TI Designs
TPS1H100-Q1 40-V, 100-mΩ, Smart High-Side Switch as Inrush Current Limiter Reference Design

Design Overview

Inrush current is a common design issue when driving a big capacitive load. This design offers a solution to the Texas Instrument's new generation, smart, high-side switch TPS1H100-Q1 by introducing an adjustable current limit function, which can clamp the inrush current effectively.

A typical application acts as a power switch for the remote display in the automotive infotainment system. The TIDA-00866 design not only offers protective measures and diagnostics for the off-board load, but also clamps the start-up inrush current effectively.

Design Resources

TIDA-00866	Tool Folder Containing Design Files
TPS1H100-Q1	Product Folder

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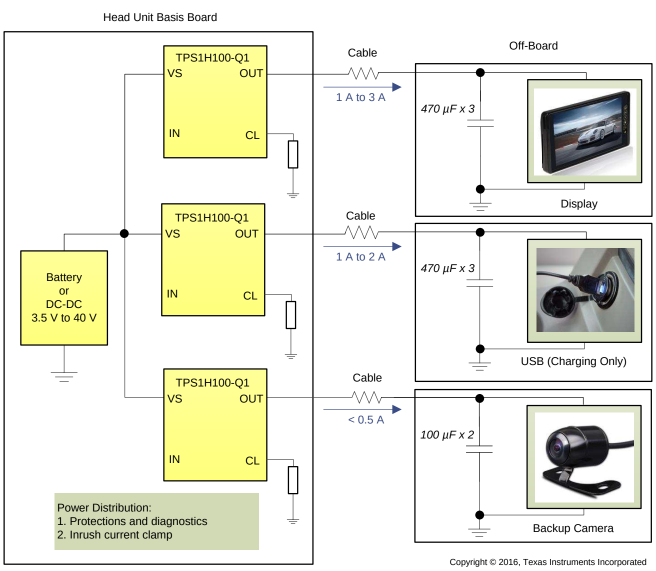
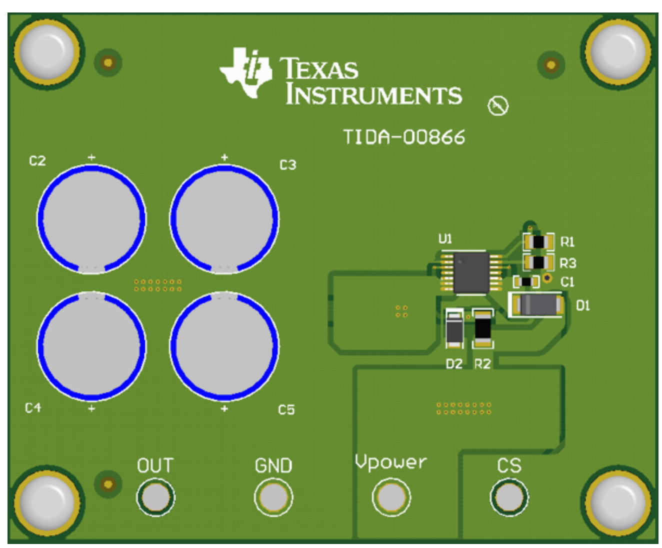
Design Features

- Clamp Inrush Current Effectively
- Provide Full Diagnosis for Off-Board Load
- Save Size With Integrated FET
- Wide Supply Range From 3.5 V to 40 V

Featured Applications

- Applications With Large Capacitive Loads
- Applications With Hot Plug-in and Plug-out
- Applications With Short-to-GND Risk





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1 Key System Specifications

Table 1. Key System Specifications

PARAMETER	SPECIFICATION
Supply voltage	5- to 36-V DC
Output current	1 A
Current limit setting value	2.5 A
Output capacitance	470 µF × 5

2 System Description

The TIDA-00866 reference design provides a solution to clamp the inrush current. The inrush current is mostly a result of abrupt, low impedance in two scenarios: driving a large capacitive load or the condition of a hot plug-in or plug-out.

To help solve the issue of inrush current, this TIDA-00866 TI Design first introduces the programmable current limit function into the field of conventional, high-side switches. Users can easily set the current limit by connecting one external resistor to the current limit pin. The external resistor is used to convert a proportional load current into a voltage, which is compared with an internal reference voltage. When the voltage on a current limit pin exceeds the reference voltage, the current is clamped.

The TIDA-00866 reference design mainly focuses on the implementation of inrush current clamping.

A typical application acts as a power switch for the remote display in the automotive system. The remote display is powered by the infotainment main board with a long cable. The design enables various protective measures and diagnostics for the off-board load, including the short-to-GND, short-to-overload, short-to-supply, open load, and thermal faults. The design can also clamp the start-up inrush current effectively, which mostly originates from the charging current for the input capacitors.

3 Block Diagram

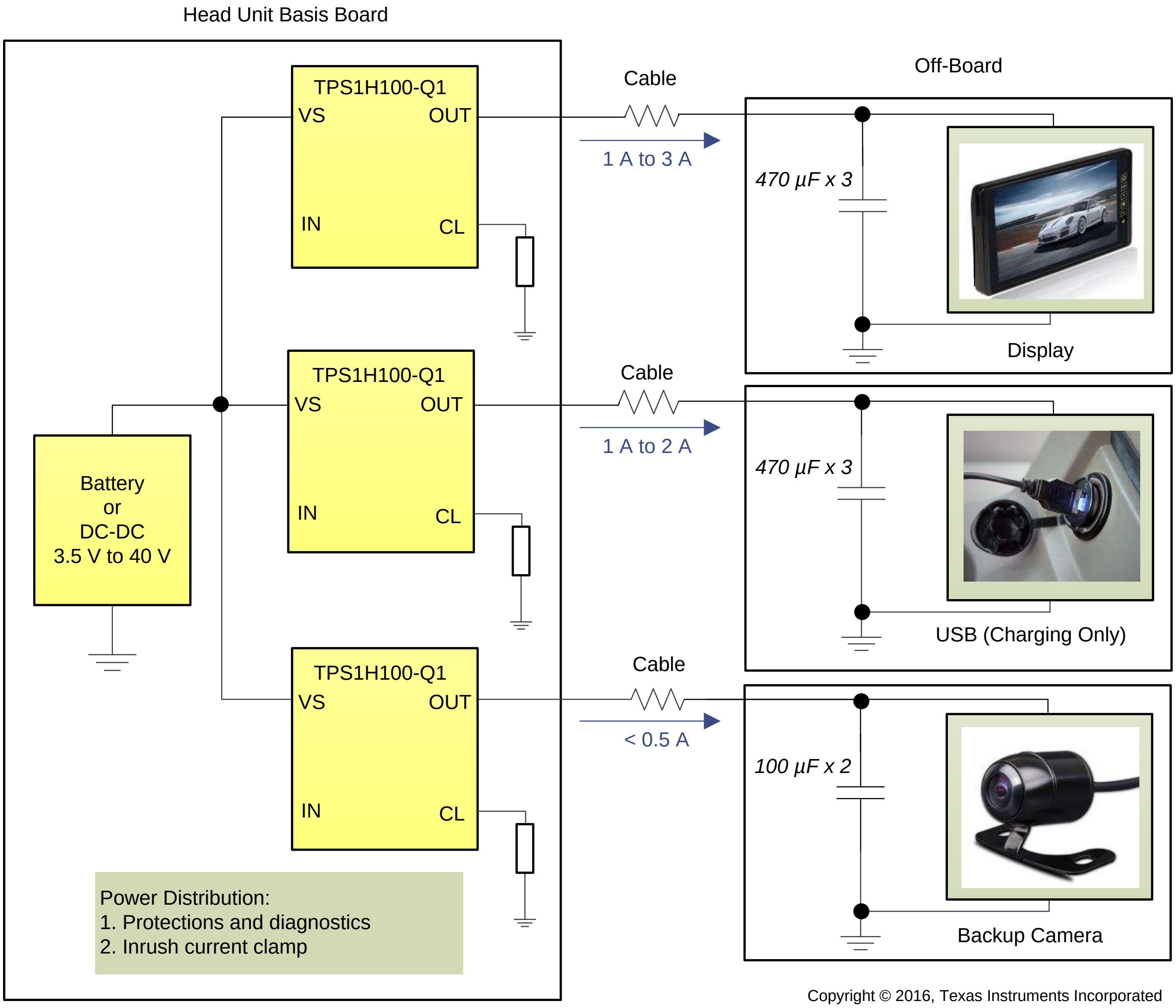

Figure 1. System Block Diagram of Inrush Current Clamping

3.1 Highlighted Products

The TIDA-00866 reference design features the following smart high-side switch from Texas Instruments (TI).

- TPS1H100-Q1: 40-V, 100-mΩ high-side smart switch with adjustable current limit feature

The key features for selecting the devices for this reference design are explained in the following sections. The complete details of these devices can be referred in the respective product folders at www.ti.com.

3.1.1 TPS1H100-Q1

The TPS1H100-Q1 is a fully protected, single-channel, high-side power switch with integrated NMOS power FET and charge pump. Full diagnostics and high-accuracy current sensing features enable intelligent control of the load. The device diagnostic reporting has two versions to support both digital status and analog current sense output. The TPS1H100-Q1 also passes the 1 million times short to GND test according to AECQ100-12 grade A.

An external, high-accuracy current limit allows the user to set the current limit value by application. This current limit highly improves the reliability of the system by clamping the inrush current effectively, under start-up or short-circuit conditions. The external current limit can also save on system cost by reducing the printed circuit board (PCB) trace, connector size, and the preceding stage power capacity. Internal current limit is also implemented in this device. The smaller value of the external or internal current limits is applied.

4 System Design Theory

A smart power high-side switch is a device with protection and diagnosis features which enables a system to easily function with high reliability and achieve intelligent fault detection. These switches are widely used in automotive and industrial applications, for example, as a power switch for a rear view camera or a liquid crystal display (LCD) screen in an entertainment system.

One common design obstacle for such an application is a large inrush current, which mostly arises because of abrupt low impedance in two scenarios: driving a big capacitive load or the hard short circuitry. Carefully consider the pre-stage power margin, post-stage device stress, or even entire PCB traces and the sizes of connectors to overcome this obstacle.

Current limit function is presently implemented in most high-side switches. The threshold limit for these switches is internally fixed because of their use in driving high wattage bulbs in automotive body control modules (BCMs); however, for other types of loads, the fixed value is too large to be effective for clamping and protection. For example, some customers tend to use a 100-mΩ R_{ON} device to drive an audio speaker amplifier module in which the nominal current is only 1 A but with two units of 470-uF input caps. For a traditional high-side switch, the fixed current limit value is larger than 10 A, so the inrush current increases up to 13 A intensely. This type of increase is problematic for the whole system design.

Texas Instruments (TI) has introduced the programmable current limit function to offer a solution to limit the overshoot of the inrush current. The TIDA-00866 reference design uses the smart high-side switch TPS1H100-Q1 to demonstrate the implementation of inrush current limiter functions.

4.1 Adjustable Current Limit

A current limit protects a load and integrated power field effect transistor (FET) from overstressing. A current limit remains at a set value and pulls the CS pin up to V_{CS_H} as diagnostic report. Two types of current limit thresholds exist:

- External programmable current limit: An external resistor is used to convert a proportional load current into a voltage, which is compared with an internal reference voltage, V_{CL_TH}. When the voltage on the CL pin exceeds V_{CL_TH}, a closed loop immediately activates. V_{GS} voltage regulates accordingly, which leads to the V_{DS} voltage regulation. After the closed loop has been set up, the current is finally clamped at the set value.
- Internal current limit: Internal current limit is fixed and typically 10 A. To use internal current limit for large current applications, ensure that the CL pin has been tied directly to the device GND.

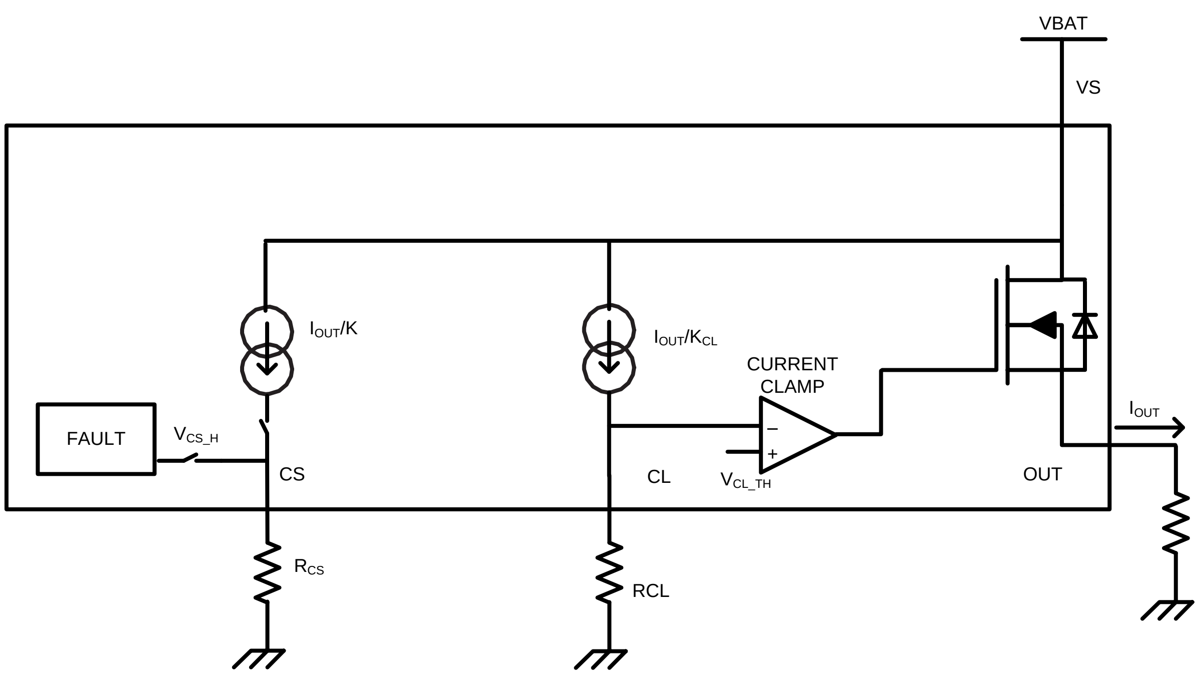

Figure 2. Current Sense and Current Limit Functions

4.2 Accurate Current Sense

The high-accuracy current sense function is internally implemented in the TPS1H100-Q1 (Version B only), which allows better real-time monitoring and more accurate diagnostics without further calibration. A current mirror is used to source 1 / K of the load current, which flows out to the external resistor between the CS pin and GND and is reflected as voltage on the CS pin.

"K" is the ratio of the output current and the sense current, which is a constant value across the temperature and supply voltage. Each device has been internally calibrated during production, so post calibration by users is not required in most cases. Ensure that the CS voltage is in the linear region (0 – 4 V) during normal operation.

When a fault condition occurs, the CS pin functions as a diagnostics report pin. When an open load or short-to-battery occurs in the ON state, V_{CS} is almost equal to zero. When a current limit, thermal shutdown, thermal swing, open load, or short-to-battery occurs in the OFF state, the voltage is pulled up to V_{CS_H}.

The following Figure 3 shows a typical current sense voltage according to the operating conditions, including fault conditions.

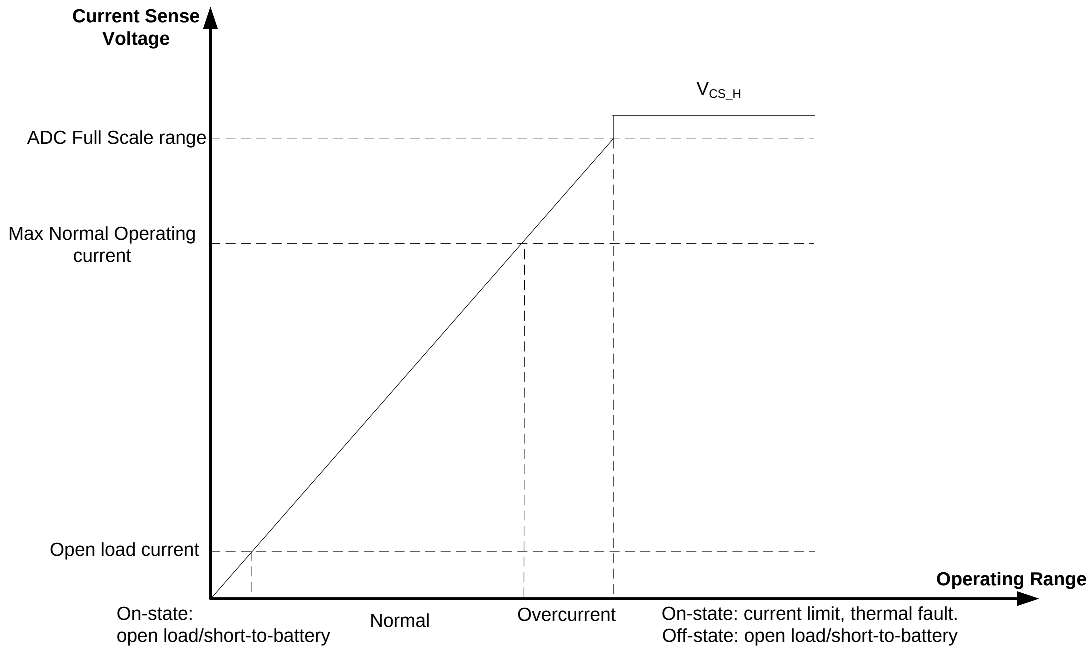

Figure 3. Current Sense Voltage Range

5 Getting Started

5.1 Current Sense Resistor

Calculate RCS by using the following formula in Equation 1:

$$R_{CS} = \frac{V_{CS}}{I_{CS}} = \frac{V_{CS} \times K}{I_{OUT}} \tag{1}$$

The nominal current target for the TIDA-00866 design is 1 A. To achieve a better voltage linear range, the V_{CS} has been set to 2 V, as the following Equation 2 shows.

$$R_{CS} = \frac{V_{CS}}{I_{CS}} = \frac{V_{CS} \times K}{I_{OUT}} = \frac{2 \times 500}{1} = 1\,\text{K}\Omega \tag{2}$$

When a fault condition occurs, the CS pin voltage is pulled up to V_{CS_H}, which means that I_{CS} can be calculated as the following Equation 3:

$$I_{CS} = \frac{V_{CS}}{R_{CS}} = \frac{4.9}{1000} = 4.9\text{ mA} < I_{CS\_H} = 10\text{ mA} \tag{3}$$

5.2 Current Limit Resistor

Calculate the current limit resistor using the following formula in Equation 4:

$$I_{CL} = \frac{V_{CL\_TH}}{R_{CL}} = \frac{I_{OUT}}{K_{CL}}$$

$$R_{CL} = \frac{V_{CL\_TH} \times K_{CL}}{I_{OUT}} \tag{4}$$

The current limit target for the TIDA-00866 design is 2.5 A.

$$R_{CL} = \frac{V_{CL\_TH} \times K_{CL}}{I_{OUT}} = \frac{1.233 \times 2000}{2.5} = 986.4\ \Omega \approx 1\,\text{K}\Omega \tag{5}$$

6 Test Data

The test data in this section applies to the parameters specified in this user's guide. For alternative configurations, TI recommends to consult the datasheets of the cited devices.

NOTE: All of the measurements in this section have been measured with calibrated lab equipment.

6.1 Test Equipment

The following Table 2 shows the test equipment used throughout testing.

Table 2. Test Equipment

TEST EQUIPMENT	MODEL
Power supply	Agilent E3634A
Oscilloscope	Tektronix DPO4104
Multimeter	Agilent E34401A
Loads	Power resistors

6.2 Test Conditions

The following waveforms have been tested under these conditions: V_S = 13.5 V, I_{OUT} = 1 A, and the output consists of five units of 470-µF electrolytic capacitors in parallel.

6.3 Test Waveforms

Figure 4 shows a zoomed-in waveform under a 25°C ambient temperature. As this waveform shows, when the current limit has been set to 2.5 A, the biggest overshoot is 2.9 A. The loop settling duration is around 50 µs. The CS pin is pulled high to 4.8 V as a fault indication.

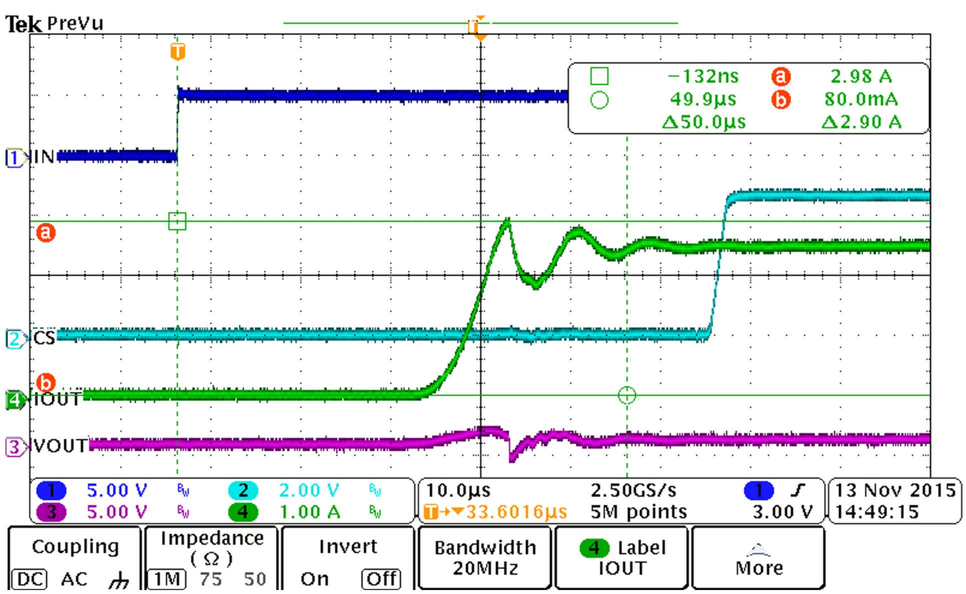

Figure 4. Zoomed-in Waveform Under 25°C Ambient Temperature

Figure 5 shows a zoomed-out waveform under a 25°C ambient temperature. The output capacitors are fully charged after an approximate 14 ms of charging. During the testing, the current sense pin jumps into the normal operation region to reflect the output current data. No unexpected thermal behaviors are triggered during the entire charging cycle.

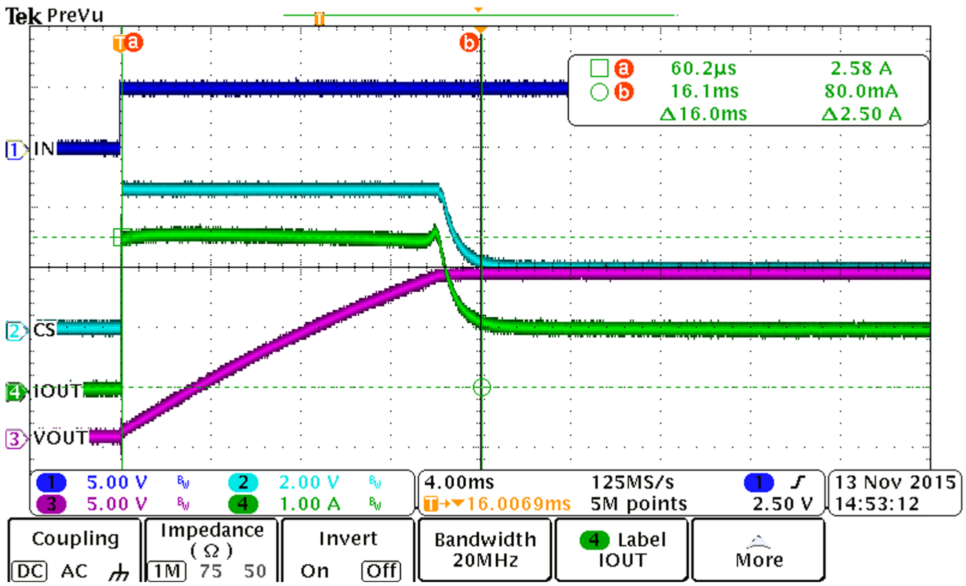

Figure 5. Zoomed-out Waveform Under 25°C Ambient Temperature

Figure 6 shows a zoomed-in waveform under a 85°C ambient temperature.

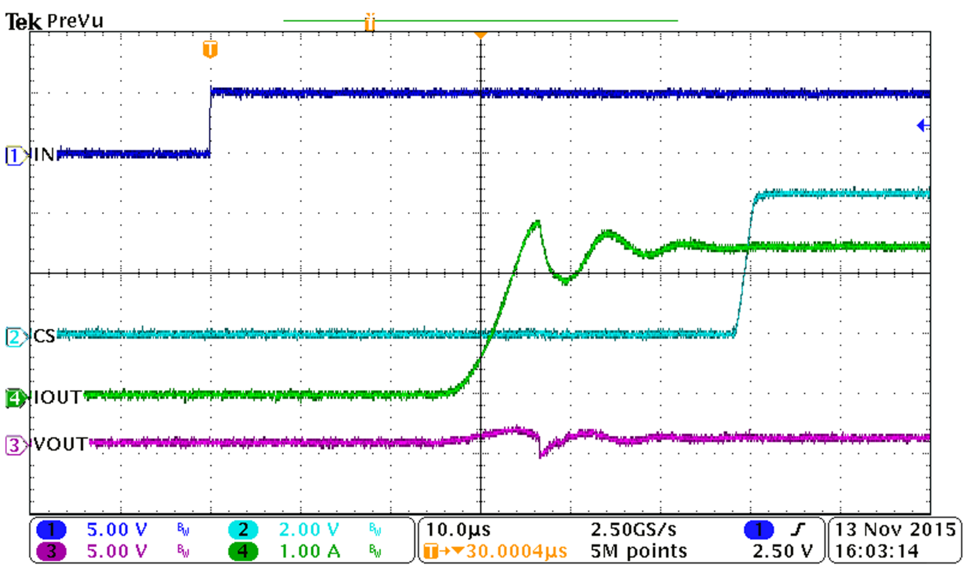

Figure 6. Zoomed-in Waveform Under 85°C Ambient Temperature

Figure 7 shows a zoomed-out waveform under a 85°C ambient temperature. No unexpected thermal behaviors are triggered during the entire charging cycle.

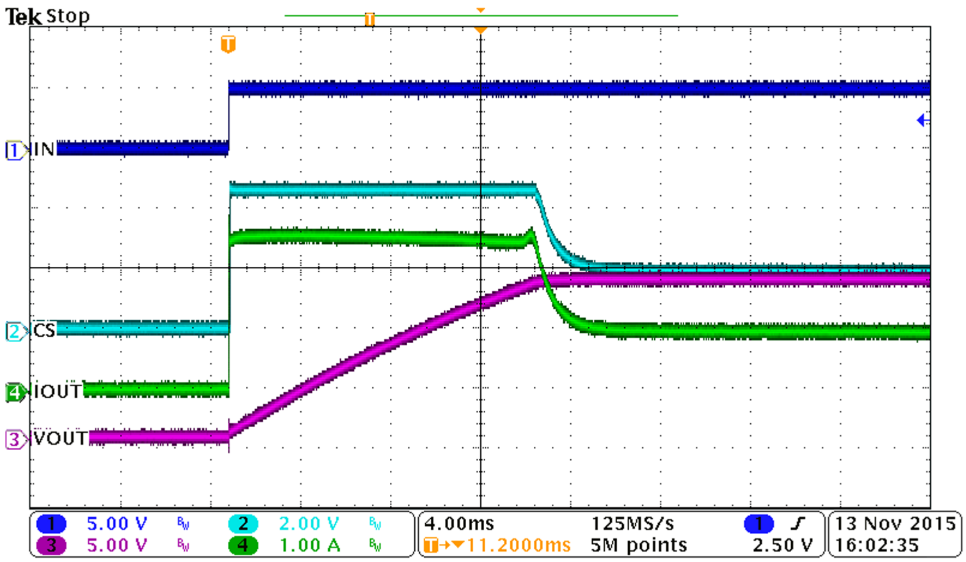

Figure 7. Zoomed-out Waveform Under 85°C Ambient Temperature

Figure 8 shows a waveform of an output open load or short-to-battery. The channel enable signal IN remains on during this test. When an open load or short-to-battery occurs, the output current drops down to zero and the CS pin accurately monitors the real-time output current. The user can observe the current information and make decisions based on this data.

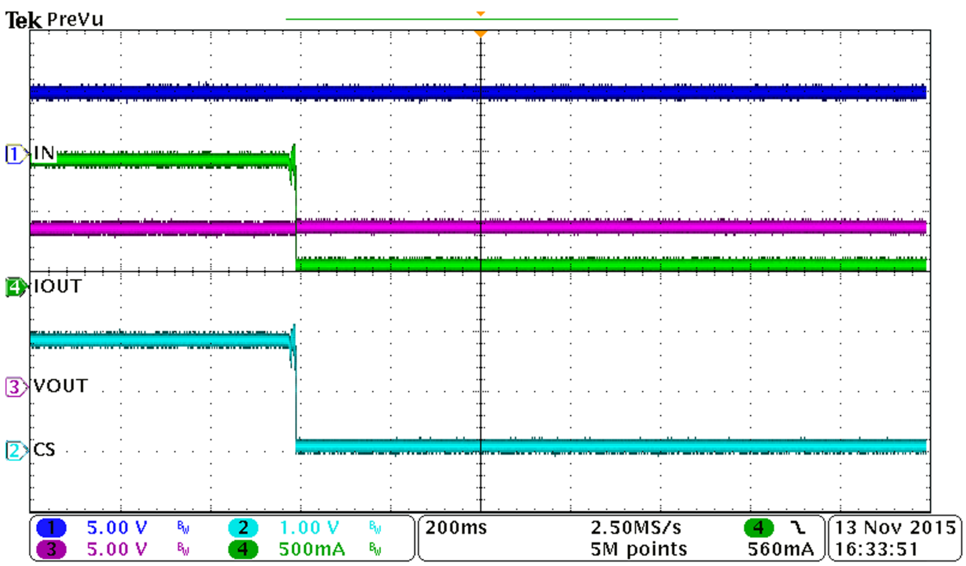

Figure 8. Output Open Load or Short-to-Battery

7 Design Files

7.1 Schematics

To download the Schematics, see the design files at TIDA-00866.

7.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-00866.

7.3 PCB Layout Recommendations

To prevent thermal shutdown, the junction temperature (TJ) must be less than 150°C. If the output current is very high, the power dissipation may be large. The HTSSOP package has good thermal impedance; however, be sure to consider the PCB layout, as this is also a very important variable. A well-designed PCB can optimize heat transfer, which is absolutely essential for the long-term reliability of the device.

- Maximize the copper coverage on the PCB to increase the thermal conductivity of the board, because the major heat-flow path from the package to the ambient is through the copper on the PCB. A maximum amount of copper coverage is extremely important when the PCB does not have any heat sinks attached on the other side of the package.
- Add as many thermal vias as possible directly under the package ground pad to optimize the thermal conductivity of the board.
- All thermal vias must be either plated shut or plugged and capped on both sides of the board to prevent solder voids. To ensure reliability and performance, the solder coverage is recommended to be at least 85%.

7.4 Layout Prints

To download the layout prints, see the design files at TIDA-00866.

7.5 Layout Guidelines

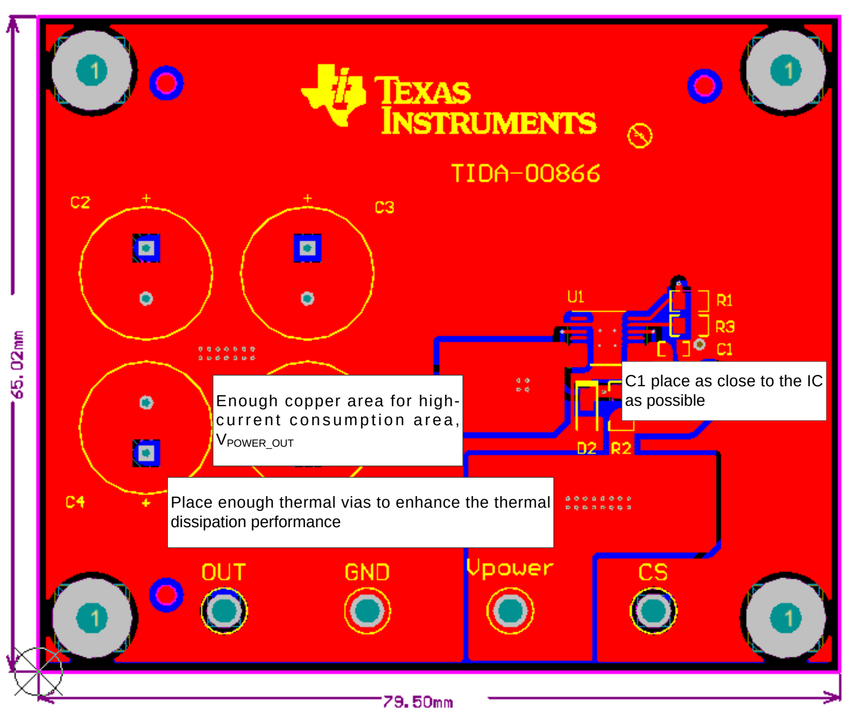

Figure 9. Layout Guidelines

7.6 Altium Project

To download the Altium project files, see the design files at TIDA-00866.

7.7 Gerber Files

To download the Gerber files, see the design files at TIDA-00866.

7.8 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-00866.

8 References

1. Texas Instruments, *PS1H100-Q1 40-V, 100-mΩ Single-Channel Smart High-Side Power Switch*, TOS1H100-Q1 Datasheet (SLVSCM2)

9 About the Author

ALEX WANG is the System Engineer at Texas Instruments. He is responsible for the smart high side switch development and support in the AVL product line of Mixed Signal Automotive (MSA).

Revision History A

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

Changes from Original (February 2016) to A Revision **Page**

- Added a paragraph to *Design Overview* section 1
- Changed to updated block diagram and added copyright 1
- Added a paragraph to *System Description* section 3

Revision History B

Changes from A Revision (May 2016) to B Revision **Page**

- Changed to another updated block diagram 1
- Changed to another updated block diagram 4

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