TI Designs: TIDA-01514

Protection and Light-Load Detection Reference Design for Antenna Module

Description

This reference design provides protection and diagnostics for antenna modules for use in automotive infotainment and navigation systems. This design is an alternate solution for antenna low-dropout linear regulators (LDOs) for the purposes of achieving lower ohmic drop (IR) while meeting the necessary protection measures such as short circuit, short-to-battery, reverse current, and overvoltage. The proposed design also meets the subsystem level diagnostic requirements such as precise light load and overload detection.

This reference design solution is specified for use in infotainment systems such as automotive navigation systems, automotive tuners, and automotive head units.

Resources

TIDA-01514	Design Folder
TPS25940-Q1	Product Folder
INA211-Q1	Product Folder
LM4040-N-Q1	Product Folder
TPS3710-Q1	Product Folder

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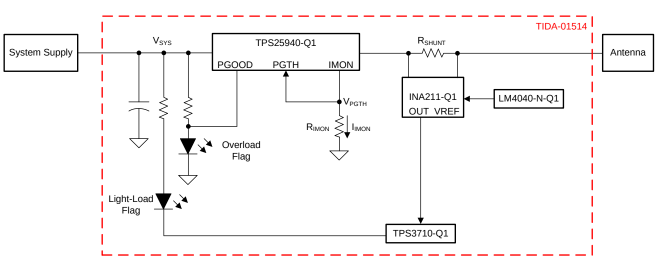
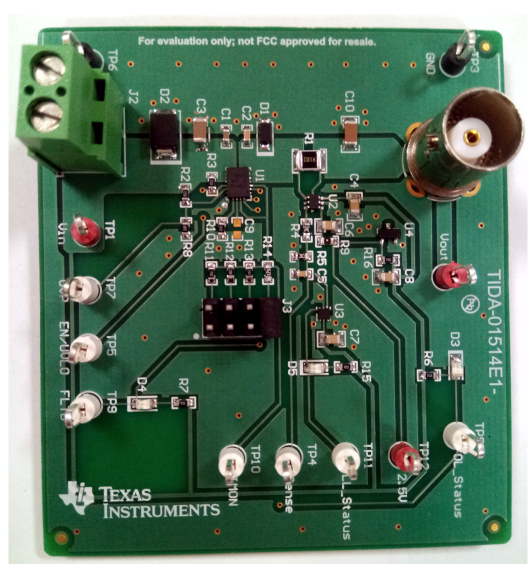
Features

- System diagnostics
  - Open Load Detection at 10 mA (Typical)
  - Selectable Overcurrent Detection at 300 mA, 600 mA, 900 mA, 1.2 A
- Shutoff in 1 µs (Typical) to Short-to-Battery Fault
- Fast Response of 200 ns (Typical) to Short-to-Ground Fault
- Low IR Drop With TPS25940-Q1 (42 mΩ R_{ON})

Applications

- Automotive Navigation Systems
- Intelligent Antenna Module
- BBU/RRU in Base Stations
- Automotive Tuners
- Automotive Head Units





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1 System Description

At the time of this writing, the electronic content in modern cars continues to increase tremendously as it has over the last few years due to the demand for in-car entertainment ("infotainment") systems and features, such as docking for smartphones, USB ports, GPS navigation systems, and satellite radios. Figure 1 shows a typical block diagram of such a system. Infotainment systems use antennas for satellite radios, AM and FM radios, and GPS navigation. These modules are considered as off-board loads and draw power through a long cable. Installing these modules can be difficult due to shorting out power to the vehicle ground or battery; therefore, protection for the power rail under fault conditions like short-circuit, short-to-battery, and overload is required.

Additionally, the system should have the ability to detect whether the antenna has been properly connected or not. The LDOs, which have diagnostic capability, generally function to feed these antennas. The large dropout voltage with LDOs leads to higher IR losses in the system.

The focus of this guide is the design of the diagnostics and protection circuit for antenna modules using the TPS25940-Q1 eFuse and INA211-Q1 current-shunt monitor. This design provides open-load detection at 10 mA and user-selectable overvoltage detection thresholds at 300 mA, 600 mA, 900 mA, and 1.2 A, respectively. The TPS25940-Q1 eFuse offers low IR drop and all the necessary protection such as short circuit, short-to-battery, reverse current, and overvoltage.

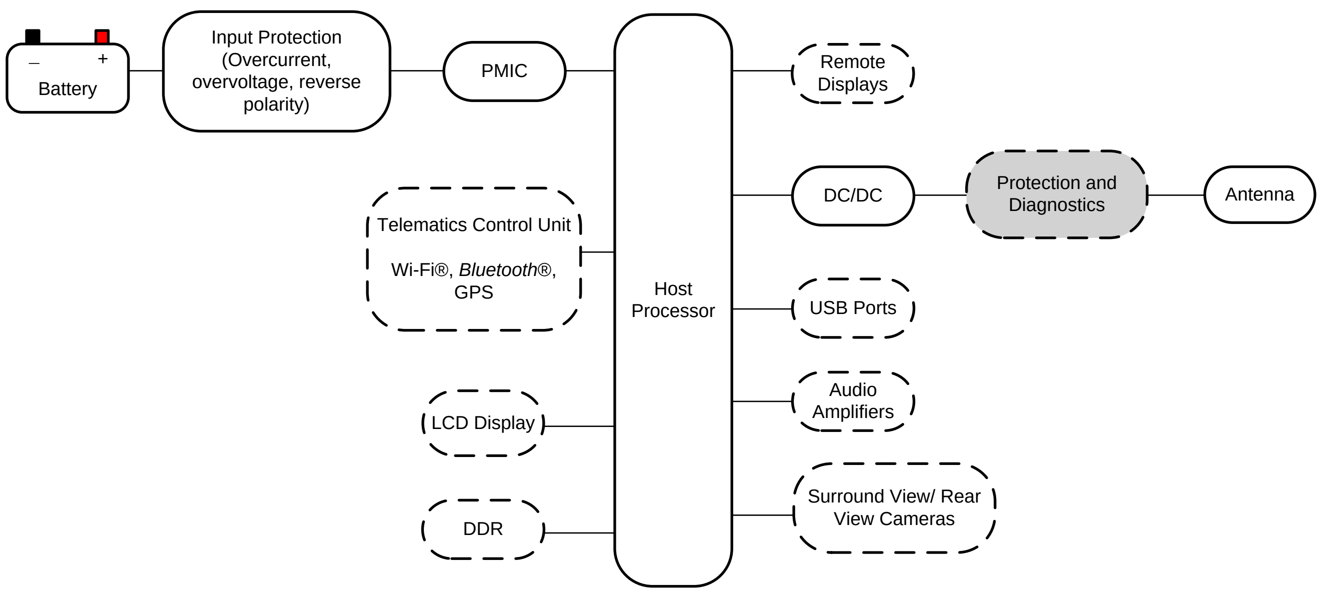

Figure 1. Typical Block Diagram of Automotive Infotainment System (TI Design Highlighted)

1.1 Key System Specifications

Table 1. Key System Specifications

PARAMETER	SPECIFICATIONS
Input voltage	Approximately 3.3 V to 12 V
Open-load detection threshold	10 mA
Overload detection threshold (selectable)	300 mA, 600 mA, 900 mA, and 1200 mA
Short-to-ground response	200 ns
Short-to-battery response	1 µs

2 System Overview

2.1 Block Diagram

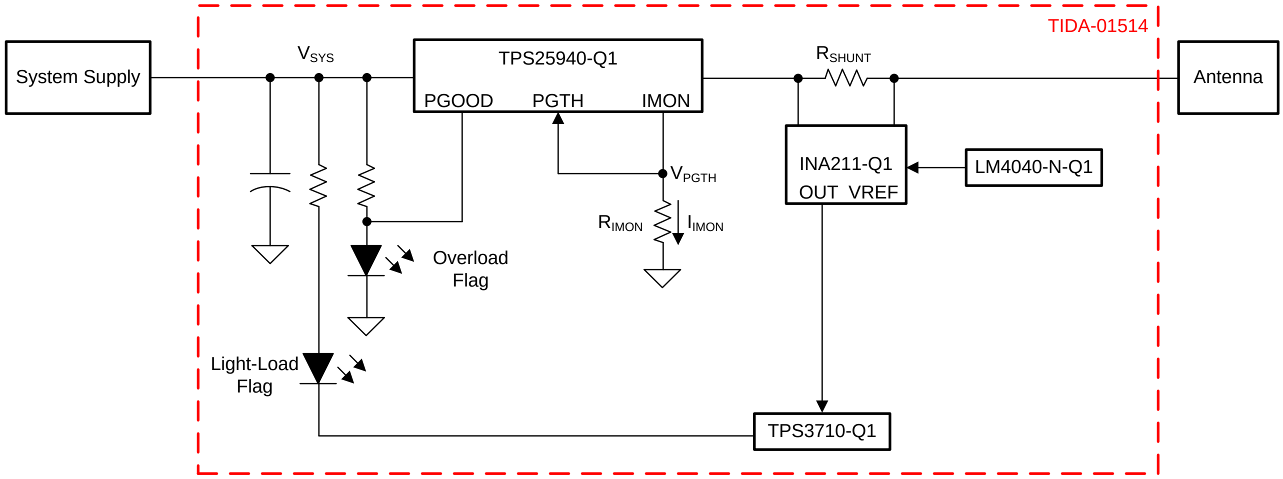

Figure 2. TIDA-01514 Block Diagram

2.2 Highlighted Products

This section highlights the key features for selecting the devices for this reference design. Find the complete details of the highlighted devices in their respective product data sheets.

2.2.1 TPS25940-Q1

The TPS25940-Q1 device is an eFuse with integrated back-to-back field-effect transistors (FETs) and enhanced built-in protection circuitry. The device provides robust protection for all systems and applications powered from 2.7 V to 18 V. Load, source, and device protection are provided with many programmable features including overcurrent, output voltage slew rate, overvoltage, and undervoltage thresholds.

The TPS25940-Q1 device monitors the reverse voltage from IN to OUT to provide true reverse current blocking from the output when an output short-to-battery fault condition or input power fail condition has been detected.

The key features that make this device unique are:

- 2.7-V to 18-V operating voltage, 20 V (maximum)
- Total R_{ON}: 42 mΩ (typical)
- 0.6-A to 5.3-A adjustable current limit (±8%)
- I_{MON} current indicator output (±8%)
- Adjustable undervoltage and overvoltage threshold (±2%)
- Reverse current blocking
- 1-µs reverse voltage shutoff
- Programmable dVo/dt control
- Power good and fault outputs
- Short-to-battery protection
- Short-to-ground protection
- Built-in thermal shutdown

2.2.2 INA211-Q1

The INA21x-Q1 are voltage-output, high-accuracy bidirectional current-shunt monitors that are commonly used for overcurrent protection, precision-current measurement for system optimization, or in closed-loop feedback circuits. This series of devices can sense drops across shunts at common-mode voltages from –0.3 V to 26 V, independent of the supply voltage. Six fixed gains are available: 50 V/V, 75V/V, 100 V/V, 200 V/V, 500 V/V, or 1000 V/V. The low offset of the zero-drift architecture enables current sensing with maximum drops across the shunt as low as 10-mV full-scale. The device can operate from a single 2.7-V to 26-V power supply.

The key features that make this device unique are:

- Wide common-mode range: –0.3 V to 26 V
- Offset voltage: ±100 µV (maximum); enables shunt drops of 10-mV full scale
- Accuracy:
  – ±1% gain error (maximum over temperature)
  – 0.5-µV/°C offset drift (maximum)
  – 10-ppm/°C gain drift (maximum)
- Quiescent current: 100 µA (maximum)

2.2.3 LM4040-N-Q1

The LM4040-N-Q1 is a precision micropower shunt voltage reference available in a SOT-23 surface-mount package. The advanced design of the LM4040-N-Q1 eliminates the requirement for an external stabilizing capacitor while ensuring stability with any capacitive load. Further reducing design effort is the availability of several fixed reverse breakdown voltages: 2.048 V, 2.5 V, 3 V, 4.096 V, 5 V, 8.192 V, and 10 V. The minimum operating current for the 2.5-V LM4040-N-Q1 is just 60 µA. The LM4040-N uses a fuse and Zener-zap reverse breakdown voltage trim during wafer sort to ensure that the prime parts have an accuracy of better than ±0.1% (A grade) at 25°C. Band-gap reference temperature drift curvature correction and low dynamic impedance ensure stable reverse breakdown voltage accuracy over a wide range of operating temperatures and currents.

The key features that make this device unique are:

- No stabilizing capacitor required
- Output voltage tolerance (A grade, 25°C): ±0.1% (maximum)
- Low output noise (10 Hz to 10 kHz): 35 μV_{RMS} (typical)
- Wide operating current range: 60 µA to 15 mA
- Low temperature coefficient: 100 ppm/°C (maximum)

2.2.4 TPS3710-Q1

The TPS3710-Q1 device is a wide-supply voltage detector that operates over a supply range of 1.8 V to 18 V. The device has a high-accuracy comparator with an internal 400-mV reference and an open-drain output rated to 18 V for precision voltage detection. The designer can set the monitored voltage at the SENSE pin with the use of external resistors. The OUT pin is driven low when the voltage at the SENSE pin drops below (V_{IT-}) and goes high when the voltage returns above the respective threshold (V_{IT+}). The comparator in the TPS3710-Q1 includes built-in hysteresis for filtering to reject brief glitches, which ensures stable output operation without false triggering.

The key features that make this device unique are:

- Wide supply voltage range: 1.8 V to 18 V
- Adjustable threshold: Down to 400 mV
- High threshold accuracy:
  – 1.0% over temperature
  – 0.25% (typical)
- Low quiescent current: 5.5 µA (typical)
- Internal hysteresis: 5.5 mV (typical)

2.3 System Design Theory

This section discusses the considerations behind the design of each subsection in the system. This section also provides necessary calculations for external components for each device and device modes to meet the system requirements of this reference design.

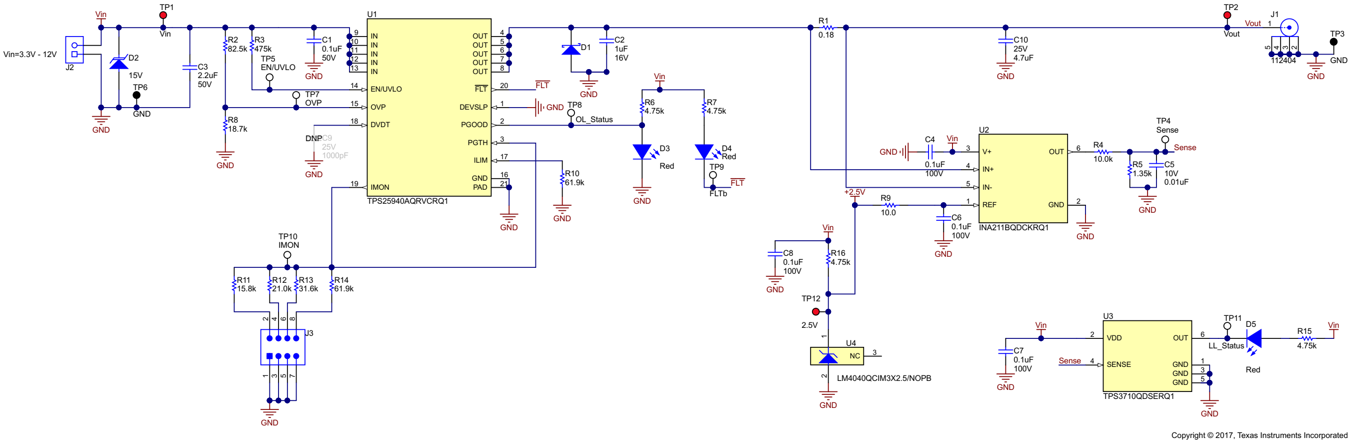

Figure 3. TIDA-01514 Schematic Circuit

2.3.1 Setting Overload Detection Threshold

The TPS25940-Q1 device is an eFuse with enhanced features such as load current monitoring and a power good comparator for voltage monitoring. In this reference design, these two functions are utilized and the external parameters are configured to flag the overcurrent event. For quick reference, see the TPS25940-Q1 block diagram in Figure 4.

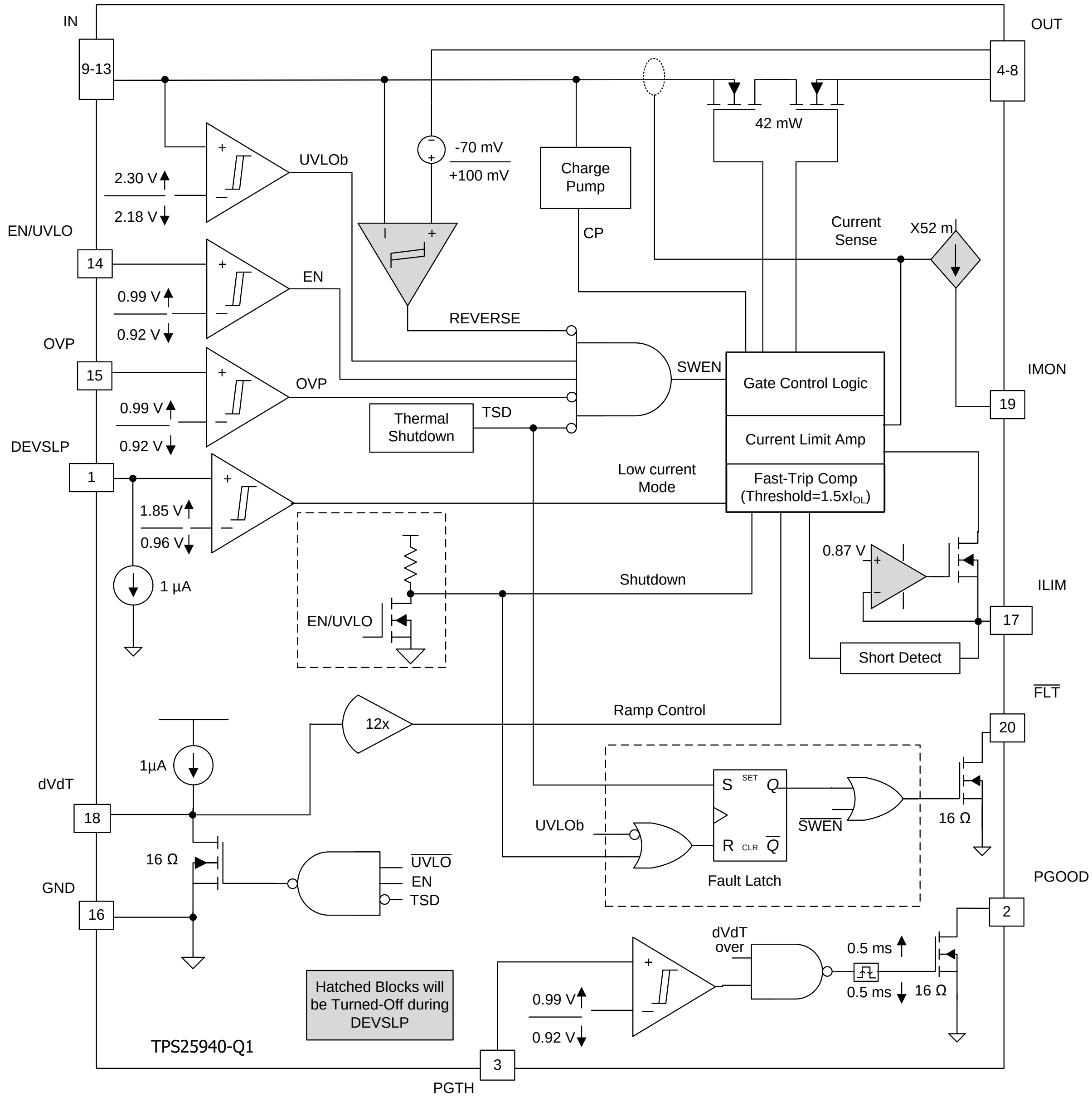

Figure 4. TPS25940-Q1 Block Diagram

The IMON terminal of the TPS25940-Q1 eFuse sources a scaled-down ratio of current flowing from IN to OUT. The designer can convert this current to a voltage by using a resistor R_{IMON} from the IMON terminal to GND, which can be used as a means of monitoring current flow through the system.

Equation 1 calculates the output voltage at the IMON terminal:

$$V_{IMON} = \left(I_{OUT} \times GAIN_{IMON}\right) \times R_{IMON} \quad (1)$$

where,

- $GAIN_{IMON}$ is the gain factor = 52 µA/A,
- I_{OUT} is the load current.

The power good comparator has an internal reference of V_{PGTHR} = 0.99 V at the negative terminal and the designer can utilize the positive terminal PGTH for monitoring the voltage of any specific rail. In this design, the output voltage at the IMON terminal (V_{IMON}) is fed to the positive terminal PGTH (V_{PGTH}) of the comparator. The comparator output (PGOOD) is an open-drain active-high signal, which can function to indicate the status to the microcontroller (MCU). PGOOD is asserted high when the internal FET is fully enhanced and the PGTH pin voltage (V_{PGTH} = V_{IMON}) is higher than the internal reference V_{PGTHR}. Figure 5 shows the circuit configuration of the TPS25940-Q1 eFuse for detecting an overcurrent event.

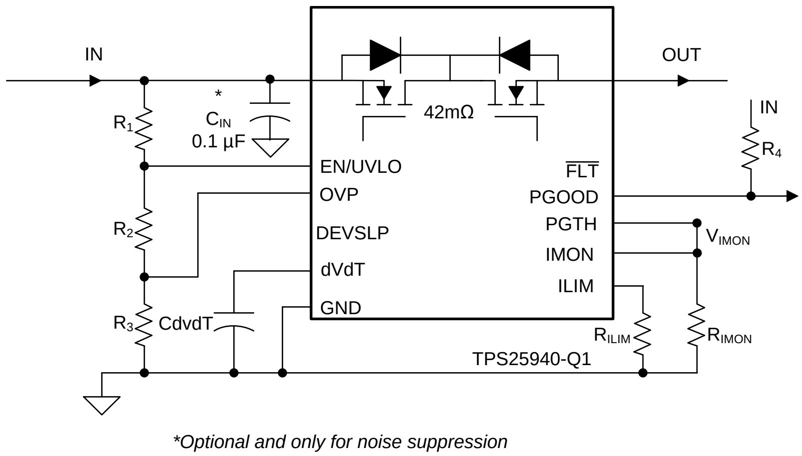

Figure 5. Circuit Configuration for Overload Detection Using TPS25940-Q1

For example, to detect an overcurrent event at a load current I_{OUT} of 300 mA, calculate the value of R_{IMON} using the following Equation 2.

$$V_{IMON} = V_{PGTHR} = \left(I_{OUT} \times GAIN_{IMON}\right) \times R_{IMON}$$
$$R_{IMON} = \frac{V_{PGTHR}}{\left(I_{OUT} \times GAIN_{IMON}\right)} = \frac{0.99\ V}{\left(300\ mA \times 52\ \mu A/A\right)} = 63.4\ k\Omega \quad (2)$$

A close value of 61.9 kΩ has been chosen for R_{IMON}. In this reference design, the evaluation board is designed with selectable overvoltage detection thresholds at 300 mA, 600 mA, 900 mA, and 1.2 A, respectively. The corresponding R_{IMON} values are 61.9 kΩ, 31.6 kΩ, 21 kΩ, and 15.8 kΩ.

2.3.2 Overload and Short-Circuit Protection

Accurate overload control and protection from short-circuit faults is essential to isolate the fault section from the upstream DC-DC converter and other system loads. The TPS25940-Q1 device can control overload within ±8% over temperature. When the overload is present, the device indefinitely regulates load current at a set current limit. If the overload is severe, the output voltage drops and increases power dissipation in the device. If the device hits the thermal limit, it turns off and attempts restart after 128 ms. This operation continues until the overload has been removed from the system. The R_{ILIM} resistor can program the overload current limit (I_{LIM}), as Equation 3 shows.

$$I_{LIM} = \frac{89}{R_{ILIM}} \quad (3)$$

where,

- I_{LIM} is overload current limit (in A),
- R_{ILIM} is the current limit resistor (in kΩ).

During a transient short-circuit event at the output, the internal fast-trip comparator shuts down the device within 200 ns, when the current through the internal FET exceeds the threshold $I_{FASTRIP}$. This trip threshold is set to more than 50% of the programmed overload current limit ($I_{FASTRIP}$ = 1.5 x I_{LIM} + 0.375). The fast-trip circuit holds the internal FET OFF for only a few microseconds, after which the device turns back ON slowly and regulates the output current to I_{LIM}.

The evaluation board is designed up to 1.2-A continuous load current; therefore, the current limit resistor R_{ILIM} is selected as 61.9 kΩ to set the overload current limit I_{LIM} at 1.44 A (20% higher than the continuous load current) and fast-trip threshold $I_{FASTRIP}$ at 2.53 A.

2.3.3 Reverse Current Protection and Short-to-Battery Protection

The antenna modules draw power through a long cable. Ensure that the cable is damage free, as a damaged cable risks the possibility of a short to the vehicle battery. The TPS25940-Q1 eFuse monitors the reverse voltage from IN to OUT, and when the reverse voltage exceeds –66 mV, the device stops the flow of reverse current in 1 µs (typical). This function supports supply bus protection from overvoltages during output short-to-battery faults. Additionally, the eFuse provides an instant warning signal (FLTb) to the controller.

2.3.4 Overvoltage Protection

A resistor divider connected from the supply to OVP terminal of the TPS25940-Q1 device to GND programs the overvoltage threshold. A voltage higher than V_{OVPR} on the OVP terminal turns off the internal FET and protects the load. Use Equation 4 to calculate the values required for setting the overvoltage.

$$V_{OVPR} = \frac{R_8}{R_8 + R_2} \times V_{OV} \tag{4}$$

where,

- V_{OVPR} is the OVP rising threshold of the device, 0.99 V typical,
- V_{OV} is the input overvoltage trip point, set at 5.35 V for this reference design.

First choose R_8 as 18.7 kΩ and then use Equation 4 to solve for R_2 = 82.5 kΩ.

2.3.5 Open-Load Detection

Figure 6 shows the circuit schematic for open-load detection. The voltage across the series current sense resistor is amplified using a current shunt monitor INA211-Q1. Equation 5 gives the output of INA211-Q1.

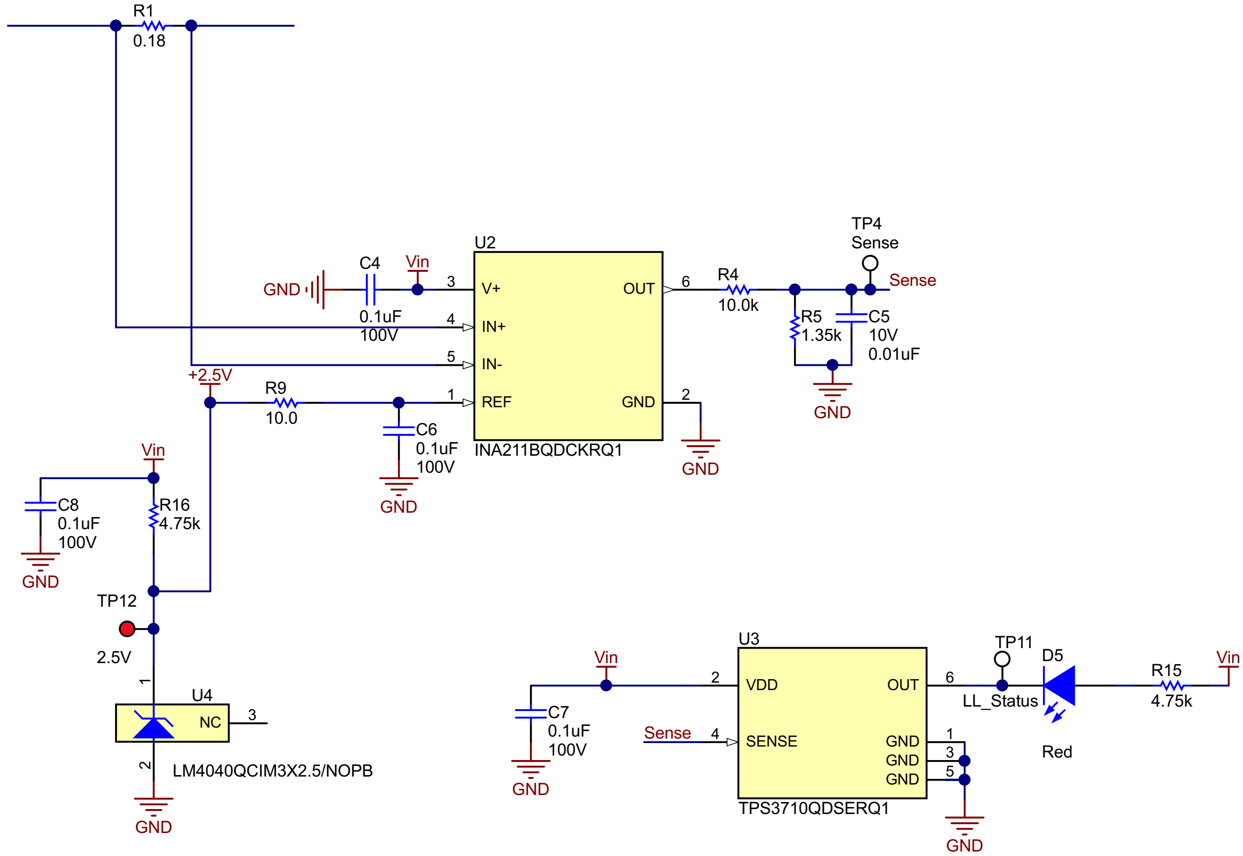

Figure 6. Open-Load Detection Schematic

$$V_{SENSE} = (I_{OUT} \times R_{SHUNT}) \times GAIN + V_{REF} \tag{5}$$

where,

- V_{SENSE} is the output voltage of the INA211-Q1 device,
- I_{OUT} is the load current,
- R_{SHUNT} is the current sense resistor,
- GAIN is the amplifier gain; 500 for the INA211-Q1 device,
- V_{REF} is the reference voltage to the INA211-Q1 device.

In this reference design, the light-load detection threshold is set at 10 mA. As the focus of the design is primarily for a 5-V system, the reference voltage for the INA device is set at 2.5 V using LM4040QCIM3X2.5/NOPB. Scale down the output of the current shunt monitor using R_4 and R_5 to match the internal fixed reference of 400 mV for the voltage detector integrated circuit (IC), which then asserts its output LL_Status for the light-load condition. Choose resistors R_4 and R_5 as 10 kΩ and 1.35 kΩ, respectively.

2.3.6 Flag Outputs

This reference design has various flag outputs to indicate the nature of a fault event to the MCU. Table 2 shows the output of fault event indicator (FLTb), overload status (OL_Status), and light-load status (LL_Status) for different fault conditions. The OL_Status is an active HIGH output whereas FLTb and LL_Status gives an active LOW output for the fault condition.

Table 2. Fault Summary and Status Indicators

EVENT OR FAULT	PROTECTION RESPONSE	FLTb	OL_Status	LL_Status
Overload	Current limiting	Yes	Yes	No
Open load	No action	No	No	Yes
Short-to-battery	Shutdown	Yes	No	No
Short-to-ground	Current limiting	Yes	Yes	No
Overvoltage	Shutdown	Yes	No	No
Overtemperature	Shutdown	Yes	No	No

3 Hardware, Software, Testing Requirements, and Test Results

3.1 Required Hardware and Software

3.1.1 Hardware

Figure 7 shows the general hardware connection test setup.Table 3 describes the accessible terminals, jumpers, LED functionality, and test points available on the board.

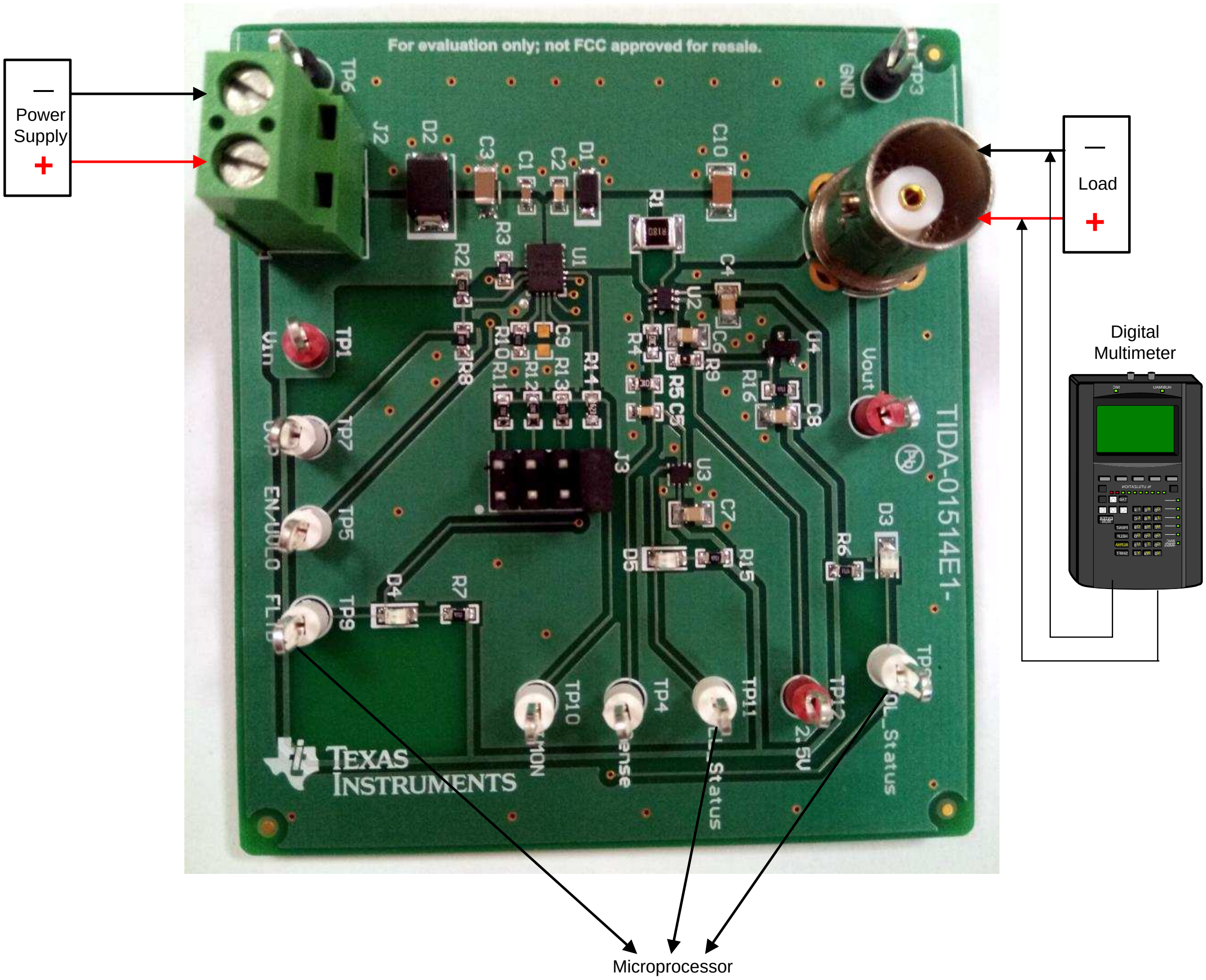

Figure 7. Hardware Connection Setup

Table 3. Jumper, Test Points, and Terminals Description

REFERENCE	LABEL	DESCRIPTION
J2	V_{IN}	Input supply terminal
J1	V_{OUT}	Output voltage or load terminal
J3	—	Overload detection threshold setting: 1-2 position sets 1.2 A 3-4 position sets 0.9 A 5-6 position sets 0.6 A 7-8 position sets 0.3 A
D4	FLTb	Circuit fault indicator: LED turns on when the internal MOSFET of the TPS25940-Q1 device has been disabled due to a fault condition such as overload, short circuit, undervoltage, and so forth
D3	OL_Status	Overload fault indicator: LED turns on when the load current exceeds the set value at J3
D5	LL_Status	Light-load fault indicator: LED turns on when the load current falls below 10 mA
TP1	V_{IN}	Input voltage to the board
TP2	V_{OUT}	Output voltage from the board
TP3, TP6	GND	GND
TP4	Sense	Analog output from INA211-Q1 device
TP5	EN/UVLO	Active high enable and undervoltage input
TP7	OVP	Active high overvoltage input
TP8	OL_Status	Open-load status test point
TP9	FLTb	Fault test point
TP10	I_{MON}	Load current monitor output
TP11	LL_Status	Light-load status test point
TP12	2.5V	Reference voltage to INA211-Q1 device

3.2 Testing and Results

3.2.1 Test Setup

Figure 8 shows the TIDA-01514 test setup.

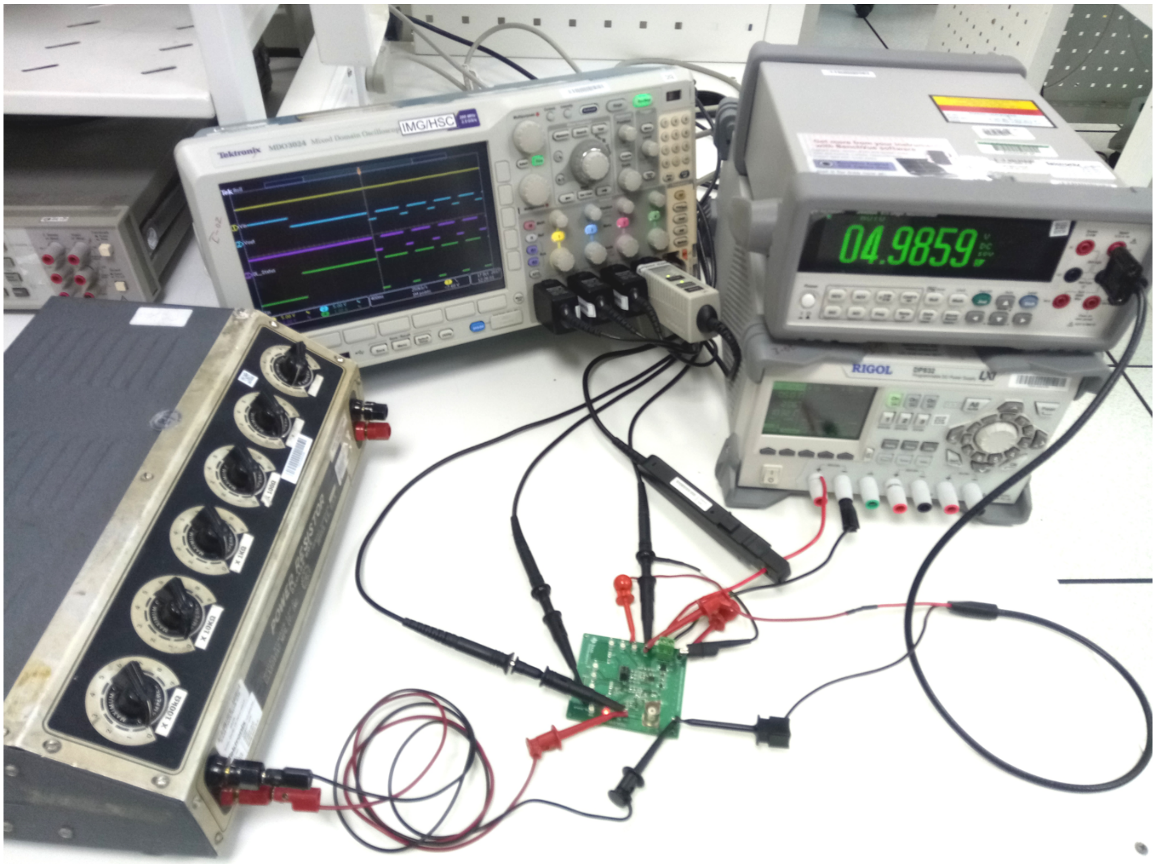

Figure 8. Test Setup

3.2.2 Test Results

3.2.2.1 Overload Test

In this test case, the overload threshold was set at 300 mA. Figure 9 shows the overload flag status when the load was changed from 150 mA to 600 mA and back. As Figure 9 shows, the overload status (OL_Status) becomes active HIGH when the load current crosses 300 mA. Figure 10 shows the overload behavior of the system. The current is limited to a programmed value of 1.44 A until thermal shutdown and then the system resumes normal operation if the overload fault has been cleared.

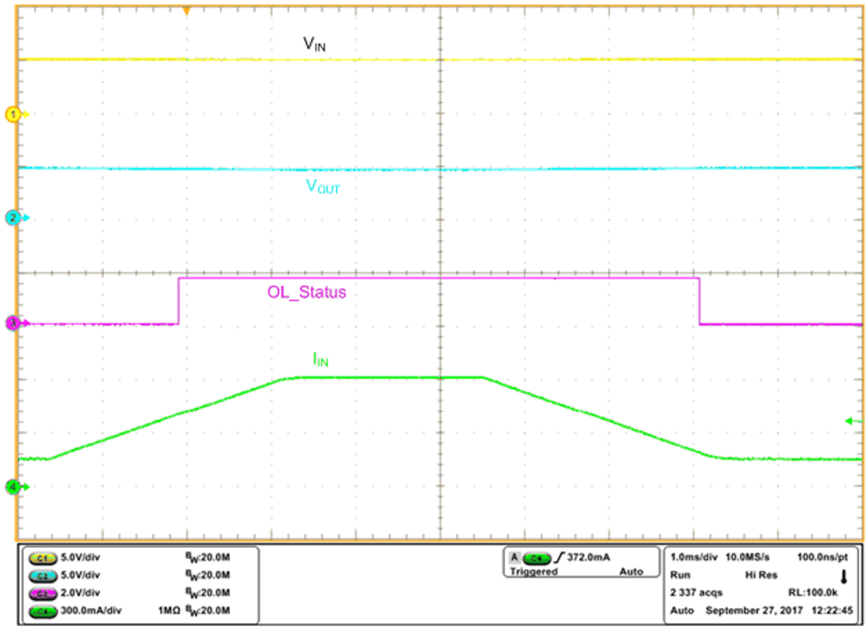

Figure 9. Overload Flag Status for Change in Load From 150 mA to 600 mA and Back

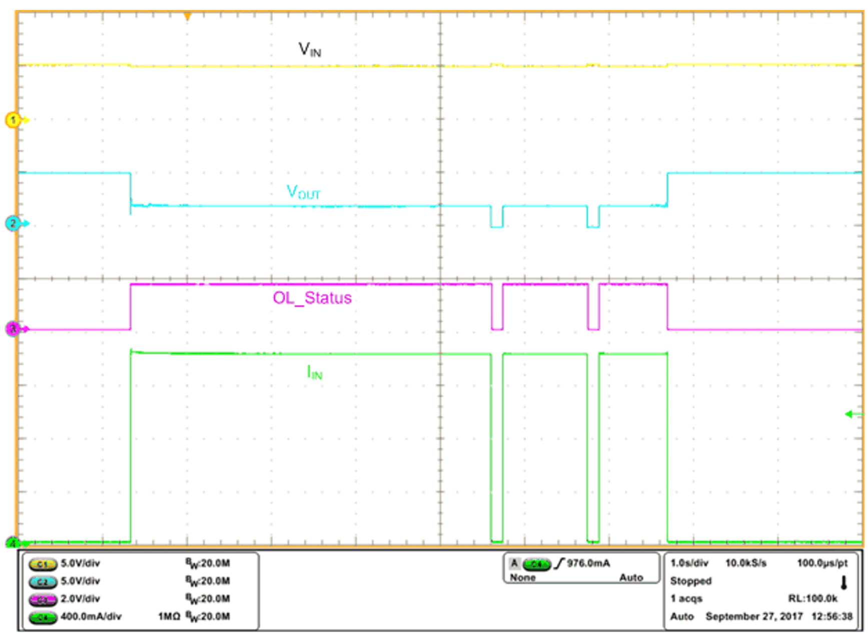

Figure 10. Overload Response and Recovery From Overload Fault

3.2.2.2 Light-Load Detection Test

Figure 11 and Figure 12 shows the light-load flag status at supply voltage 5 V and 12 V, respectively. The LL_Status becomes active LOW when the load current drops below 10 mA. The OPEN load condition can be detected easily.

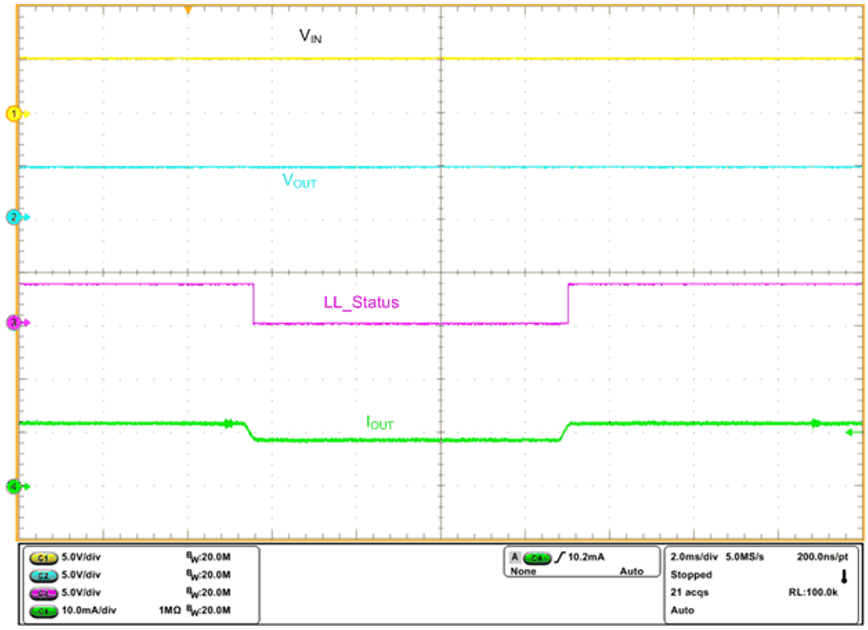

Figure 11. Light-Load Flag Status for Change in Load from 11 mA to 8 mA and Back at V_{IN} = 5 V

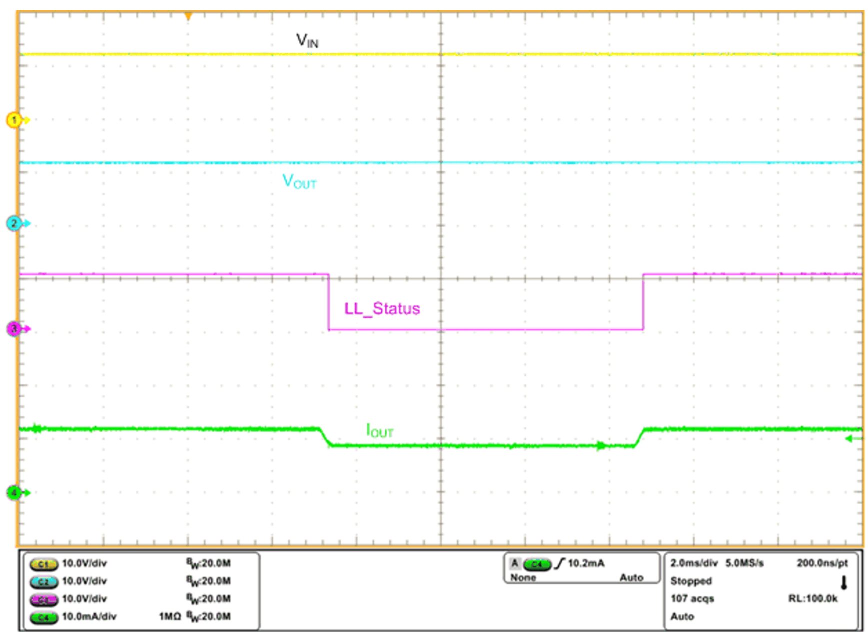

Figure 12. Light-Load Flag Status for Change in Load from 11 mA to 8 mA and Back at V_{IN} = 12 V

3.2.2.3 Short-Circuit Protection

Figure 13 shows the hot-short behavior of the system. The fast-trip comparator turns off the internal FET immediately and promptly starts the system in current limit mode. Figure 14 shows the response when the system wakes up with a short on the output. In this case, the system starts in current limit mode.

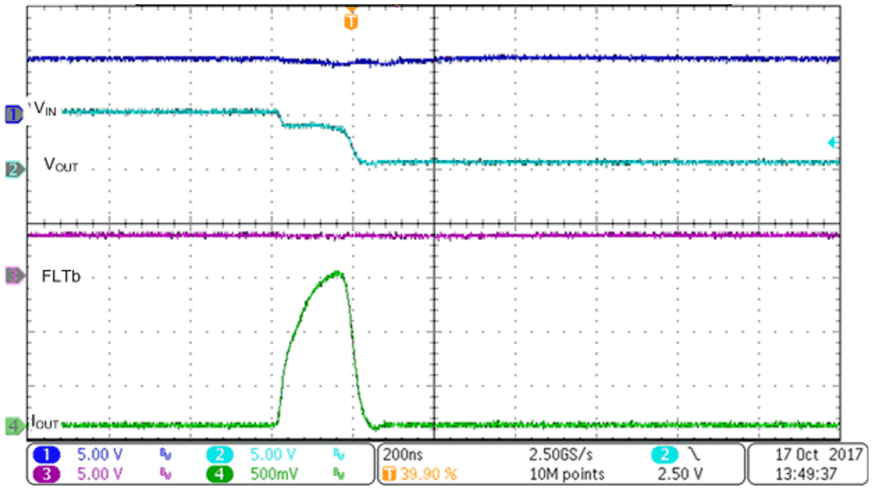

Figure 13. Hot-Short Response With Current Limit at 1.44 A

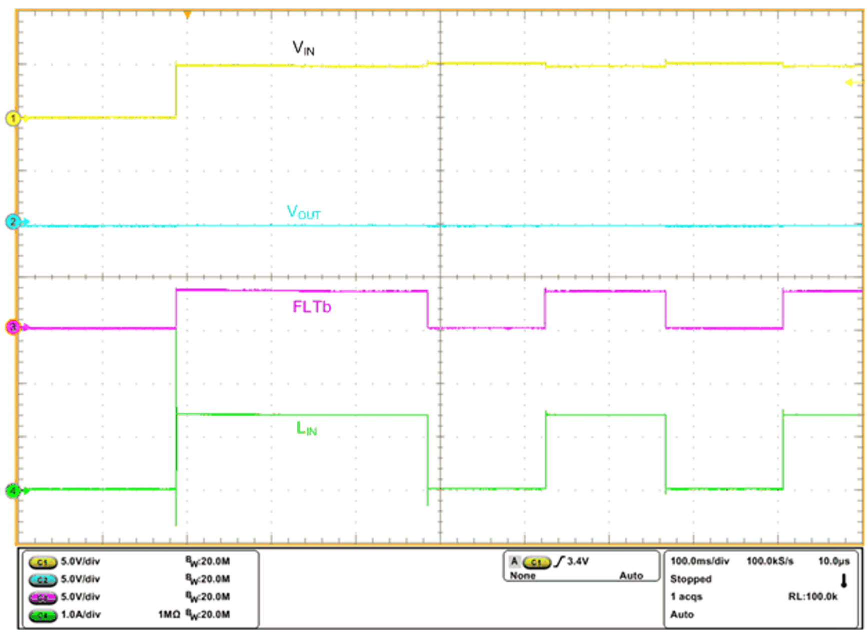

Figure 14. Hot-Plug Response With Short on Output

3.2.2.4 Short-to-Battery Protection

Figure 15 shows the performance of the TPS25940-Q1 device under a short-to-battery fault. In this test case, the input supply voltage is 5 V and the output is shorted to 12 V (battery voltage). The FLTb output becomes active LOW for a short-to-battery fault.

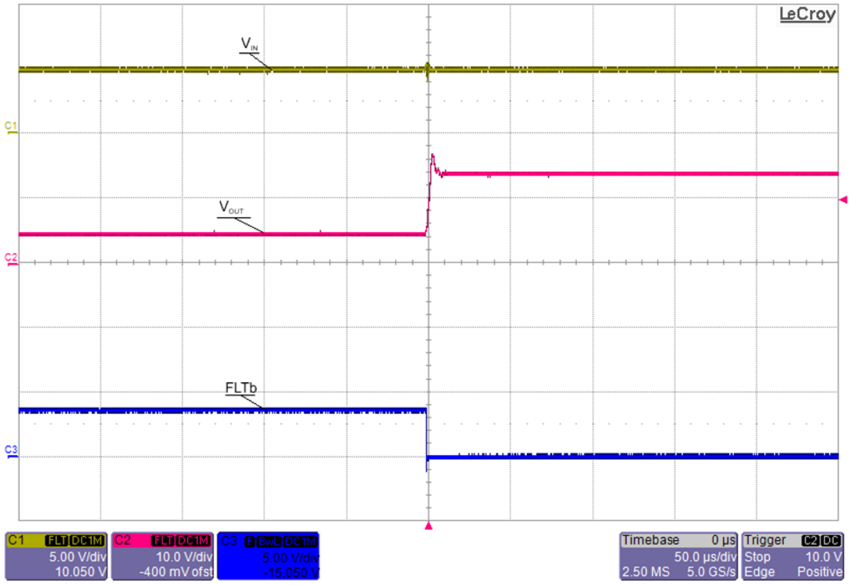

Figure 15. Response of TPS25940-Q1 During Output Short-to-Battery Fault

3.2.2.5 Overvoltage Protection

Figure 16 demonstrates the device response for an input overvoltage fault. The TPS25940-Q1 device shuts down when the input voltage exceeds the overvoltage trip level of 5.35 V.

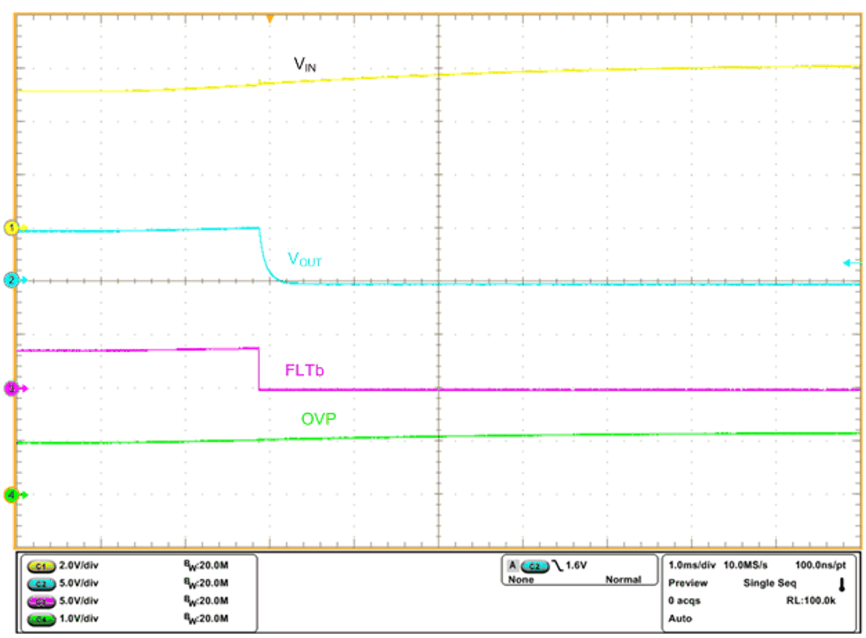

Figure 16. Output Voltage Cutoff for Overvoltage Condition

3.2.2.6 Dropout Voltage

Table 4 lists the output voltage and power path voltage drop at various load currents.

Table 4. Voltage Drop at Various Loads

I_{OUT} (mA)	V_{OUT} (V)	DROPOUT VOLTAGE (mV)
50.5	4.988	11.8
100.2	4.977	23.4
199.8	4.953	46.6
300.1	4.930	69.8
400.7	4.907	92.9
499.3	4.884	116.2

4 Design Files

4.1 Schematics

To download the schematics, see the design files at TIDA-01514.

4.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-01514.

4.3 PCB Layout Recommendations

4.3.1 Layout Prints

To download the layer plots, see the design files at TIDA-01514.

4.4 Altium Project

To download the Altium project files, see the design files at TIDA-01514.

4.5 Gerber Files

To download the Gerber files, see the design files at TIDA-01514.

4.6 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-01514.

5 Software Files

To download the software files, see the design files at TIDA-01514.

6 Related Documentation

1. Texas Instruments, *TPS25940-Q1 2.7-V to 18-V eFuse with Integrated Short-to-Battery Protection*
2. Texas Instruments, *INA21x Voltage Output, Low- or High-Side Measurement, Bidirectional, Zero-Drift Series, Current-Shunt Monitors*
3. Texas Instruments, *LM4040-N/-Q1 Precision Micropower Shunt Voltage Reference*
4. Texas Instruments, *TPS3710-Q1 Wide VIN Voltage Detector*

6.1 Trademarks

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