Application Brief

48V to 12V/5V Short Testing with TI Load Drivers

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Introduction

Automotive mixed supply systems consisting of 12V and 48V are vulnerable to rail-to-rail short circuit events. Figure 1 shows what such an event can look like from an ECU in the vehicle. During these events, a large amount of current will be pushed through the 12V rail, from the 48V rail. This causes a few problems:

1. A large current draw from the 48V rail
2. A voltage increase on the 12V rail
3. Energy surge in the reverse direction across the 12V/5V Load Driver

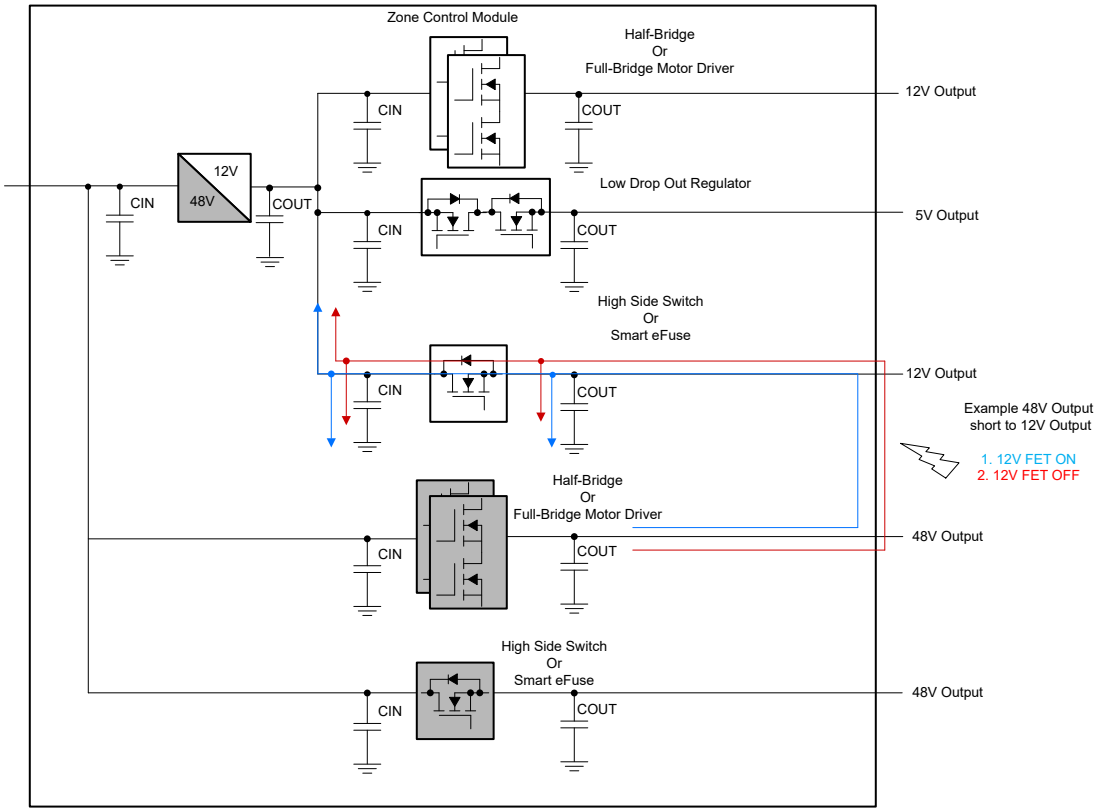


Figure 1. 48V -> 12V Short Overview Diagram

In Zone Control Module (ZCM) applications, many devices are vulnerable to these short events. Affected devices fall into two categories: *Inputs* and *Outputs*. This paper focuses on the following output (off-board load driver) device types:

1. Smart eFuses
2. High Side Switches (HSS)
3. Motor Drivers (MD)
4. Voltage-Tracking Low Dropout Regulators (LDOs)

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48V Load Driver Shutdown Behaviors

In any 48V to 12V/5V short, the safety of the lower voltage device relies on the ability of the 48V load driver to shutoff power. Therefore, it is important to consider the shutdown behavior of the 48V load driver, as this significantly impacts the survivability of downstream 12V and 5V devices. Two overcurrent protection behaviors are featured:

1. Immediate Shutdown: The FET turns off instantly when the short circuit current threshold is reached.
2. Current Regulation: The device regulates current and only turns off the FET upon reaching thermal shutdown (TSD).

Smart eFuses

The TPS2HCS08-Q1 was selected as the 12V smart eFuse device under test (DUT). Tests were conducted using both a 48V HSS (TPS1HTC30-Q1) and a 48V MD (DRV8163-Q1) as the 48V load driver, since their differing behavioral responses impact the survival of downstream 12V devices.

Figure 2 shows the first test setup, which uses the TPS1HTC30-Q1 for the 48V HSS and the TPS2HCS08-Q1 smart eFuse.

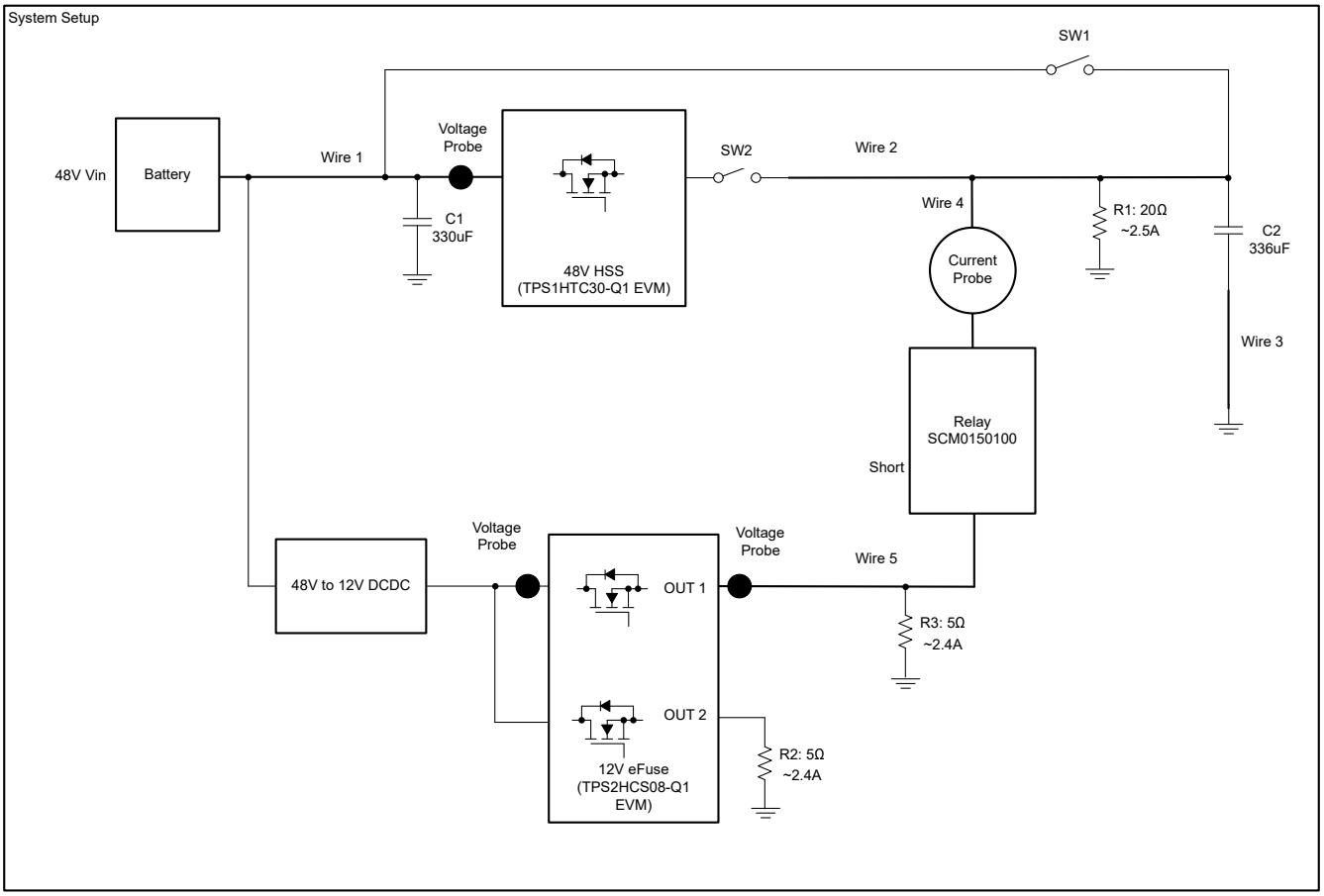


Figure 2. Test Setup with TPS2HCS08-Q1 and TPS1HTC30-Q1

See Test Procedure and Setup Parameters for the procedure followed.

Figure 3 and Figure 4 show test results.

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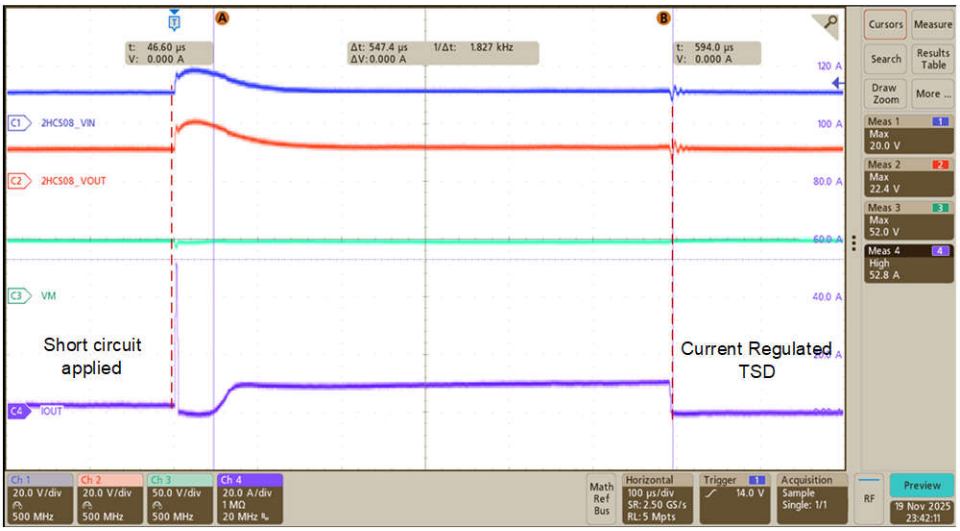


Figure 3. TPS2HCS08-Q1 FET On Short to TPS1HTC30-Q1

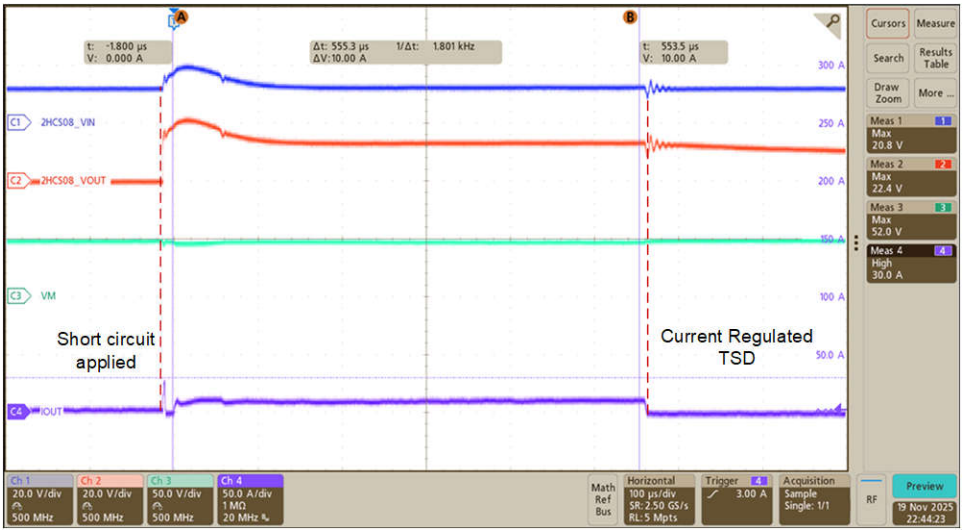


Figure 4. TPS2HCS08-Q1 FET Off Short to TPS1HTC30-Q1

Figure 3 and Figure 4 show the results of shorting the 12V eFuse output to the 48V HSS output, with the 12V eFuse FET initially ON (Figure 3) and initially OFF (Figure 4). Both results show a voltage rise on the input and output of the 12V eFuse channel, with the 48V input rail remaining stable. The short circuit current is consistent with the expected behavior documented in the TPS1HTC30-Q1 datasheet. No failures were observed across repeated tests.

Figure 5 shows the second test setup, which uses the DRV8163-Q1 for the 48V HSS and the TPS2HCS08-Q1 smart eFuse.

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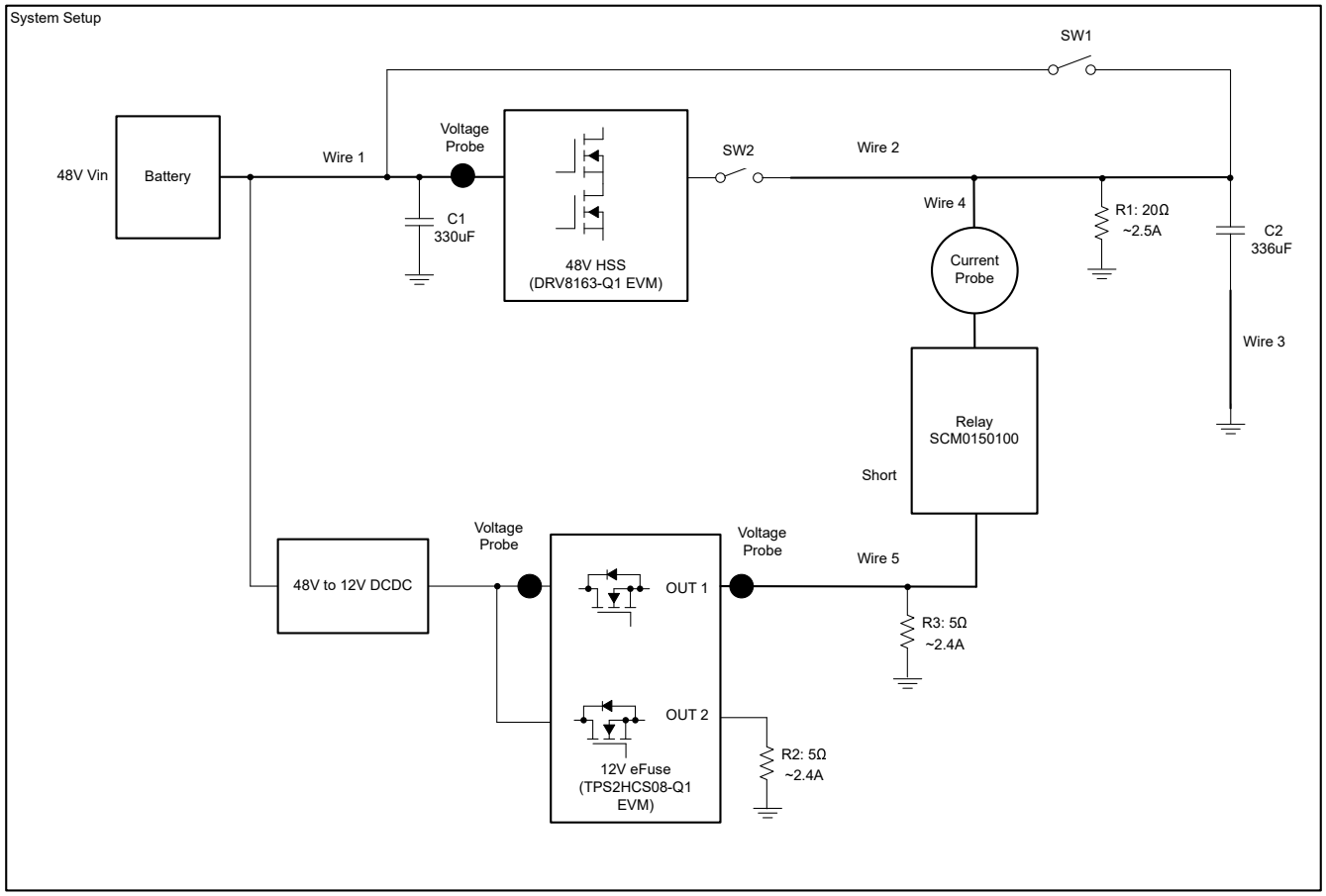


Figure 5. Test Setup with TPS2HCS08-Q1 and DRV8163-Q1

See Test Procedure and Setup Parameters for the procedure followed.

Figure 6 and Figure 7 show test results.

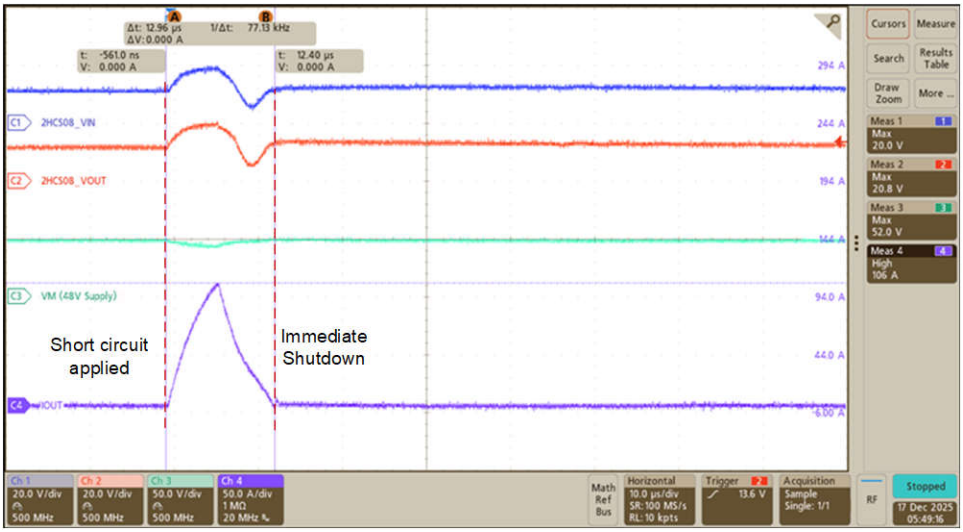


Figure 6. TPS2HCS08-Q1 FET On Short to DRV8163-Q1

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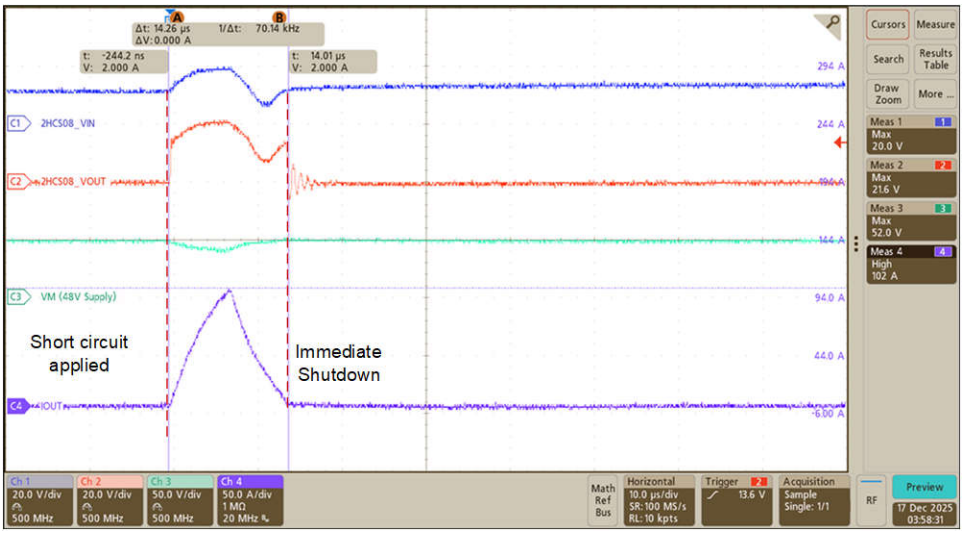


Figure 7. TPS2HCS08-Q1 FET Off Short to DRV8163-Q1

Figure 6 and Figure 7 show the results of shorting the 12V eFuse output to the 48V MD output — with the 12V eFuse FET initially ON (Figure 6) and initially OFF (Figure 7). Both results show a voltage rise on the input and output of the 12V eFuse channel, with the 48V battery rail remaining relatively stable. The short circuit current is consistent with the expected behavior of the DRV8163-Q1 at the configured short circuit threshold. No failures were observed across repeated tests.

Smart eFuse Test Summary:

No device damage was observed in any of the above tests. Based on these results, no additional protection circuitry is required for the 12V smart eFuse.

To conclude, wire inductance may affect motor drivers (or ICs with an immediate short circuit shutdown) more than HSS. Since V = Ldi/dt, and assuming V is constant, if L increases, then di/dt decreases. Thus, cable inductance can *widen* the area under the short circuit curve for these devices, which can affect the energy across the TPS2HCS08. Wire inductance seems to be less crucial for the HSS since these devices shutdown once they reach TSD (thermal shutdown). The energy across these HSS devices may differ, but so will the amount of time the devices see this energy. Ultimately the concern for the HSS is not inductance but more so the amount of capacitance, which determines how much energy is dumped across this device, which determines how long the device survives for.

High Side Switch (HSS)

The TPS4HC120-Q1 was selected as the 12V DUT. See Test Procedure and Setup Parameters for the procedure followed.

Figure 8 shows the first test setup, which uses the TPS1HTC30-Q1 for the 48V HSS and the TPS4HC120-Q1 HSS.

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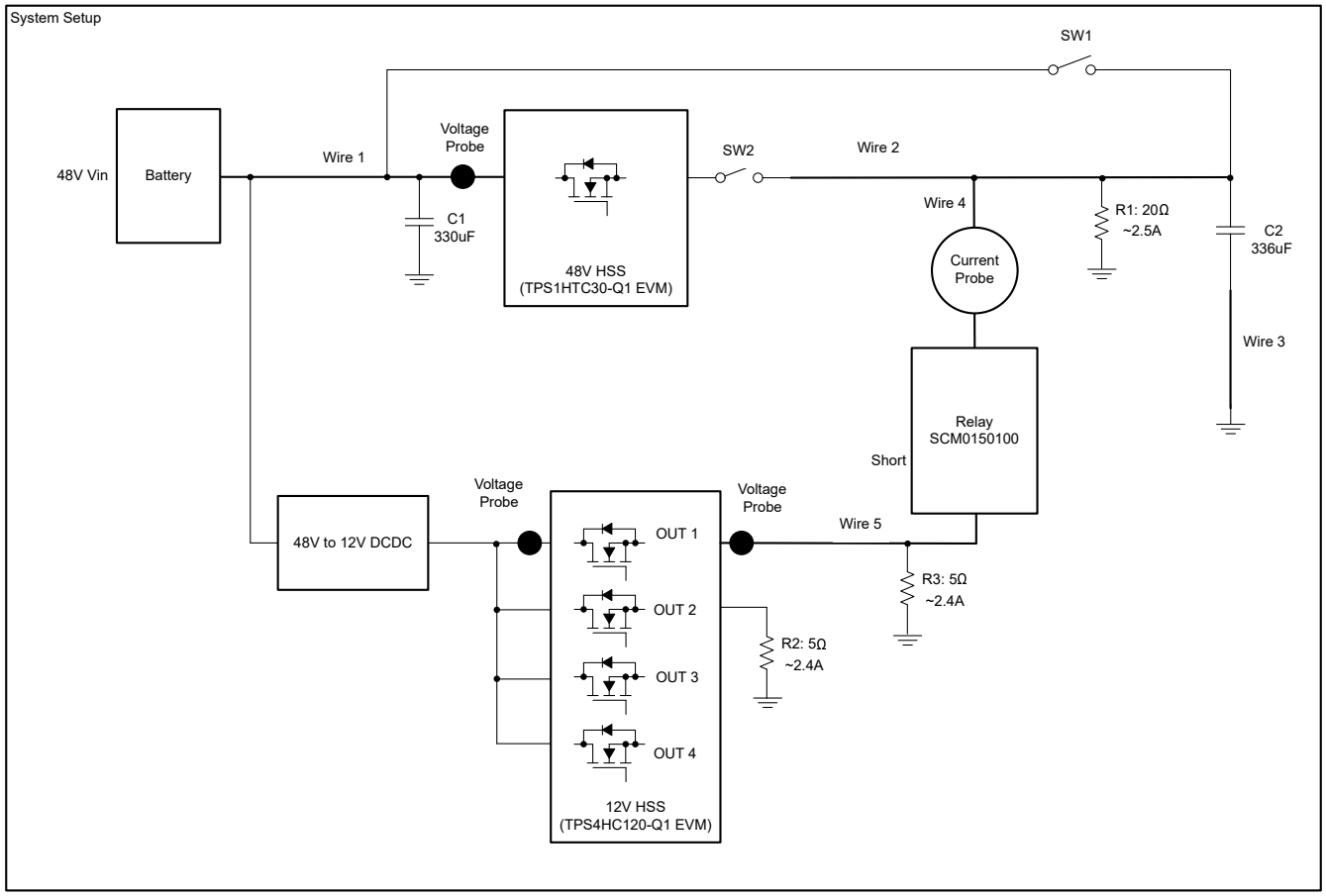


Figure 8. Test Setup with TPS4HC120-Q1 and TPS1HTC30-Q1

Figure 9 and Figure 10 shows test results.

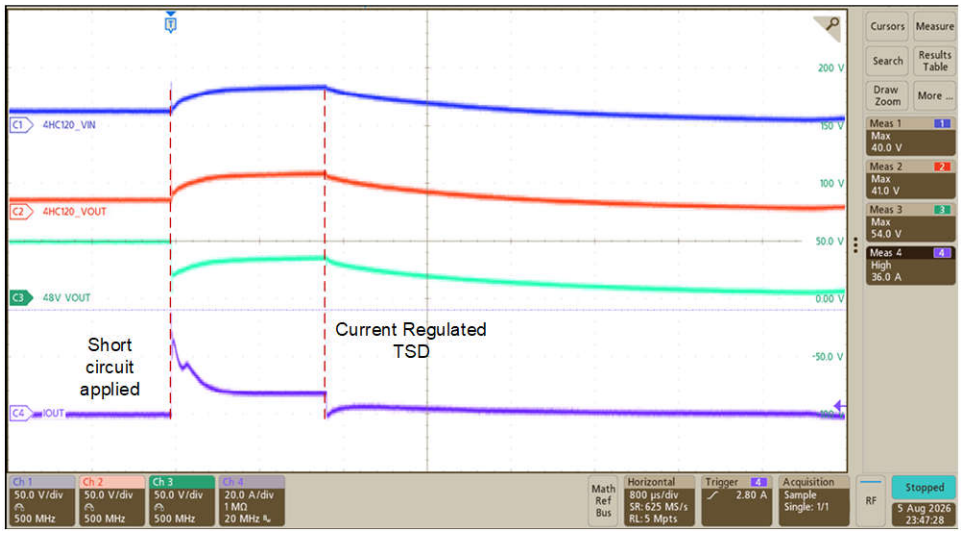


Figure 9. TPS4HC120-Q1 FET On Short to TPS1HTC30-Q1 (8A CL)

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Figure 10. TPS4HC120-Q1 FET On Short to TPS1HTC30-Q1 (16A CL)

Figure 11 shows the second test setup, which uses the DRV8163-Q1 for the 48V HSS and the TPS4HC120-Q1 HSS.

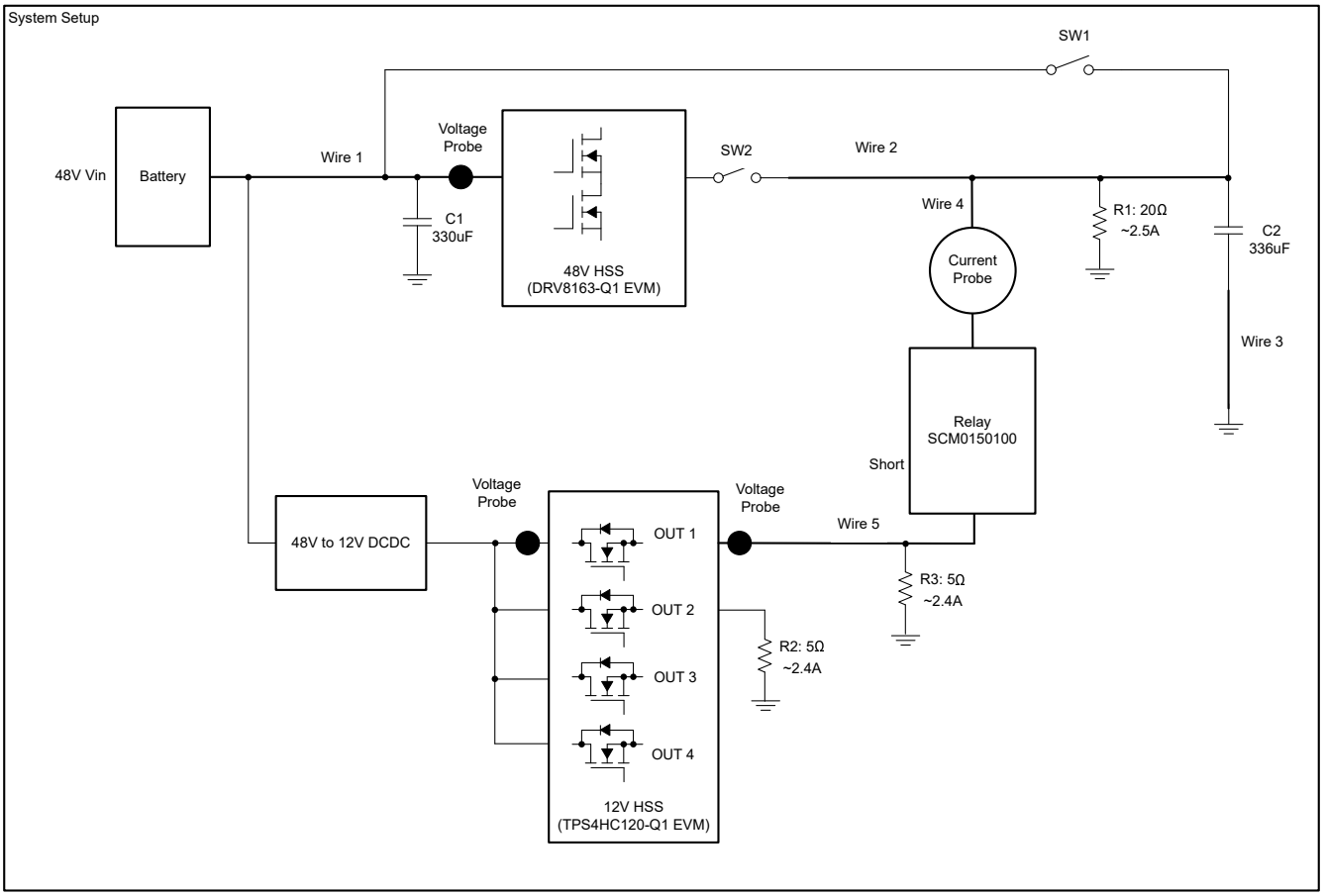


Figure 11. Test Setup with TPS4HC120-Q1 and DRV8163-Q1

Figure 12 shows test results.

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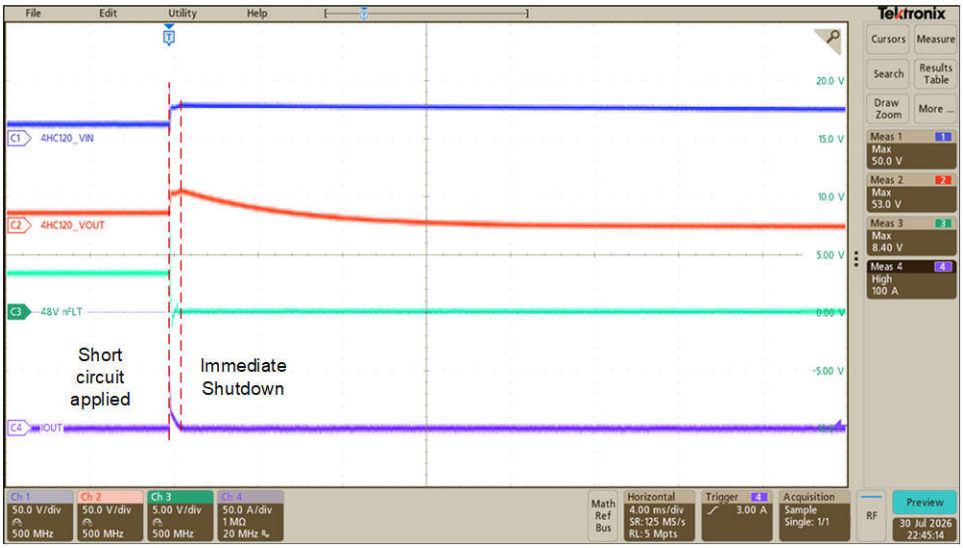


Figure 12. TPS4HC120-Q1 FET Short to DRV8163-Q1

HSS Test Summary

When shorting to the DRV8163-Q1, the short circuit protection (SCP) shuts off the output, protecting the downstream TPS4HC120-Q1. When shorting to the TPS1HTC30-Q1, the current limiting response does not make sure that current flow will be interrupted before damage occurs to the TPS4HC120-Q1.

Proposed Protection: Place a series input blocking diode on the HSS input to prevent reverse current from damaging the device.

Motor Drivers (MD)

The DRV8245-Q1 was selected as the 12V DUT. See Test Procedure and Setup Parameters for the procedure followed.

Figure 13 shows details the first test setup, which uses the TPS1HTC30-Q1 for the 48V HSS and the DRV8245-Q1 MD.

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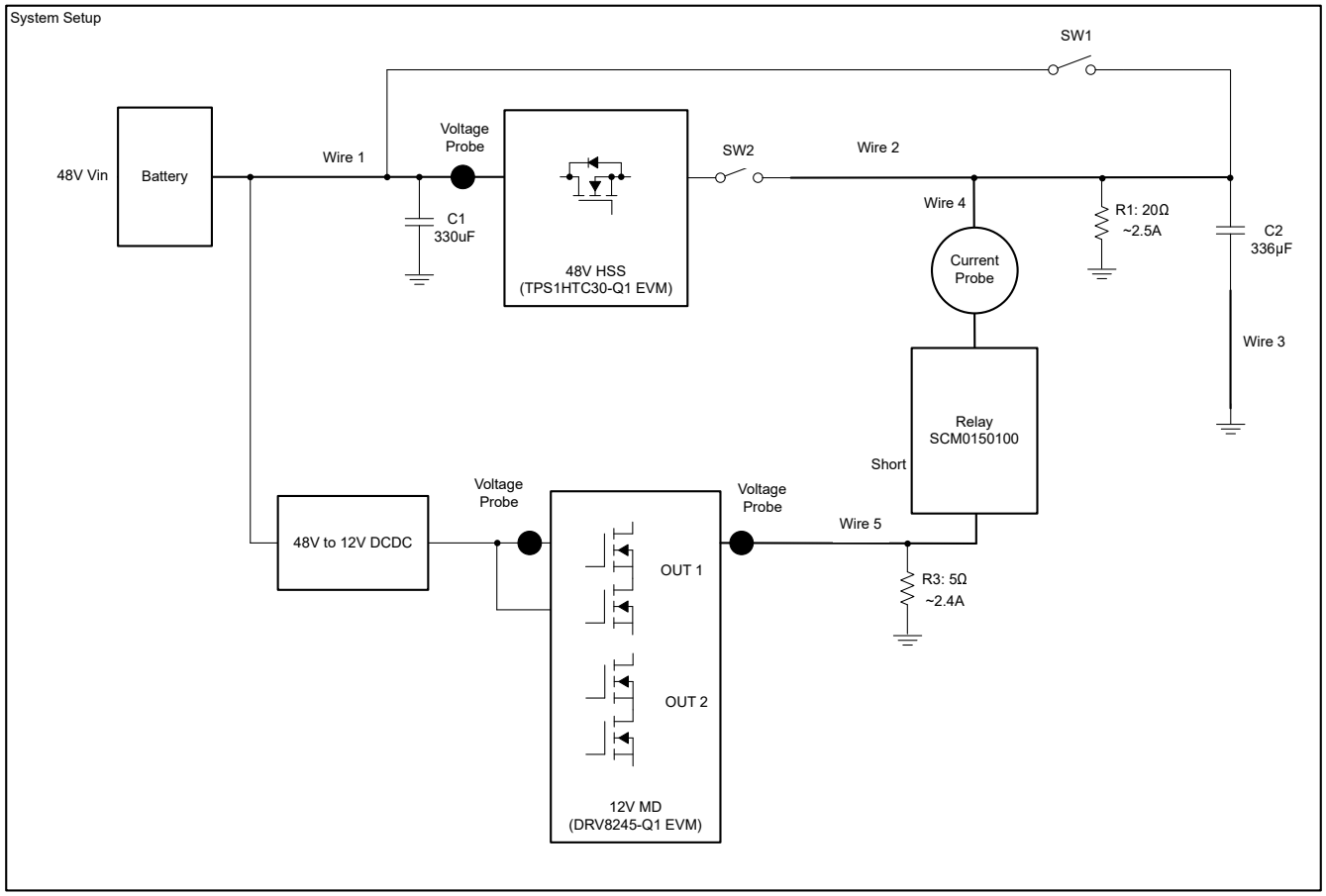


Figure 13. Test Setup with DRV8245-Q1 and TPS1HTC30-Q1

Figure 14 and Figure 15 show test results.

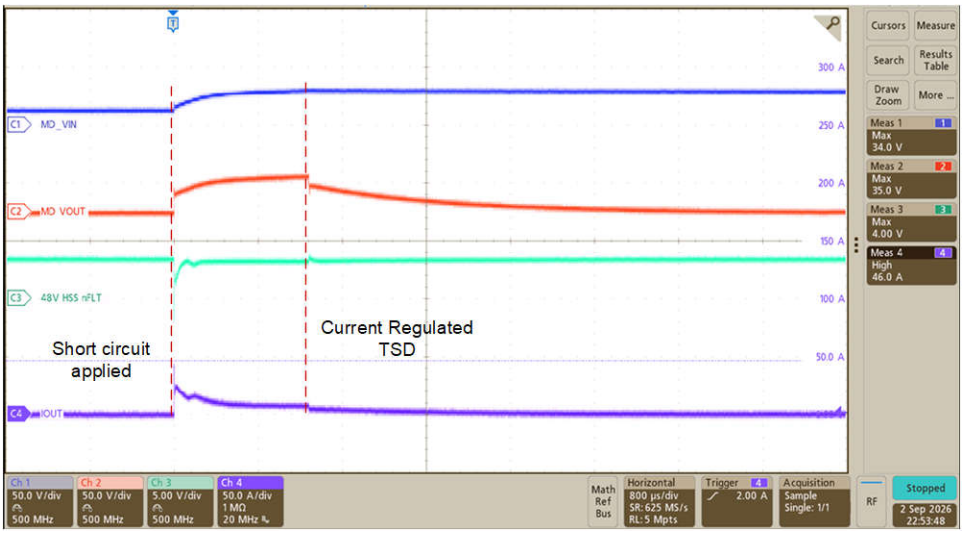


Figure 14. DRV8245-Q1 FET Short to TPS1HTC30-Q1 (8A CL)

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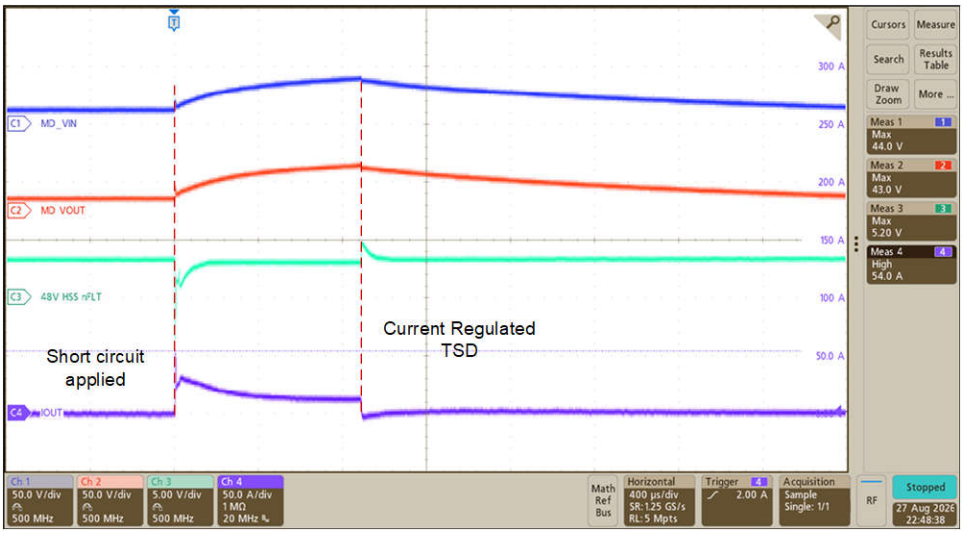


Figure 15. DRV8245-Q1 FET Short to TPS1HTC30-Q1 (16A CL)

Figure 16 shows the second test setup, which uses the DRV8163-Q1 for the 48V HSS and the DRV8245-Q1 MD.

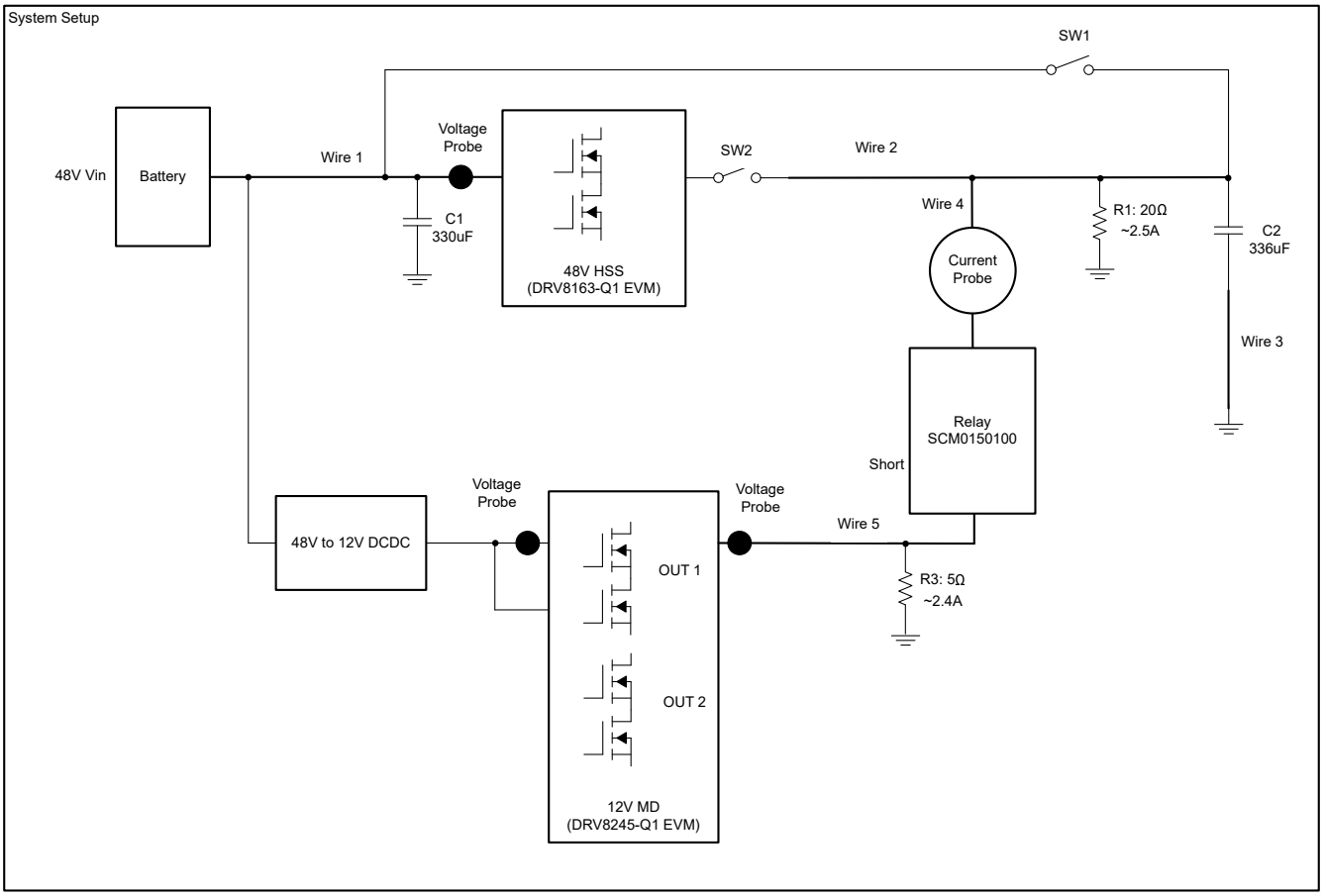


Figure 16. Test Setup with DRV8245-Q1 and DRV8163-Q1

See Test Procedure and Setup Parameters for the procedure followed.

Figure 17 shows test results.

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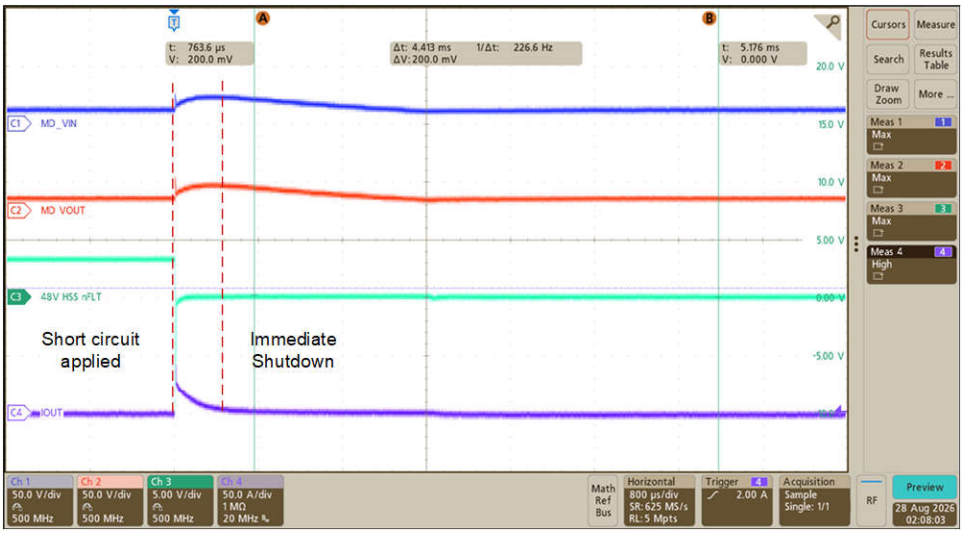


Figure 17. DRV8245-Q1 FET On Short to DRV8163-Q1

MD Test Summary:

When shorting to the TPS1HTC30-Q1, it is not verified that the device shuts off in time to prevent reverse current flow into the DRV8245-Q1. When shorting to the DRV8163-Q1, while the DRV8163-Q1 does shut off via SCP, this does not occur before the absolute maximum voltage rating of the DRV8245-Q1 is violated.

Proposed Protection

- Series input blocking diode placed at the input of the 12V MD to prevent reverse current from damaging the device
- Output TVS diode placed on the output of the 12V MD to clamp the output voltage below the device's absolute maximum rating

Voltage-Tracking LDO

Tracking LDOs supply power off-board to loads and sensors through long wire harnesses, making them susceptible to output-side shorts to the 48V battery — even when powered from a 12V supply. The TPS7B4255-Q1 was selected as the DUT. Refer to the test procedure section for the procedure followed.

Figure 18 shows the first test setup, which uses the TPS1HTC30-Q1 for the 48V HSS and the TPS7B4255-Q1 LDO.

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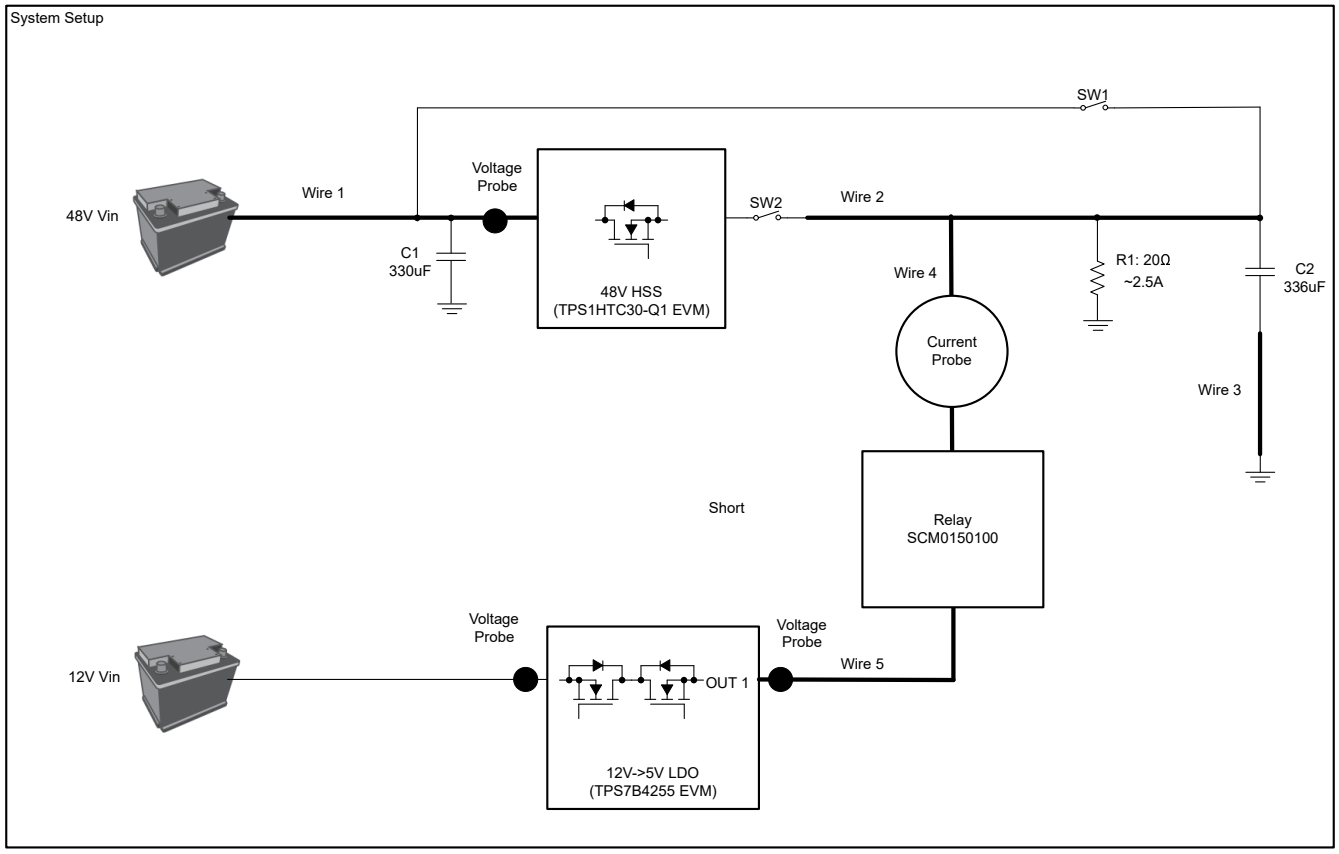


Figure 18. Test Setup with TPS7B4255-Q1 and TPS1HTC30-Q1

Figure 19 shows test results.

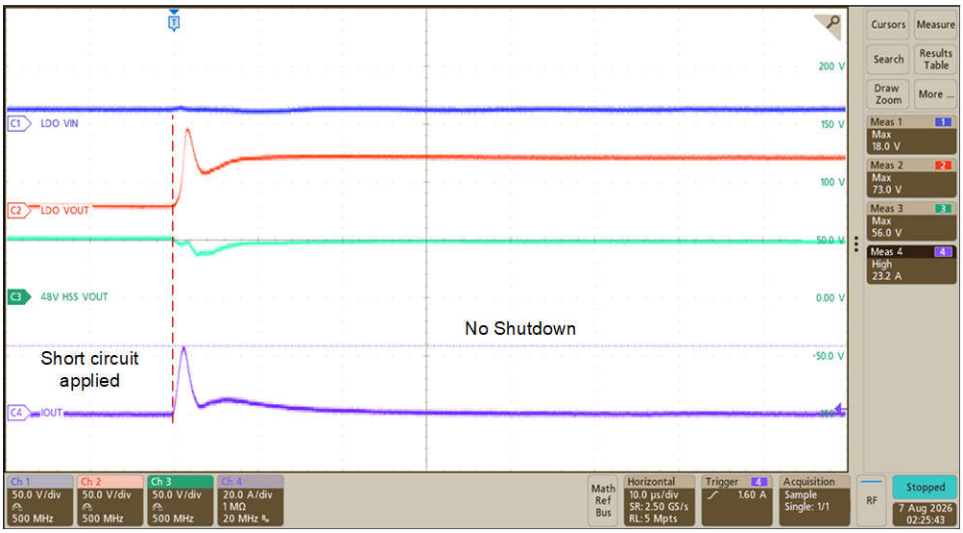


Figure 19. TPS7B4255-Q1 Short to TPS1HTC30-Q1 (8A CL)

Figure 20 shows the second test setup, which uses the DRV8163-Q1 for the 48V HSS and the TPS7B4255-Q1 LDO.

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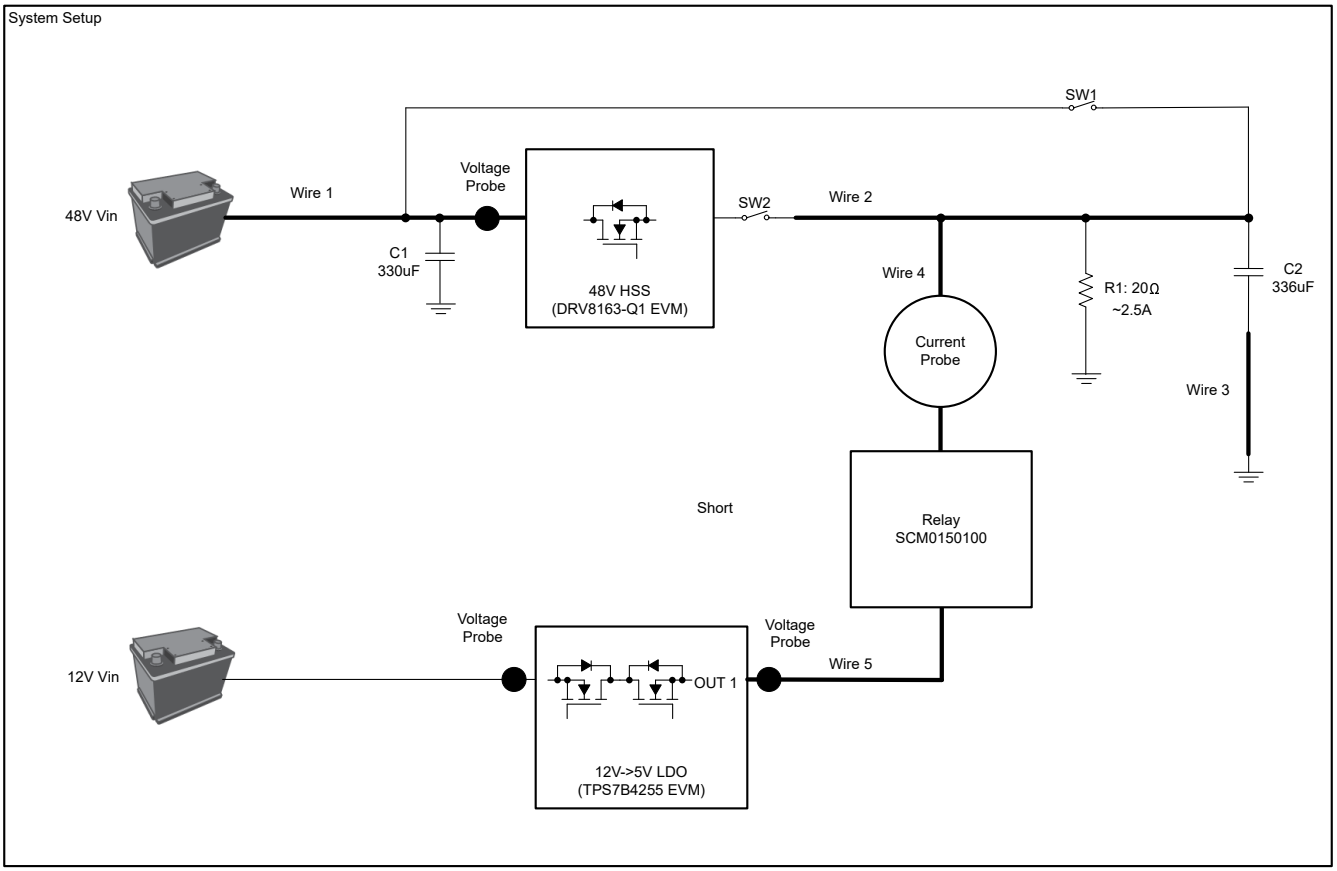


Figure 20. Test Setup with TPS7B4255-Q1 and DRV8163-Q1

Figure 21 and Figure 22 show test results.

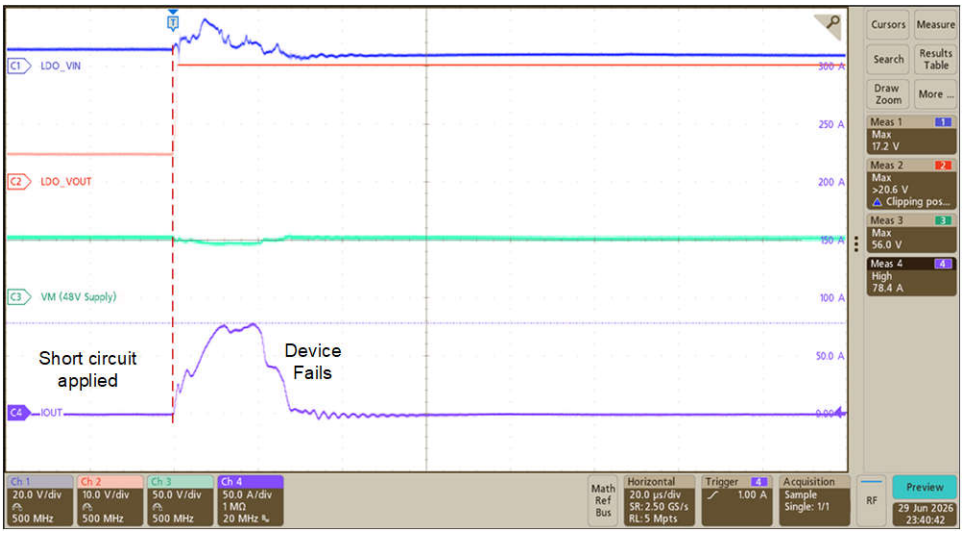


Figure 21. TPS7B4255-Q1 Short to DRV8163-Q1 (C_{OUT} Additional = 0uF)

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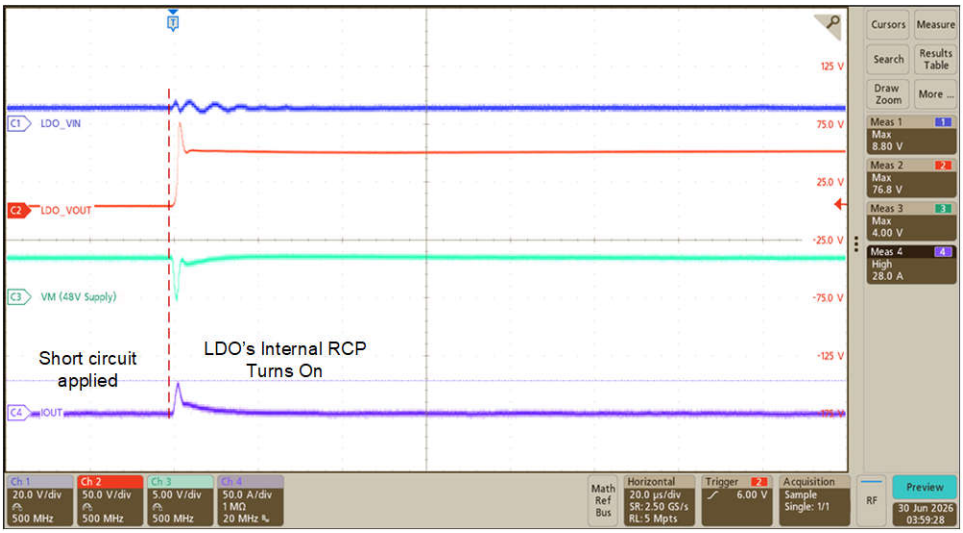


Figure 22. TPS7B4255-Q1 Short to DRV8163-Q1 (C_{OUT} Additional = 2.2uF)

Tracking LDO Test Summary

Without additional output capacitance: The device's internal reverse current protection (RCP) does not respond quickly enough, allowing high current to flow through the internal FET and cause damage. The TPS7B4255-Q1's RCP response time is 0.5µs maximum for the given test conditions. Therefore, it follows that the reverse current condition occurs in <0.5µs, a timescale shorter than that which is required for an output short to a 12V automotive battery

With additional output capacitance (tested as low as 2.2 µF): The device survives. The extra capacitance provides sufficient response time for the LDO to activate RCP (within 0.5µs) before damage occurs. However, although the device survives, the V_{OUT} abs max is still violated. Therefore adding more C_{OUT} is not a sufficient protection solution.

For more information on preventing reverse current in LDOs, see *LDO Basics: Preventing Reverse Current*

To verify the tracking LDOs remain protected, the circuit in Figure 23 is proposed:

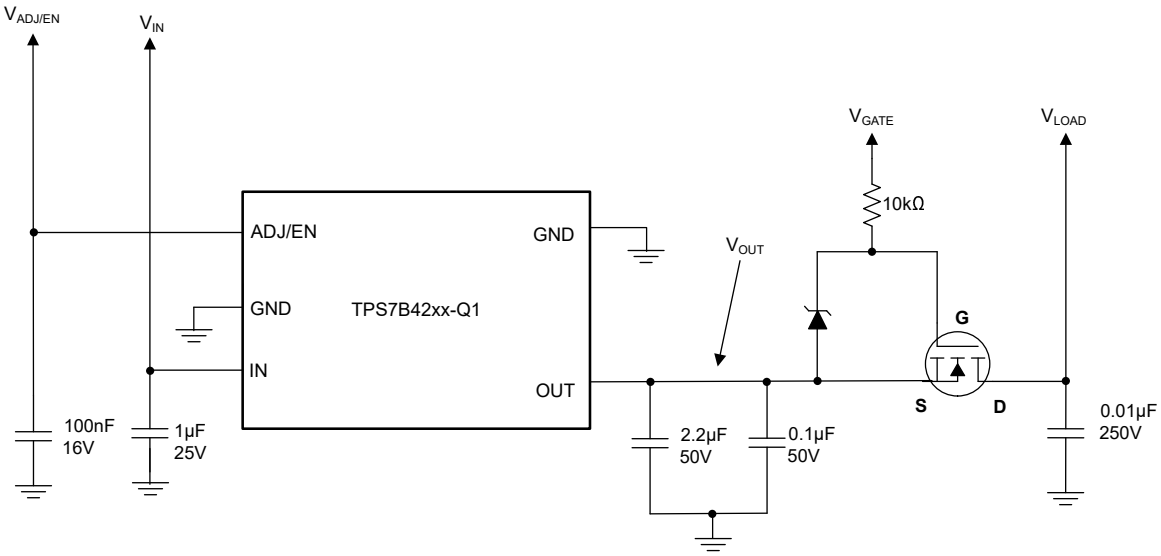


Figure 23. LDO Protection Circuit

The protection circuit limits the voltage on OUT to V_{GATE} + V_{DIODE} steady state during a short to the $_{48V}$ battery on the output.

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A fast transient from typical operation to output short can cause an initially higher voltage on OUT, as a result of leakage through the protection FET. With nominal V_{OUT} of the TPS7B4255-Q1 programmed as high as 35V, the voltage transient is limited within device absolute maximum ratings. If the short condition persists, the voltage on OUT eventually settles to V_{GATE} + V_{DIODE}. This is because once the LDO sees the higher voltage on OUT, it will attempt to regulate the output down, which will drive V_{GATE} low and turn the protection FET off. If the short on the LDO output is cleared, output recovers and the protection FET returns to the ON state.

Test Results and Protection Designs Summary

Table 1. Test Results

12V DUT	48V Load Driver (Shutdown behavior)	Failures/Faults?	Additional Protections Needed?
smart eFuse (TPS2HCS08-Q1)	Immediate	NO	NO
	Current regulation	NO	
HSS (TPS4HC120-Q1)	Immediate	NO	YES
	Current regulation	YES	
MD (DRV8245-Q1)	Immediate	YES	YES
	Current regulation	YES	
Voltage-Tracking LDO (TPS7B4255-Q1)	Immediate	YES	YES
	Current regulation	YES	

Table 2. Protection Design

Use Cases	Design	Cost	Pros	Cons
Uni-directional low current load drivers	Input Blocking Diode	Low	Simple design	Inefficient
High Current/Low Rds(on) High-side switches	Reverse Current Blocking FET	High	Power efficient	Larger size
			Robust	
Voltage-Tracking LDOs	LDO Active Clamp	Med	Power efficient	Larger size
			Robust	
Full (H) Bridge Motor Drivers (Bi-directional load drivers)	TVS Output Clamp	Med	Simple design	Energy Limitations

Test Procedure and Setup Parameters

Test procedure when using the TPS1HTC30-Q1 48V HSS:

1. Make sure both switches (SW1, SW2) and the relay are open.
2. Close SW1.
3. Turn on 48V supply.
4. Enable the TPS1HTC30-Q1 FET.
5. Close SW2.
6. Open SW1.
7. Drive the relay to create the short between 48V and the lower voltage rail.

Test procedure when using the DRV8163-Q1 48V MD:

1. Make sure both switches (SW1, SW2) and the relay are open.
2. Close SW1.
3. Turn on 48V supply.
4. Drive DRV8163-Q1 HS FET.
5. Close SW2.
6. Open SW1.
7. Drive the relay to create the short between 48V and the lower voltage rail.

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The following test setup parameters were used for all test setups.

Table 3. Test Setup Parameters

Designator	Value
C1	330uF
C2	336uF
R1	20Ω
R2	5Ω
R3	5Ω
Wire 1	3.5m (18AWG)
Wire 2	1m (18AWG)
Wire 3	1m (18AWG)
Wire 4	300mm (18AWG)
Wire 5	300mm (18AWG)

Conclusion

TI is not only a market leader in 48V-capable devices, but is also actively testing and solving system-level challenges related to 48V adoption in automotive applications. Among the most pressing of these challenges is the risk of 48V-to-12V/5V rail short circuit events between load drivers. Whether a specific device can survive these events on its own or requires additional protection circuitry, TI is equipped to provide complete, system-level solutions to customers as they transition to 48V architectures.

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