TI Designs: TIDA-060009
Automotive Trunk Lift Drive Reference Design

Description

This reference design describes how to drive an automotive trunk lift or rear gate lift. In this design, a brushed DC (BDC) lift motor and electromagnetic clutch drive mechanisms for a typical gear-driven lift. The design includes a warning beeper, light-emitting diode (LED) indicator, and directional control that uses an automotive motor driver and highside switch. The MOSFET supplies up to 30 A of drive current for a BDC lift motor. A current-controlled gate driver with slew rate control helps improve MOSFET efficiency and decrease switching spikes. The drain-to-source voltage (VDS) of the MOSFET monitors for current sensing. This design lets the user manually operate the trunk through control of the electromagnetic clutch. This design includes the standard interface using the TI LaunchPad™ development kit for flexible microcontroller use. This design gives a simple, robust implementation with a low component count and small board space compared to relay solutions.

Resources

TIDA-060009	Design Folder
DRV8703-Q1	Product Folder
TPS1H100-Q1	Product Folder
LM74610-Q1	Product Folder
TPS7B82-Q1	Product Folder
SN74LVC2G17-Q1	Product Folder

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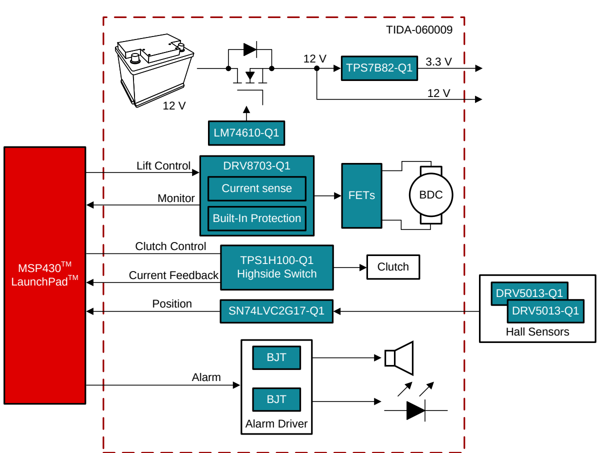
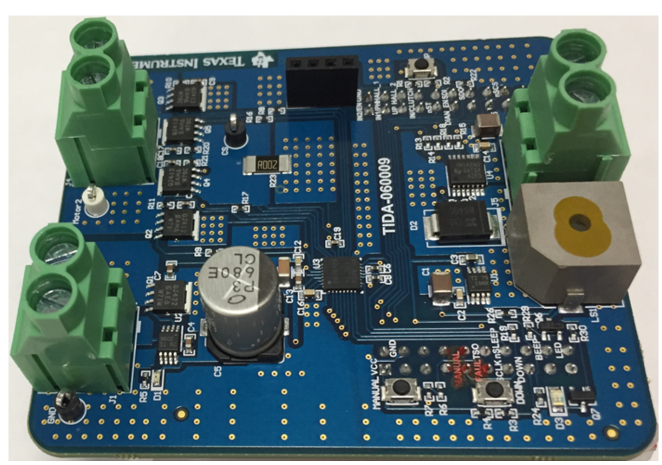
Features

- Operates from 12-V Automotive Battery System
- Output Power for Lift to a Maximum of 360 W
- Output Power for Clutch to a Maximum of 48 W
- Low-Power Sleep Mode Less Than 55 µA
- On-Board Linear Regulator Supplies to a Maximum of 300 mA at 3.3 V
- Overcurrent and Short-Circuit Protection Through VDS Sensing
- Single PWM Control
- Undervoltage and Overtemperature Protection Features
- Operating Ambient Temperature from –40°C to 125°C

Applications

- Power Trunk Lifts
- Power Liftgate
- Power Hood Lift





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1 System Description

The use of electrically-powered drivers to raise and lower automotive trunk lids, liftgates, and engine hoods is becoming more common. The most common types of trunk liftgates use a brushed DC motor that responds to commands from control switches in the cabin or switches on a key fob.

These drivers typically have a series of mechanical gears with a mechanical advantage to supply sufficient torque to move the large mechanical load. This advantage increases the effective torque from the motor and decreases the rotation speed. A mechanical arm and connected linkage convert the rotation into a force that is used to open or close the gate. Figure 1 shows an example of the mechanical assembly of a liftgate.

Figure 1. Liftgate Mechanism

One consideration in the design of the trunk lift is that some users prefer manual operation without electrical drive. Manually opening or closing the lid when the unpowered motor must be *back-driven* is very difficult because of the mechanical advantage of the gear train from the motor to the lifting arm. A clutch mechanism is typically used to disconnect the motor and some of the gear train from the remaining mechanism and the lid to make manual operation easier.

1.1 Key System Specifications

Table 1. Key System Specifications

PARAMETER	SPECIFICATIONS	DETAILS
Input power source	Automotive 12-V battery	Section 3.1.1.2
Input voltage range (nominal)	8 V to 16 V	—
Output power lift	360 W (maximum), 240 W (typical)	Section 2.3.1
Output power clutch	48 W maximum	Section 2.3.2
Power for microcontroller	3.3 V	Section 3.2.1
Standby current (without LaunchPad development kit)	Less than 55 µA	
Manual operation	Yes	—
Alarming	Yes	Section 3.2.12
Speed control	With PWM commands	Section 3.2.10
Protection	Overcurrent protection (OCP), undervoltage lockout (UVLO), and thermal shutdown	Section 3.2.9
Device qualification for automotive applications	AEC-Q100	—
Printed circuit board (PCB)	2 layers with 2-oz copper	—

2 System Overview

2.1 Block Diagram

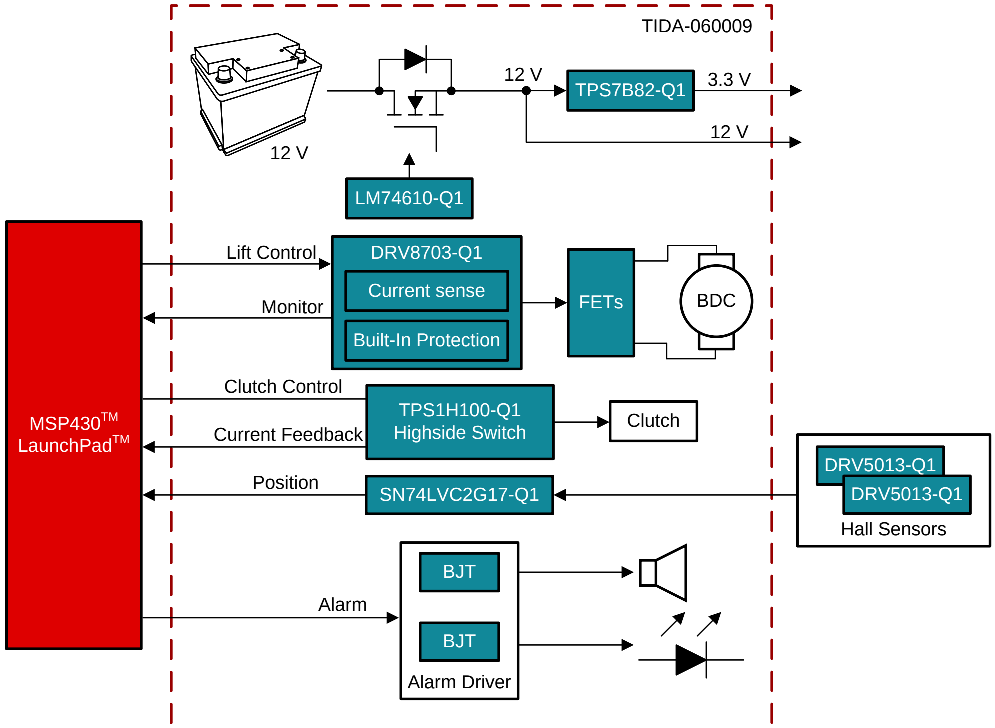


Figure 2. TIDA-060009 Block Diagram

For more information on each of these devices, see their respective product folders at www.ti.com

2.2 Highlighted Products

2.2.1 DRV8703-Q1

The DRV8703-Q1 device is an automotive H-Bridge gate driver that uses four external N-channel MOSFETs to drive a bidirectional brushed-DC motor. The DRV8703-Q1 device also has protection features beyond traditional discrete implementations including: undervoltage lockout (UVLO), overcurrent protection (OCP), gate driver faults, and thermal shutdown (TSD).

A PH/EN, independent H-Bridge, or PWM interface lets the user interface simply with the control circuits. An internal sense amplifier gives adjustable current control. Integrated charge pump gives 100% duty cycle support and can be used to drive an external reverse battery switch. The gate driver includes circuitry to regulate the use of fixed off-time PWM current chopping. The DRV8703-Q1 device drives both highside and lowside FETs with a 10.5-V VGS gate drive. The gate drive current for all external FETs is configurable through the Serial Peripheral Interface bus (SPI) that gives flexibility to reducing EMI. The device has a low-power sleep mode that shuts down internal circuitry to achieve a very low quiescent-current draw. The small device package of 5 mm × 5 mm and small number of external component lets the designer create a very compact design.

2.2.2 TPS1H100-Q1

The TPS1H100-Q1 device is a single-channel, fully protected highside power switch, with integrated NMOS power FET and charge pump. Accurate current-sense and programmable current limit features differentiate the devices from equivalent devices. The internal function for high-accuracy current-sense improves the real-time monitoring effect and makes diagnostics more accurate without more calibration.

2.2.3 TPS7B82-Q1

The TPS7B82-Q1 device is a low-dropout (LDO) linear regulator designed for off-battery operation in automotive systems. The device has an input voltage (V_{IN}) to a maximum of 40 V and can source up to 300 mA of current. The device can be used in a system with always-on components such as an MCU that can go to a low-power mode in automotive applications because of the 2.7-µA typical quiescent current (I_Q) at light loads. The device has integrated short-circuit protection and overcurrent protection. The device is AEC-Q100 qualified under Grade 1 requirements and operates in ambient temperatures from –40°C to +125°C. The 3.3-V version of the TPS7B82 device (TPS7B8233Q) can be used as a power supply for different automotive applications because of these features.

2.2.4 LM74610-Q1

The LM74610-Q1 device is a zero I_Q controller device that can be used with an N-channel MOSFET in circuity for reverse polarity protection. The device drives an external MOSFET to imitate an ideal diode rectifier when connected in series with a power source.

The device has a fast response internal comparator to discharge the MOSFET gate in the event of reverse polarity. If opposite polarity is sensed, this fast pulldown feature sets a limitation on the quantity and length of time of the reverse current flow. The LM74610-Q1 device also meets CISPR25 Class 5 EMI specifications and automotive ISO 7637 transient requirements with a suitable TVS diode.

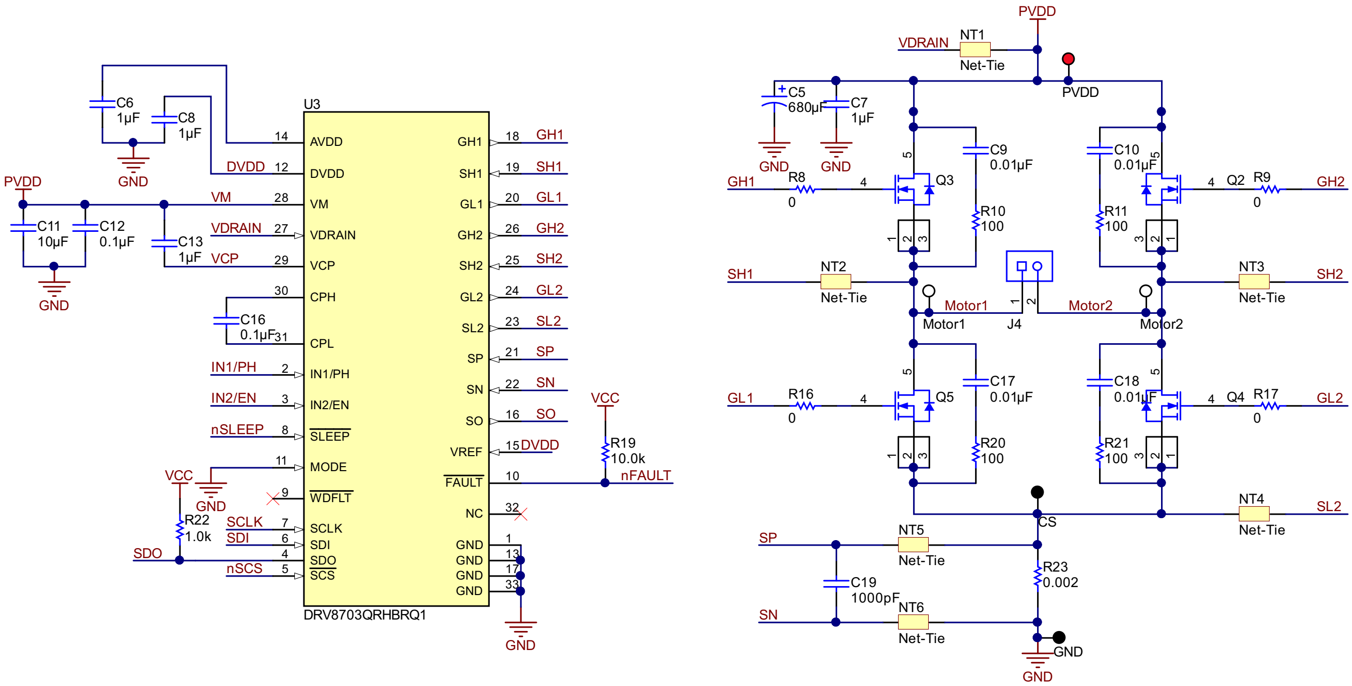
2.3 System Design Theory

The electronic circuit for a trunk lift contains subcircuits. The sub-circuits are for lift drive, clutch drive, power protection, voltage regulator, position feedback, warning indicators, and the controller. The sections that follow describe the design decisions for each subcircuit.

2.3.1 Lift Drive Circuit

The lift drive circuit supplies voltage and current to the brushed motor of the lift. The typical power supply in automotive applications is the 12-V automotive battery system. The supply voltage of the drive circuit can be to a maximum of 40 V because of possible conditions such as start-up or load-dump. The operation voltage range of 8 V to 16 V is sufficient in most cases because the operation of the liftgate does not occur when the vehicle starts, stops, or moves.

Figure 3 shows the lift drive circuit using the DRV8703-Q1 device. The DRV8703-Q1 device is an H-bridge gate driver for brushed motors. The device has two half-bridge drivers that can drive two N-MOSFETs. One of the two N-MOSFETs is for the high side and one is for the low side. The FETs are rated for a maximum of 33 A of continuous drain current at a temperature of 125°C and are AEC-Q101 qualified for automotive applications.



(1) The VM pin on the DRV88703-Q1 device supplies the PVDD voltage.

Figure 3. Lift Drive Circuit

The C11 and C12 components in Figure 3 are decoupling capacitors for the VM and VDRAIN pins. The VM and VDRAIN pins are connected to the 12-V nominal MOSFET supply. The C5 component is the bulk capacitor for the MOSFET to hold a standby voltage. The C6 and C8 components are the $C_{(DVDD)}$ decoupling capacitors specified in the DRV8703-Q1 data sheet. The voltage on the AVDD pin is 5 V. The voltage on the DVDD pin is 3.3 V. The C13 and C16 components are the $C_{(VCP)}$ and $C_{(SW)}$ charge pump capacitors specified in the DRV8703-Q1 data sheet. This design uses the PH/EN mode of the DRV8703-Q1 device. Connect the MODE pin to ground to use the EN PWM duty cycle to control the speed and the PH signal to control the direction. The fault conditions in the DRV8703-Q1 are reported the nFAULT pin and SPI status register.

The Q2 through Q5 components are the transistors for the high side and lowside power stage. These transistors are AEC-Q101 qualified for automotive applications with a maximum rated value of 40 V for VDS and a rated value of 32 A for the continuous drain current. The snubber circuits help protect the MOSFET and improve EMI. The snubber circuits contain C9, R10, C10, C11, C17, R20, C18, and R21

2.3.1.1 Current Regulation for DRV8703-Q1

The DRV8703-Q1 device has high-performance current regulation to set a limitation on the maximum current through the motor winding. Current rises through the winding when an H-bridge is enabled. The DC voltage and inductance of the winding select the rate at which the current rises. The chopping current is set by a comparator. The comparator compares the voltage across a current sense resistor connected to the SP pin that is multiplied by a factor of A_V (shunt-amplifier gain) with a reference voltage from the VREF pin. The DRV8703-Q1 device has four configuration options for A_V factor: 10, 19.8, 39.4 or 78 V/V. Use the DRV8703-Q1 GAIN_CS register to select the A_V setting.

Set the VREF_SCL bit to 01b and the GAIN_CS bit to 10b, in the Config Control register for the current requirement of this design of 20 A to 30 A. Use Equation 1 to calculate the chopping current ($I_{(CHOP)}$).

$$I_{(CHOP)} = \frac{V_{VREF} - V_{IO}}{A_V \times R_{(SENSE)}}$$

where

- $V_{VREF} = 3.3\ V \times 0.75$

- V_{IO} = (5 mV to 10 mV) × A_V
- A_V = 39.4 V/V
- $R_{(SENSE)}$ = Equation 2 (1)

Use Equation 2 to calculate the value of the current sense resistor ($R_{(SENSE)}$).

$$R_{(SENSE)} = (3.3\text{ V} \times 0.75 - 10\text{ mV} \times 39.4\text{ V/V}) / (39.4\text{ V/V} \times 30\text{ A}) = 0.0018\ \Omega \quad (2)$$

Use Equation 3 to calculate the chopping current for a 0.002-Ω current sense resistor.

$$I_{(CHOP)} = (3.3 \times 0.75 - 10\text{mV} \times 39.4\text{ V/V}) / (39.4\text{ V/V} \times 0.002\ \Omega) = 26.4\text{ A} \quad (3)$$

Use Equation 4 to calculate the power of the resistor (P).

$$P = I^2 \times R = 900 \times 0.002 = 1.8\text{ W} \quad (4)$$

A 2-mΩ, 2-W, 2512-package resistor was selected for this design based on these calculations. Adjust the VREF voltage and chopping current for different applications.

2.3.1.2 IDRIVE Setting

The DRV8703-Q1 device has a configurable IDRIVE current for each MOSFET with reasonable turnon and turnoff times that can improve EMC performance. The peak sink current is approximately two-times the peak source current. The adjustment of the peak current changes the output slew rate. The switching time also depends on the FET input capacitance and gate charge.

The sink current is more than the source current to help make sure that the transistor to be turned off changes state before the resistor to be turned on changes state. This sequence prevents accidental shoot-through currents.

Use Equation 5 to calculate the IDRIVE current for this design with a FET gate-to-drain charge of 12.3nC and a rise time of 150 ns.

$$I_{DRIVE} = Q_{gd} / t_r = 12.3\text{ nC} / 150\text{ ns} = 82\text{ mA} \quad (5)$$

Set the IDRIVE bit to 010b. The IDRIVE value is approximately 50 mA for the source current and approximately 95 mA the sink current for this application based on Equation 5.

2.3.2 Clutch Drive Circuit

The clutch drive circuit applies voltage to the electromagnetic coil. The electromagnetic coil acts as an electromagnet when voltage is applied. Two sections of the clutch make contact when the voltage is applied which moves torque from the motor side of the gear train to the load side of the gear train. The clutch coil resistance is 4.1 Ω for the lift mechanism in this design. This resistance gives a nominal clutch current of 2.9 A when the battery supply is 12 V.

The $\overline{ST}$ pin monitors the current sense on the TPS1H100A-Q1 device. Add a pullup resistor on the $\overline{ST}$ pin because it is an open drain output. Use Equation 6 to calculate the typical current limit (I_{lim}).

$$I_{lim} = 1.233\text{ V} \times 2000 / 499\ \Omega = 4.91\text{ A} \quad (6)$$

The current limit range is from 4.25 A to 5.663 A with 14% accuracy. Add a 10-kΩ resistor for a 5-V microcontroller.

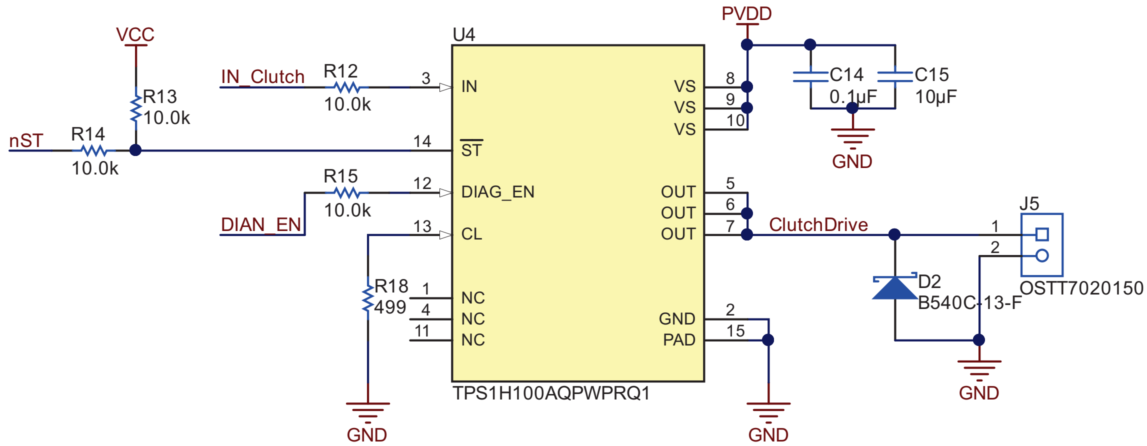


Figure 4. Clutch Drive Circuit

The rated value of reverse blocking for the D4 diode must have a high sufficient value to be resistant to the anticipated maximum voltage on the supply which is 40 V in this case. The current and power rated values for the D4 diode must be sufficient to support the full load current, although the current is only present for a short time and quickly decays after the switch turns off. The B540C-13 device is rated for a 40-V blocking voltage, 5-A average current, and is qualified to AEC-Q101 standards.

2.3.3 Power Reverse Protection

Figure 5 shows the electrical schematic of the subcircuit for reverse battery protection with the LM74610-Q1 device. The selection of the Q1 FET depends primarily on the rated value of drain-to-source voltage and the rated value for the current carrying capability. The transistor selected for Q1 in this design is rated for automotive applications with a maximum temperature of 175°C and for a drain-to-source voltage with a maximum of 40 V. The continuous current is up to 62 A at temperatures up to 125°C.

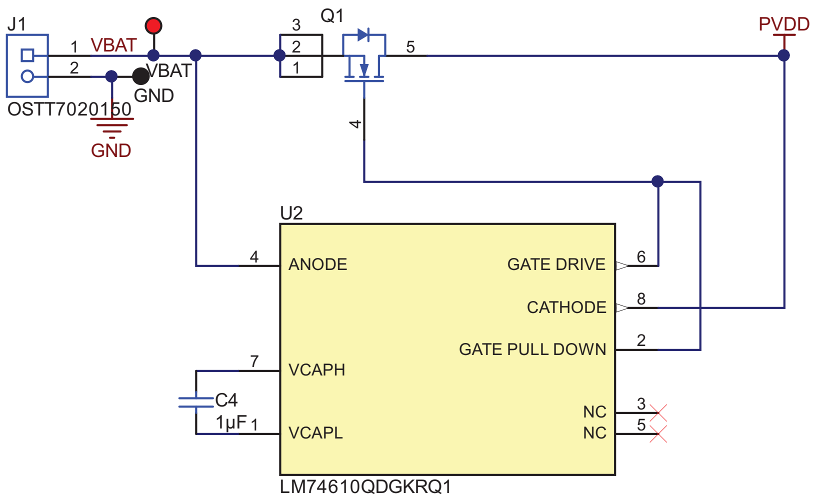


Figure 5. Power Reverse Protection

The selection of the C4 capacitor affects the length of time and frequency at which the LM74610-Q1 device refreshes its bias supply. The Q1 pass transistor turns off and the supply current passes through the FET body diode when the bias supply refreshes. While the Q1 transistor turns off, the V12 voltage drops because of the higher diode drop as compared to the channel. The selection of the value of C4 selects the period and length of time of the V12 voltage drop although the duty cycle of the refresh pulse is constant.

2.3.4 Voltage Regulator

The 3.3-V supply gives power to the board for the LaunchPad development, the Hall effect sensors, the Schmitt trigger buffers, and the push-button switches. A simple linear regulator can be used without a large quantity of power position feedback being dissipated because the typical total current is less than 50 mA. The 3.3-V version of the TPS7B82 device (TPS7B8233Q) gives a 300-mA current and has a fixed-output in a very small size with few external components. The input capacitors (C1 and C2) and output capacitor (C3) have excellent stability with small size.

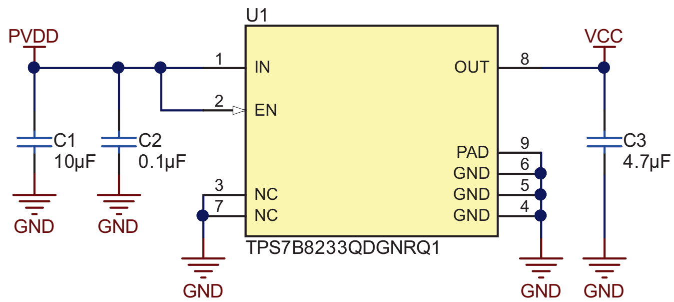


Figure 6. Voltage Regulator

2.3.5 Position Feedback

Hall effect sensors are commonly used to detect the motion of a mechanism. A wheel in the tested lift system has a magnetic band on the circumference. The magnetic band has alternating north and south poles. Two Hall effect sensors that are mounted near each other to detect the poles. The wheel rotation corresponds to the lift arm motion as the mechanism moves with a much higher speed because of the gear train between the magnetic wheel and the lift arm.

The location of the Hall effect sensors is such that their output signals is 90° out of phase. The Hall effect sensor that produces a rising edge first selects the direction of motion. A change in the position of the lift arm can be determined with high precision by the number of cycles of Hall effect signals. The Hall effect sensors do not directly show the absolute position of the arm. The Hall effect sensors show only changes in position. The origin and limits of the motion of the lift mechanism must be determined in an existent system by other effects, such as motor stall conditions when reaching the limits of travel.

Figure 7 shows the hall sensor circuit. The R25 and R26 resistors are connected to the 3.3-V supply because the Hall effect sensors are typically open-drain outputs. The U5 dual-buffer has a Schmitt trigger function for each Hall effect signal. This functions prevents noise from causing multiple transitions. In this design, the DRV5013-Q1 device is used as a Hall sensor. The DRV5013-Q1 device has hysteresis that can prevent magnetic fluctuations from causing unintended transitions. The U5 buffer decreases the electrical noise added to the signals after the Hall effect sensor. The electrical fields near the connection between the Hall effect sensors and the control board is one example of where noise can occur.

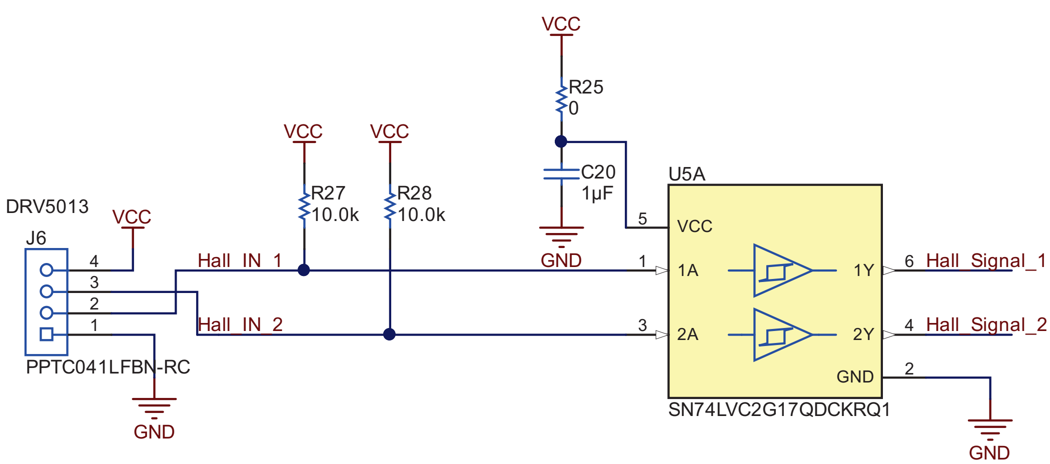


Figure 7. Hall Effect Sensor Circuit

2.3.6 Warning Indicators

A series of warning beeps make sound to alert anyone in proximity of the vehicle before the trunk or gate lid is raised or lowered. The warning sounds are to make sure that anyone hear by avoid interference with the moving mechanism. A series of light typically flashes as a warning of the motion. The system might use lights near the trunk or gate lid, such as the rear lights or center brake light to flash. If something that causes an overcurrent current stops the truck or gate, the warning beep sounds becomes a harsh noise and the LED lights all time.

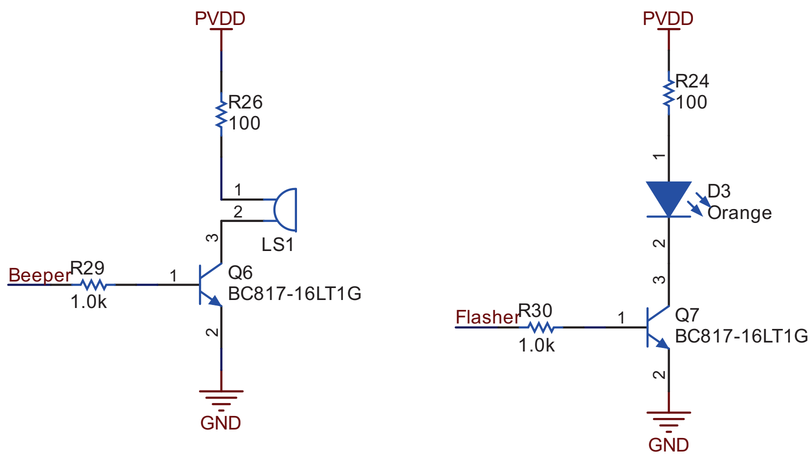


Figure 8. Warning Indicator

A self-driving acoustic transducer, LS1, is used as an audible warning in this design. The transducer operates directly from a 12-V nominal power supply with a rated operating voltage range of 8 V to 15 V. A bipolar junction transistor (BJT) lets a higher current of 30 mA drive the beep and LED. The audible tone of the beep has a frequency from 2000 Hz to 2600 Hz at an amplitude of a minimum of 85 dB.

The board has a warning indicator LED, D3, to demonstrate the warning light feature. The lift control board is typically mounted in an existent system such that it cannot be seen. External warning indicators alert users that the trunk lift is in operation when the board cannot be seen.

2.3.7 Push-Button Circuit

The open and close buttons are typically located in the cabin or on a key fob in an automotive system. The board in this design has two push-buttons that make operation of the system easy without more external hardware. The UP_Button and DOWN_Button signals can show switch bounce on transitions because the design does not use filtering capacitors. The board in this design has another push-button (MAN_Button) for manual operation. The circuit for manual operation is the same with UP_Button and DOWN_Button.

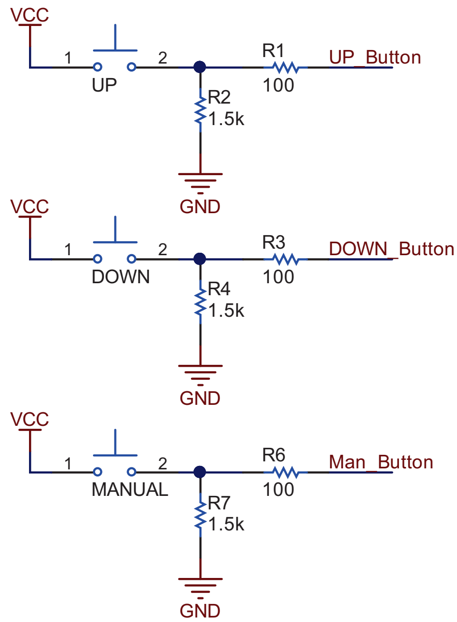


Figure 9. Push-Button Circuit

The R2 and R5 resistors are pulldown resistors to make sure that the default state of each button signal is low. The in-line resistors, R1 and R4, make sure that no direct path goes from the 3.3-V supply to the output signal pins. An indirect path decreases the risk of damage caused by short-circuit faults on the connector.

2.3.8 Controller Interface

Figure 10 shows board connections of the LaunchPad development kit and TIDA-060009.

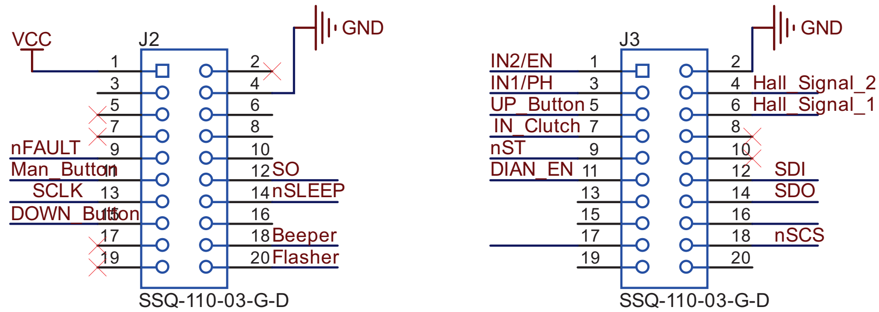


Figure 10. Interface Connector

Table 2 shows the signals between the design board and board of the LaunchPad development kit.

Table 2. TIDA-060009 Firmware Connection

System Component	Description
Development environment	Code Composer Studio™ IDE (CCS)
Controller	MSP430F5529
PWM frequency	20 kHz, programmable for higher or lower frequencies
Interrupts	Button, Hall
PWM generation for TIMER2	TA2.2 clock is 1 MHz
DRV8703-Q1 SPI pins	• PJ3.12 to SDI • PJ3.14 to SDO • PJ2.13 to SCLK • PJ3.18 to nSCS
DRV8703-Q1 input and output pins	• PJ3.1 to IN2/EN • PJ3.3 to IN1/PH • PJ2.9 to nFAULT • PJ2.12 to SO • PJ2.14 to nSLEEP
Clutch drivers pins	• PJ3.7 to IN_CLUTCH • PJ3.9 to nST • PJ3.11 to DIAN_EN
Hall sensor pins	• PJ3.4 to Hall_Signal_2 • PJ3.6 to Hall_Signal_1

3 Hardware, Software, Testing Requirements, and Test Results

3.1 Required Hardware and Software

3.1.1 Hardware

The design must have this hardware:

- TIDA-060009 board
- MSP430F5529 USB LaunchPad development kit (MSP-EXP430F5529LP)
- Electromechanical lift assembly with brushed DC motor, electromagnetic clutch, and Hall effect sensors

Figure 11 shows the TIDA-060009 connection with the LaunchPad development kit.

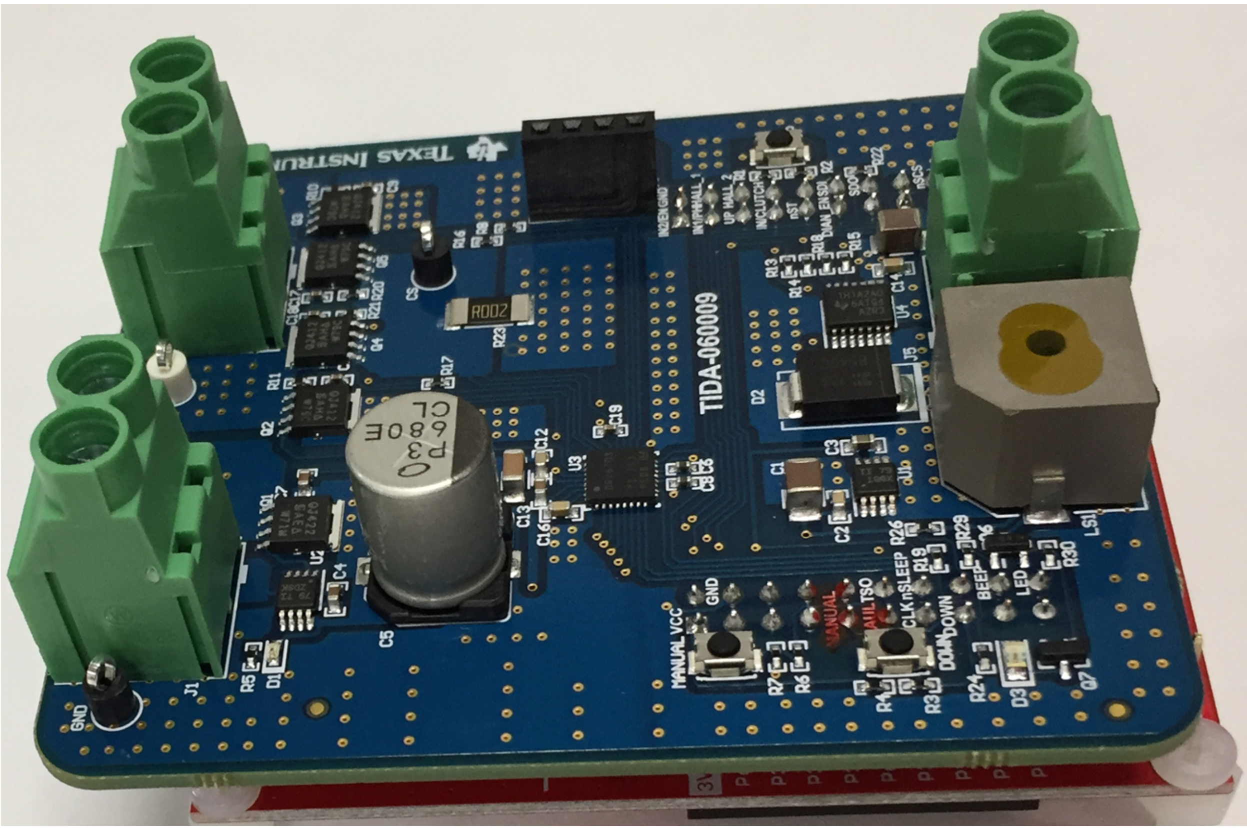


Figure 11. TIDA-060009 Connection With LaunchPad™ Development Kit

3.1.1.1 Hardware Setup

Install the TIDA-06009 board on the LaunchPad development kit. Align all pins of each header. Figure 12 shows the setup of the hardware with the boards aligned completely (see).

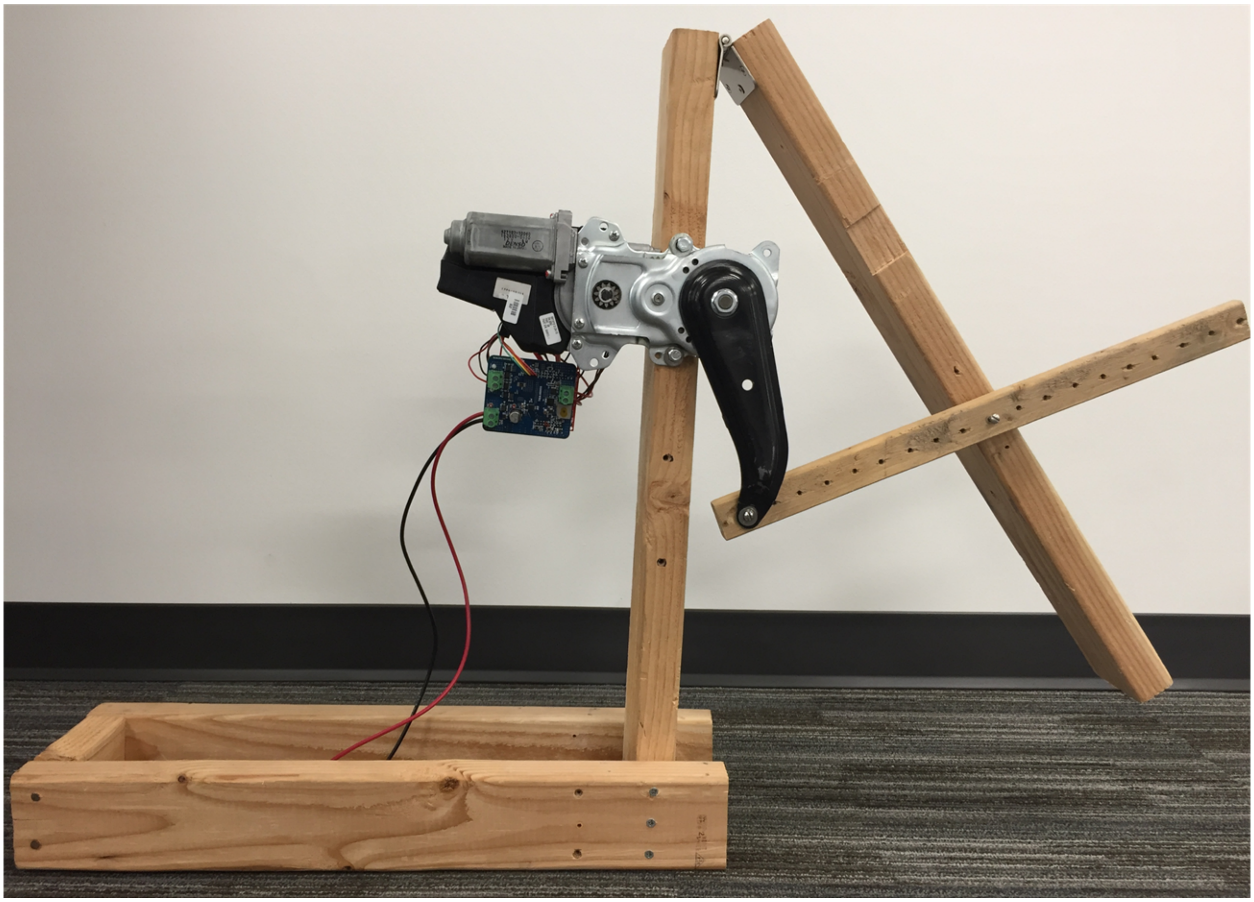


Figure 12. TIDA-060009 Setup

3.1.1.2 Power Supply

The operation of a typical lift assembly must have a power supply that can supply a minimum of 30 A at 12 V. The size and rated value of the lift drive motor and clutch determine the existent maximum power of the supply.

3.1.1.3 Motor Connection

Connect the two wires of the lift motor to the J4 terminal block. The J4 terminal block has a label of *Lift* on the top of the board. The mechanical arrangement of the motor and mechanism selects the polarity of the connections to the motor. Apply a positive voltage on J4-1 (LiftMotor1) with respect to J4-2 (LiftMotor2) to rotate the motor in the direction necessary to lift the test mechanism. Apply a positive voltage on J4-2 with respect to J4-1 to rotate the motor in the direction necessary to lower the test mechanism. If rotation of the motor is not the desired response to commands from the microcontroller, interchange the motor wires on J4-1 and J4-2 to invert the polarity of the motor.

3.1.1.4 Clutch Connection

Connect the two wires of the clutch coil to the J5 terminal block. The J5 terminal block has a label of *Clutch* on the top of the board. Connect the wires in any order because the polarity of the voltage applied to the clutch coil does not affect its performance.

3.1.1.5 Hall Effect Sensor Connection

The four-contact header (J8) has connections for Hall effect (or similar) sensors with incremental position feedback from the mechanism.

3.1.2 Software

The TIDA-060009 reference design uses a simple parallel interface to the LaunchPad development kit for signal control. The interface uses SPI communication to read and write the DRV8703-Q1 registers. Table 3 shows the functions to control LaunchPad the TIDA-060009 board from the LaunchPad development kit.

Table 3. TIDA-060009 Functions

Function	Description
GPIO_init()	Initial GPIO used for input and output
SPI_Init()	Initial SPI pins
PWM()	TIMER2 configure and PWM frequency set
Write register()	Write a DRV8703-Q1 register address and data
Read register()	Read a DRV8703-Q1 register
UP_button()	Control UP button interrupt
Down_button()	Control DOWN button interrupt
Warning()	BEEP warning
Reverse()	Set PH to 0 for the reverse direction of the motor
Forward()	Use Forward() for the forward direction of the motor
Hall()	Initial Hall pins and interrupt for position detect
En_clutch()	Set IN_CLUTCH to 1 to activate the clutch

Users can operate the trunk lift system with minimal software functions that use simple bitwise control of the GPIO signals for the LaunchPad development kit. Figure 13 shows a flow chart of the software functions for trunk lift operation.

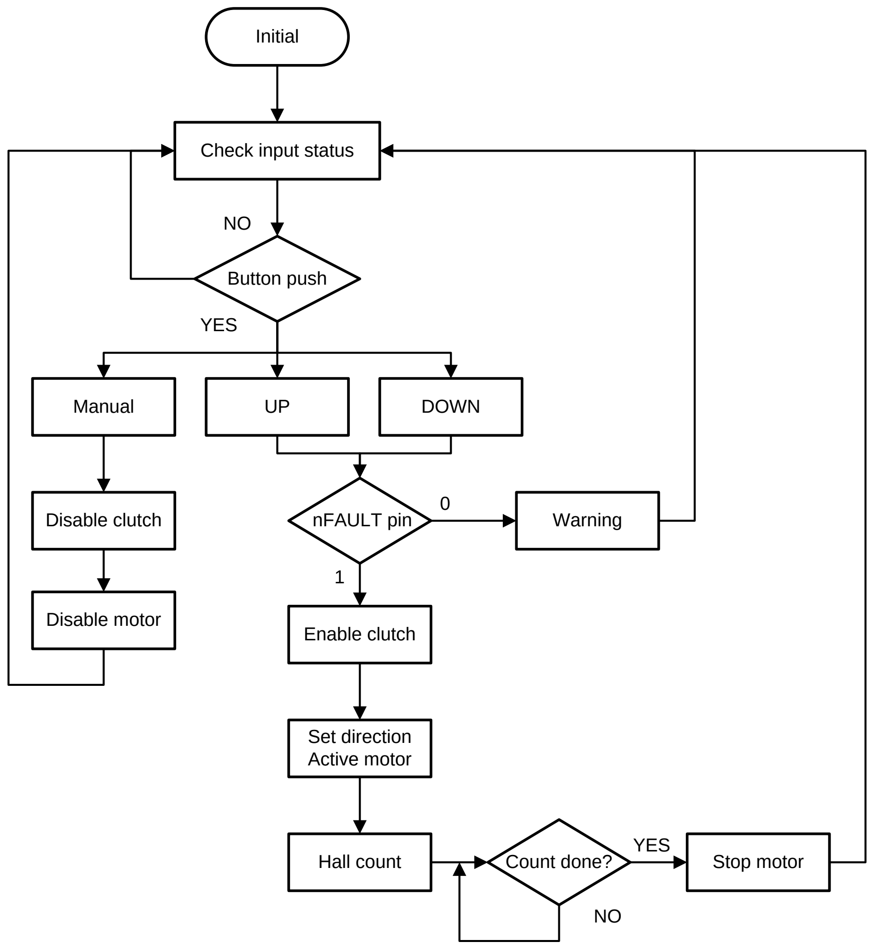


Figure 13. Software Flow Chart

3.2 Testing and Results

3.2.1 3.3-V Voltage Regulator

Figure 14 shows the 3.3-V voltage output from the TPS7B8233Q device with a power supply from 8 V to 16 V.

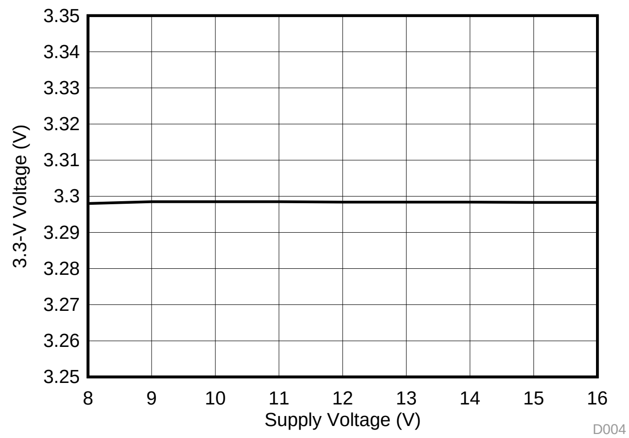


Figure 14. 3.3-V Voltage With Supply Voltage

Figure 15 show the 3.3-V voltage generated from the TPS7B8233Q device. Figure 15 also shows the ripple in the 3.3-V rail. The ripple is less than 30 mV which is less than 1%.

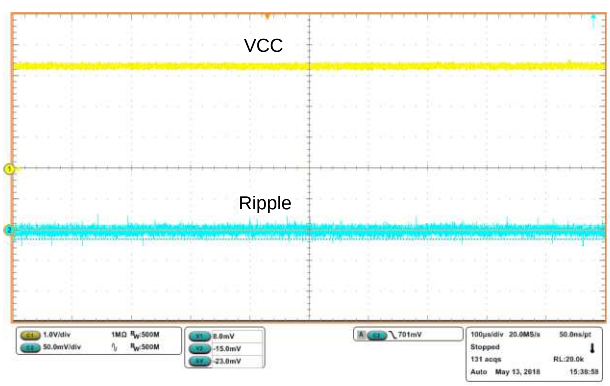


Figure 15. 3.3-V Voltage and Ripple

3.2.2 Standby Input Current

Disconnect the LaunchPad development kit to measure the standby current of the TIDA-060009 design. The current is less than 55 µA when the voltage is from 8 V to 16 V. Figure 16 shows the current for different supply voltages.

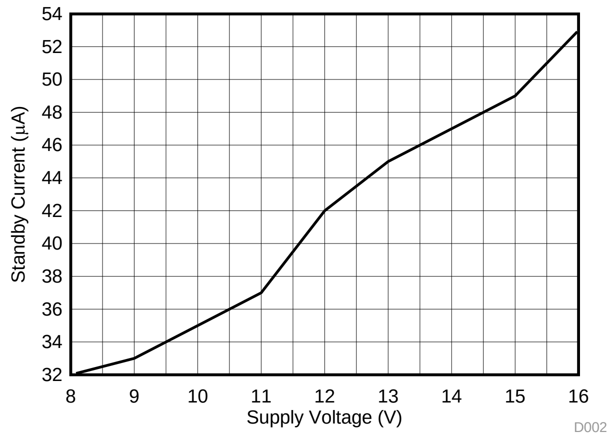


Figure 16. Standby Current

3.2.3 Leakage Current With Reverse Battery

A system usually must have reverse battery protection. Figure 17 shows the leakage current with reverse voltage from 8 V to 16 V. The leakage current in Figure 17 is less than 71 µA.

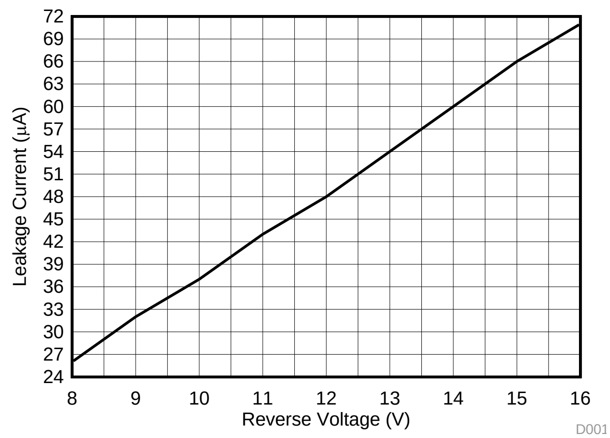


Figure 17. Leakage Current

3.2.4 Gate Drive Signals

Figure 18 shows the PWM signals of the LaunchPad development kit and the output voltage of the DRV8703-Q1 gate driver at a 12-V DC voltage with forward motor direction.

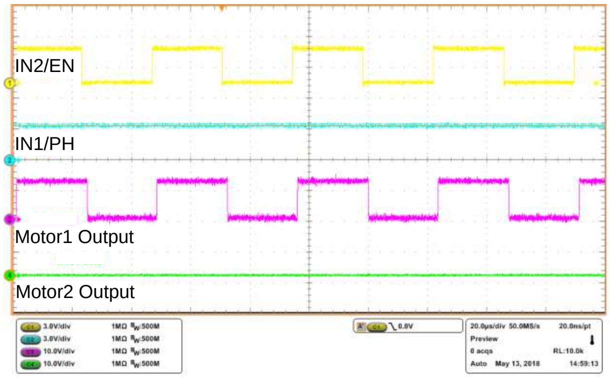


Figure 18. Forward Gate Drive Signals

Figure 19 shows the PWM signals of the LaunchPad development kit and the output voltage of the DRV8703-Q1 gate driver at a 12-V DC voltage with reverse motor direction.

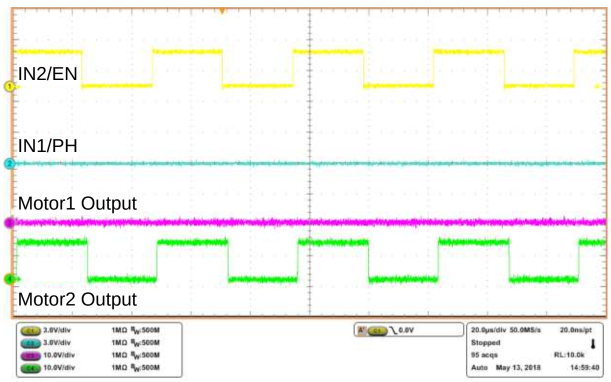


Figure 19. Reverse Gate drive Signals

3.2.5 Clutch Response Time and Output Power

The clutch response time is an electrical delay that results from the propagation time through the TPS1H100-Q1 highside switch. The clutch response time in Figure 20 is approximately 54 µs and the rise time is approximately 25 µs.

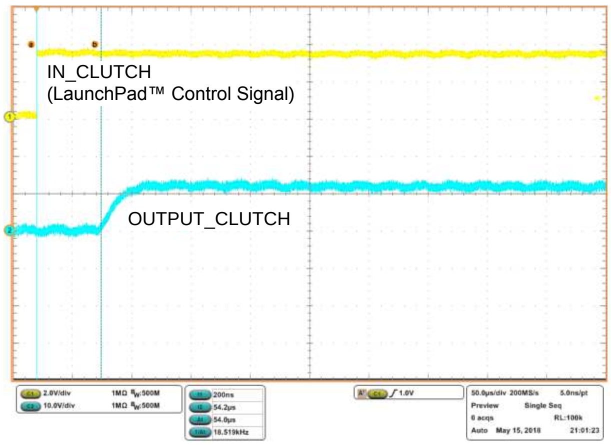


Figure 20. Clutch Response Time

Figure 21 shows the output current with a power supply from 8 V to 16 V.

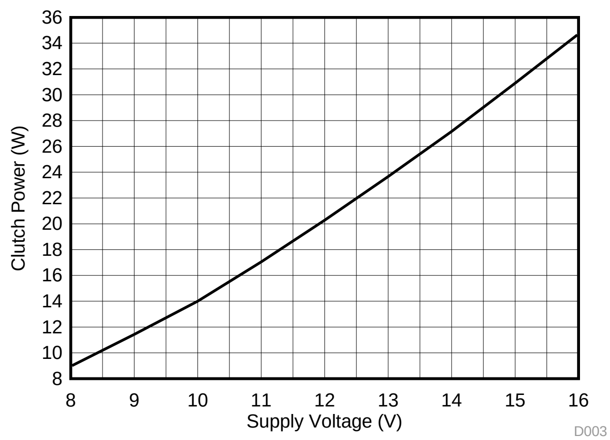


Figure 21. Clutch Power

3.2.6 MOSFET Switching Waveform

Figure 22 and Figure 23 show with IDRIVE bit set to 010b. If the IDRIVE bit is set to 010b, the highside source current is 50 mA the lowside source current is 45 mA, the highside and lowside sink current is 95 mA. The switching waveforms do not have any overshoot ring because of the IDRIVE and TDRIVE features of the DRV8703-Q1 device. These features help shape the gate current to optimize the switching.

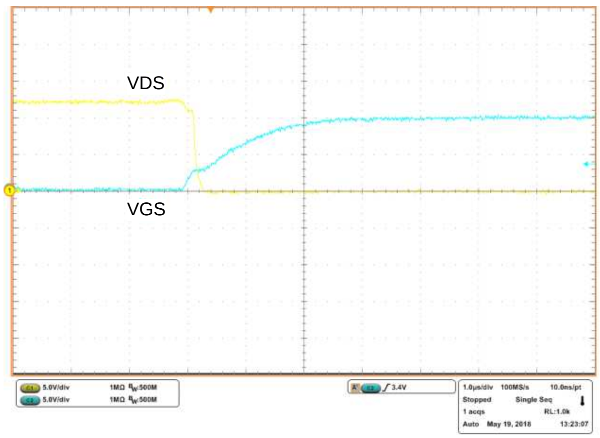


Figure 22. Turnon Waveform

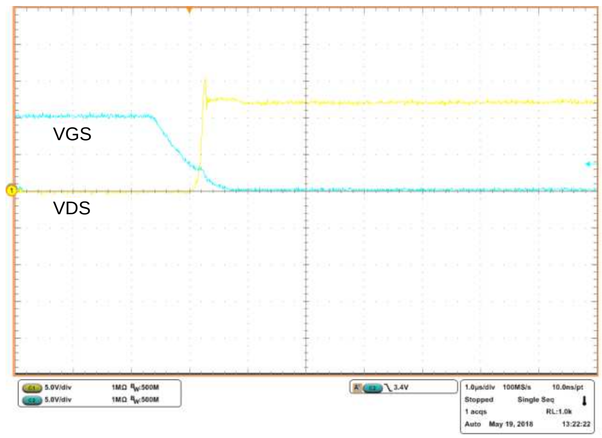


Figure 23. Turnoff Waveform

3.2.7 Dead Time of DRV8703-Q1

The dead time ($t_{(DEAD)}$) of the DRV8703-Q1 device is measured as the time when the SHx pin is in the Hi-Z state between turning off one of the H-bridge FET and turning on the other. The $t_{(DEAD)}$ in Figure 24 is 300 ns and Figure 25 is 180 ns.

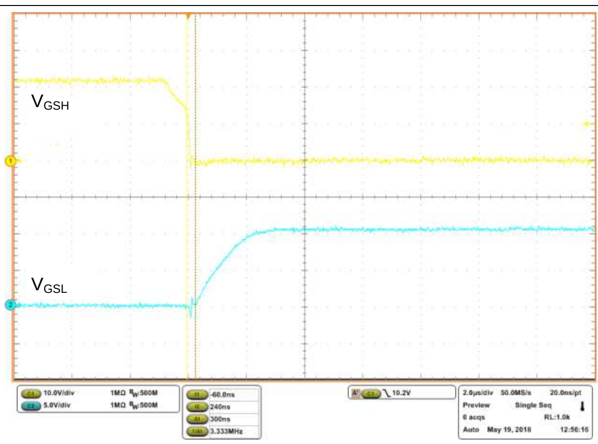


Figure 24. Highside Turnon and Lowside Turnoff

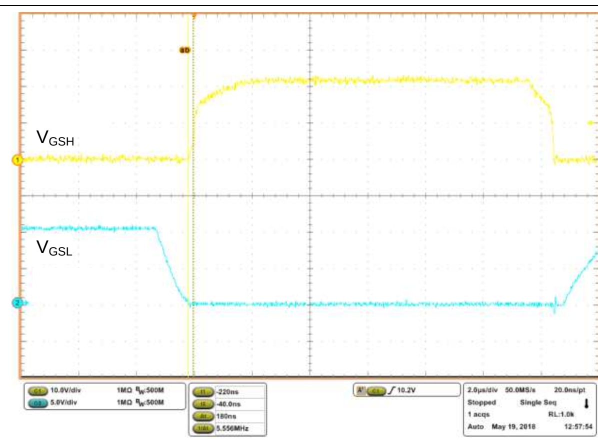


Figure 25. Highside Turnoff and Lowside Turnon

3.2.8 DRV8703-Q1 Current Regulation

The current through the motor can become more than the rated value for motor overload or motor stall condition. The DRV8703-Q1 device has an integrated function for current regulation that uses VDS sensing. This function is tested by using a 0.6-Ω power resistor and 8.4-µH inductor.

Use Equation 1 to set the chopping current to 15.9 A with a load current of 18.2A.Figure 26 shows the current waveform with a chopping current of 15.9 A (see Equation 1) and a load current of 18.2 A. The voltage on the SO pin is equal to the SP voltage times the amplifier gain (A_V) plus an offset. The SO output voltage in Figure 26 is 1.65 V and the current is approximately 15.4 A.

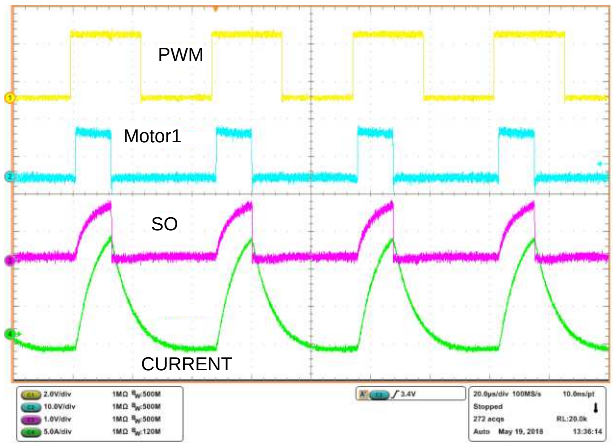


Figure 26. Current Regulation

3.2.9 Overcurrent Protection

The DRV8703-Q1 device implements overcurrent protection through VDS sensing. Use Equation 7 to calculate the current limit (I_{OCP}) for a VDS reference voltage of 0.06 V for the overcurrent limit and a MOSFET $R_{DS(on)}$ resistance of 0.0041 Ω.

$$I_{OCP} = V_{DS} / R_{DS(on)} = 0.06\ V / 0.0045\ \Omega = 13.3\ A \quad (7)$$

Figure 27 shows the overcurrent waveform. When the current is more than 13.3 A, the nFAULT pin goes low, the devices pull all of the gate drive outputs low. The response time is less than 1 µs.

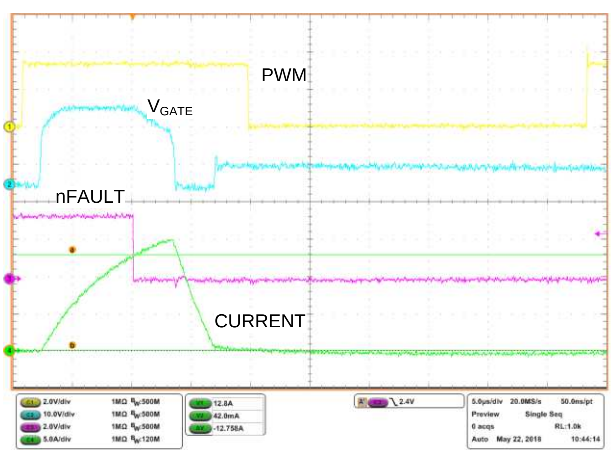


Figure 27. DRV8703-Q1 Overcurrent Protection

The highside switch, TPS1H100-Q1, identifies an overcurrent event through the $\overline{ST}$ pin. The range of the clutch current limit is from 4.25 A to 5.663 A (see Equation 5). If the current limit condition occurs, the $\overline{ST}$ pin and output go low (see Figure 28).

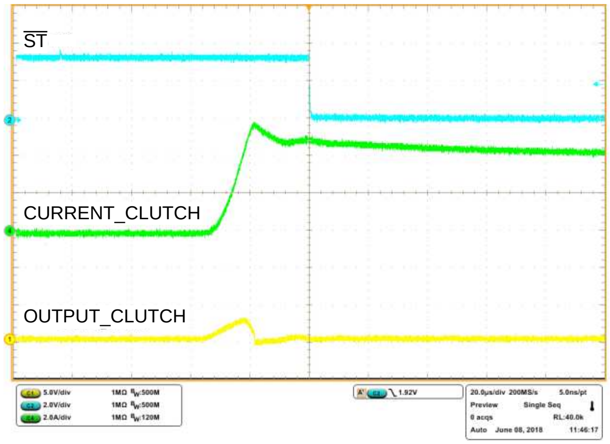


Figure 28. TPS1H100-Q1 Overcurrent Protection

3.2.10 Motor Speed Control

The PWM duty cycle can control the motor speed. The speed of the motor increases as the PWM duty cycle increases. The trunk has gears to decrease motor speed and increase torque. Figure 29 shows the relationship between the motor speed and PWM duty cycle.

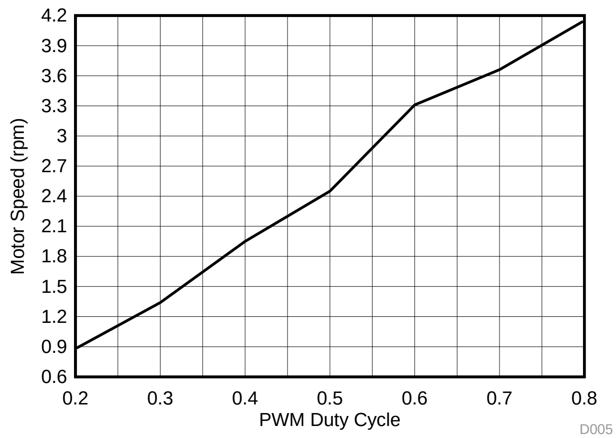


Figure 29. Motor Speed With PWM Duty Cycle

As the motor speed increases, the VM voltage also increases. Figure 30 shows the relationship between the motor speed and supply voltage with 50% PWM duty cycle.

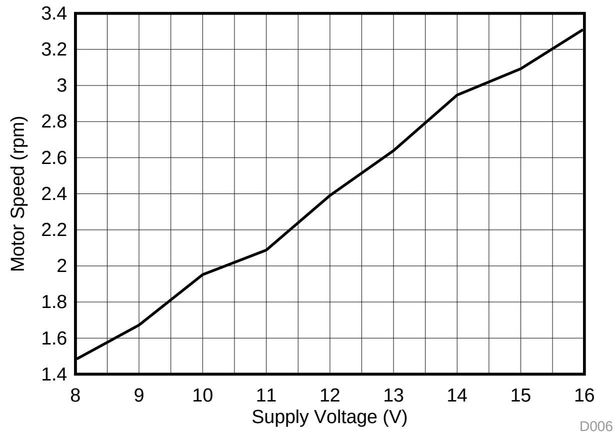


Figure 30. Motor Speed With Supply Voltage

3.2.11 Thermal Test

A thermal camera can measure the temperature of the system. The board was operated in open air with a 12-V nominal supply at the normal room temperature in each thermal test. Figure 31 shows the standby temperature profile of the boards with a 12-V battery and no motor and clutch operation. The DRV8703-Q1 temperature is approximately 25.4°C, which is similar to the ambient temperature.

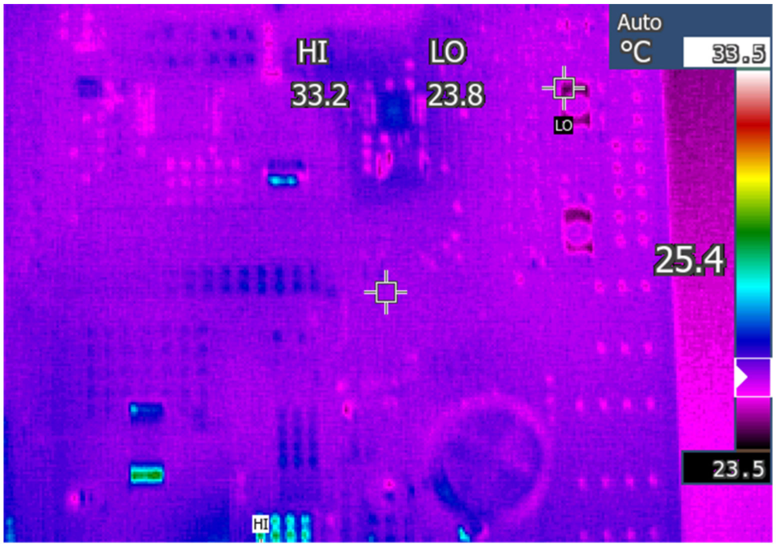


Figure 31. Standby Thermal Test

Figure 32 shows the temperature profile of the boards with clutch and motor operation. The highside device temperature is 45.2°C with approximately 2 A of current. The DRV8703-Q1 temperature is 37.6°C.

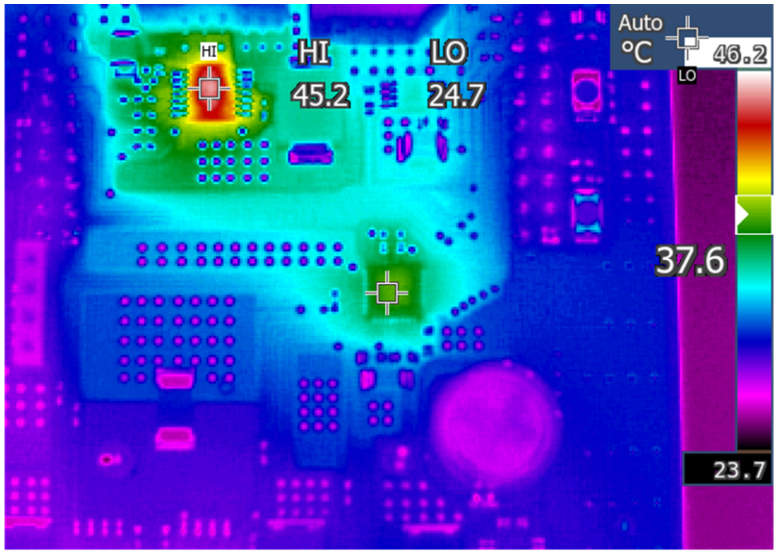


Figure 32. Motor and Clutch Thermal Test

Figure 33 shows the temperature of the forward MOSFET on the board with the resistor load. Figure 34 shows the temperature of the reverse MOSFET on the board with the resistor load. The peak current is approximately 18.25 A, the maximum temperature of the high side is 88.7°C, and the maximum temperature of the low side is approximately 75.8°C. The temperature of the low side is less than the temperature of the high side because the low side of layout has a better heat dissipate. To get a better thermal performance, more vias and copper area can be used.

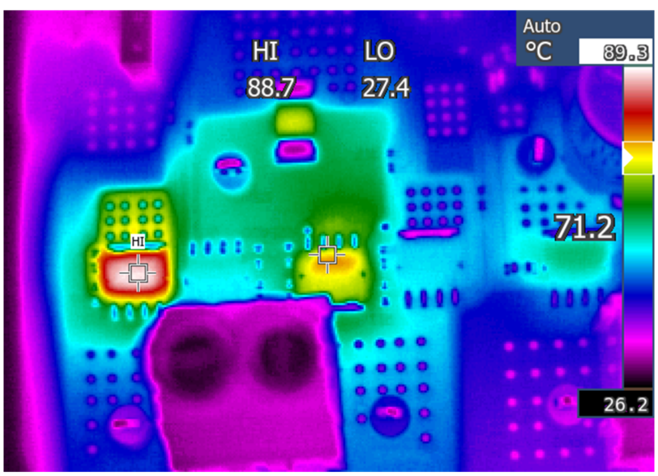


Figure 33. Forward Thermal Test

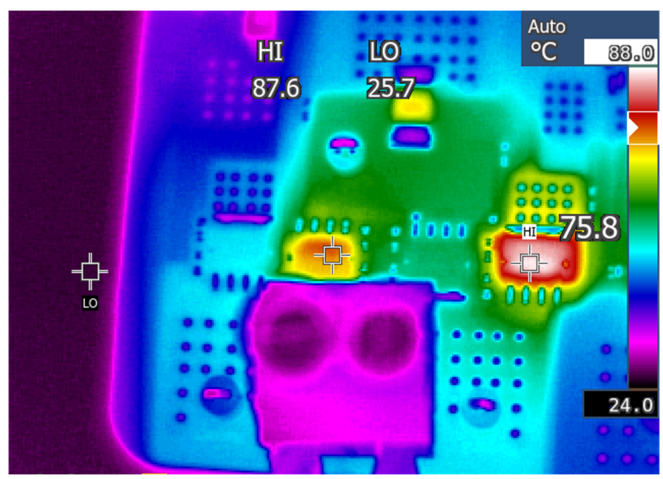


Figure 34. Reverse Thermal Test

3.2.12 Warning Alarms

If the system detects a fault condition, a beep sound is used as a warning. The volume of the audible alarm was tested using a sound meter application on an Apple iPhone™ mobile digital device with a 12-V power supply (see Figure 35).

Figure 35. Alarming

3.2.13 Position Feedback

Sequential Hall sensor signals can show the motor direction. Table 4 shows the logic for the Hall signals for forward and reverse motor direction.

Table 4. Hall Logic

Forward		Reverse	
Hall_1	Hall_2	Hall_1	Hall_2
0	0	0	0
1	0	0	1
1	1	1	1
0	1	1	0

Figure 36 and Figure 37 show the test results.

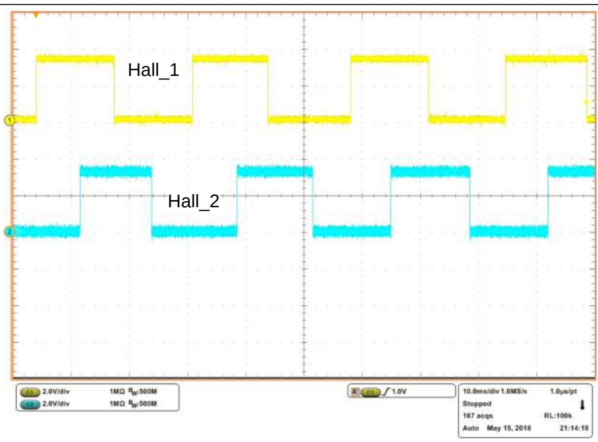


Figure 36. Forward Hall Signals

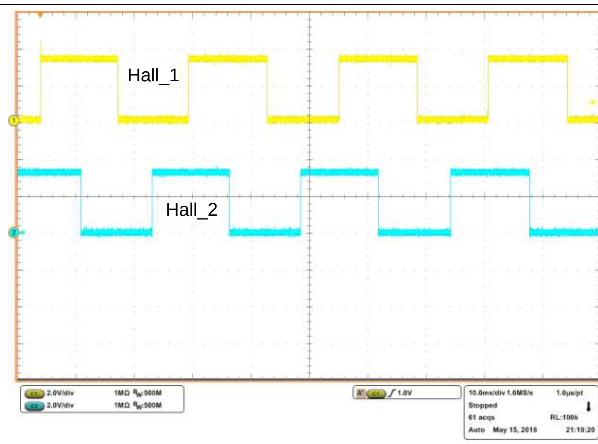


Figure 37. Reverse Hall Signals

4 Design Files

4.1 Schematics

To download the schematics, see the design files at TIDA-060009.

4.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-060009.

4.3 PCB Layout Recommendations

Follow these recommendations for the PCB layout for this design:

- Make sure that the PCB has a two-layer layout with 2-oz copper thickness in each layer.
- Increase the copper area and use arrays of vias below the drain pad of the MOSFET for better thermal dissipation from the MOSFET to PCB. This layout dissipates heat better to the area of the bottom surface copper (see Figure 38).

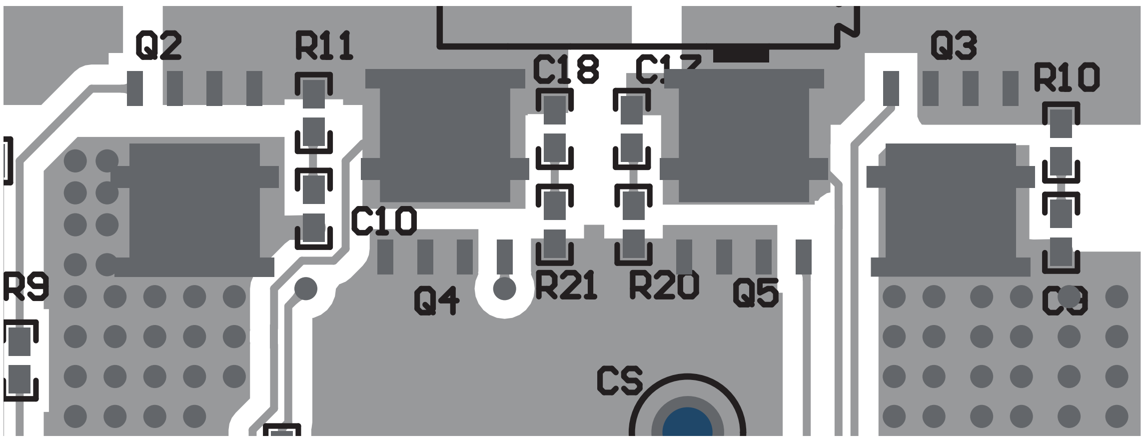


Figure 38. MOSFET Drain Layout

- Put the bypass capacitors at the AVDD and DVDD pins (see Figure 39).
- Make sure that the bypass capacitors and charge pump capacitor are on the same layer.

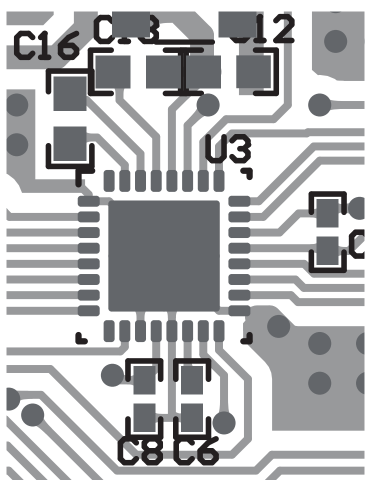


Figure 39. Bypass Capacitors of AVDD and DVDD

- Put a large bulk capacitor on the PVDD pins for higher current.
- Clear the space around and below the DRV8703-Q1 device to let heat spread better from the thermal pad.

- Consider the layout of the high-current trace for input power, motor drive, and clutch drive.
- Use a copper trace with 2-oz thickness for the input power which can carry 40 A of current with a maximum temperature increase of 10℃.
- Use a copper trace with 2-oz thickness for the motor current to make sure that it can support 30 A of current (see Figure 40).

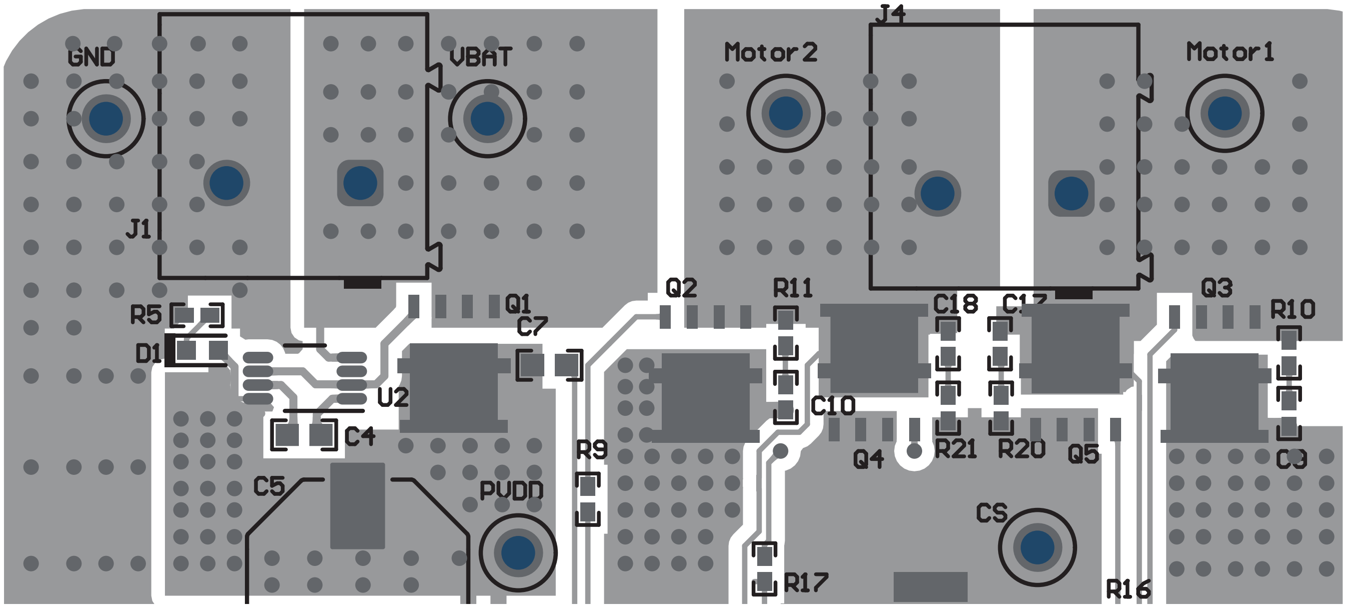


Figure 40. High Current Traces

4.4 Altium Project

To download the Altium Designer® project files, see the design files at TIDA-060009.

4.5 Gerber Files

To download the Gerber files, see the design files at TIDA-060009.

4.6 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-060009.

5 Software Files

To download the software files, see the design files at TIDA-060009.

6 Related Documentation

For related documentation, see:

1. Texas Instruments, *DRV5013-Q1 Automotive Digital-Latch Hall Effect Sensor* data sheet
2. Texas Instruments, *DRV870x-Q1 Automotive H-Bridge Gate Driver* data sheet
3. Texas Instruments, *LM74610-Q1 Zero IQ Reverse Polarity Protection Smart Diode Controller* data sheet
4. Texas Instruments, SN74LVC2G17-Q1 *Dual Schmitt-Trigger Buffer* data sheet
5. Texas Instruments, *TPS1H100-Q1 40-V, 100-mΩ Single-Channel Smart High-Side Power Switch* data sheet
6. Texas Instruments, *TPS7B82-Q1 300-mA High-Voltage Ultralow-*I_Q *Low-Dropout Regulator* data sheet

6.1 Trademarks

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7 About the Author

Betty Guo is a field application engineer with the South China team at Texas Instruments. Betty has been at Texas Instruments since 2017 and brings her experience in analog signal chain. Betty earned her Bachelor of Measurement and Control Technology and Instrument and Master of Instrument Science and Technology from China University of Geosciences.

Clark Kinnard is a Systems Applications Engineer at Texas Instruments. As a member of the Automotive Systems Engineering team, Clark works on various types of motor drive end-equipment, creating reference designs for automotive manufacturers. Clark earned his Bachelor of Science and Master of Science in Engineering from the University of Florida, and his Ph.D. in Electrical Engineering from Southern Methodist University.