Design Guide: TIDA-020094
48V Zone Reference Design

Description

This reference design demonstrates trends in advanced automotive 48V low voltage rail architectures. The design includes the 48V backbone architecture and 48V to 12V power conversion. The reference design highlights 48V load drivers across key products. These products include high side switches (HSS) and controllers (HSSC), smart eFuses, and motor drivers (MD).

Resources

TIDA-020094	Design Folder
TPS1212-Q1, TPS1214-Q1	Product Folders
TPS1HTC30-Q1, TPS482H85-Q1	Product Folders
TPS1211-Q1, TPS2HCS10-Q1	Product Folders
TPS4HC120-Q1, DRV8245-Q1	Product Folders
DRV8263-Q1, DRV8363-Q1	Product Folders
TPLD1201-Q1, TXE8124-Q1	Product Folders
LM68645-Q1, LM74900-Q1	Product Folders

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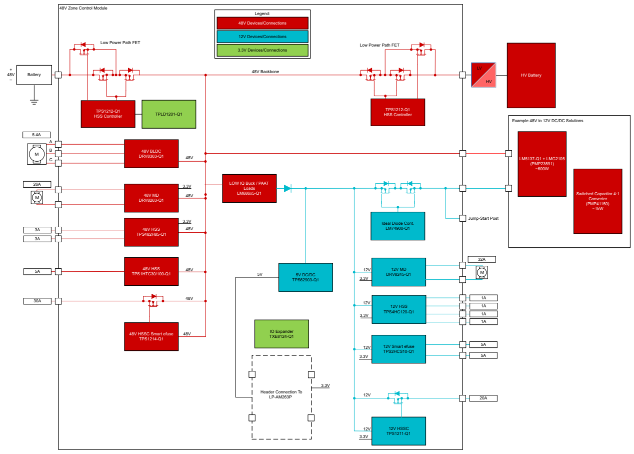
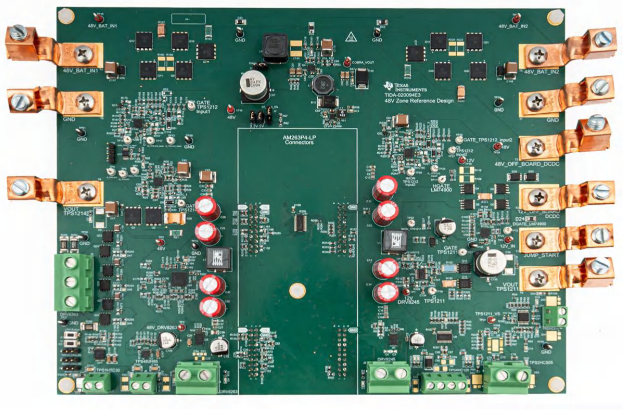
Features

- 48V backbone architecture with dual TPS1212-Q1 high-side switch controllers (HSSC)
- The board enables series connection of multiple 48V zone control modules to evaluate the backbone at a system level
- Separate connector evaluates various 48V to 12V power conversion topologies
- The design evaluates system-level considerations due to mixed supply voltages including 48V and 12V load driver short
- Easy-to-use graphical user interface (GUI) provides board evaluation

Applications

- Zone control module





1 System Description

As automakers adopt zone architecture and a 48V low voltage rail, the vehicle power distribution continues to evolve. Moving to a 48V low voltage rail significantly decreases current requirements in power distribution boxes. Traditional power distribution boxes become unnecessary, leading to backbone introduction. The backbone architecture connects each zone control module (ZCM) in series. This connection enables bidirectional power distribution across each ZCM. Traditional power distribution architecture uses power distribution boxes for primary power distribution. The ZCM handles secondary power distribution in traditional architectures. The backbone architecture enables the ZCM to perform both primary and secondary power distribution. The backbone architecture allows further consolidation of electronic control units (ECU). This approach reduces vehicle wiring.

The input supply moves to 48V, but the transition to full 48V takes time. The 12V rail remains necessary to supply power to legacy 12V loads. The power requirements of 12V loads dictate the type of 48V to 12V power conversion. Zone applications contain large numbers of 12V legacy loads. These loads create high power requirements in the range of 500W to 1kW. Power topologies under consideration include switched capacitor converter and switched tank converter. Additional topologies include inductor-inductor capacitor (LLC), buck-boost, and buck converters. Engineers compare these topologies for cost, size, ease of use, efficiency, and bidirectional functionality.

2 System Overview

2.1 Block Diagram

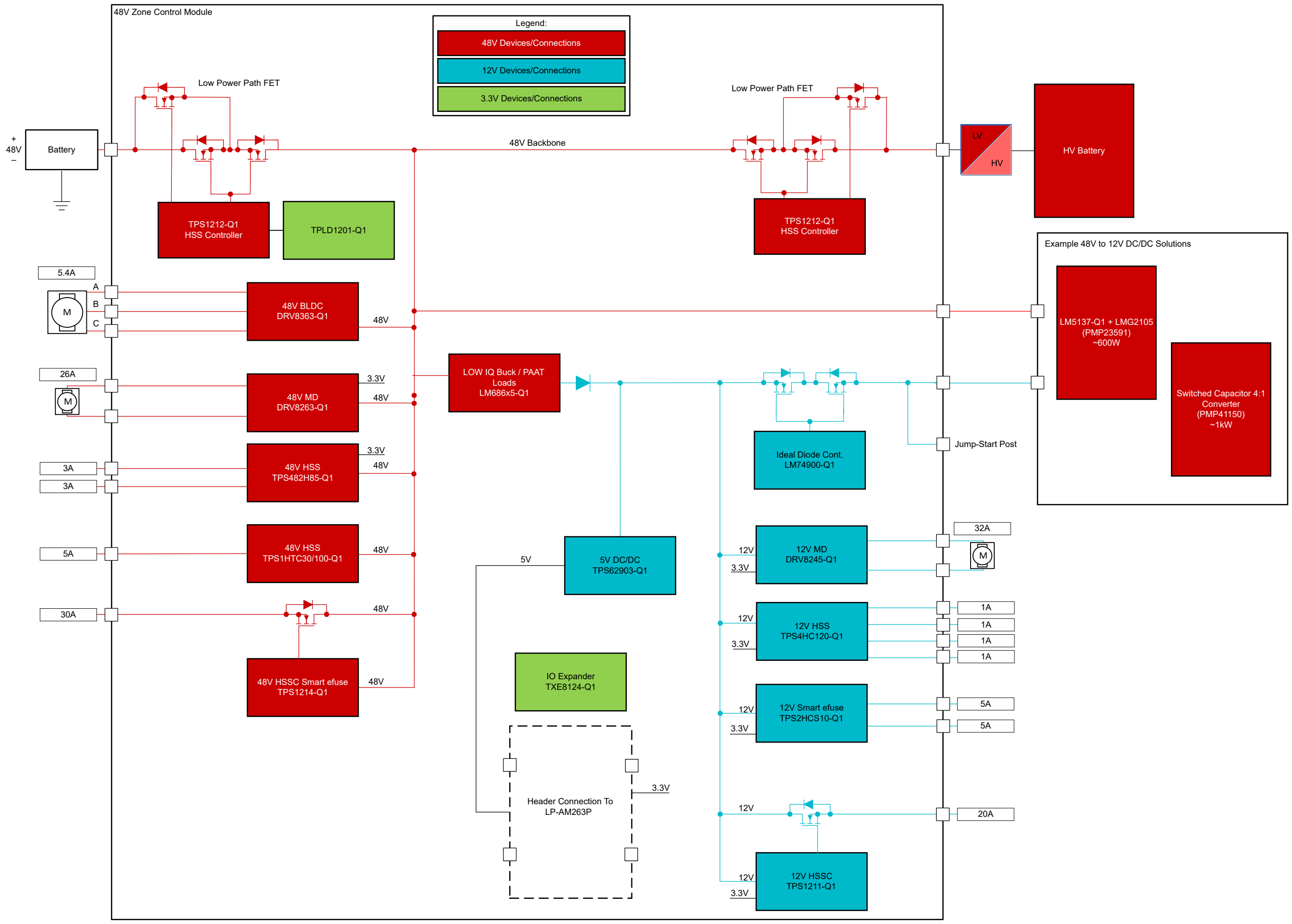


Figure 2-1. TIDA-020094 Block Diagram

2.2 Design Considerations

2.2.1 Backbone

The backbone removes the need for a traditional PDB by controlling power flow in a modular series connection format throughout each zone. Reduced current requirements and reduced thermals enable this backbone approach. The backbone approach performs both primary and secondary power distribution in each zone. See also Figure 2-2 to view backbone configuration in a zone architecture.

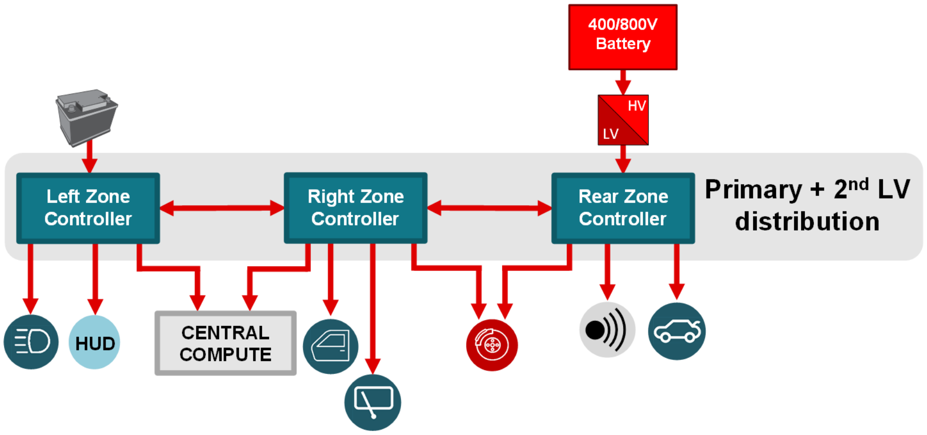


Figure 2-2. Backbone in Zone

Using a backbone approach brings forth many design considerations and challenges, which include:

1. The system maintains always-on power flow through each zone in active and park (LPM) mode
2. The system protects against overcurrent and short-circuit scenarios

This design implements the backbone using two TPS1212-Q1 HSSCs. Each TPS1212-Q1 device facilitates constant power flow through the zones. The device uses either the LPM path in a parked state or the main path in a running state. The TPS1212-Q1 devices provide automatic load wakeup from LPM to active state. The devices protect against short-to-ground scenarios at the inputs to each zone. The TPS1212-Q1 monitors current bidirectionally but can only protect from short-to-ground scenarios in the forward direction. Discrete logic with the TPLD1201-Q1 programmable logic device provides the reverse direction short-to-ground protection. This design enables the backbone to provide automatic load wakeup with the TPS1212-Q1 devices independent of the MCU. Figure 2-3 shows the overall architecture of the backbone in this design.

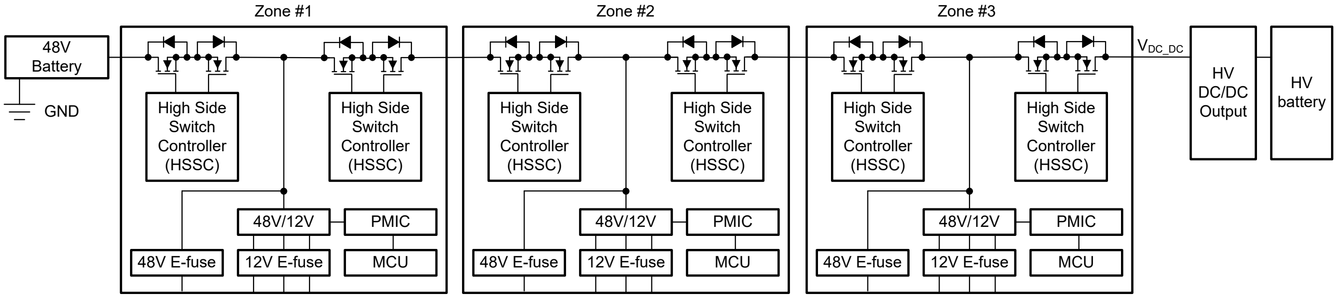


Figure 2-3. High-Level Backbone Configuration

Figure 2-4 shows a more detailed diagram of the backbone design for this board. Some key things to note about Figure 2-4 is the configuration directions of low power mode wake, SCP, and OCP I2t for each of the TPS1212-Q1 devices.

The TPS1212-Q1 on the left side of the zone (EVM 1) is configured for low power mode wakeup for current flowing left to right across the R_{BYPASS} resistor in the low power path. Due to the configuration of the low power mode wakeup, the SCP for this TPS1212-Q1 connects left to right as well, which does not provide the desired behavior. By implementing a TPLD1201-Q1 logic circuit, the backbone now allows for SCP in the reverse direction (right to left). The OCP I2t direction connects with respect to the CS1+ and CS1– pins, flowing from + (right) to – (left).

The TPS1212-Q1 on the right side of the zone (EVM 2) is configured for low power mode wakeup for current flowing left to right across the R_{BYPASS} resistor in the low power path. This configuration matches the other TPS1212-Q1 because in this design, it is assumed that a load wakeup event does not occur from the right side of the zone, since this side connects to the HV/LV DCDC that is only on in active state. This design assumed every load wakeup event originates from the left input. Due to the configuration of the low power mode wakeup, the SCP for this TPS1212-Q1 connects in the same direction, from left to right. No additional circuitry is required. The design configured OCP I2t from left to right with respect to the CS1+ and CS1– pins, flowing from + (left) to – (right).

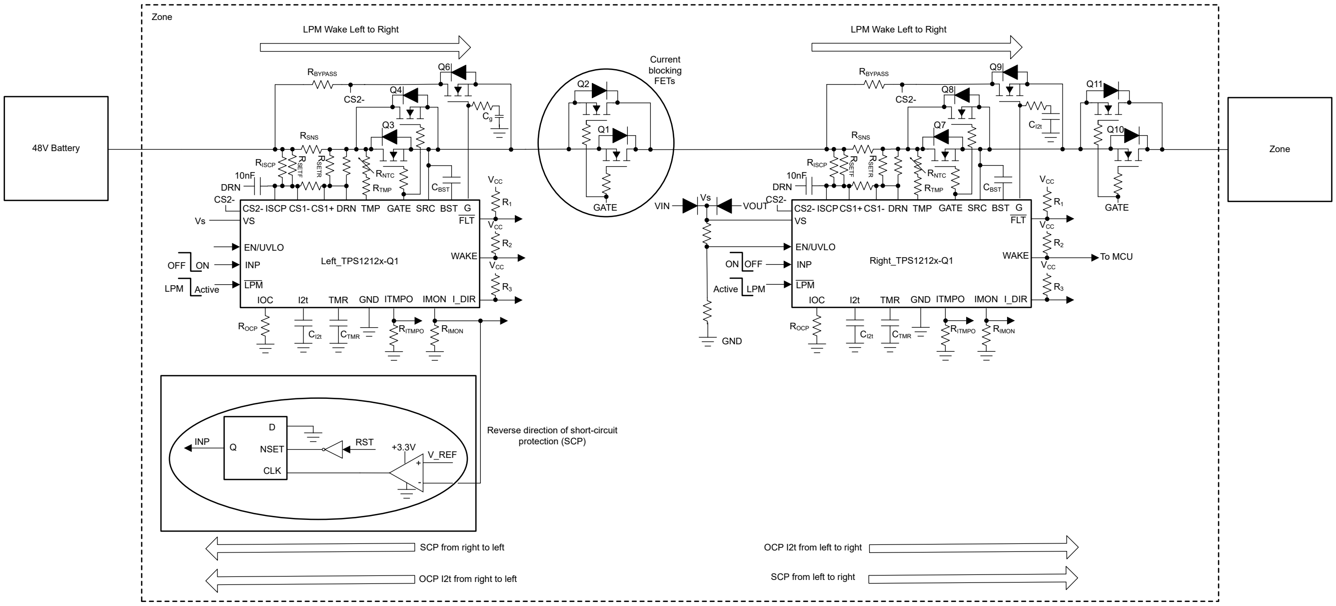


Figure 2-4. Backbone Design for TIDA-020094

See Section 3.4 for backbone test results.

2.2.2 TPLD1201-Q1 For Reverse ISCP Protection

Engineers implemented the reverse SCP protection for TPS1212-Q1 (EVM 1) using a TI Programmable Logic Device (TPLD), TPLD1201-Q1. The TPLD1201-Q1 consists of various ICs including those designed for combinational logic, sequential logic, and analog blocks. Figure 2-5 shows the TPLD circuit configuration for enabling reverse SCP.

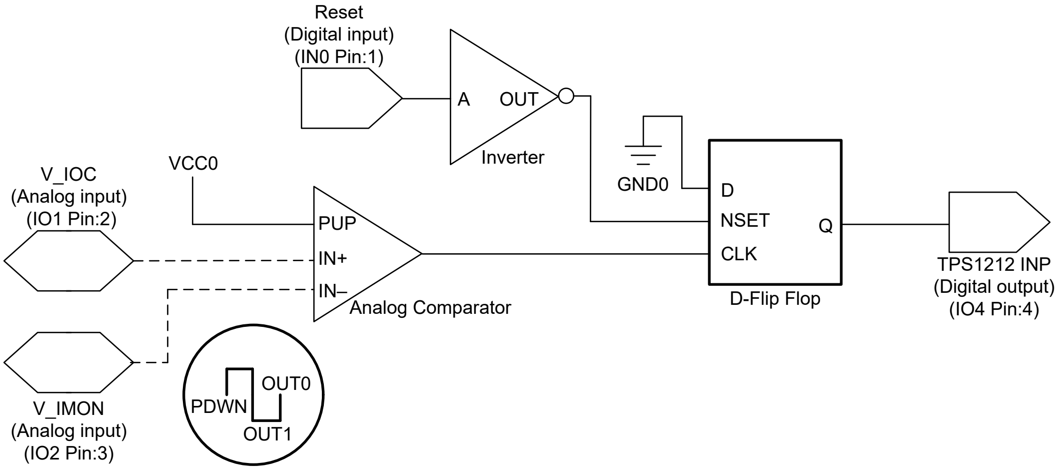


Figure 2-5. TPLD Reverse SCP for TPS1212-Q1 Implementation

This circuit compares the voltage at the TPS1212-Q1 current monitoring pin (IMON) to a set reference voltage (VIOC) that engineers calculate based on where the desired SCP point exists. While VIMON remains less than VIOC, the comparator outputs high, which does not clock the D-type flip-flop (DFF), so the output (INP) remains under MCU control. Once VIMON becomes greater than VIOC, the comparator outputs low, which clocks the DFF and latches the output INP to GND, shutting off the gate of the TPS1212-Q1. The DFF can only be reset through a high signal from the MCU to pin 0 on the TPLD. Table 2-1 shows the truth table logic for the analog comparator.

Table 2-1. TPLD1201-Q1 Analog Comparator Truth Table

VOLTAGE COMPARATOR	RESET	OUTPUT
VIMON < VIOC	0	1
VIMON < VIOC	1	1
VIMON > VIOC	0	0
VIMON >VIOC	1	1

The test parameters for this circuit follow:

- The system sets VIOC to 2.9V.
- VIMON operates as a sawtooth wave rising from 0V to 3.3V.
- While VIMON < VIOC output remains high.
- When VIMON > VIOC, output goes low and latches until Reset goes high.
- When Reset goes low again and VIMON > VIOC again, output latches low. The output remains latched due to the absence of a high reset signal.

Figure 2-6 shows the simulation results for this test.

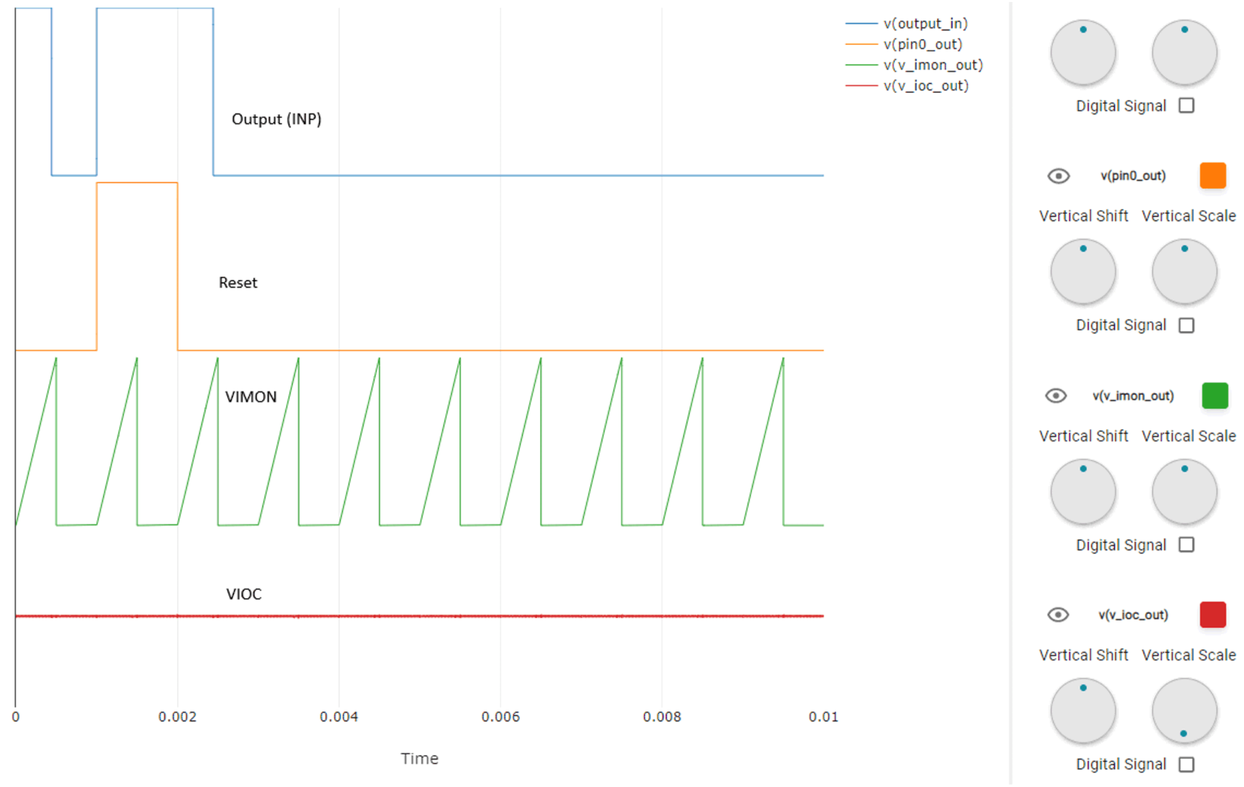


Figure 2-6. TPLD1201-Q1 Simulation Results

2.2.3 48V to 12V Conversion

The 12V rail must operate efficiently at high power during active state, and during a parked (low power) state. Challenges exist designing a converter that can meet high efficiency needs at both full load and light load. Engineers implemented the 12V low voltage rail through two DCDC converters in an *ORing* configuration. This ORing allows a dedicated 48V to 12V low power mode DCDC converter (typically less than 100W) to provide power during light load scenarios, and the other 48V to 12V high-power DCDC converter (typically 500W to 1kW) to provide power during high-power operation. To perform this ORing function, engineers set the 48V to 12V low power mode DCDC converter to output a voltage slightly lower than that of the 48V to 12V high-power

DCDC converter, so the device only provides power when in a parked state (since the disabled main DCDC operates at a lower potential than that low-power DCDC). To prevent current flow back into the unidirectional low-power DCDC, a series diode is required at the output of this DCDC. To prevent current flow back into the high-power DCDC, an ideal diode controller (LM74900-Q1) is required at the output of this DCDC.

This reference design uses the LM68645-Q1 set at approximately 9V, and designed to handle approximately 4A as the low power mode DCDC converter. This reference design allows for various high-power 48V to 12V topologies to connect to the board to validate the overall board function, and the performance of the different conversion topologies. This connection occurs through an off board 48V port, and a 12V input port connection. Figure 2-7 shows the power distribution structure for TIDA-020094, and some additional power blocks associated with a typical zone control module.

Figure 2-7 also shows the additional power components needed in first generation 48V zone control modules. A 48V to 12V functional safety (FuSa) DCDC is needed to supply 12V to a power management integrated circuit (PMIC) which then powers the microcontroller. The reference design does not implement these components, but mentions these components as key components found in the system.

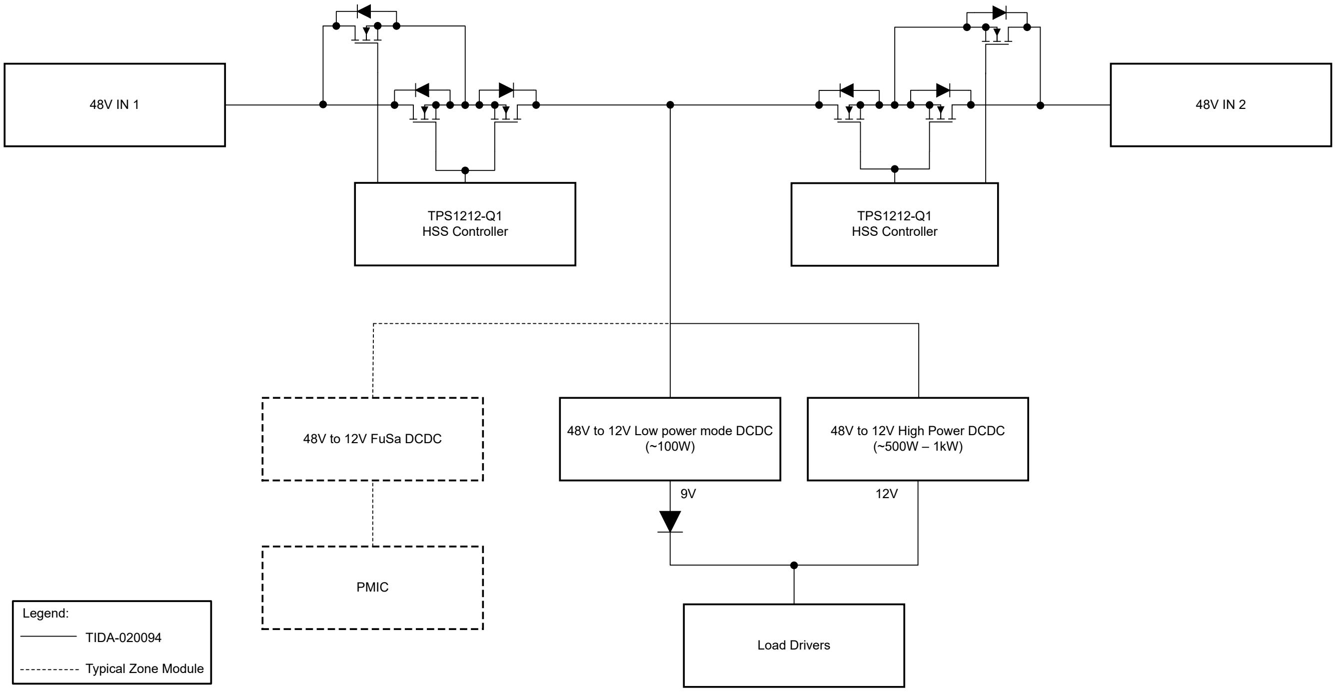


Figure 2-7. TIDA-020094 Power Distribution

Engineers can find other related power conversion designs and additional details here:

1. 20VIN to 60VIN, 600W, automotive two-phase buck converter with GaN switches reference design
2. TI Reference Designs Library

2.2.4 Jump Post

With the transition to a 48V battery system, the need to jump start the car battery becomes slightly more complicated. Since 48V does not provide a safe voltage for consumer interaction, jump starting must be done from a lower, safer voltage. Due to the significant number of legacy loads in vehicles that operate on a 12V rail, engineers can perform the jump starting from this rail. To perform this jump start from the 12V rail to the 48V battery, the jump post must work in combination with a bidirectional 48V to 12V DCDC or boost converter, that allows the jump start functionality to flow back to charge the 48V battery. Requirements for a jump post vary across auto makers, but the jump post generally appears only in one zone.

2.2.5 LP-AM263P

This reference design consists of GPIO and SPI controlled load drivers, and therefore does not need all the functionality of a typical MCU. The board connects to and remains compatible with the LP-AM263P by using BoosterPack™ Plug-in Module headers to gain access to a handle of GPIO and ADC pins, and a SPI bus. One challenge with zone architecture; however, involves the need for more GPIO than a typical MCU can handle. To meet these needs for this design, engineers included the TXE8124-Q1 SPI IO Expander on this board, and placed the device on the same SPI bus as the load drivers.

TIDA-020094 uses a 5V DCDC (TPS62903-Q1) to provide 5V to the LP-AM263P. The LP-AM263P uses this 5V to power the device, and converts this to 3.3V on the LP that powers all devices on TIDA-020094.

2.3 Highlighted Products

2.3.1 TPS1212-Q1 (48V)

TPS1212-Q1 is a low I_Q smart high-side driver with protection and diagnostics. The device has two integrated gate drives with 0.5A, 2A (GATE) and 100µA, 0.39A (G). With LPM low, the low power path is kept ON and the main FETs are turned OFF with I_Q of 20µA (typ). The auto load wakeup threshold is adjusted using R_{BYPASS} resistor placed across DRN and CS2–. I_Q reduces to 1µA (typ) with EN/UVLO low. The device has accurate bidirectional current sensing (±2%) output (IMON) with adjustable I2t based overcurrent and short-circuit protection using an external RSNS resistor and FLT indication. Auto-retry and latch-off fault behavior can be configured. The device also has NTC-based temperature sensing (TMP) and monitoring output (ITMPO) output for overtemperature detection of external FETs.

2.3.2 TPS1HTC30-Q1 (48V)

TPS1HTC30-Q1 is a single-channel, smart high-side switch, with integrated NMOS power FET and charge pump. The low R_{ON} (30 mΩ) minimizes device power dissipation driving a wide range of output load current up to 6A DC, and the 60V DC operating range improves system robustness. The device integrates protection features such as thermal shutdown, output clamp, and current limit. TPS1HTC30-Q1 implements an adjustable current limiting circuit that reduces inrush current when driving large capacitive loads and minimizing overload current. The device also provides an accurate load current sense that allows for improved load diagnostics such as overload and open-load detection enabling better predictive maintenance.

2.3.3 TPS482H85-Q1 (48V)

The TPS4H82H85-Q1 device is fully protected dual-channel smart high-side switch with two integrated 85mΩ NMOS power FETs. Protection and diagnostic features include accurate current sense, selectable current limit levels, OFF-state open-load and short-to-battery detection and thermal shutdown. High-accuracy current sensing provides a better real-time monitoring effect and more accurate diagnostics without further calibration. The external selectable-level high-accuracy current limit allows setting the current limit value by application. The device highly improves the reliability of the system by effectively clamping the inrush current under start-up or short-circuit conditions.

2.3.4 TPS1214-Q1 (48V)

TPS1214-Q1 is a low I_Q smart high side driver with protection and diagnostics. The device has two integrated gate drives with 0.5A source and 2A sink (GATE) and 100µA source and 0.39A sink (G). With LPM low, the low power path is kept ON and the main FETs are turned OFF with I_Q of 20µA (typ). Auto load wakeup threshold adjusted using R_{BYPASS} resistor placed across CS2+ and CS2–. I_Q reduces to 1µA (typ) with EN/UVLO low. The device has accurate current sensing (±2%) output (IMON) with adjustable I2t based overcurrent and short-circuit protection using an external RSNS resistor and FLT indication. Auto-retry and latch-off fault behavior can be configured. The device also has NTC based temperature sensing (TMP) and monitoring output (ITMPO) output for overtemperature detection of external FETs.

2.3.5 DRV8263-Q1 (48V)

The DRV8263-Q1 is a wide-voltage, high-power, fully integrated H-bridge driver. The device integrates an N-channel H-bridge, charge pump, high-side current sensing with regulation, current proportional output, and protection circuitry. The integrated sensing uses a current mirror, removing the need for shunt resistors, saving board area, and reducing system cost. A low-power sleep mode is provided to achieve low quiescent current. The device offers voltage monitoring and load diagnostics, as well as protection features against overcurrent and overtemperature. Fault conditions are indicated on the nFAULT pin. The device is available in two variants: HW interface and SPI. The SPI variant offers more flexibility in device configuration and fault observability.

2.3.6 DRV8363-Q1 (48V)

The DRV8363-Q1 is an integrated smart gate driver for 48V three-phase BLDC applications. The device provides three half-bridge gate drivers, each capable of driving high-side and low-side N-channel power MOSFETs. The DRV8363 generates the correct gate drive voltages using an external 12V supply and an integrated bootstrap diode for the high-side MOSFETs. A trickle charge pump allows for the gate drivers to support 100% PWM duty cycle control and provides overdrive gate drive voltage of external switches. The DRV8363 provides low-side current sense amplifiers to support resistor based low-side current sensing.

2.3.7 TPS2HCS10-Q1 (12V)

The TPS2HCS10-Q1 is an automotive, dual-channel, 10mΩ smart high-side switch with I2T wire protection, low I_Q mode, and SPI. This device supports an SPI-configurable capacitive charging mode for ECU loads in power distribution switch applications. This smart eFuse integrates a programmable fuse profile that turns off the switch under persistent overload conditions to reduce the overhead on the MCU.

2.3.8 TPS4HC120-Q1 (12V)

The TPS4HC120-Q1 is an automotive quad-channel, smart high-side switch, with integrated NMOS power FET and charge pump, designed to meet the requirements of 12V automotive battery systems. The low R_{ON} (120mΩ) minimizes the device power dissipation when driving a wide range of output load current up to 2A when all four channels are enabled or 2.5A when only one channel is enabled. The device integrates protection features such as thermal shutdown, output clamp, and current limit. These features improve system robustness during fault events such as short circuit. The TPS4HC120- Q1 implements a selectable current limiting circuit that improves the reliability of the system by reducing inrush current when driving large capacitive loads and minimizing overload current. The device offers 10 selectable current limit settings (0.25A to 5A) based on the external resistor used on the ILIM pin. The device also provides an accurate load current sense that allows for improved load diagnostics such as overload and open-load detection, which enables better predictive maintenance.

2.3.9 DRV8245-Q1 (12V)

The DRV824x-Q1 is a fully integrated H-bridge driver that can be configured as a single full-bridge driver or as two independent half-bridge drivers. This device provides an identical pin function with scalable R_{ON} (current capability) to support different loads. The devices integrate a N-channel H-bridge, charge pump regulator, high-side current sensing with regulation, current proportional output, and protection circuitry. A low-power sleep mode is provided to achieve low quiescent current. The devices offer voltage monitoring and load diagnostics as well as protection features against overcurrent and overtemperature. Fault conditions are indicated on nFAULT pin.

2.3.10 TPS1211-Q1 (12V)

The TPS1211-Q1 is a 45V, smart high-side driver with protection and diagnostics. 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. The device has accurate current sensing (±2% at 30mV) output (IMON) enabling system designs for energy management. The device has integrated two-level overcurrent protection with $\overline{\text{FLT\_I}}$ 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 $\overline{\text{FLT\_T}}$ output. The TPS12111-Q1 integrates a pre-charge driver (G) with control input (INP_G). This features enables designs that must drive large capacitive loads. In shutdown mode (EN/UVLO < 0.3V), the controller draws a total shutdown current of 0.9µA (typical).

2.3.11 TPLD1201-Q1

The TPLD1201-Q1 is part of the TI programmable logic device (TPLD) family of devices that feature versatile programmable logic ICs with combinational logic, sequential logic, and analog blocks. TPLD provides a fully integrated, low-power design to implement common system functions, such as timing delays, voltage monitors, system resets, power sequencers, I/O expanders, and more. This device features configurable I/O structures that extend compatibility within mixed-signal environments, reducing the number of discrete components required.

2.3.12 TXE8124-Q1

The TXE81XX-Q1 devices provide general purpose parallel I/O expansion for the four-wire serial peripheral interface (SPI) protocol and is designed for 1.65V to 5.5V V_{CC} operation. The device supports 10MHz from 3.3V to 5.5V and 5MHz from 1.65V to 5.5V. I/O expanders, such as the TXE81XX-Q1, provide a simple approach when additional I/Os are needed for switches, sensors, push-buttons, LEDs, and fans. The TXE81XX-Q1 devices have I/O ports, which include additional features designed to enhance the I/O performance in terms of speed, power consumption, and flexibility. The additional features include: enable and disable pullup and pulldown resistors, latchable inputs, maskable interrupt, interrupt status register, programmable open-drain or push-pull outputs, and a fail-safe register mode that the $\overline{\text{FAIL-SAFE}}$ pin enables.

3 Hardware, Software, Testing Requirements, and Test Results

3.1 Hardware Requirements

The following hardware is required to use the TIDA-020094:

1. TIDA-020094 reference design board
2. 48V power supply
3. LP-AM263P

3.2 Software Requirements

The TIDA-020094 GUI is required to use the TIDA-020094.

3.3 Test Setup

Use the following steps to set up the TIDA-020094 reference design:

1. Figure 3-1 shows the LP-AM263P placement on top of the TIDA-020094 board.

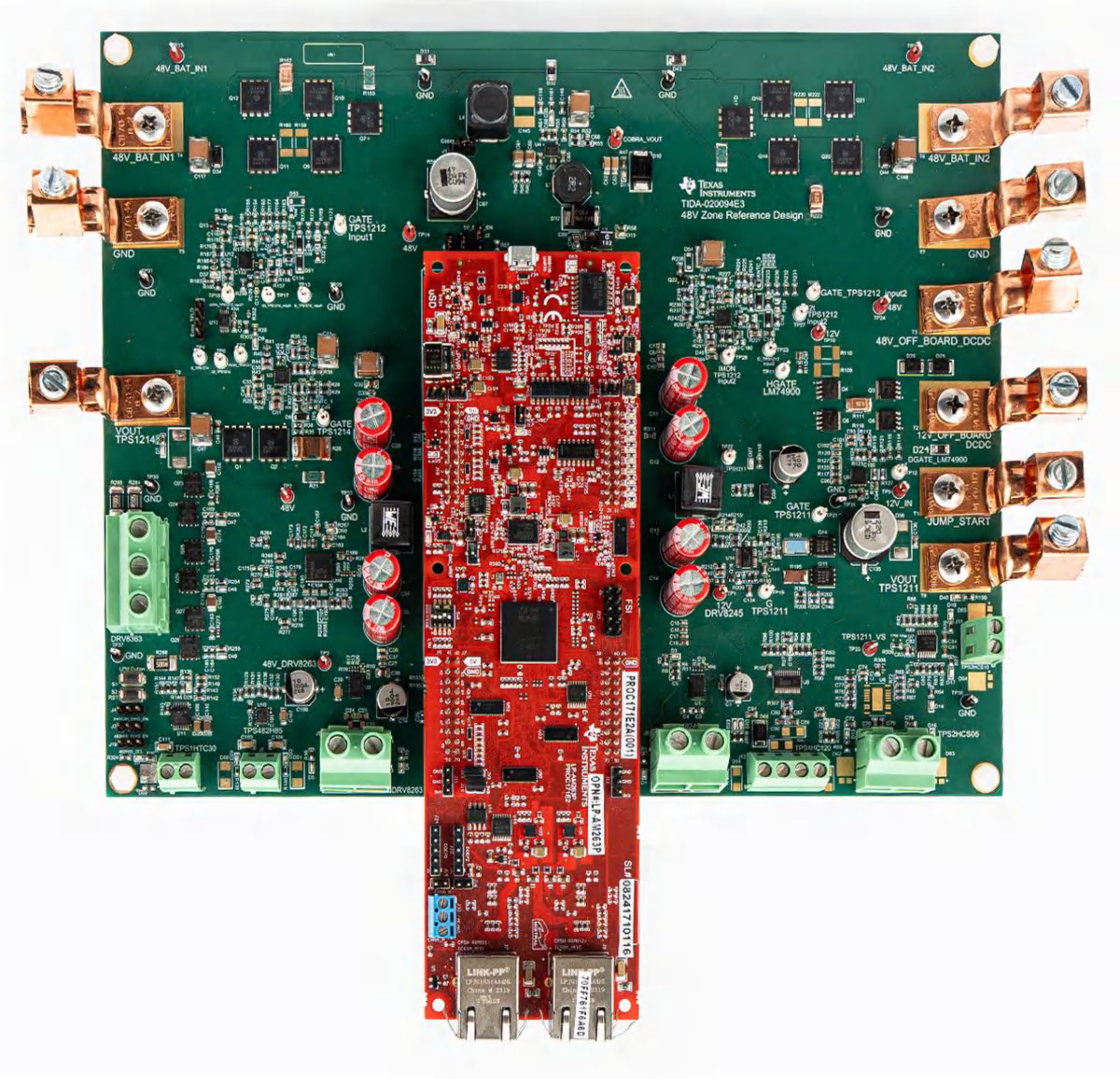


Figure 3-1. TIDA-020094 + LP-AM263P

2. Provide 48V into 48V_BAT_IN1
3. Run the GUI

3.4 Test Results

To verify proper functionality of the backbone, engineers performed key tests, including:

1. The first test performed verified the ability of the backbone to properly sense a load wakeup event and respond correctly. Figure 3-2 shows the gate pin of each TPS1212-Q1 device go high from 48V (LPM) to about 60V (active) when the devices detect an increase in output current.

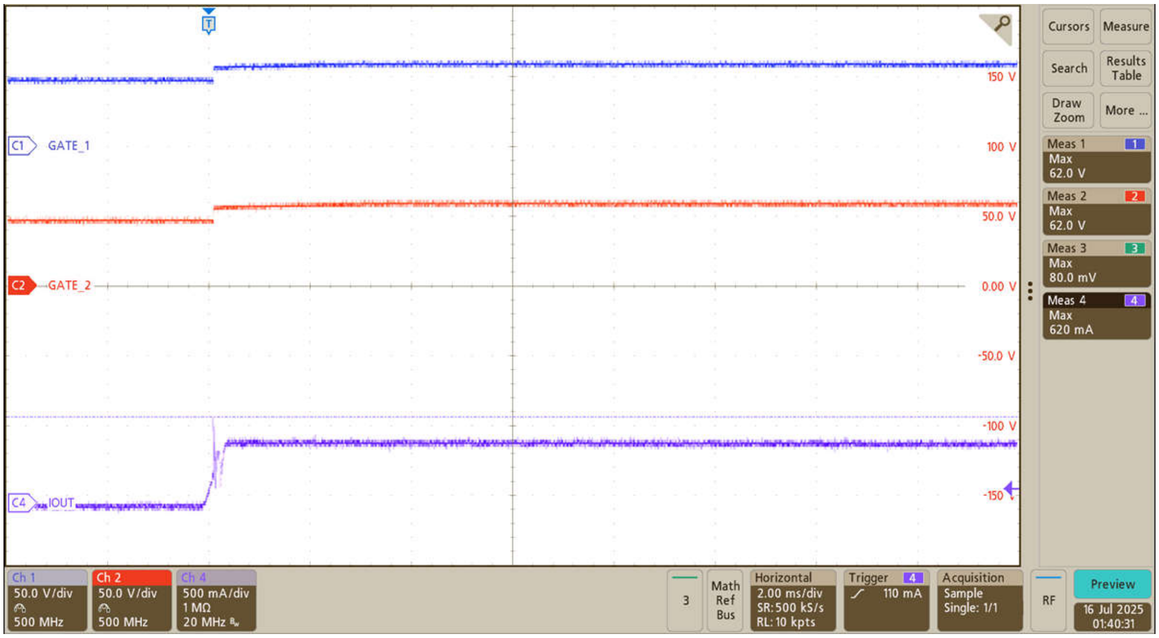


Figure 3-2. Backbone Load Wakeup Response

2. The second test performed verified the ability of the backbone to properly sense an SCP event on EVM 2 (forward direction) as well as an SCP event on EVM 1 (reverse direction) and respond correctly. Figure 3-3 shows the forward SCP event, where TPS1212-Q1_2 (EVM 2) shuts off when IOUT exceeds the ISCP threshold.

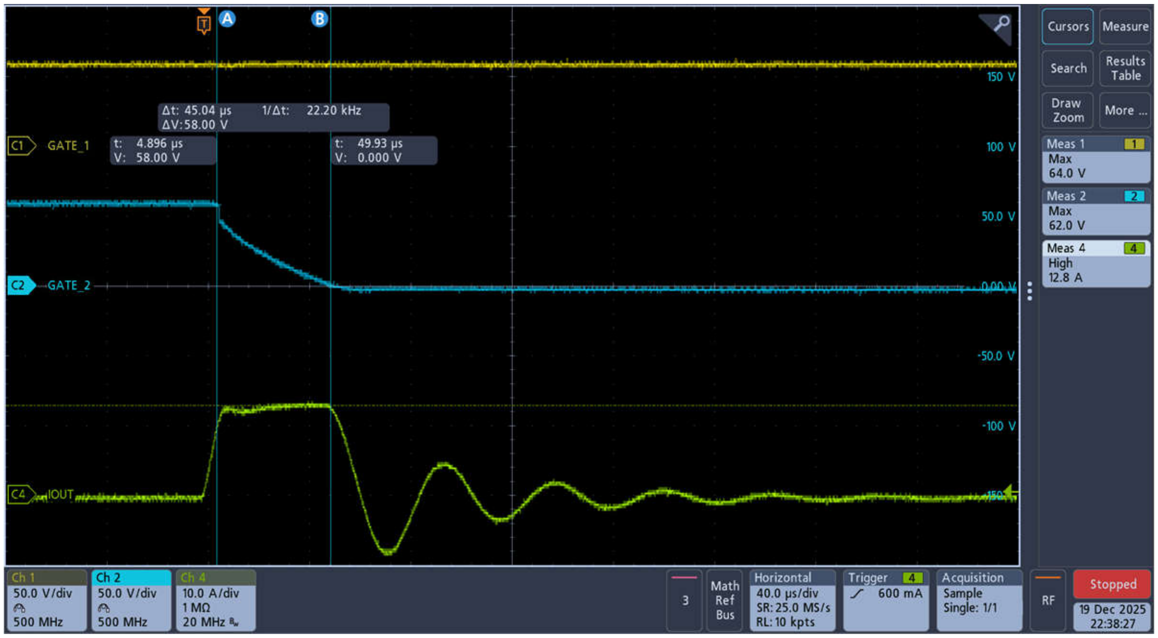


Figure 3-3. Forward SCP Protection

3. Figure 3-4 shows the reverse SCP event, where TPS1212-Q1_1 detects the reverse SCP event with the TPLD1201-Q1 (EVM 1) and shuts off when IOUT exceeds the ISCP threshold.

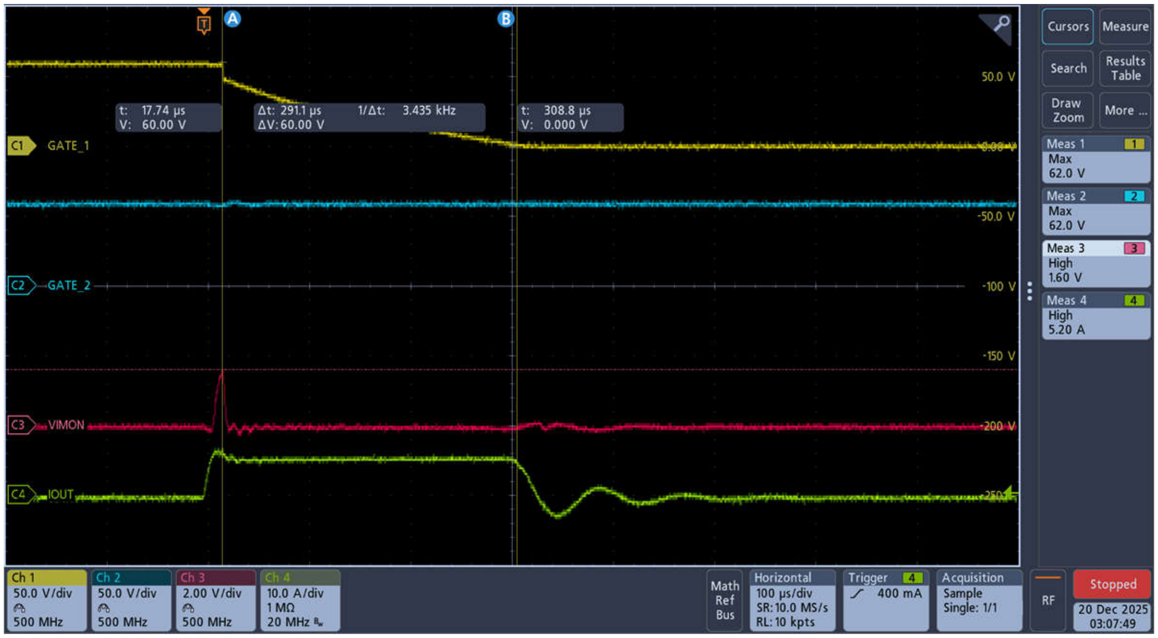


Figure 3-4. Reverse SCP Protection

4 Design and Documentation Support

4.1 Design Files

4.1.1 Schematics

To download the schematics, see the design files at TIDA-020094.

4.1.2 BOM

To download the bill of materials (BOM), see the design files at TIDA-020094.

4.2 Tools and Software

Tools

SYSCONFIG	System Configuration Tool

Software

MCU-PLUS-SDK-AM263PX	AM263Px software development kit (SDK) for Sitara™ microcontrollers

4.3 Documentation Support

1. Texas Instruments, *48V Automotive Systems: Why Now?*
2. Texas Instruments, *TIDA-020079 Zone reference design*
3. Texas Instruments, *TPS1212-Q1 Low I_Q Automotive High-Side Switch Controller With Bidirectional IMON, Low Power Mode, Load Wakeup, I2t, and Diagnostics Datasheet*
4. Texas Instruments, *TPS1214-Q1 Low I_Q Automotive High Side Switch Controller With Low Power Mode, Load Wakeup, I2 t, and Diagnostics Datasheet*
5. Texas Instruments, *TPS1HTC30-Q1, 30-mΩ, 6-A Single-Channel Automotive Smart High-Side Switch Datasheet*
6. Texas Instruments, *TPS482H85-Q1: 48V, 85mΩ Automotive Dual-Channel Smart High-Side Switch Datasheet*
7. Texas Instruments, *DRV8263-Q1 Automotive 65V H-Bridge Driver with Integrated Current Sense and Diagnostics Datasheet*
8. Texas Instruments, *DRV8363-Q1 48V Battery Three-Phase Smart Gate Driver with Accurate Current Sensing and Advanced Monitoring Datasheet*
9. Texas Instruments, *LM749x0-Q1 Automotive Ideal Diode With Circuit Breaker, Undervoltage, and Overvoltage Protection With Fault Output Datasheet*
10. Texas Instruments, *TPS2HCS10-Q1 11.3mΩ , Automotive Dual-Channel , SPI Controlled High-Side Switch With Integrated I2T Wire Protection and Low Power Mode Datasheet*
11. Texas Instruments, *TPS4HC120-Q1 120mΩ, 2A, Quad-Channel Automotive Smart High-Side Switch Datasheet*
12. Texas Instruments, *TPS1211-Q1 45V Automotive Smart High-Side Driver With Protection and Diagnostics Datasheet*
13. Texas Instruments, *DRV8245-Q1 Automotive H-Bridge Driver with Integrated Current Sense and Diagnostics Datasheet*
14. Texas Instruments, *TPS62903-Q1 3-V to 18-V, 3-A, Automotive Low I_Q Buck Converter with +165°C T_J Datasheet*
15. Texas Instruments, *LM686x5-Q1 High Performance, Functional Safety Power Converter, 3V to 70V , Pin-Compatible, 2.5A/3.5A/4.5A, Automotive , Low EMI, Synchronous Buck Converter Datasheet*
16. Texas Instruments, *AM263Px LaunchPad User Guide*
17. Texas Instruments, *TPLD1201-Q1 Automotive Programmable Logic Device with 8-GPIO Datasheet*
18. Texas Instruments, *TXE81XX-Q1 Automotive 16-Bit and 24-Bit SPI Bus I/O Expander with Interrupt Output, Reset Input, and I/O Configuration Registers Datasheet*

4.4 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.

4.5 Trademarks

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5 About the Author

MIGUEL ROBERTSON is an automotive systems engineer focusing on 48V, power switches and zone and body domain controllers. He has a BSEE from Rose-Hulman Institute of Technology.

6 Revision History

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

Changes from Revision * (November 2025) to Revision A (April 2026)	Page
• Updated backbone diagrams to reflect a broader backbone architecture for this design guide.........................	3

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