Using Hall Effect Sensors* application note.

3.1 Power Stage Design: Three-Phase Inverter

The three-phase inverter is realized using six CSD18510Q5B power MOSFETs as shown in Figure 3-1. The MOSFET is rated for a maximum drain-to-source voltage of 40 V and a peak current of 400 A. The design has the provision to use the RC snubber across all the FETs. The voltage ringing is expected to be maximum across the FETs due to diode reverse recovery. With bipolar control, a snubber is not necessarily required across all the FETs and the need depends on the current direction, PWM strategy, and diode reverse recovery.

The snubber capacitor is selected as approximately several times the output capacitance of the FET, which is 832 pF in this design. The snubber resistor value is tuned during board testing to sufficiently damp the VDS switching overshoot ringing during switching. C30, C31, and C32 are decoupling capacitors between the VDC input and the source terminal of the bottom FET of each leg. This decoupling capacitor reduces the ringing in the supply lines caused by the parasitic inductance added by the sense resistor and the power track. The design also has an optional external capacitance between the gate to source of each FET, to reduce the gate pick up or gate ringing during switching.

3.1.1 Selecting Sense Resistor

Power dissipation in sense resistors and the input offset error voltage of the op amps are important in selecting the sense resistance values. This design uses two sense resistors in parallel. Individually, each sense resistor is designed to carry a nominal RMS current of greater than 60 A, which combined in parallel allows for a total nominal RMS current exceeding 120 A. Choose the sense resistor according to power needs during design. A high sense resistance value increases the power loss in the resistors. The internal op amps of the MSPM0G1507 have an input offset error of 1.5 mV.

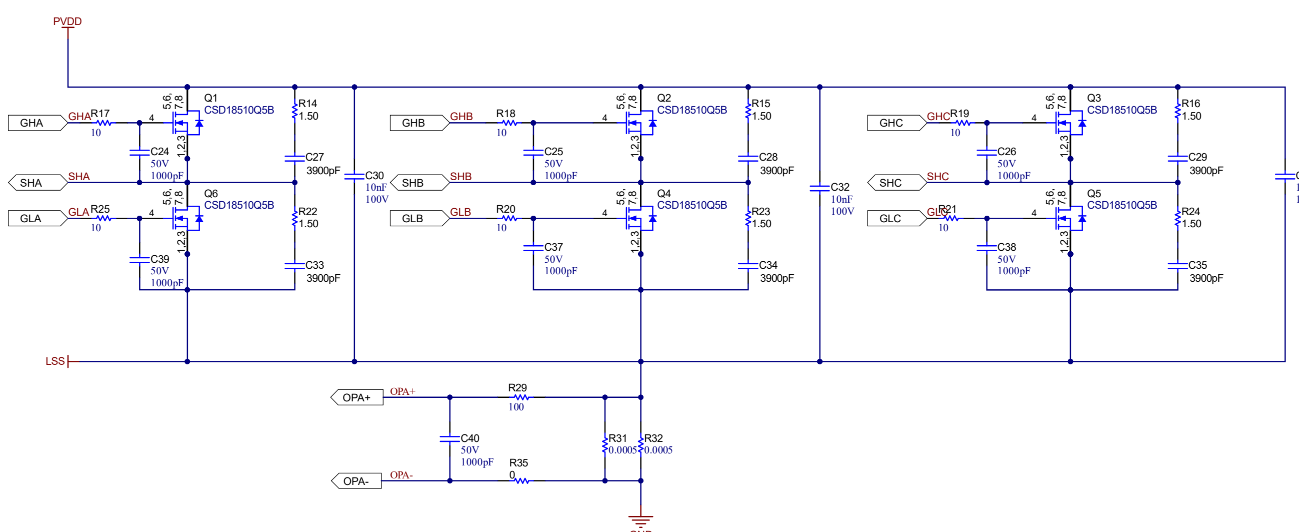


Figure 3-1. Three-Phase MOSFET Inverter

3.2 Power Stage Design: DRV8328 Gate Driver

Figure 3-2 shows the DRV8328 gate driver schematic. PVDD is the DC supply input; in this case, PVDD is the battery voltage of 18 V. A 10-μF capacitor (C6) is used as the PVDD capacitor. C10 is a charge pump capacitor. The supply voltage of the low-side gate driver is generated using a charge pump with linear regulator GVDD from the PVDD power supply that regulates to 12 V. For the voltage rating and selection of the capacitors, see the *DRV8328 4.5 to 60 V Three-phase BLDC Gate Driver* data sheet.

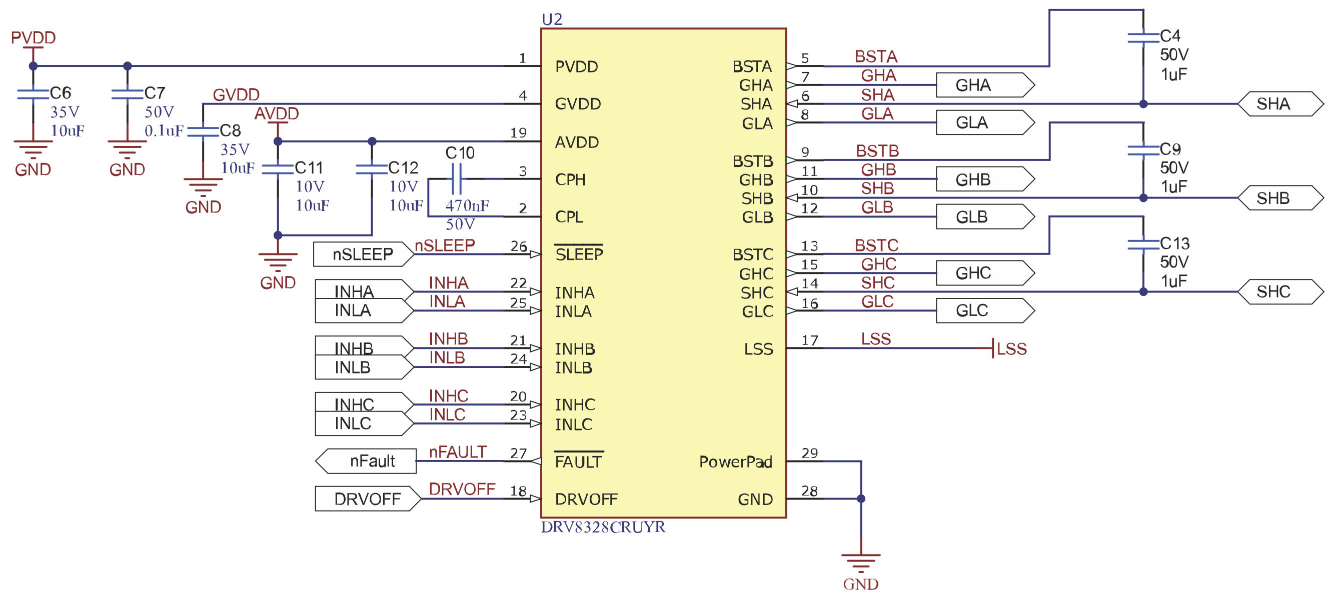


Figure 3-2. DRV8328 Gate Driver Circuit

3.2.1 DRV8328 Features

The DRV8328 family of devices decrease system component count, cost, and complexity by integrating three independent half-bridge gate drivers, trickle charge pump, and a charge pump with linear regulator for the 12-V supply voltages of the high-side and low-side gate drivers. The device also integrates an accurate low voltage regulator (AVDD) capable of supporting 3.3 V at 80-mA output. A hardware interface allows for simple configuration of the motor driver and control of the motor.

The gate drivers support external N-channel high-side and low-side power MOSFETs and can drive up to 1-A source, 2-A sink peak gate drive currents with a 30-mA average output current. A bootstrap circuit with capacitor generates the supply voltage of the high-side gate drive and a trickle charge pump is employed to support 100% duty cycle. The supply voltage of the low-side gate driver is generated using a charge pump with linear regulator GVDD from the PVDD power supply that regulates to 12 V.

In addition to the high level of device integration, the DRV8328 family of devices provides a wide range of integrated protection features that help in making a reliable power stage:

- Power supply undervoltage lockout
- Regulator undervoltage lockout
- Bootstrap voltage undervoltage lockout
- VDS overcurrent protection
- SENSE resistor overcurrent monitoring
- Overtemperature shutdown
- Fault event detection

3.2.2 AVDD Linear Voltage Regulator (LDO)

A 3.3-V, 80-mA linear regulator is available for use by external circuitry. The output of the LDO is fixed to 3.3-V. This regulator can provide the supply voltage for a low-power MCU or other circuitry with low supply current needs.

Table 3-1 shows the specifications of the linear regulator used for this reference design.

Table 3-1. Regulator Specifications

PARAMETER	SPECIFICATION
Maximum load current	80 mA
I_Q in low-power sleep mode	< 1 µA at 25˚C
Voltage tolerance	±3%

3.3 Power Stage Design: MSPM0 Microcontroller

Figure 3-3 shows the schematic for configuring the MSPM0G1507 MCU. This reference design uses 10-µF decoupling capacitors (C1 and C2). The GPIO functionality of the MCU is used for PWM generation. One timer instance and the corresponding pins are mapped to the high-side switch PWM. Another timer instance and the corresponding pins are mapped to the low-side switch PWM.

The reference design uses bipolar BLDC control where the high-side switches switching at a high frequency. The low-side switches switch at the electrical frequency of the motor current, which is much lower and the same switches at a high frequency (complementary to high-side switch) during the freewheeling period to enable active freewheeling and hence low losses. All the feedback signal voltages including the input power voltage monitoring, potentiometer voltage for speed control, and temperature sensor output are interfaced to the 12-bit successive approximation (SAR) ADC channels of the MCU.

This design also utilizes the integrated op amp with programmable gain peripherals within the MCU to perform low-side current sensing. This is achieved by inputting the voltage across the sense resistors on the low-side of the three-phase inverter to positive and negative terminals of the one of the op-amp inputs on the MCU (OPA+ and OPA–). This reduces the need for an external current sense amplifier in the design.

3.3.1 Low-Side Current Sensing With MSPM0G1507

The MSPM0G1507 incorporates two zero-drift, zero-crossover op amps with programmable gain among other high-performance analog peripherals. Low-side current measurements are commonly used to implement overcurrent protection, external torque control, or brushless DC commutation with the external controller. One of the integrated op amps on the MCU can be used to sense the sum of the half-bridge currents. The gain of the current sense measurement can be configured with software and requires no additional components beyond the current sense resistors and input series resistors.

The OPA peripherals also support the following key features for current sensing:

- Software selectable zero-drift chopper stabilization for improved accuracy and drift performance
- Factory trimming to remove offset error
- Burnout current source integrated to monitor sensor health
- Programmable gain amplification up to 32

The output of the op amp is read directly by the one of the channels of the integrated 12-bit successive approximation (SAR) ADC on the MCU. The voltage across the OPA+ and OPA– pins is multiplied by the selected programmed gain of the op amp (PGA).

3.3.2 Temperature Sensing

Figure 3-3 shows the temperature sensing circuit used to measure the PCB temperature. The TMP61 silicon linear thermistor has a linear positive temperature coefficient (PTC) that results in a uniform and consistent temperature coefficient resistance (TCR) across a wide operating temperature range. The TMP61 offers higher accuracy and easier speed acquisition compared to NTC. (No temperature form is required.)

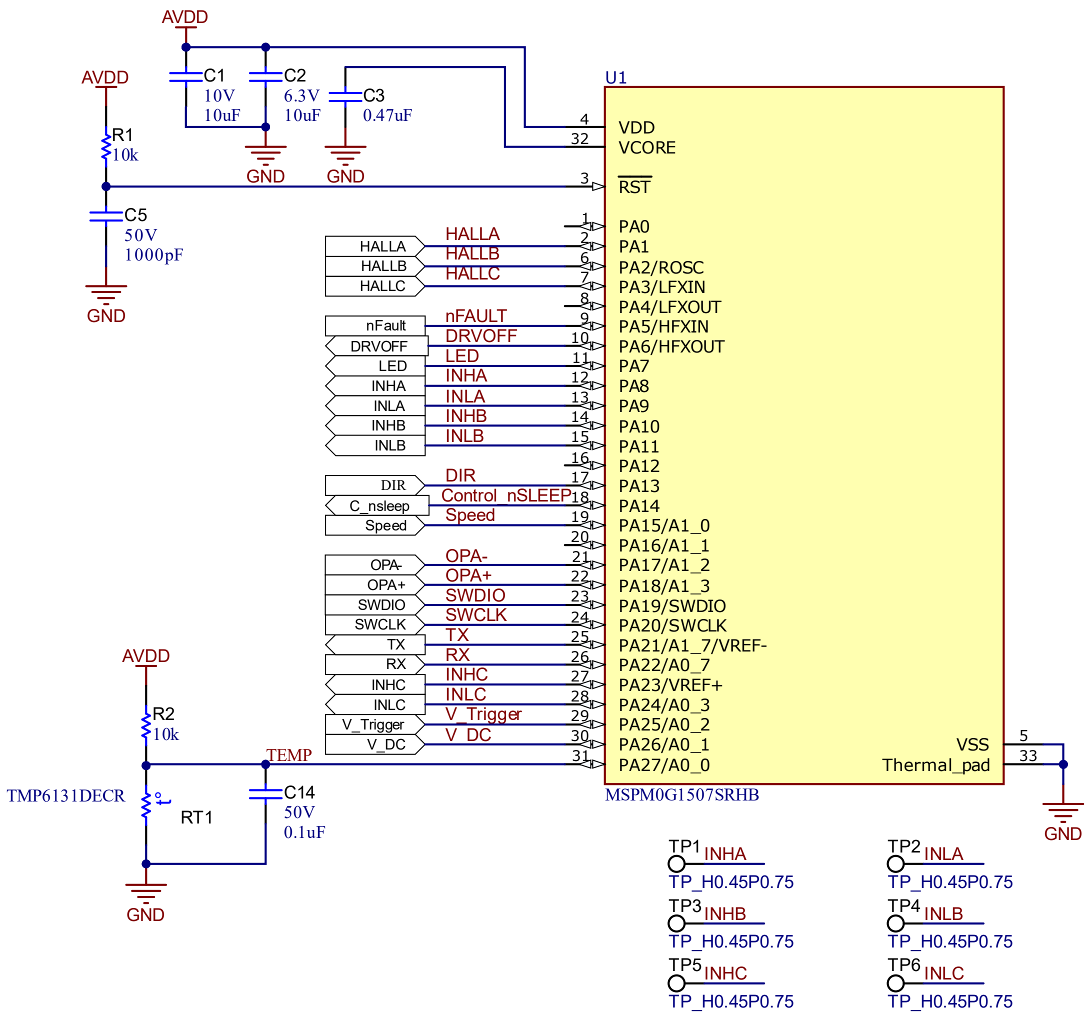


Figure 3-3. MSPM0G1507 Schematic

3.4 Power Stage Design: External Interface Options and Indications

3.4.1 Hall Sensor Interface

Figure 3-4 shows the Hall sensor interface from the motor to the board. The AVDD output from the DRV8328 gate driver is used as the power supply for the Hall sensor. Usually, the Hall sensors have an open drain or open collector configuration. R4, R5, and R6 are used as the pullup resistors. R9, R11, and R12, along with C21, C22, and C23, form noise filters at the Hall sensor input.

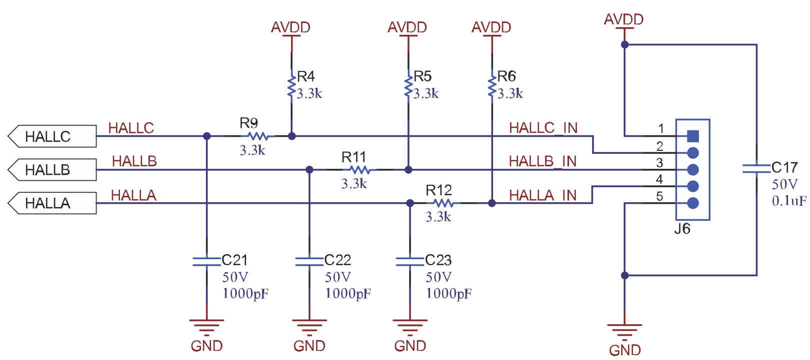


Figure 3-4. Hall Sensor Interface

3.4.2 Input Power Voltage Monitoring

The input power voltage (PVDD) is measured using a resistor divider composed of resistors R7 and R28. The voltage across R28 and capacitor C20 (V_DC) is read by one of the channels of the integrated ADC of the MCU to monitor the input power voltage.

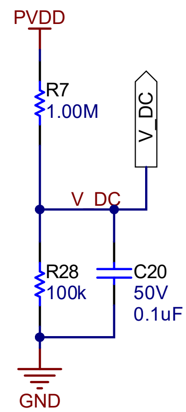


Figure 3-5. Voltage Sensing Circuit

3.4.3 Motor Speed Control

The speed control is done using a potentiometer (POT), and the POT voltage is fed to the ADC of the MCU. Figure 3-6 shows the circuit. The POT is supplied from AVDD. A 20-kΩ POT can be connected externally to the jumper J2. Connect the fixed terminals of the POT to terminal 1 and 3 of J2 and the mid-point to terminal 2 of J2.

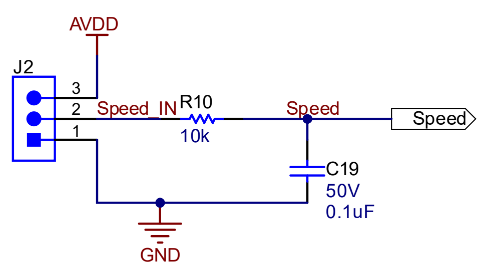


Figure 3-6. Speed Control Interface

3.4.4 Direction of Rotation: Digital Input

Figure 3-7 shows that the J3 jumper is used to set the direction of rotation of the motor. Close or open the jumper to change the direction of rotation.

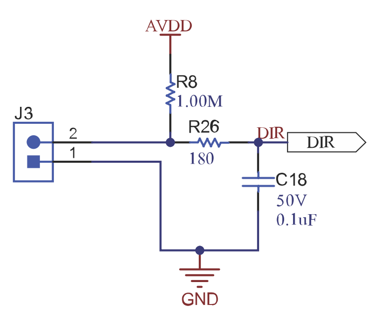


Figure 3-7. Direction Control Interface

3.4.5 Programming Interface for MCU

Figure 3-8 shows that the J5 jumper is used to interface between the MCU and an MCU debugger. An MCU debugger is used to program the MSPM0G1507 MCU.

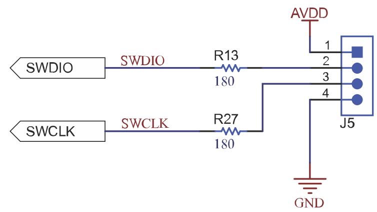


Figure 3-8. Programming Interface

3.4.6 Data Transmission

The jumper J8 (shown in Figure 3-9) is used to transmit and receive data between the MSPM0G1507 MCU in this design and another external MCU or host over universal asynchronous receiver transmitter (UART). This data can be the readings collected by the integrated ADC for external monitoring. Connect an external TX pin to terminal 3 of J8 and connect an external RX pin to terminal 2 of J8 to achieve this.

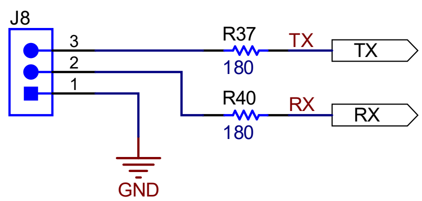


Figure 3-9. UART Interface

3.4.7 LED Indicators

Three light-emitting diodes (LEDs) (D3, D5) are used to indicate different conditions related to the operation of this design, see Figure 3-10. D3 is a green LED that indicates when the board is properly powered and the AVDD voltage is correctly being produced by the DRV8328. The LED is turned on when the AVDD voltage is enabled via the integrated LDO. D5 is a yellow LED available for debugging to test whether the MSPM0G1507 is working properly. Program the LED signal (the fault signal, for example) from the MCU to toggle D5, if desired.

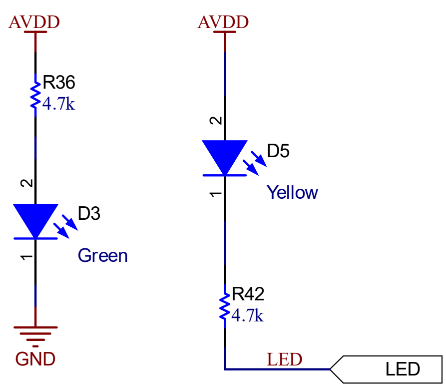


Figure 3-10. LED Indicators

3.4.8 Sleep Mode Entry Control

The sleep mode entry control sub-circuit (shown in Figure 3-11) is used to control the sleep mode entry pin of the DRV8328. When this pin is pulled logic low the device goes to a low-power sleep mode. The control nSLEEP signal from the MSPM0G1507 MCU is used to toggle the sleep mode entry pin with the sub-circuit.

When the signal is pulled logic high, the sleep mode entry pin of the DRV8328 is pulled low and goes into low-power sleep mode. When the signal is pulled logic low, the sleep mode entry pin is pulled high and the DRV8328 remains on.

When J7 is disconnected, nSLEEP can be controlled by the MCU to be at a low level to enter sleep mode. During normal testing, the J7 can be shorted (always nSLEEP enable).

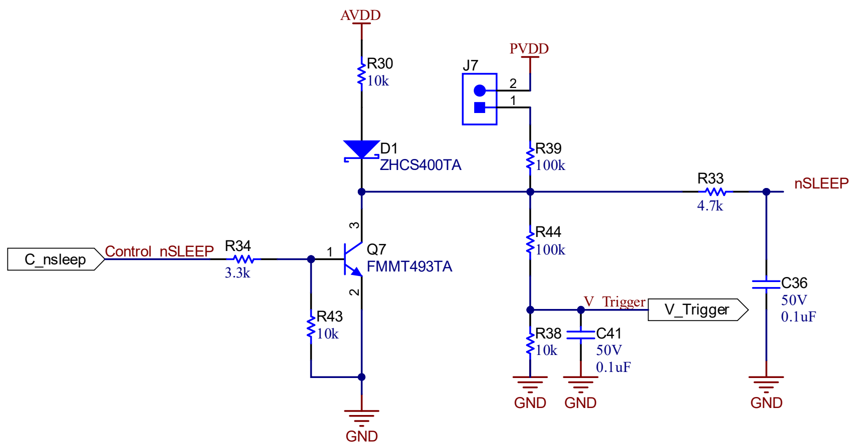


Figure 3-11. Sleep Mode Interface

4 Hardware, Software, Testing Requirements, and Test Results

4.1 Hardware Requirements

4.1.1 Hardware Board Overview

Figure 4-1 identifies different items on the TIDA-010251 board. Descriptions of these parts are provided in the following list:

- Two-terminal input for power supply: This pin is used to connect the input DC supply from the battery. The positive and negative terminals can be identified as shown in Figure 4-1.
- Three-terminal output for motor winding connection: The phase output connections for connecting to the three-phase BLDC motor winding, marked as PHA, PHB, PHC
- 3-pin connector J2: Use J2 to interface an external potentiometer for speed reference
- 2-pin connector J3: Use J3 for the motor direction change. Externally shorting or opening this connector changes the direction of rotation of the motor
- 4-pin connector J5: This is the programming connector for the MSPM0 MCU
- 5-pin connector J6: This is the interface for connecting the Hall-position sensors from the motor
- 2-pin connector J7: Closing the J7 jumper enables the NSLEEP pin
- 2-pin connector J8: This connector is used for external UART communication interface

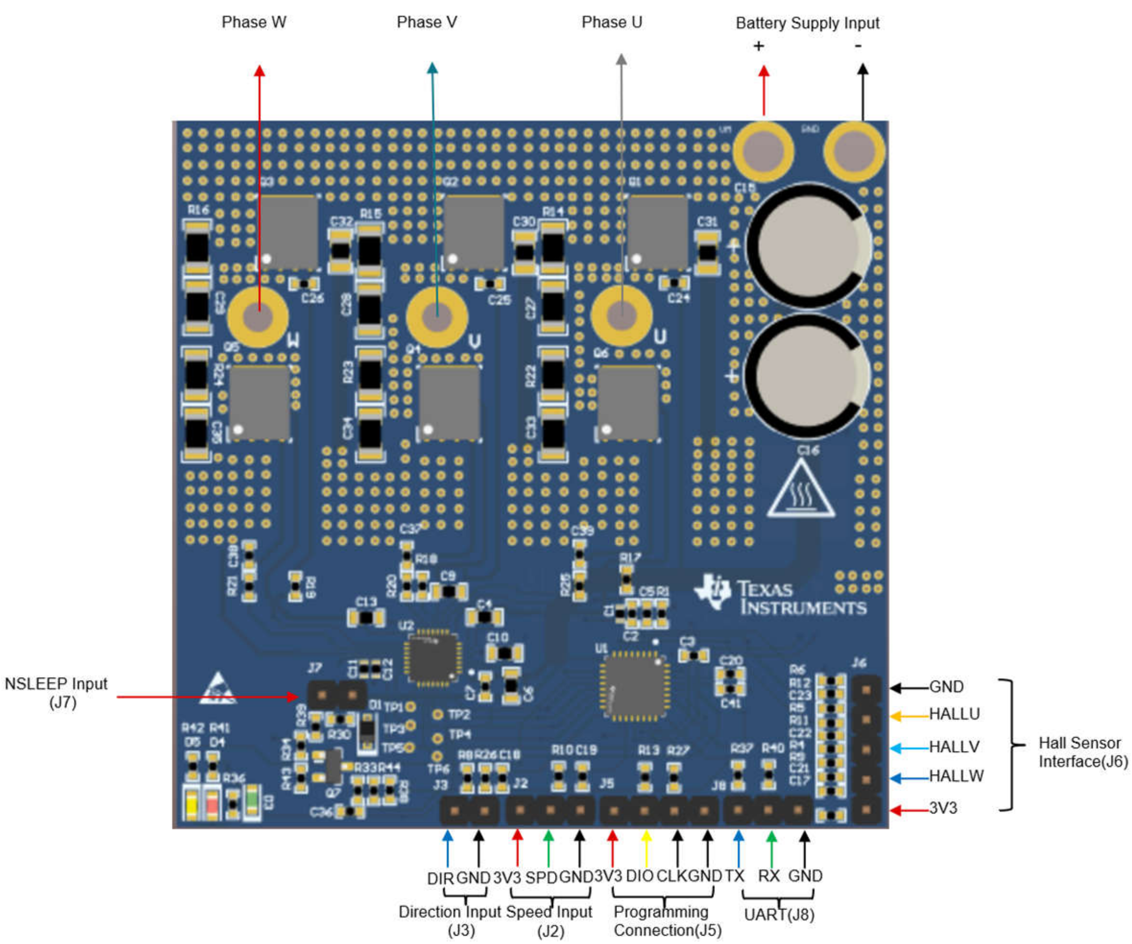


Figure 4-1. Hardware Board Overview

4.2 Software Requirements

TI provides simple sensor trap code to help with evaluation. Install the following software:

- CCSTUDIO: https://www.ti.com/tool/CCSTUDIO
- SYSCONFIG: https://www.ti.com/tool/SYSCONFIG
- MSPM0-SDK: https://www.ti.com/tool/MSPM0-SDK

For code introduction please view the following files:

- TI Resource Explorer: https://dev.ti.com/tirex/explore/node?node=A__AF0H5agzc7PawvYX9sgMZw__MSPM0-SDK__a3PaaoK__LATEST&placeholder=true
- MSPM0-SDK:<*install_location*>mspm0_sdk_1_20_00_05\docs\english\middleware\motor_control_bldc_sensored_trap_hall

  (Please use mspm0_sdk_1_20_00_05 and above versions)

Use the following steps to for the *reference code*:

1. Open CCS and import the code project (<*install_location*>\mspm0_sdk_1_20_00_05\examples\nortos\LP_MSPM0G3507\motor_control_bldc_sensored_trap_hall\drv8328\tida-010251-gui-firmware) into CCS
2. Change lines 65 to 67 in Main.c to adapt to the TIDA-010251 board:

```
65    hallTrap.phaseA     = HAL_PWM_01;
66    hallTrap.phaseB     = HAL_PWM_02;
67    hallTrap.phaseC     = HAL_PWM_03;
```

3. Build and debug the firmware, select *guiVar* and *reading* and ADD WATCH EXPRESSION, adjust the parameters in the following image as needed. Set CSA Gain, PWM frequency, and so forth, from *guiVar* and observe voltage and current data in *reading*.

guiVar	struct GUI_Params	{motorDirection=MOTOR_DIR_FORWARD,ns...
(x)= motorDirection	enum volatile MOTOR_DIR	MOTOR_DIR_FORWARD
(x)= nsleepSignal	enum volatile drv8328_DRV_NSLEEP_STAT	drv8328_DRV_NSLEEP_SLEEP
(x)= drvoffSignal	enum volatile drv8328_DRVOFF_PIN_STAT	drv8328_DRVOFF_PIN_LOW
(x)= stopMotor	enum volatile MOTOR_STATE	MOTOR_STATE_RUN
(x)= motorBraketype	enum volatile MOTOR_BRAKE_TYPE	MOTOR_BRAKE_TYPE_COAST
(x)= CSAGain	unsigned short	0
(x)= pwmFreq	unsigned short	0
(x)= deadTime_ns	unsigned short	0
(x)= accRate	unsigned short	0
(x)= pulseWidth	unsigned short	0
(x)= adcVRef	enum volatile HAL_ADC_VREF	HAL_ADC_VREF_VDDA
(x)= adcInternalVRef	enum volatile HAL_ADC_INT_VREF	HAL_ADC_INT_VREF_2P5V
(x)= adcExternalVRef	unsigned short	0
reading	struct GUI_readings	{busVoltage=0.0,voltagePhaseA=0.0,voltage...
(x)= busVoltage	float	0.0
(x)= voltagePhaseA	float	0.0
(x)= voltagePhaseB	float	0.0
(x)= voltagePhaseC	float	0.0
(x)= busCurrent	float	0.0

4. Speed pin inputs 0- to 3.3-V voltage, and the code is converted into Duty drive motor according to the input.
5. Observe the changes in *busvoltage* and *busCurrent* in the *reading* structure.

CAUTION

When doing high-power testing, make sure you understand the code and configure the parameters correctly.

4.3 Test Setup

Follow this procedure for board bring-up and testing, also refer to Figure 4-1:

- Remove the motor connections from the board, and power on the input DC supply. Make sure that a minimum of a 15-V DC input is applied and the 3.3 V is generated in the board.
- Program the MCU as detailed
- Remove the programmer, and switch off the DC input supply
- Connect the inverter output to the motor winding terminals
- Connect the position Hall sensor inputs, and make sure that the winding connection and Hall sensor connections match
- Connect the J7 to enable nSLEEP
- Connect the POT at the interface J2 and set the speed reference
- Use a DC power supply with current-limit protection and apply 18-V DC to the board. If the Hall sensors and winding are connected properly in the matching sequence, then the motor starts running at a speed set by the POT
- If the motor is not rotating and takes high current, or rotates and draws a distorted peak winding current waveform, then check the winding and Hall sensor connection matching and, if wrong, correct the connection sequence to match
- Adjust the POT voltage for change in speed
- To change direction, close the J3 jumper

4.4 Test Results

The following sections show the test data. The test results are divided into multiple sections that cover the steady state performance and data, functional performance waveforms, and transient performance waveforms of a BLDC motor.

4.4.1 Functional Evaluation of DRV8328 Gate Driver

4.4.1.1 DRV8328 Linear Regulator Performance

DRV8328C takes an 18-V input voltage and generates 3.3 V and is designed to deliver an average current of 80 mA. Figure 4-2 shows the voltage ripple on the 3.3-V line at a load current of about < 10 mA. The ripple is less than 10 mV, and is assumed to be enough for the MCU ADC pin voltage reference for back EMF sensing and current sensing.

- CH2 (Cyan): LDO Output

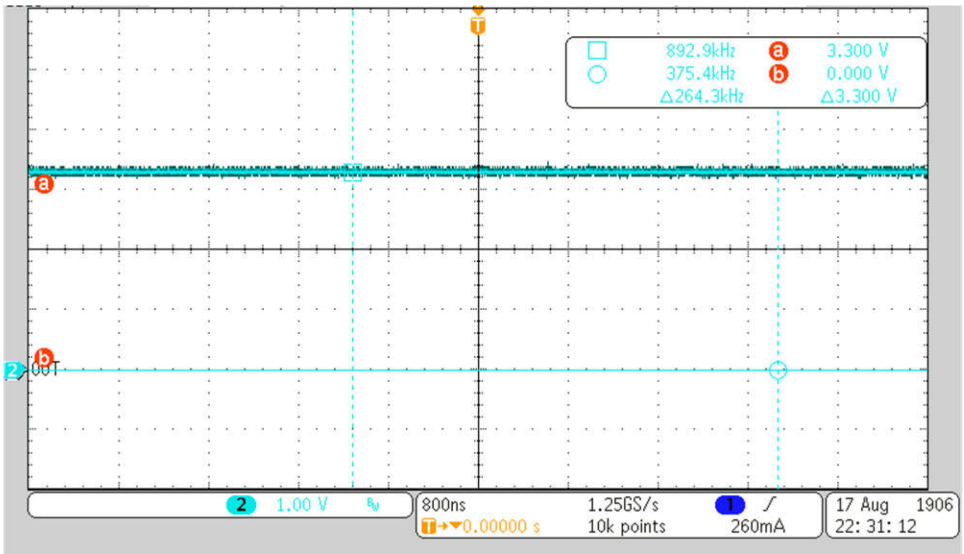


Figure 4-2. DRV8328C LDO Output

4.4.1.2 Gate Drive Voltage Generated by Gate Driver

Figure 4-3 shows the gate drive output voltage of DRV8328 and the corresponding MCU PWM signals at a DC bus voltage of 18-V DC. The gate drive voltage is approximately 13 V, which means effective gate driving of standard MOSFETs.

Figure 4-4 shows the gate drive voltage of the DRV8328 at a DC bus voltage of 5 V, which can be the minimum voltage available from a discharged Li-ion battery. The gate drive output voltage is approximately 9 V.

- CH1 (Blue): High-side V_{GS}
- CH2 (Cyan): Low-side V_{GS}

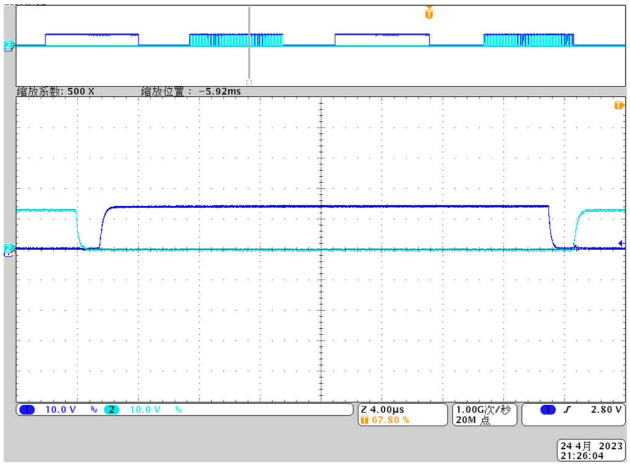


Figure 4-3. High-Side and Low-Side V_{GS} at 18-V DC

- CH1 (Blue): High-side V_{GS}
- CH2 (Cyan): Low-side V_{GS}

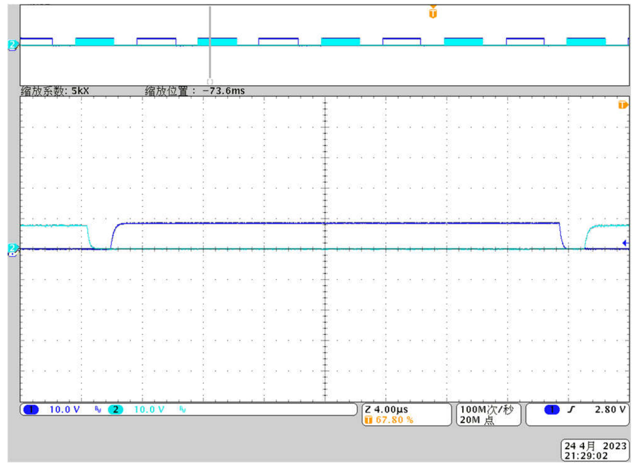


Figure 4-4. High-Side and Low-Side V_{GS} at 5-V DC

4.4.2 MOSFET Switching Waveforms

Figure 4-5 shows the PWM scheme used in the reference design testing for trapezoidal control of the BLDC motor. The control is a six-step block commutation where PWM is applied to the top switch and the bottom switch is operated in active freewheeling during the positive phase winding current for 120° electrical period. The bottom MOSFET switch is kept continuously ON during the negative phase winding current for 120° electrical period.

- CH2 (Cyan): High-side PWM
- CH3 (Purple): Low-side PWM

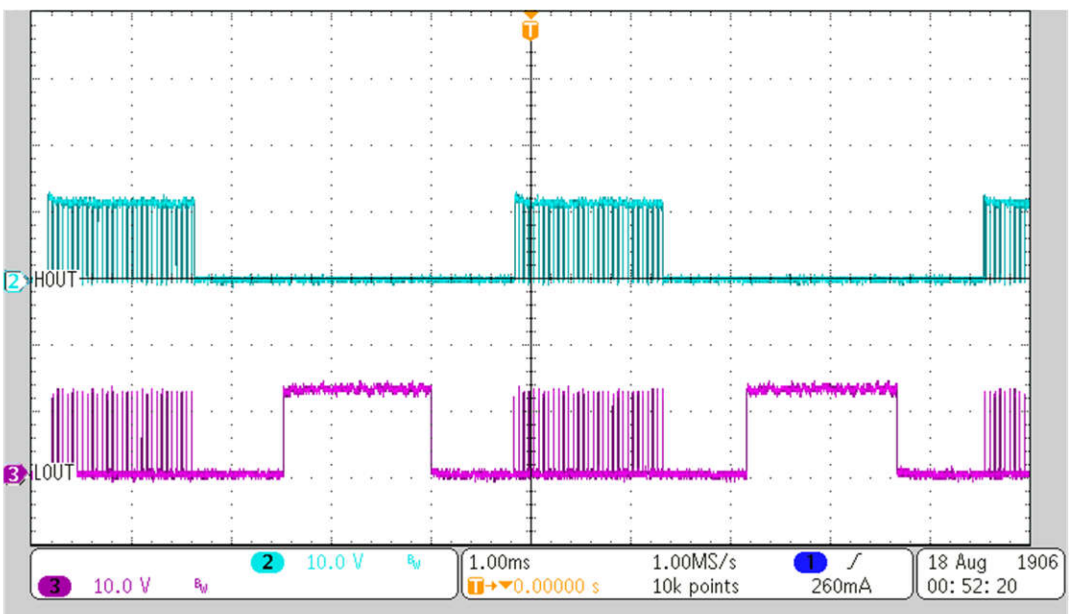


Figure 4-5. Low- and High-Side FET PWM Generated by MCU

Figure 4-6 and Figure 4-7 show the VDS and VGS waveforms of the low-side and high-side MOSFETs The switching waveforms are captured with a 10-Ω gate resistor for each FET. Switching waveforms are clean without any overvoltage ringing.

- CH1 (Blue): High-side V_{DS}
- CH2 (Cyan): High-side V_{GS}

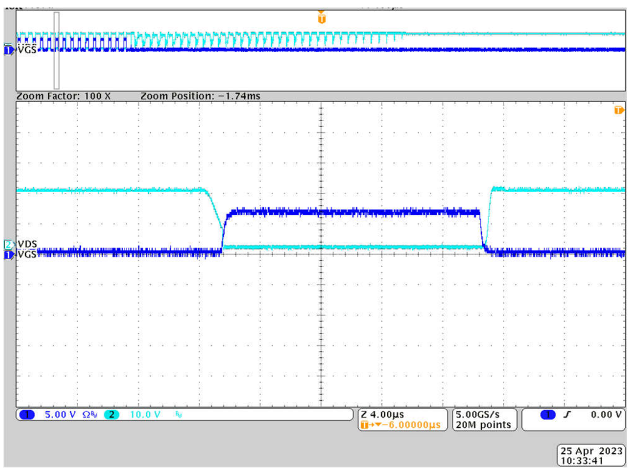


Figure 4-6. High-Side VGS and VDS

- CH1 (Blue): Low-side V_{GS}
- CH2 (Cyan): Low-side V_{DS}

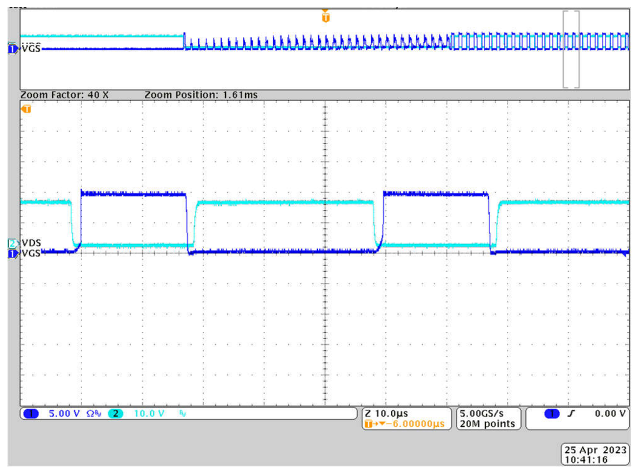


Figure 4-7. Low-Side V_{GS} and V_{DS}

4.4.3 Current Open Loop Test

This test shows software behavior to generate phase current under open loop mode. The normal trapezoidal wave voltage, and the current generated by the trapezoidal BLDC control can be examined.

- CH1 (Blue): U Phase Current
- CH3 (Purple): U Phase Voltage

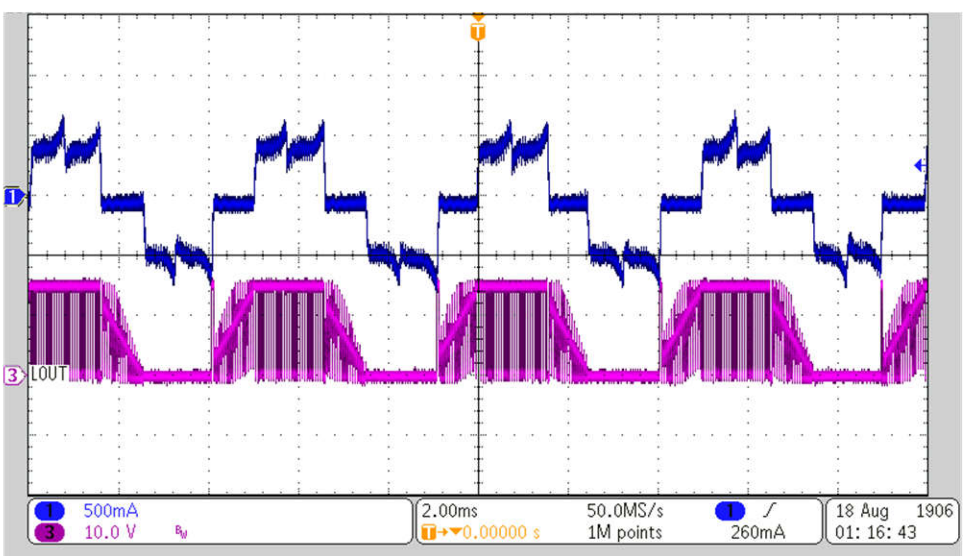


Figure 4-8. Motor Running in Open Loop

4.4.4 Current Open Loop Load Test

Figure 4-9 through Figure 4-12 show the motor winding current and winding voltage waveforms at a 18-V DC input and a 10-A_{RMS}, 33-A winding current, and the thermal images under the same conditions. The testing is done at 15% duty cycle.

Current waveform and thermal behavior when a large current is passed through the device can be observed. The input power is 18 V at 4 A to 5.5 A, 72 W to 100 W.

- CH1 (Blue): U Phase Voltage
- CH4 (Green): U Phase Current

Under the provided test conditions, in the case of 10-A_{RMS} current, the current of the maximum MOSFET is 49.3°C.

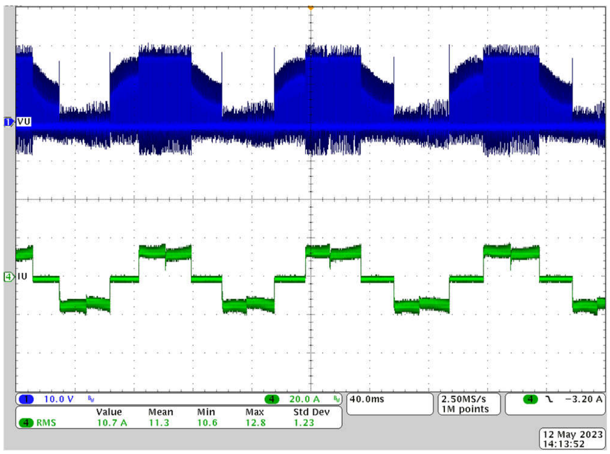


Figure 4-9. 18-V DC Input, 10-A_{RMS} Winding Current, 15% Duty Cycle

Figure 4-10. Thermal Image at 10-A_{RMS} Winding Current, 15% Duty Cycle

Under the given test conditions, in the case of 33-A_{RMS} current, the current of the maximum MOSFET is 97.1°C.

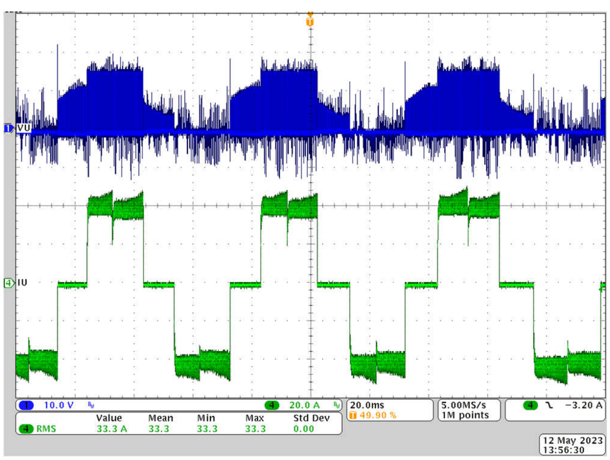


Figure 4-11. 18-V DC Input, 33-A_{RMS} Winding Current, 15% Duty Cycle

Figure 4-12. Thermal Image at 33-A_{RMS} Winding Current, 15% Duty Cycle

Figure 4-13 shows load test setup with a dynamometer.

Figure 4-13. Load Test Setup

5 Design and Documentation Support

5.1 Design Files

5.1.1 Schematics

To download the schematics, see the design files at TIDA-010251.

5.1.2 BOM

To download the bill of materials (BOM), see the design files at TIDA-010251.

5.2 Tools and Software

Tools

Code Composer Studio™	Code Composer Studio is an integrated development environment (IDE) for TI's microcontrollers and processors. The IDE comprises a suite of tools used to develop and debug embedded applications. Code Composer Studio is available for download across Microsoft® Windows®, Linux® and macOS® desktops. The software can also be used in the cloud by visiting the TI developer zone.

Software

TI.com	Contact the local TI sales for the software.

5.3 Documentation Support

1. Texas Instruments, *MSPM0G150x Mixed-Signal Microcontrollers Data Sheet*
2. Texas Instruments, *DRV8328 4.5 to 60 V Three-phase BLDC Gate Driver Data Sheet*
3. Texas Instruments, *CSD18510Q5B N-Channel NexFET Power MOSFET Data Sheet*
4. Texas Instruments, *TMP61 ±1% 10-kΩ Linear Thermistor With 0402 and 0603 Package Options Data Sheet*

5.4 Support Resources

TI E2E™ support forums are an engineer's go-to source for fast, verified answers and design help — straight from the experts. Search existing answers or ask your own question to get the quick design help you need.

Linked content is provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's Terms of Use.

5.5 Trademarks

6 About the Author

JENSON FANG is a System Engineer at Texas Instruments where he is responsible for developing appliance system related Motor control and BMS Solutions, and so on.

7 Revision History

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

Changes from Revision * (May 2023) to Revision A (December 2023)	Page
• Added *Software Requirements* section	13