

TI Designs: TIDA-01514

适用于天线模块的保护和轻负载检测参考设计



说明

该参考设计为用于汽车信息娱乐系统和导航系统的天线模块提供保护和诊断。该设计是天线低压降线性稳压器 (LDO) 的替代解决方案，用于实现更低的电阻压降 (IR)，同时提供必要的保护措施（如短路、电池短路、反向电流和过压保护）。建议的设计还符合子系统级诊断要求（如精确的轻负载和过载检测）。

该参考设计解决方案适用于汽车导航系统、汽车调谐器和汽车音响主机等信息娱乐系统。

资源

TIDA-01514	设计文件夹
TPS25940-Q1	产品文件夹
INA211-Q1	产品文件夹
LM4040-N-Q1	产品文件夹
TPS3710-Q1	产品文件夹



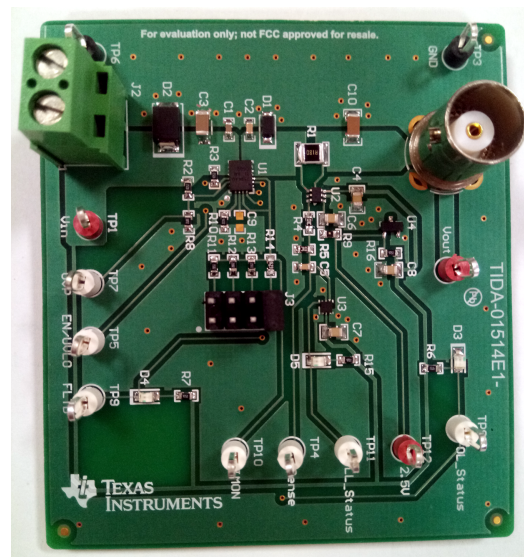
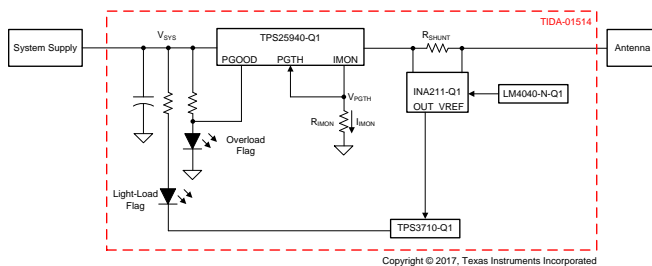
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特性

- 系统诊断
 - 在 10mA（典型值）电流下进行开路负载检测
 - 可选的过流检测（300mA、600mA、900mA、1.2A）
- 在发生电池短路故障时在 1 μ s（典型值）内关断
- 在 200ns（典型值）内对接地短路故障快速作出响应
- 利用 TPS25940-Q1 (42m Ω R_{ON}) 实现低 IR 压降

应用

- [汽车导航系统](#)
- [智能天线模块](#)
- [基站中的 BBU/RRU](#)
- [汽车调谐器](#)
- [汽车音响主机](#)



该 TI 参考设计末尾的重要声明表述了授权使用、知识产权问题和其他重要的免责声明和信息。

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. 图 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.

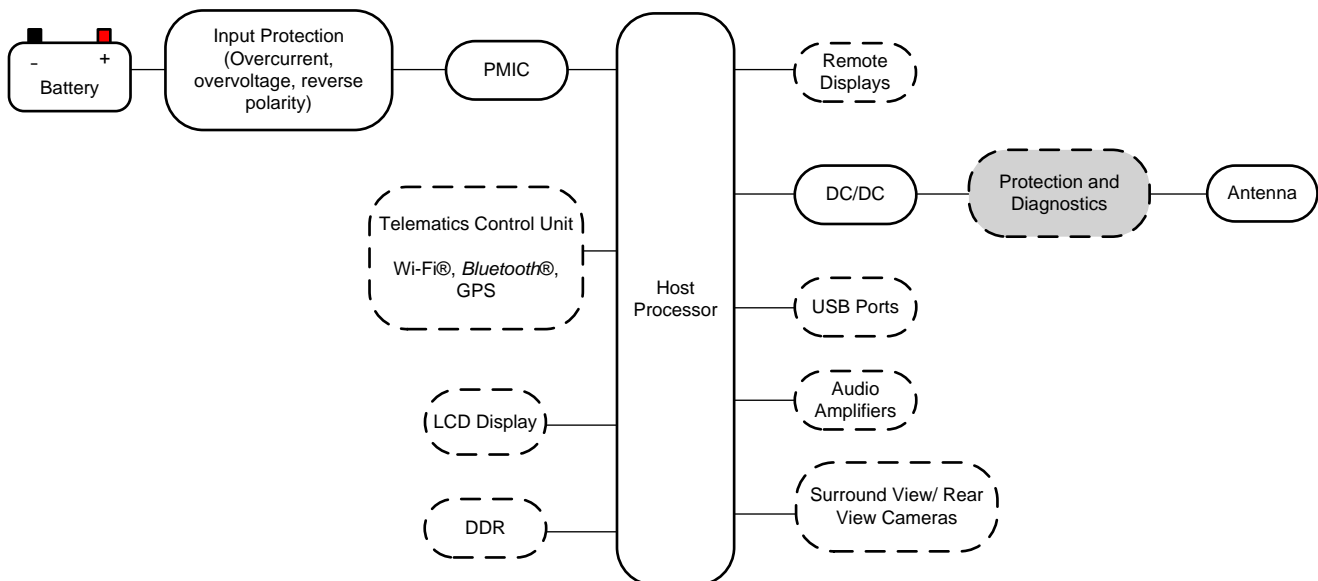


图 1. Typical Block Diagram of Automotive Infotainment System (TI Design Highlighted)

1.1 Key System Specifications

表 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

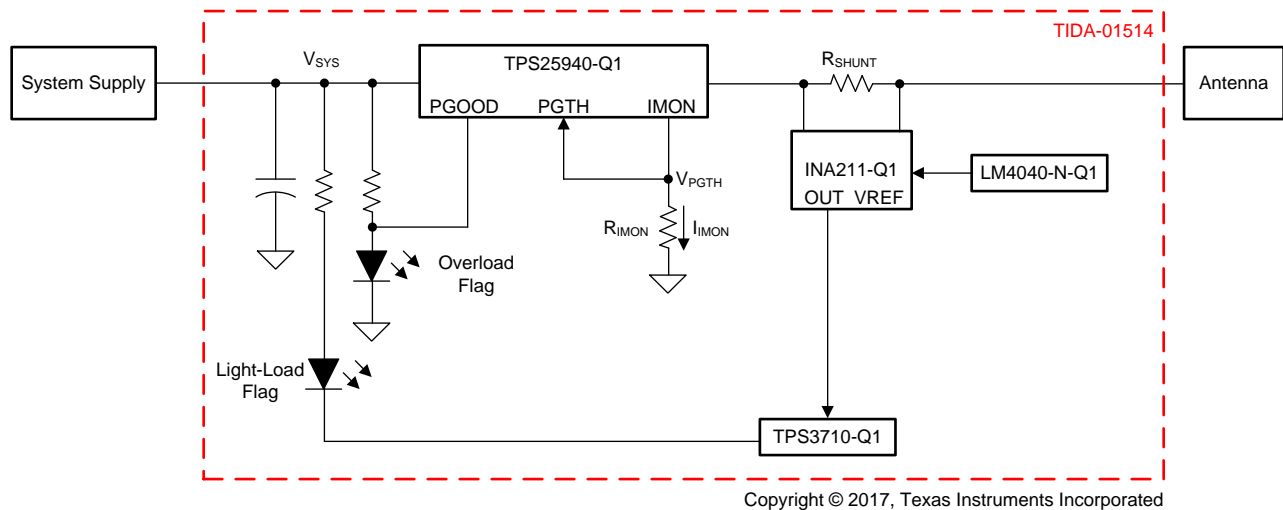


图 2. TIDA-01514 Block Diagram

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 m Ω (typical)
- 0.6-A to 5.3-A adjustable current limit ($\pm 8\%$)
- I_{MON} current indicator output ($\pm 8\%$)
- Adjustable undervoltage and overvoltage threshold ($\pm 2\%$)
- Reverse current blocking
- 1- μ s 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 , 75 V/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: $\pm 100\text{ }\mu\text{V}$ (maximum); enables shunt drops of 10-mV full scale
- Accuracy:
 - $\pm 1\%$ gain error (maximum over temperature)
 - $0.5\text{-}\mu\text{V}/^\circ\text{C}$ offset drift (maximum)
 - $10\text{-ppm}/^\circ\text{C}$ gain drift (maximum)
- Quiescent current: $100\text{ }\mu\text{A}$ (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 $60\text{ }\mu\text{A}$. 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 $\pm 0.1\%$ (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): $\pm 0.1\%$ (maximum)
- Low output noise (10 Hz to 10 kHz): $35\text{ }\mu\text{V}_{\text{RMS}}$ (typical)
- Wide operating current range: $60\text{ }\mu\text{A}$ to 15 mA
- Low temperature coefficient: $100\text{ ppm}/^\circ\text{C}$ (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 μ A (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.

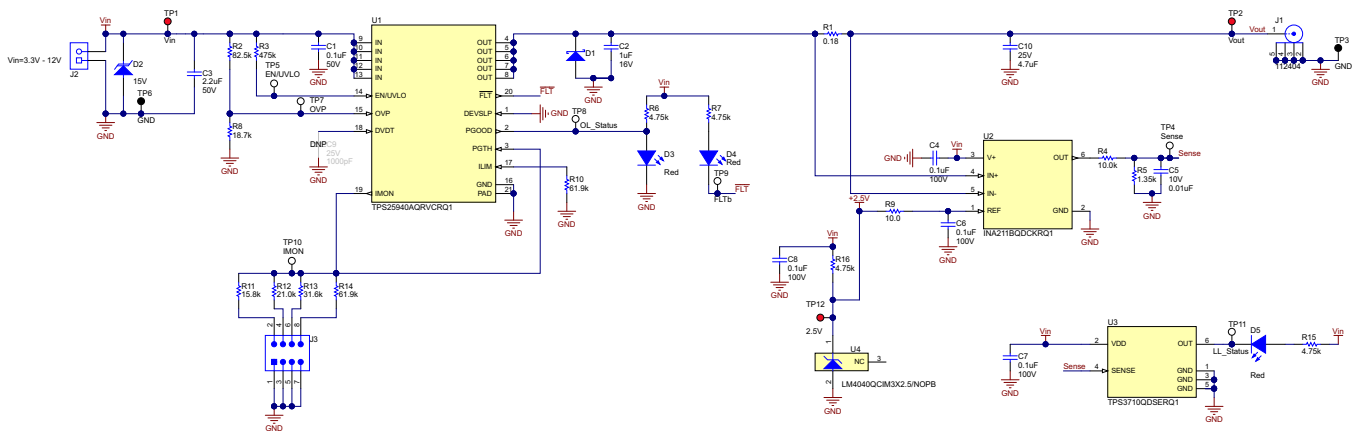
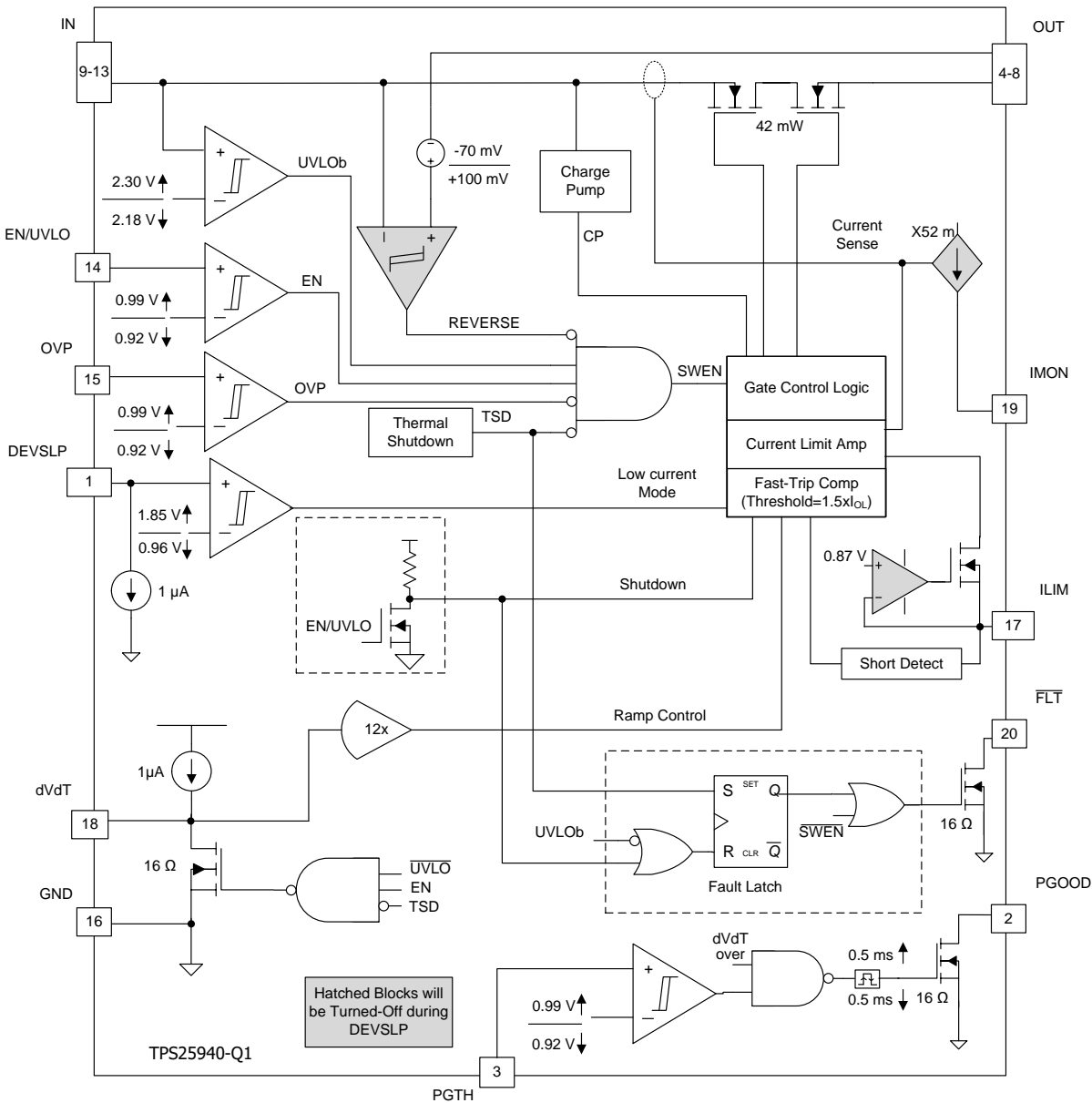


图 3. TIDA-01514 Schematic Circuit

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 图 4.



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图 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.

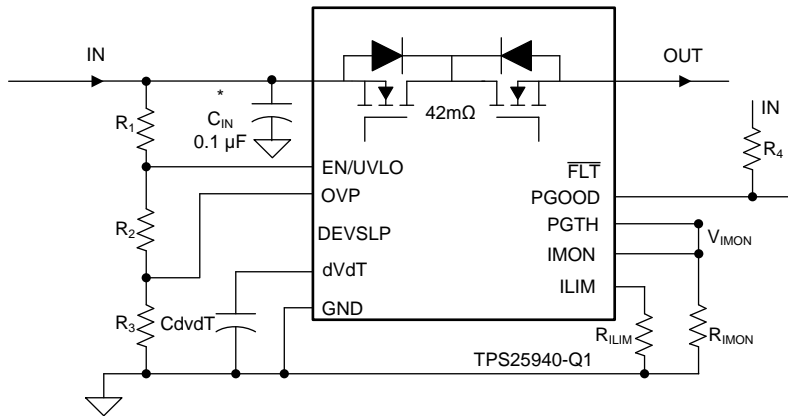
公式 1 calculates the output voltage at the IMON terminal:

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

where,

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

The power good comparator has an internal reference of $V_{PGTHR} = 0.99\text{ V}$ 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} . 图 5 shows the circuit configuration of the TPS25940-Q1 eFuse for detecting an overcurrent event.



*Optional and only for noise suppression

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图 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 公式 2.

$$V_{IMON} = V_{PGTHR} = (I_{OUT} \times GAIN_{IMON}) \times R_{IMON}$$

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

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 $\pm 8\%$ 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 公式 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_{FASTTRIP} . This trip threshold is set to more than 50% of the programmed overload current limit ($I_{\text{FASTTRIP}} = 1.5 \times I_{\text{LIM}} + 0.375$). 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 k Ω to set the overload current limit I_{LIM} at 1.44 A (20% higher than the continuous load current) and fast-trip threshold I_{FASTTRIP} 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 [公式 4](#) to calculate the values required for setting the overvoltage.

$$V_{\text{OVPR}} = \frac{R_8}{R_8 + R_2} \times V_{\text{OV}} \quad (4)$$

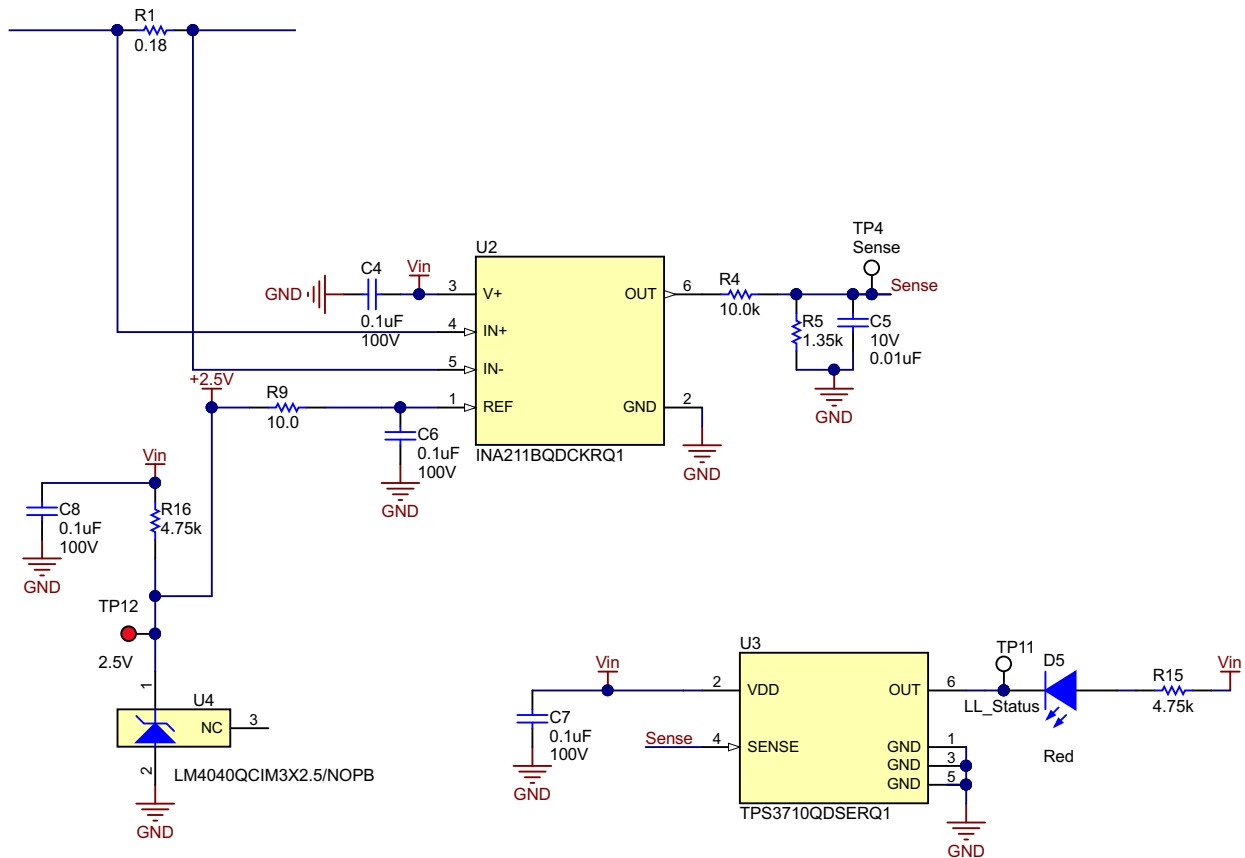
where,

- 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 k Ω and then use [公式 4](#) to solve for $R_2 = 82.5$ k Ω .

2.3.5 Open-Load Detection

图 6 显示了用于开路检测的电路原理图。跨串联电流检测电阻的电压使用电流分流监测器 INA211-Q1 进行放大。公式 5 给出了 INA211-Q1 的输出。



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图 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 k Ω and 1.35 k Ω , respectively.

2.3.6 Flag Outputs

This reference design has various flag outputs to indicate the nature of a fault event to the MCU. 表 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.

表 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

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

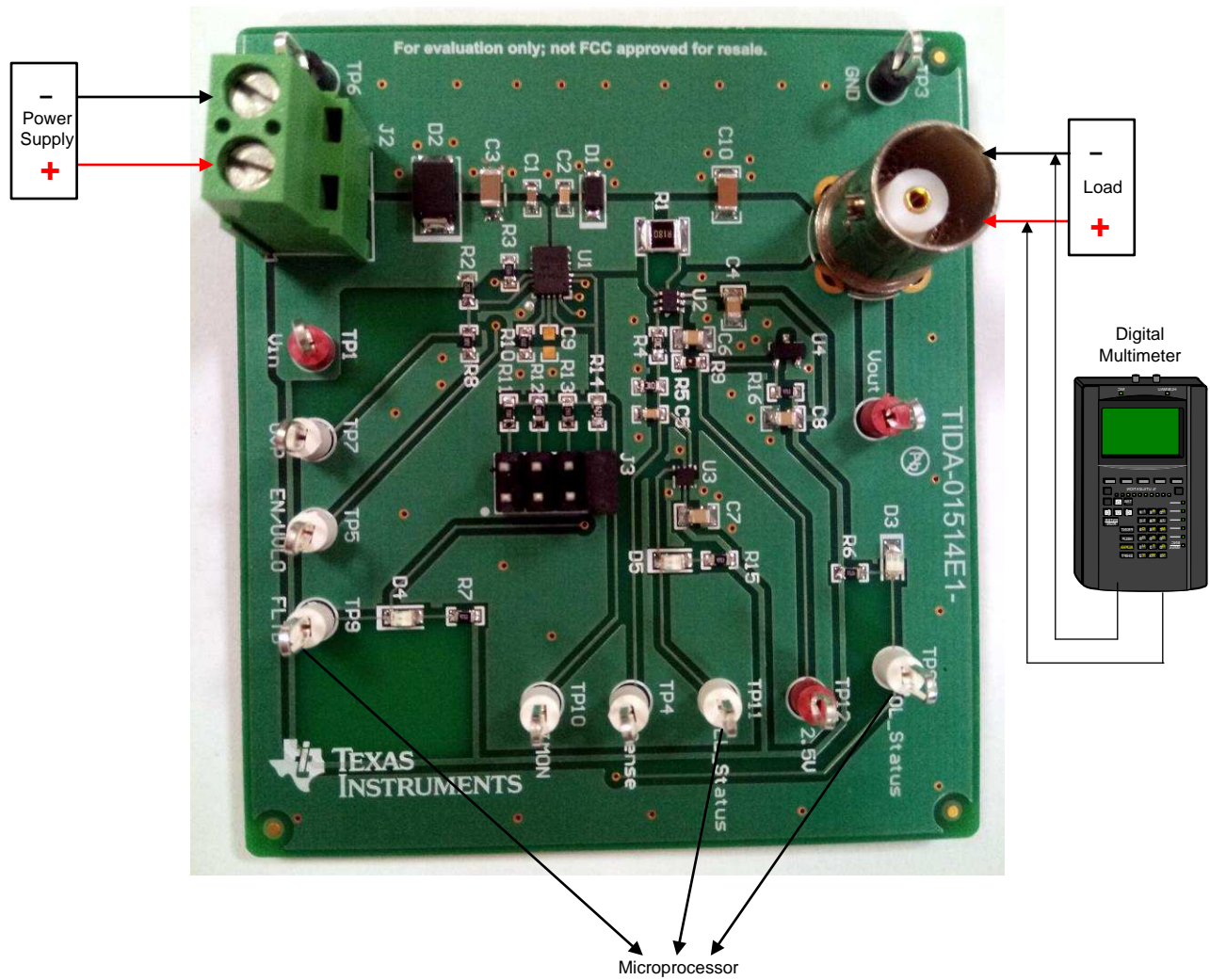


图 7. Hardware Connection Setup

表 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

图 8 shows the TIDA-01514 test setup.

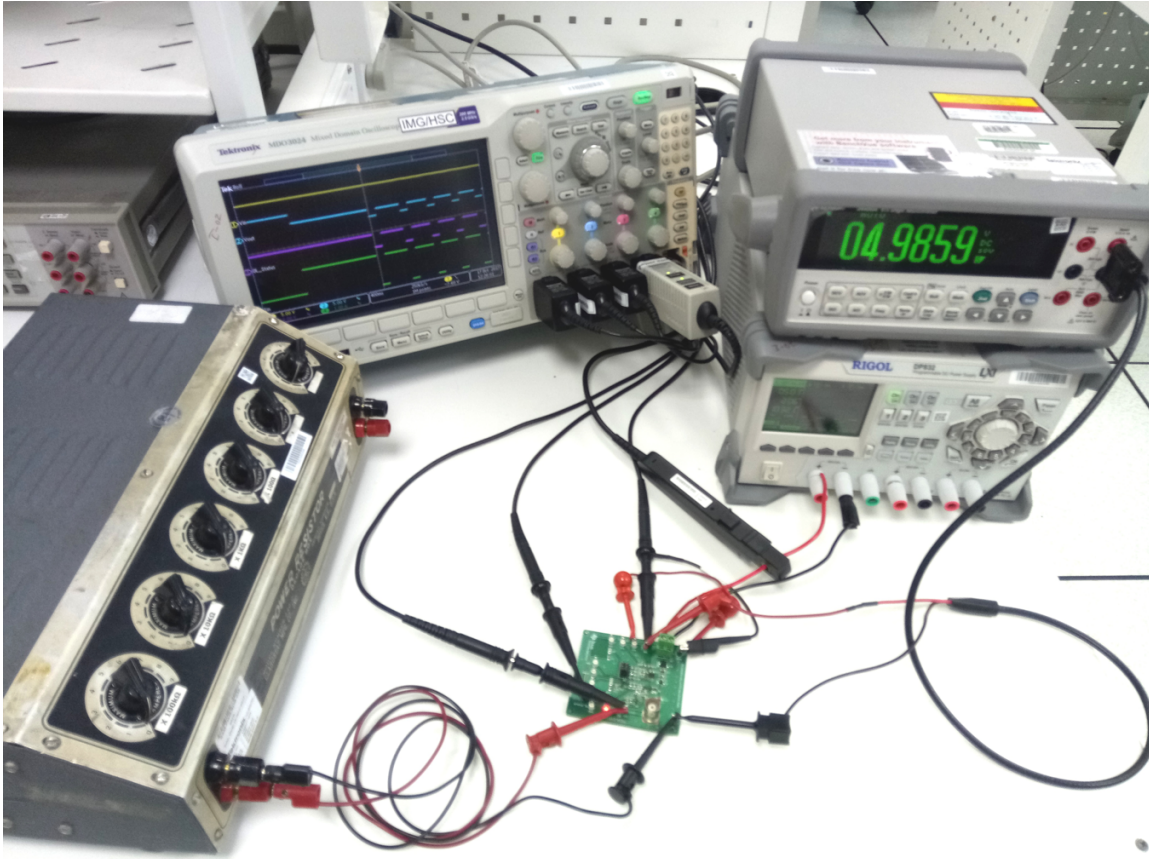


图 8. Test Setup

3.2.2 Test Results

3.2.2.1 Overload Test

In this test case, the overload threshold was set at 300 mA. 图 9 shows the overload flag status when the load was changed from 150 mA to 600 mA and back. As 图 9 shows, the overload status (OL_Status) becomes active HIGH when the load current crosses 300 mA. 图 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.

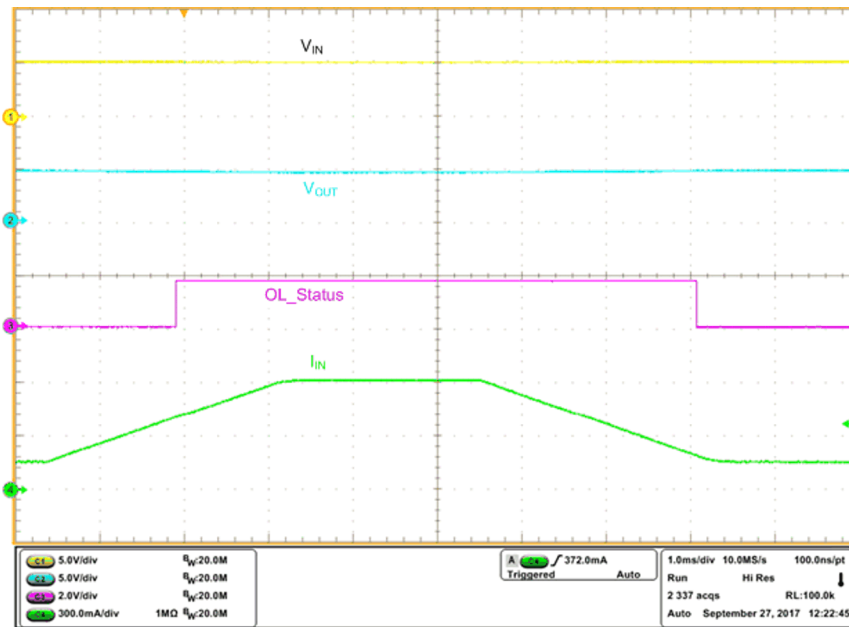


图 9. Overload Flag Status for Change in Load From 150 mA to 600 mA and Back

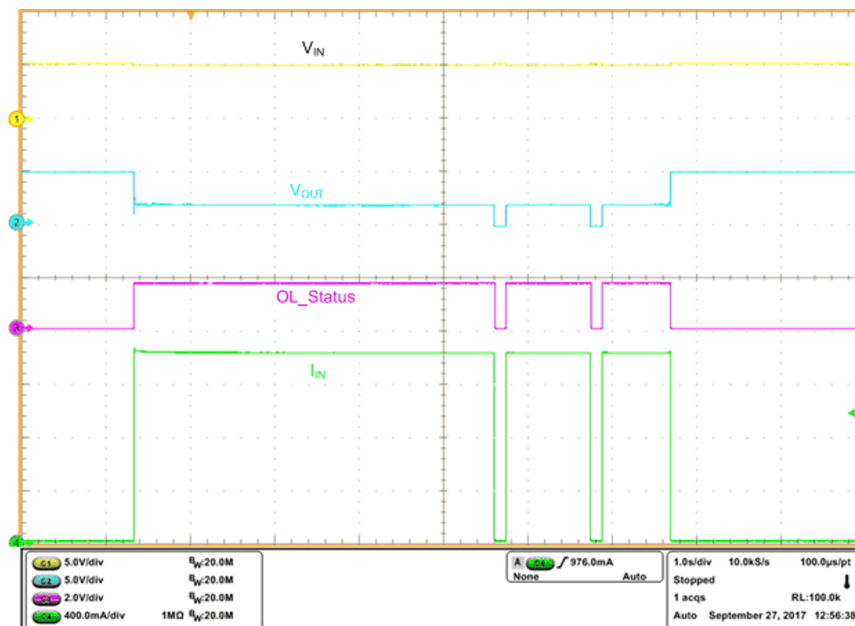


图 10. Overload Response and Recovery From Overload Fault

3.2.2.2 Light-Load Detection Test

图 11 和 图 12 显示了在 5 V 和 12 V 供电电压下的轻负载标志状态。当负载电流降至 10 mA 以下时，LL_Status 变为主动低电平。可以轻松检测到开路负载条件。

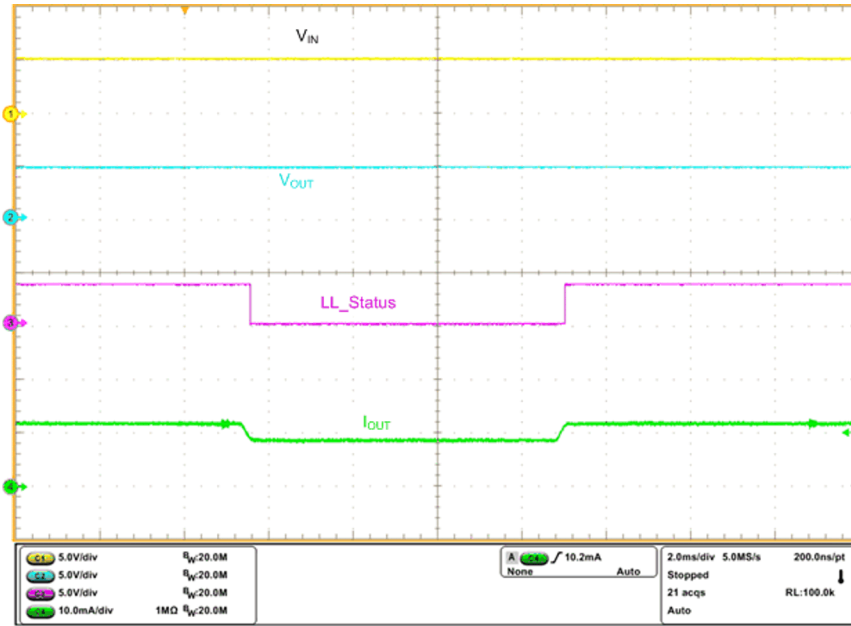


图 11. Light-Load Flag Status for Change in Load from 11 mA to 8 mA and Back at $V_{IN} = 5\text{ V}$

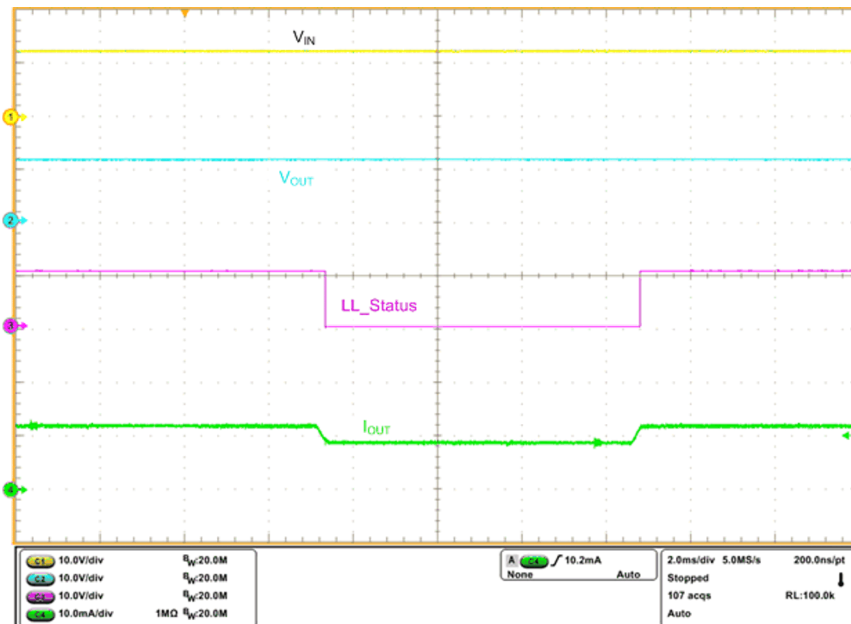


图 12. Light-Load Flag Status for Change in Load from 11 mA to 8 mA and Back at $V_{IN} = 12\text{ V}$

3.2.2.3 Short-Circuit Protection

图 13 显示了系统的热短路行为。快速跳闸比较器立即关闭内部 FET 并将系统迅速切换到电流限制模式。图 14 显示了当系统唤醒时输出端短路的情况。在这种情况下，系统启动时进入电流限制模式。

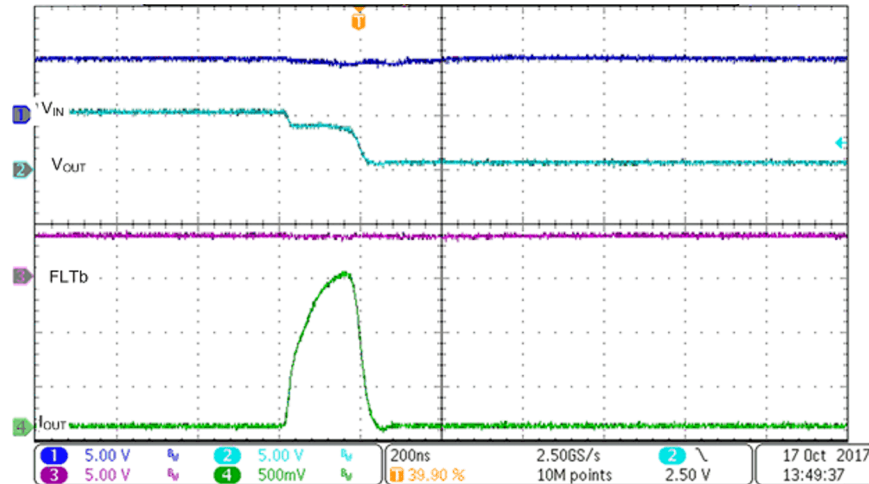


图 13. Hot-Short Response With Current Limit at 1.44 A

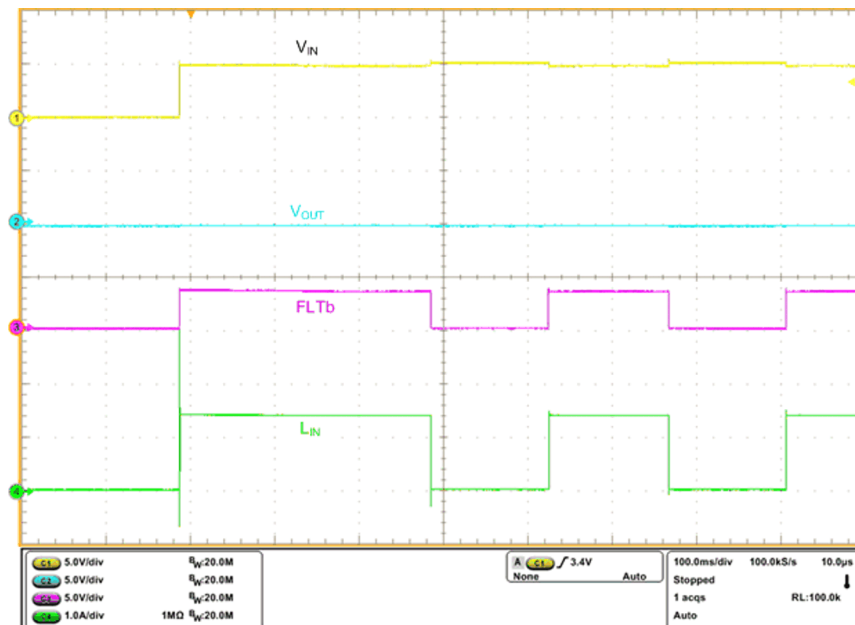


图 14. Hot-Plug Response With Short on Output

3.2.2.4 Short-to-Battery Protection

图 15 显示了 TPS25940-Q1 设备在短路到电池故障下的性能。在此测试案例中，输入电源电压为 5 V，输出短路到 12 V（电池电压）。FLTb 输出在短路到电池故障时变为主动低电平。

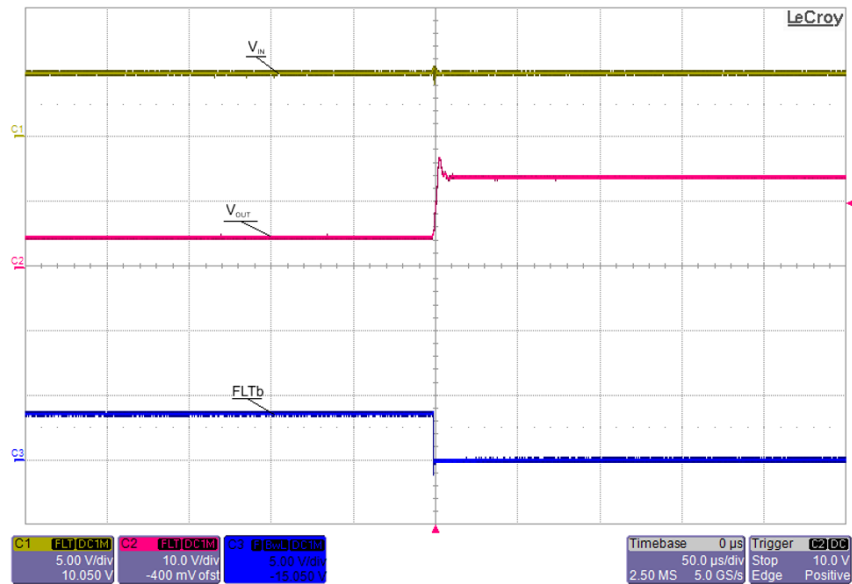


图 15. Response of TPS25940-Q1 During Output Short-to-Battery Fault

3.2.2.5 Overvoltage Protection

图 16 演示了设备对输入过电压故障的响应。TPS25940-Q1 设备在输入电压超过 5.35 V 的过电压跳变电平时关闭。

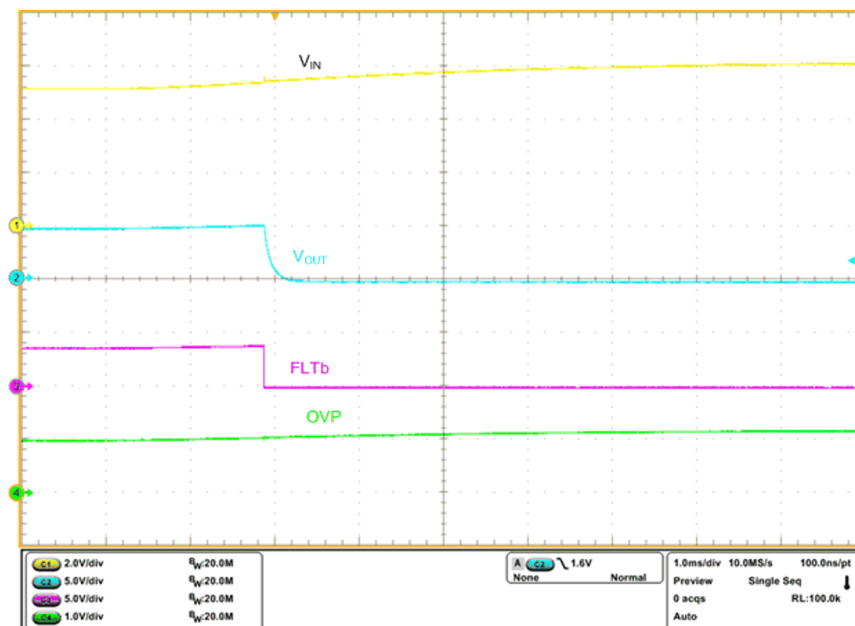


图 16. Output Voltage Cutoff for Overvoltage Condition

3.2.2.6 Dropout Voltage

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

表 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 商标

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邮寄地址：上海市浦东新区世纪大道 1568 号中建大厦 32 楼，邮政编码：200122
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