

# Achieving Reverse Battery Protection Using TI High Side Switch Controllers



Dilip Jain, Naveen Bevara

## ABSTRACT

With evolving zonal architectures in automotive power distribution system, there is an increase in demand for high-side switch controllers to drive most of the primary and secondary high current loads with external MOSFETs. These system designs include power distribution box and loads such as PTC heaters, body motors, and so on.

One of the key system requirement from car OEMs in 12V automotive systems is to protect the DUT against the reverse battery connection. During maintenance of car battery or jump start of the vehicle, the battery can be connected in reverse polarity during re-installation and this can cause damage to the connected subsystems, circuits, and components. Appropriate protection circuits need to be designed to make sure the DUT is protected and withstand the reverse battery condition. Based on the load type, the reverse battery protection can be implemented either with a back to back power switch or with a forward load switch topology.

This application note highlights how TI's high-side switch controllers such as TPS1211-Q1, TPS1214-Q1 can be used to achieve reverse battery protection for various high current body loads with various circuit configurations.

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## 1 TPS1211-Q1 High Side Switch Controller Overview

The TPS1211-Q1 family is a 45V smart high-side drivers with protection and diagnostics. With wide operating voltage range of 3.5V – 40V, the device is an excellent choice for 12V system designs. The device has a strong 3.7A peak source (PU) and 4A peak sink (PD) gate driver that enables power switching using parallel FETs in high current system designs. Use INP as the gate driver control input. MOSFET slew rate control (ON and OFF) is possible by placing external R-C components.

The device has accurate current sensing ( $\pm 2\%$  at 30mV) output (IMON) enabling system designs for energy management. The device has integrated two-level, overcurrent protection with FLT\_I output with complete adjustability of thresholds and response time. Auto-retry and latch-off fault behavior can be configured. The device features remote overtemperature protection with FLT\_T output enabling robust system protection. TPS12110-Q1 has an accurate overvoltage protection ( $< \pm 2\%$ ), providing robust load protection. The TPS12111-Q1 integrates a precharge driver (G) with control input (INP\_G).

This feature enables system designs that must drive large capacitive loads by precharging first and then turning ON the main power FETs. TPS1211-Q1 has an accurate undervoltage protection ( $< \pm 2\%$ ) using the EN/UVLO pin. Pull EN/UVLO low ( $< 0.3V$ ) to turn OFF the device and enter into shutdown mode. In shutdown mode, the controller draws a total shutdown current of 0.9 $\mu A$  (typical) at 12V supply input. Figure 1-1 shows the TPS12111-Q1 functional block diagram.

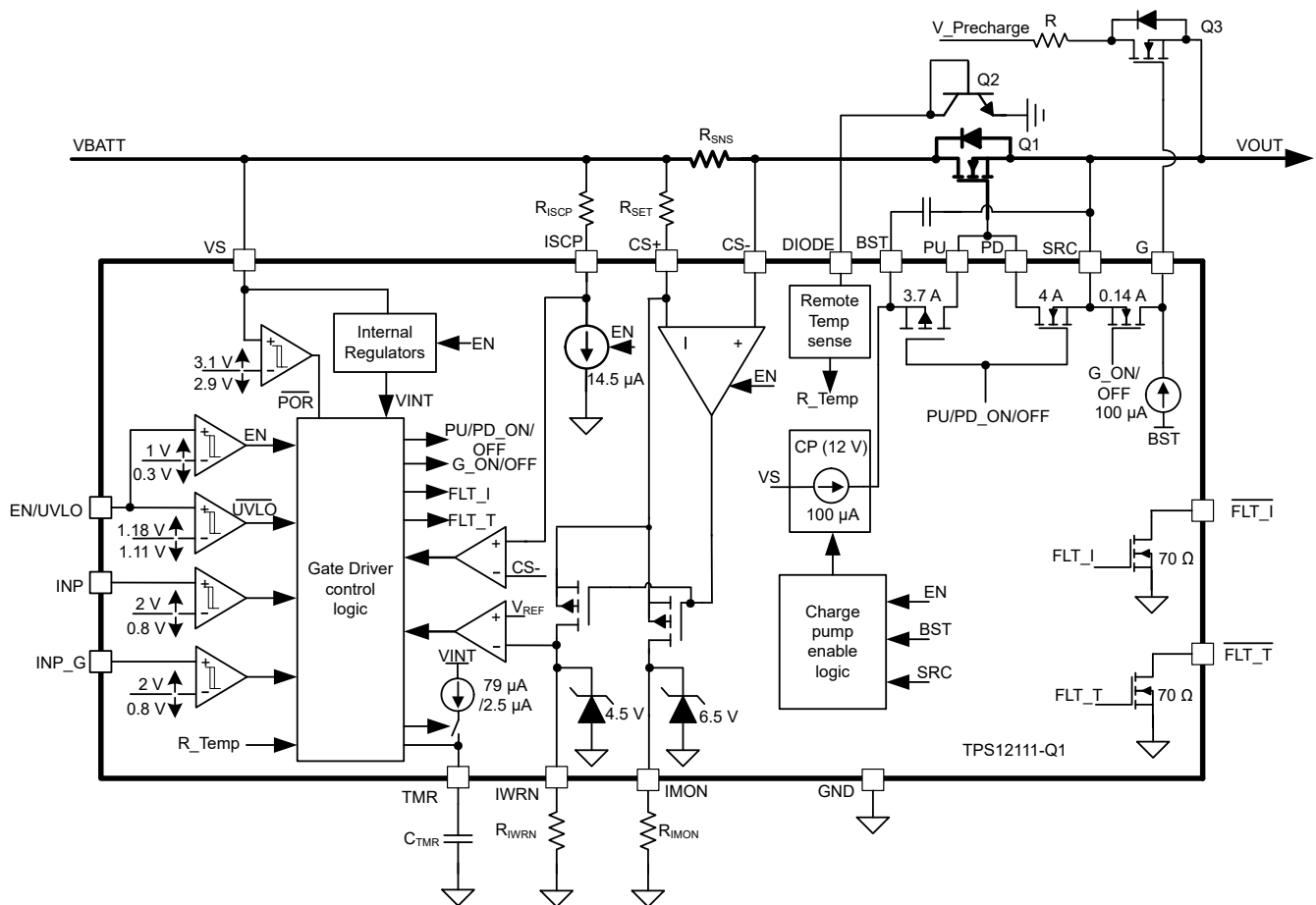


Figure 1-1. TPS12111-Q1 Functional Block Diagram

## 2 System Design Examples with Reverse Battery Protection

### 2.1 Design 1: Power Distribution Box

Figure 2-1 shows an example of power distribution box with two-channel outputs VOUT1 and VOUT2. Input power source can be from a battery or a DC-DC. A grouped input reverse battery protection scheme is implemented using LM74500-Q1 reverse polarity protection controller and an external MOSFET Q1.

The output of the LM74500-Q1 reverse battery protection stage is connected to the TPS12110-Q1 high side switch controllers. The TPS12110-Q1 ICs and the loads connected to the outputs gets protected from the input reverse battery condition by the LM74500-Q1 circuit. During input reverse battery condition the LM74500-Q1 controller pulls GATE to SOURCE and the MOSFET Q1 gets turned OFF disconnecting the input battery connection to the downstream TPS12110-Q1 ICs and the loads.

TPS12110-Q1 does not see reverse voltages and therefore does not need any special reverse protection techniques for this section of the system design.

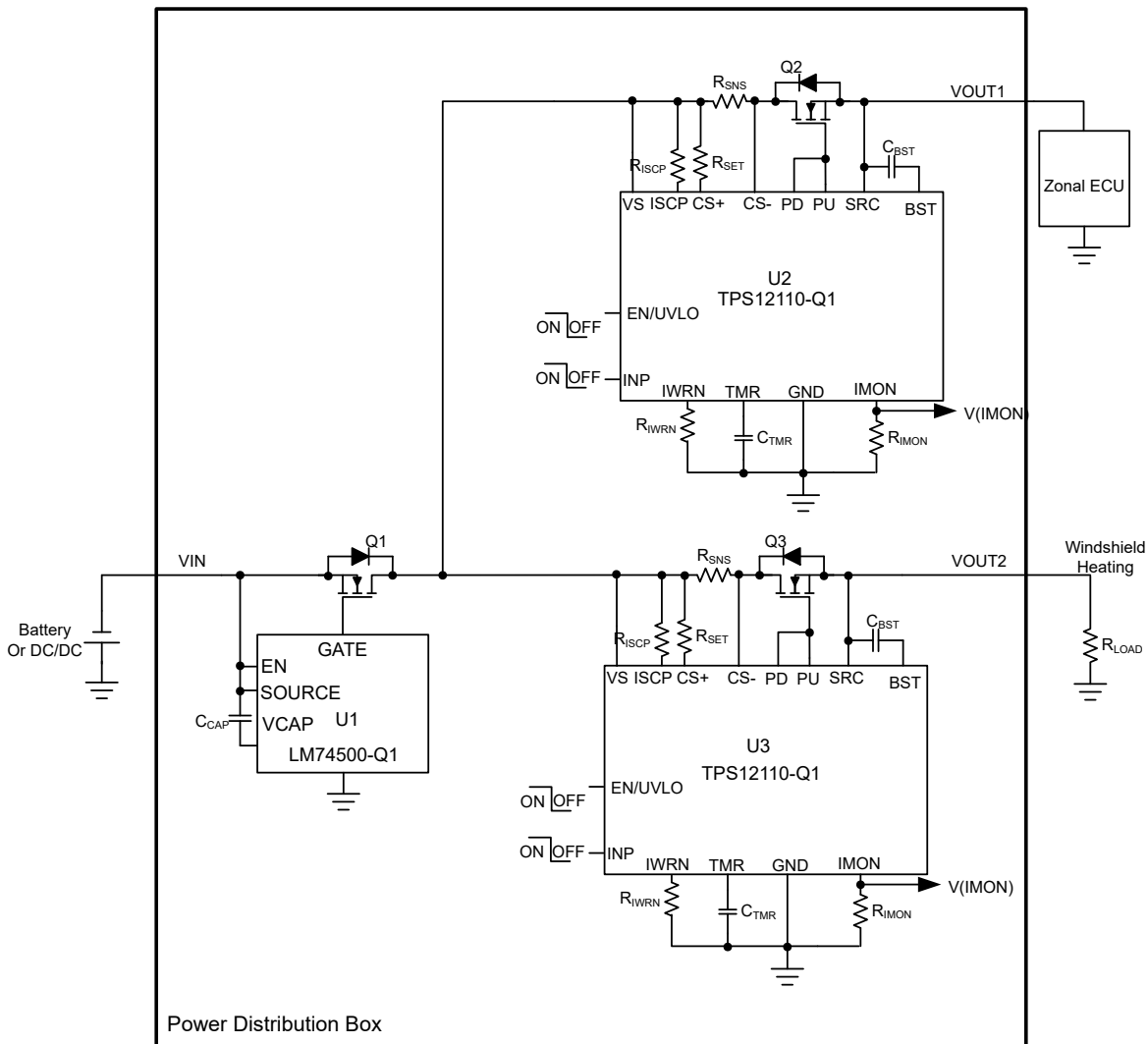
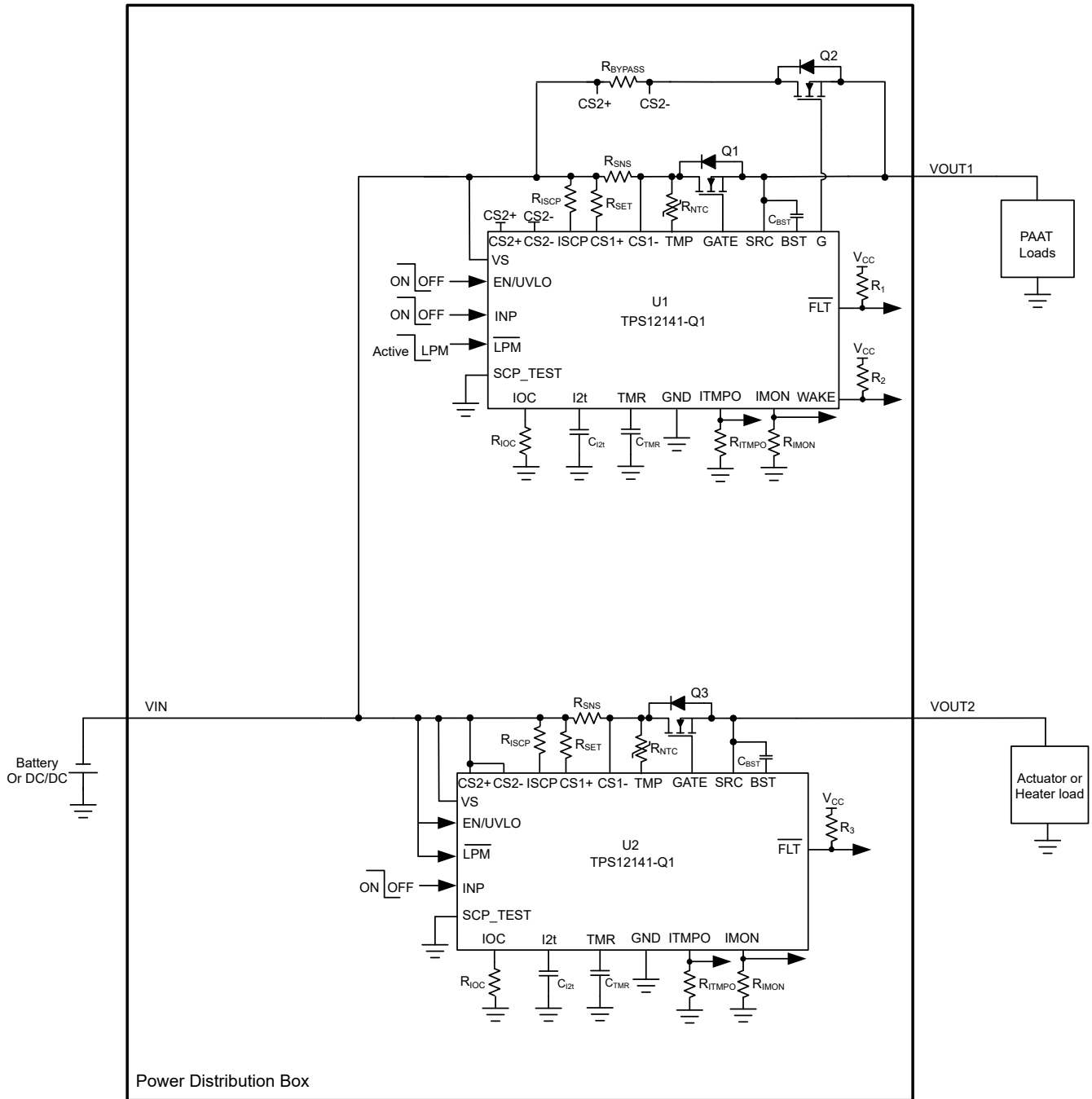


Figure 2-1. Power Distribution Box with Grouped Reverse Battery Protection Using LM74500-Q1 Controller

Figure 2-2 shows an example of a smartFuse based power distribution box system design without input reverse battery protection switch. VOUT1 is an always ON channel to drive power available all time (PAAT) loads such as door locks, power windows, wireless key system ECU, etc. VOUT2 is a switchable channel allowed to turn OFF during vehicle parking state. This channel can be used to drive actuator or heater loads.



**Figure 2-2. Power Distribution Box with Reverse Battery Protection using TPS12141-Q1 smartFuse controller**

In system architectures based on the load type the reverse battery, protection is done locally on the load side. However, loads such as heaters do not have any reverse battery protection and can result in reverse currents during reverse battery faults. In this scenario, turn on the MOSFETs to prevent damage due to excessive power dissipation due to body diode conduction. The TPS12141-Q1 from TPS1214-Q1 smartFuse controller family has integrated reverse battery protection with MOSFET turn ON feature. The other features of the TPS1214-Q1, such as low IQ LPM mode with automatic load wakeup functionality, adjustable I<sub>2T</sub> over current protection makes the device an excellent choice for smartFuse system design.

Figure 2-3 shows reverse battery protection performance of TPS12141-Q1 at -14V input. As shown, the MOSFET turns ON with a gate drive level of 12V.

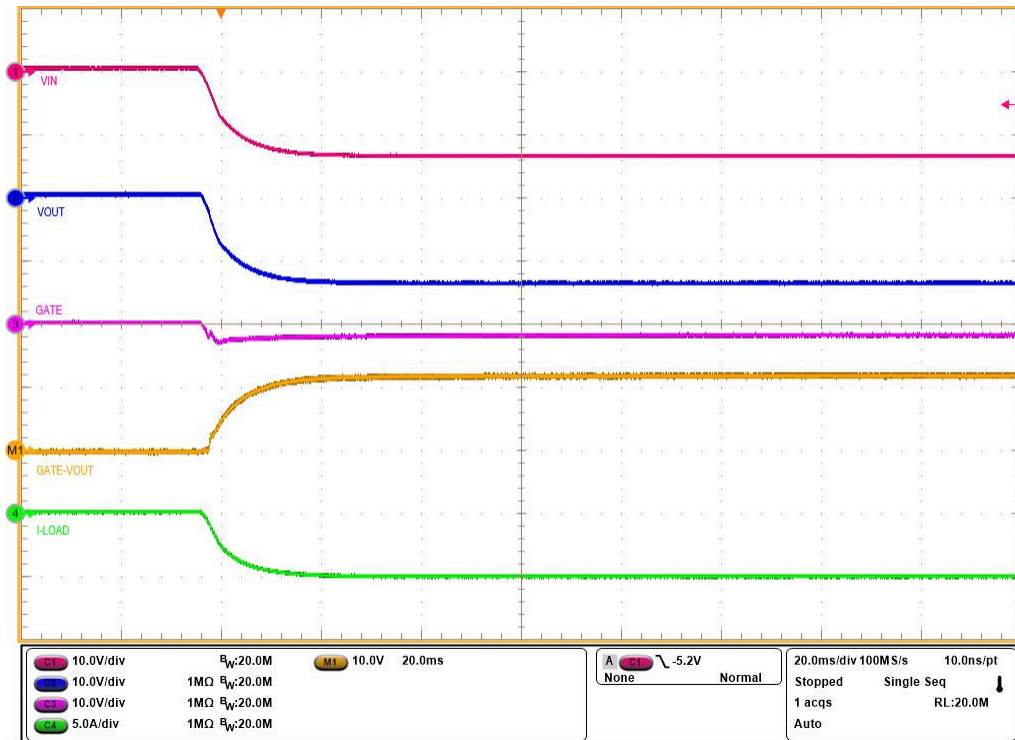


Figure 2-3. Performance Graph Showing Reverse Battery Protection with MOSFET ON with TPS12141-Q1 smartFuse controller

## 2.2 Design 2: Body Motors Load Driving

In automotive systems, loads like body motors, and so on can potentially deliver energy back to the input supply and can require a protection against reverse over current flow. Figure 2-4 shows the TPS12111-Q1 typical application circuit based on back to back MOSFETs (Q1 and Q2) to design a safety disconnect switch for body motor load.

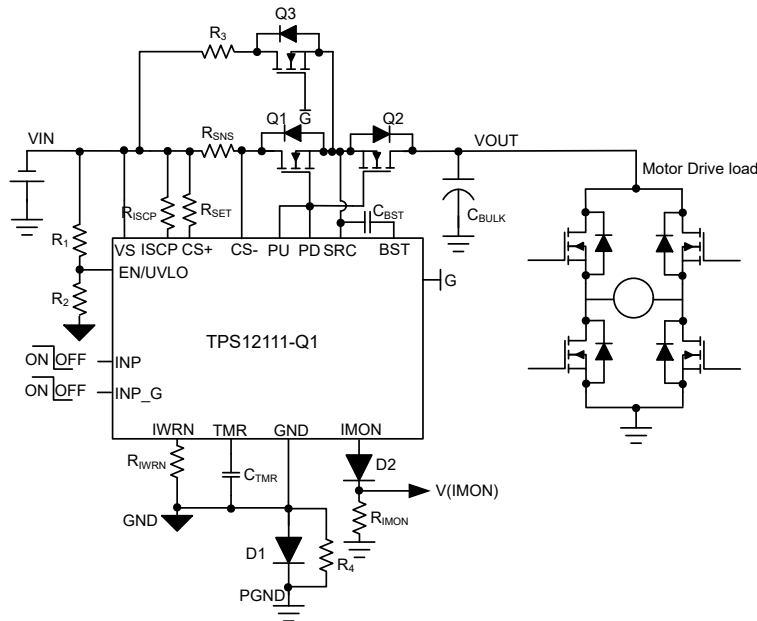


Figure 2-4. TPS12111-Q1 Application Schematic for Driving Motor Loads

The precharge resistor  $R_3$  and MOSFET Q3 forms a path for output capacitor  $C_{(BULK)}$  charging. The precharge path is commonly used in the system designs with parallel connection of the main FETs Q1 and Q2 in high current designs. Q1 MOSFET serves the purpose of load disconnection during system faults such as over current, short circuit and under voltage.

In the absence of MOSFET Q2, during input reverse battery condition there are very high reverse currents due to the closed circuit formed from PGND, the motor bridge MOSFETs, and MOSFET Q1. This high current is limited by the circuit parasitics and can damage the motor bridge, MOSFET Q1 and the PCB traces. Use the MOSFET Q2 to block the reverse current during this condition as the TPS12111-Q1 pulls PD to SRC keeping the Q2 in OFF state.

Diode D1 and resistor  $R_4$  are needed to protect the TPS12111-Q1 from reverse current injection during reverse battery condition. The diode D1 adds an offset voltage to the control input signals and also to the threshold setting for under voltage fault detection.

This offset voltage can be eliminated by replacing the D1 and R4 circuit with a disconnect switch Q4 as shown in Figure 2-5. D1 is a gate clamp Zener with a  $V_z$  below the  $V_{GS}$  abs max rating of Q4.

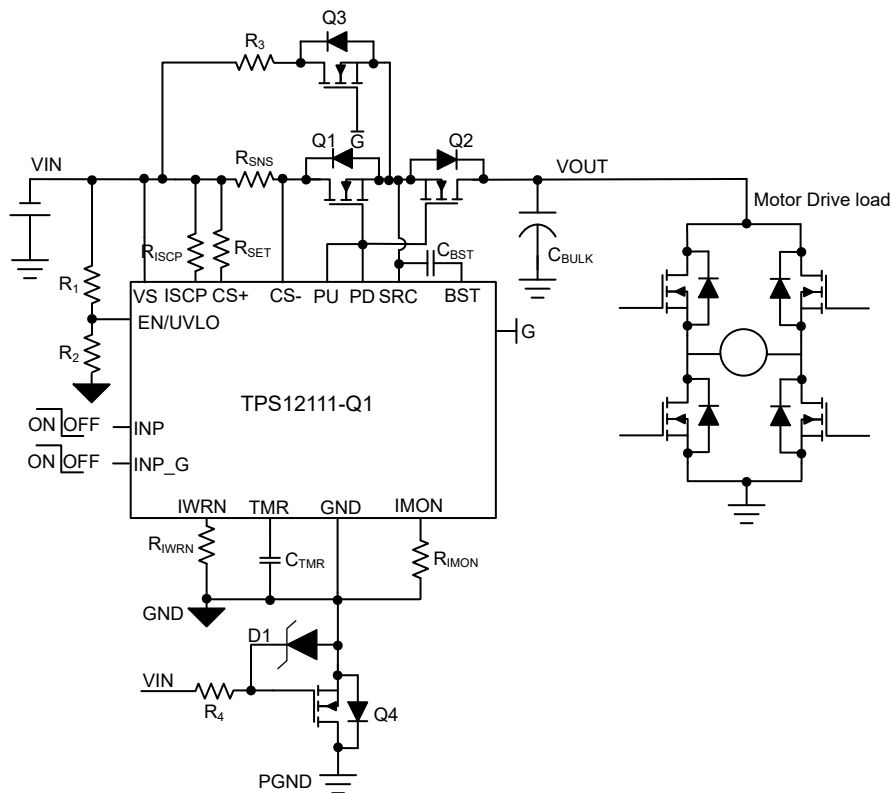


Figure 2-5. TPS12111-Q1 Application Schematic with MOSFET Based Ground Side Disconnect Switch

### 2.3 Design 3: Heater Load Driving

Resistive loads such as PTC heaters used for seat heating and windshield heating do not generate reverse currents unlike in the case of body motors and then there is no technical need to have back-to-back MOSFETs in the power switching path.

The following section describes the reverse battery protection techniques in the case of such loads.

#### 2.3.1 Reverse Battery Protection with MOSFET OFF

Figure 2-6 shows TPS12110-Q1 application circuit to drive heater loads. PWM signal can be applied to the INP pin for controlling the ON or OFF duration of the load.

Since there is no reverse blocking MOSFET in the power path, during the reverse battery condition there is reverse current flow from PGND, load, MOSFET Q1 body diode and to the battery as shown in the Figure 2-6.

In this condition, the MOSFET Q1 can see high-power dissipation and can damage due to excess heat and current stress on the body diode. Adding a reverse blocking MOSFET can be one technical design to avoid this stress and protect the MOSFET Q1. However, the blocking MOSFET characteristics like  $R_{DS(ON)}$ , current rating must be the same as a MOSFET Q1. This design results in double the cost of the power stage and increases the design size which is not acceptable in high-current system designs.

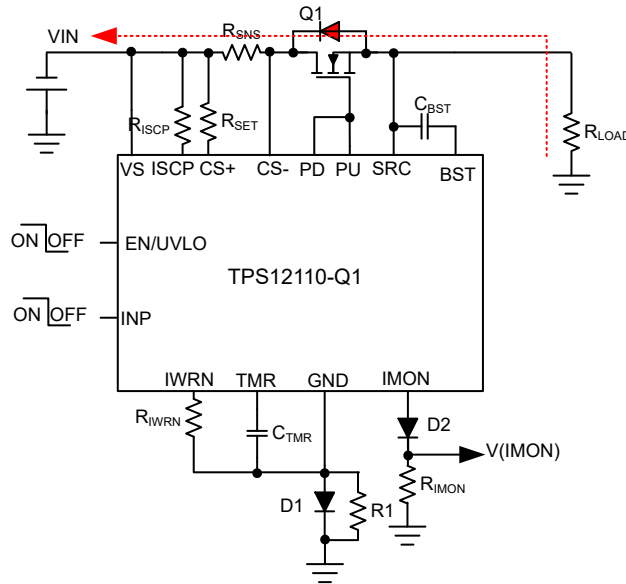


Figure 2-6. TPS12110-Q1 Application Schematic for Driving PTC Heater Load with MOSFET OFF During Reverse Battery Condition

### 2.3.2 Reverse Battery Protection with MOSFET ON

Turning the MOSFET Q1 ON during input, the reverse-battery condition address the challenges mentioned in Section 2.3.1. Figure 2-7 shows the TPS12110-Q1 application circuit to turn ON the MOSFET Q1 during reverse battery condition.

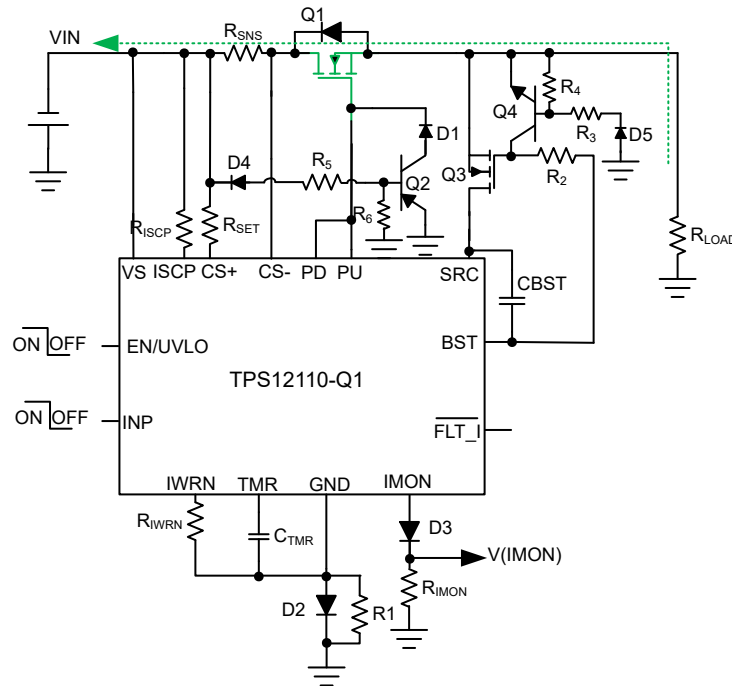


Figure 2-7. TPS12110-Q1 Application Schematic for Driving PTC Heater Load with MOSFET ON During Reverse Battery Condition

With the application circuit shown in Figure 2-7, the MOSFET Q1 can be turned on during input reverse battery condition. During input reverse battery condition, the source of the MOSFET Q1 follows the input reverse voltage. D5, R3, R4 path conducts during this condition and turns on Q4. This, then turns off Q3. Q3 is a signal N-FET to disconnect the source of the Q1 to device SRC pin during input reverse battery condition. R6, R5, D4 path conducts and turns ON Q2. The anode of the D1 gets connected to GND through Q2. GATE voltage of Q1 gets pulled to VF of D1 (-1V) and SOURCE terminal to negative VIN minus body diode drop of Q1 (-14V+1V = -13V). This results in VGS drive of -1V-(-13V) = 12V turning on the MOSFET Q1 and load current conducts through the MOSFET of the RDS(on) of the Q1.

The TPS1211-Q1 gets protected by disconnecting the GND with the help of D2. D3 is placed on the top side of the IMON resistor. With this placement, the IMON signal does not include the D3 voltage drop.

During the normal operation at positive VIN levels, Q2 and Q4 gets turned OFF. Q3 is turned on by the BST drive from TPS1211-Q1 connecting the source of the MOSFET Q1 to the SRC terminal of the TPS1211-Q1. Diode D1 gets disconnected from the GND.

Figure 2-8 shows the waveform of the above application circuit during the -14 V automotive reverse battery test. As shown, the MOSFET Q1 turns on as the gate to source is at approximately 12 V level during this test. The following bill of material components were used.

- D1, D2, D3, D4, D5 = BAS40H,115
- Q2 = MMBT3906WT1G
- Q3 = PMV60ENEAR
- Q4 = MMBT3904WT1G
- R1, R4, R6 = 10kΩ
- R2 = 100kΩ
- R3, R5 = 1kΩ

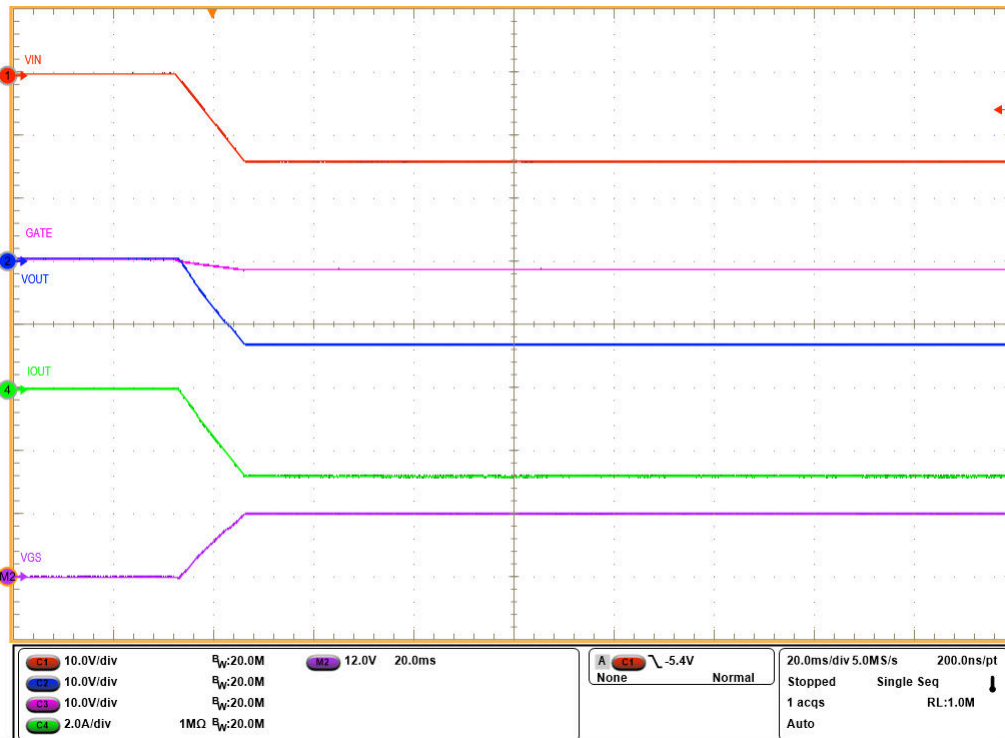


Figure 2-8. Performance Graph Showing Reverse Battery Protection with MOSFET ON



### 3 Summary

Based on the load type, the reverse battery protection can be implemented either with a back-to-back power switch or with a forward load switch topology. Various reverse battery protection system design examples are based on TPS1211-Q1 and TPS1214-Q1 High side switch controllers, as described in this application note, can be adopted based on the load type.

### 4 References

- Texas Instruments, [TPS1211-Q1 45V, Automotive, Smart High-Side Driver With Protection and Diagnostics](#), data sheet.
- Texas Instruments, [TPS1214-Q1, Automotive, Automotive, high-side switch controller with low-Iq, low power, load wakeup, I<sup>2</sup>t and diagnostics](#)Smart High-Side Driver With Protection and Diagnostics, data sheet.
- Texas Instruments, [LM74500-Q1 Reverse Polarity Protection Controller](#), data sheet.

### 5 Revision History

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

<b>Changes from Revision * (April 2023) to Revision A (November 2024)</b>	<b>Page</b>
• Added additional Power Distribution Box system design architecture based on TPS1214-Q1.....	3

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