TI Designs: TIDA-01184
座席ヒーター用スマート電源スイッチのリファレンス・デザイン

TEXAS INSTRUMENTS

概要

このシステムでは、座席ヒーター、エアコン、デフロスター、グロー・プラグ、タンク・ヒーターなど、あらゆる種類の制御された車載用発熱体向けの設計を紹介します。このデザインは、メイン基板と、車載用座席ヒーターに見られる抵抗性発熱部品を模した発熱体で構成されており、各座席の温度を個別に制御できます。また、フォルト・イベントに対応するために堅牢な診断および保護機能を備えています。これらの機能を実現するため、本システムはTPS1HA08-Q1デバイスを使用して車載用座席ヒーターの電流供給、診断、保護を行っています。

リソース

TIDA-01184	デザイン・フォルダ
TPS1HA08-Q1	プロダクト・フォルダ
TLC59116-Q1	プロダクト・フォルダ
PCF8574A	プロダクト・フォルダ
CSD17577Q3A	プロダクト・フォルダ
LM74610-Q1	プロダクト・フォルダ
TPS7B67-Q1	プロダクト・フォルダ
TPD6F002-Q1	プロダクト・フォルダ

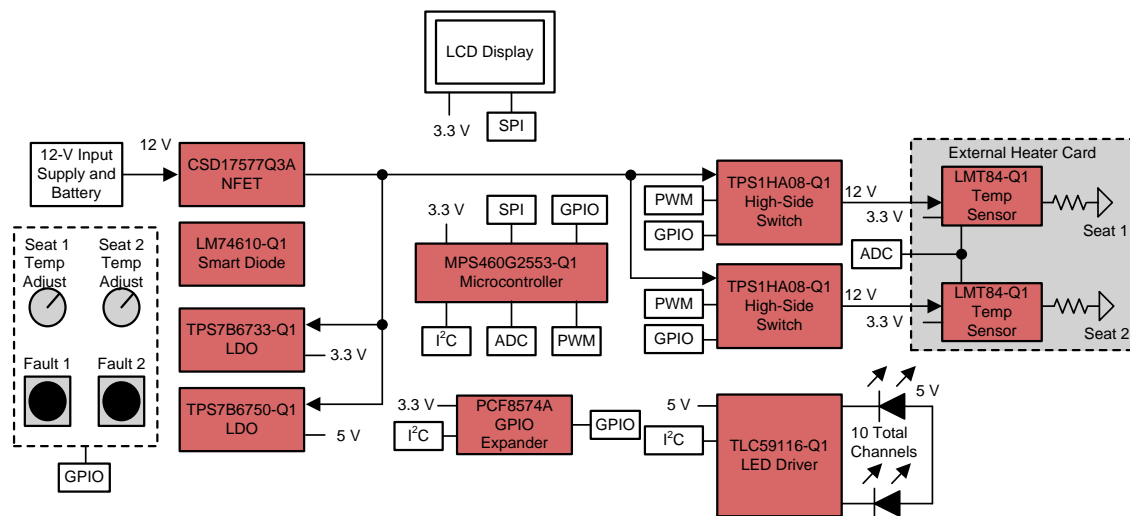TI E2E™ Community   E2E エキスパートに質問

特長

- 抵抗性負荷発熱体をアクティブに監視して制御
- フォルト表示と、負荷電流、電圧、温度を正確に検出するためのアナログ検出出力
- TLC59116-Q1によるLEDステータス表示
- 開放負荷およびバッテリへの短絡の検出

アプリケーション

- 座席ヒーター
- エアコン
- 車体制御モジュール
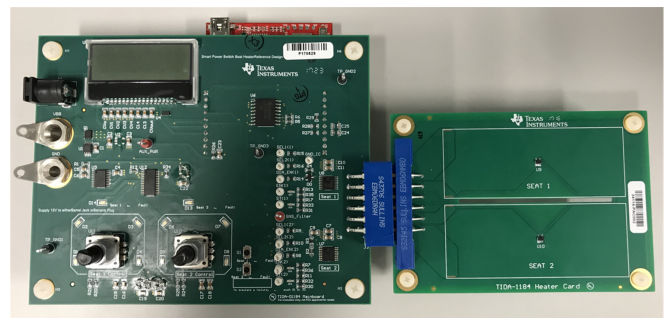
1　System Description

This TI Design showcases a reference design to actively monitor and control an automotive seat heater. The system consists of a main board and heating element, which represents the resistive heating component found inside the seat of a vehicle. This system demonstrates the ability to independently control the temperature of each seat as well as provide robust diagnostics and protection to account for fault events.

The TIDA-01184 TI Design utilizes the accurate current-sensing feature of the TPS1HA08-Q1 smart high-side power switch. Accurate current-sensing features are achieved by connecting the current sense output pin (SNS) to the microcontroller (MCU). Diagnostic information such as device voltage, current, and temperature is relayed back to the main host system. This information can be used to determine the operating conditions of each device and detect whether or not the load is connected properly.

The functionality of the TIDA-01184 emulates full operation of an automotive seat heater. When the seat control knob is rotated, the corresponding smart high-side switch begins to supply current to the load, thus heating up the resistive heating element to the selected temperature setting. The heater card has an onboard LMT84-Q1 analog temperature sensor which provides real-time temperature feedback to the MCU control algorithm, which adjusts the duty cycle of the pulse-width modulated (PWM) signal that drives the smart high-side switch. The TLC59116-Q1 light-emitting diode (LED) driver provides status indication and fault illumination on the selected heat setting, while the liquid-crystal display (LCD) provides more detailed diagnostics such as the exact seat temperature and current consumption of the load.

1.1 Key System Specifications

表 1. Key System Specifications

PARAMETER	SPECIFICATIONS	DETAILS
POWER DELIVERY – HIGH-SIDE SWITCH		
Input voltage range	—	3 V to 28 V
Current limit	—	30 A
Current sense ratio	—	5000
EXTERNAL HEATER CARD		
Resistance of heating element	—	6 Ω per seat
Typical continuous load current	—	2 A per seat
Range of temperature sensor	—	–50°C to 150°C
POWER DELIVERY: 3.3-V LDO		
Input voltage range	—	3.3 V to 40 V
Output voltage	—	3.3 V
POWER DELIVERY: 5-V LDO		
Input voltage range	—	5 V to 40 V
Output voltage	—	5 V
MICROCONTROLLER – SENSING		
ADC reference voltage	—	3.3 V
ADC resolution	—	10 bit
GPIO EXPANDER		
Interface type	—	I^{2}C
GPIO ports	—	8
VISUAL INDICATION – LED DRIVER		
Interface type	—	I^{2}C
Channel current (forward current through each LED)	—	20 mA
Typical LED forward voltage	$V_{FWD,BLUE}$	3.2 V
	$V_{FWD,RED}$	1.9 V

2   System Overview

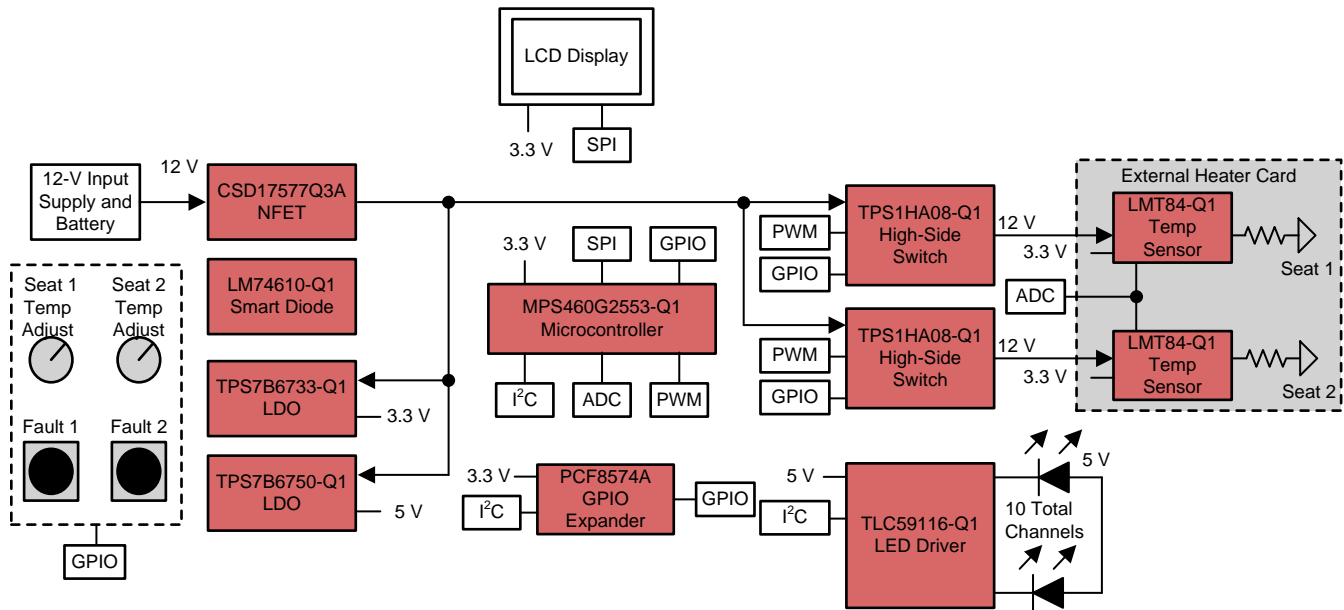### 2.1   *Block Diagram*

図 **1. TIDA-01184 Functional Block Diagram**

2.2   *Design Considerations*

The core of this design implements a regulated seat heating system by controlling two TPS1HA08-Q1 smart power switches to provide power to a resistive heating load. An external MPS460G2553-Q1 microcontroller launchpad provides a PWM signal through the TPS1HA08-Q1 that delivers current to the resistive load. This current dissipates in the resistor to provide heat to the environment to mimic an automotive seat heater. On the seat heater, there are two LMT84-Q1 temperature sensors measuring the temperature and reporting back to the microcontroller. These temperature sensors provide a feedback loop to allow the microcontroller to change the PWM duty cycle and regulate the temperature to a set point. This set point is determined by the temperature adjustment knobs that allow a user to turn the temperature to various seat points from cool to very hot. Depending on the orientation of each of these switches, the feedback loop will ensure that each seat is set to it's respective temperature set point.

In addition to the core functionality, this design also uses various other devices to implement the system. The LM74610-Q1 smart diode driving a CSD17577Q3A NFET allows for reverse current protection on the input 12 V power with a very low voltage drop, which is a requirement given the high levels of current that this system can utilize. The TPS70933-Q1 and the TPS7B6750-Q1 LDO's take the 12 V input power and lower it to 3.3 V and 5 V respectively to power the rest of the system circuitry. The PCF857A GPIO expander enables the system to have enough GPIO's to drive all of the functionality necessary, and the TLC59116-Q1 LED Driver allows the system to have LED feedback to the user so that they can visually verify the temperature and operation of the system. Finally, the system has two fault buttons that simulate a fault in the seat heater. This allows the user to test and verify that the TPS1HA08-Q1 is able to measure fault conditions in the seat heater system and safely turn off the power to the heater, significantly lowering the risk of a fire or burning the user.

2.3 Highlighted Products

2.3.1 TPS1HA08-Q1

The TPS1HA08-Q1 is a single-channel, high-side load switch intended for use with 12-V automotive batteries. The device integrates many protection and diagnostic features.

The device operates with an input voltage down to 3 V, which allows for continued operation during cold crank conditions. The TPS1HA08-Q1 provides a high-accuracy analog current sense that allows for improved diagnostics of complex loads (such as multiple parallel loads driven by the same switch). The TPS1HA08-Q1 is available with both a high current limit and low current limit. The high-current limit option is designed for loads that require a large transient current.

2.3.2 TLC59116-Q1

The TLC59116 is an I^2C-bus-controlled, 16-channel light-emitting-diode (LED) driver that is optimized for red-green-blue-amber (RGBA) color mixing and backlight applications. Each LED output has an 8-bit resolution, fixed-frequency pulse-width modulated (PWM_ controller that operates at 97 kHz with an adjustable duty cycle from 0% to 99.6%.

2.3.3 MSP430G2553-Q1

The Texas Instruments MSP430™ family of ultra-low-power microcontrollers (MCUs) consists of several devices featuring different sets of peripherals targeted for various applications. The architecture, combined with five low-power modes, is optimized to achieve extended battery life in portable measurement applications. The device features a powerful 16-bit RISC CPU, 16-bit registers, and constant generators that contribute to maximum code efficiency. The digitally controlled oscillator (DCO) allows the device to wake up from low-power modes to active mode in less than 1 µs.

The MSP430G2x53 series are ultra-low-power mixed signal MCUs with built-in 16-bit timers, up to 24 I/O capacitive-touch enabled pins, a versatile analog comparator, a 10-bit analog-to-digital converter (ADC), and built-in communication capability using the universal serial communication interface.

The MSP420G2x53 is not populated on this TI Design, but is intended to be used as an external launchpad that connects with the TI Design.

2.3.4 PCF8574A

This 8-bit input/output (I/O) expander for the two-line bidirectional bus (I^2C) is designed for 2.5-V to 6-V VCC operation. The PCF8574A device provides general-purpose remote I/O expansion for most MCU families through the I^2C interface. The device features an 8-bit quasi-bidirectional I/O port (P0–P7), including latched outputs with high-current drive capability for directly driving LEDs. Each quasi-bidirectional I/O can be used as an input or output without the use of a data-direction control signal.

2.3.5 CSD17577Q3A

The CSD17577Q3A is a 30-V, 4.0 mΩ, SON 3.3-mm x 3.3-mm NexFET™ power MOSFET. This device is designed to minimize resistance in power conversion applications.

2.3.6 LM74610-Q1

The LM74610-Q1 is a smart diode controller device that is used with an external N-Channel MOSFET in a reverse polarity protection circuitry. This device is designed to drive an external MOSFET to emulate an ideal diode rectifier when connected in series with a power source. A unique advantage of this scheme is that it is not referenced to ground and thus has zero I_Q.

2.3.7 TPS7B6733-Q1

The TPS7B6733-Q1 is a low-dropout linear regulator (LDO) designed for up to 40-V V_{IN} operations with a fixed output of 3.3 V. With only 15-µA quiescent current at a light load, which greatly increases the endurance time of the automotive battery, the device drives loads up to 450 mA. This device features integrated short-circuit and overcurrent protection.

2.3.8 TPS7B6750-Q1

The TPS7B6750-Q1 is a low-dropout linear regulator designed for up to 40-V V_{IN} operations with a fixed output of 5 V. With only 15-µA quiescent current at a light load, which greatly increases the endurance time of the automotive battery, the device drives loads up to 450 mA. This device features integrated short-circuit and overcurrent protection.

2.3.9 LMT84-Q1

The LMT84-Q1 is a precision CMOS integrated-circuit temperature sensor with an analog output voltage that is linearly and inversely proportional to temperature. The device features make it suitable for many general temperature-sensing applications. This device can operate down to a 1.5-V supply with 5.4 µA of power consumption, which makes it ideal for battery-powered devices. The LMT84-Q1 has an accuracy specified in the operating range of −50°C to 150°C.

2.3.10 TPD6F002-Q1

The TPD6F002-Q1 is a highly-integrated device that provides a six-channel electromagnetic interference (EMI) filter and a transient-voltage-suppression (TVS) based electrostatic discharge (ESD) protection diode array <Suggested rewording:" and an electrostatic-discharge (ESD) protection-diode array that is transient-voltage-suppression (TVS) based.">. The low-pass filter array suppresses EMI and request for information (RFI) emissions for data ports subject to EMI. The TVS diode array is rated to dissipate ESD strikes above the maximum level specified in the IEC 61000-4-2 international standard. The high level of integration, combined with its small, easy-to-route DSV package, allows this device to provide great circuit protection for LCD displays, memory interfaces, GPIO lines, and FPD-Link.

3 Hardware, Software, Testing Requirements and Test Results

3.1 Required Hardware and Software

3.1.1 Hardware

The TIDA-01184 reference design is powered by one of two inputs: an external bench power supply or an AC-DC converter with a barrel jack connector. Either of these supplies must provide 12 V. If using an external supply, connect the positive terminal to VBB and negative terminal GND. The power supply and cables used for connection must be rated for 5 A. 図 2 shows the main board with the heater card attached.
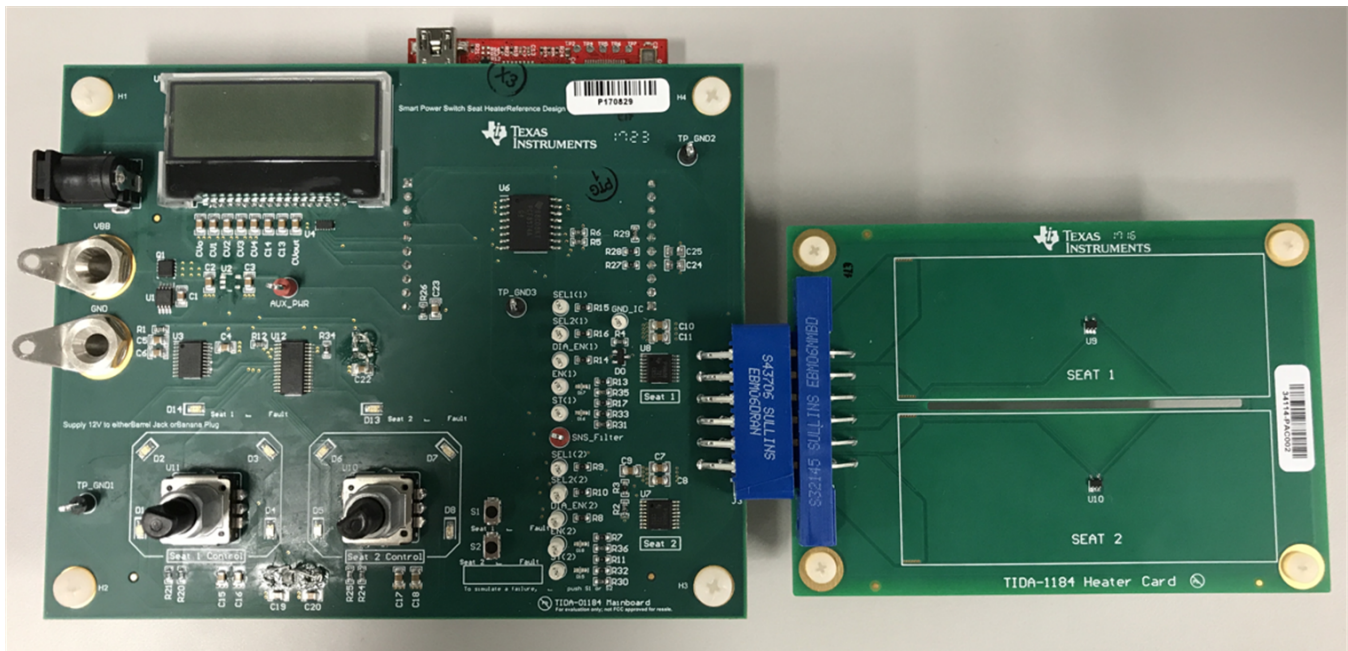
図 2. Default Board Setup With Heater Card Attached

3.1.2 System Setup

表 2 lists the function of each test point.

表 2. Test Pin Functions

TEST POINTS	NAME	DESCRIPTION
RED TEST POINTS		
TP1	AUX_PWR	LDO output
TP2	SNS_Filter	SNS filter output
WHITE TEST POINTS		
TP3	SEL1(1)	Seat 1 diagnostics select 1
TP4	SEL2(1)	Seat 1 diagnostics select 2
TP5	DIA_EN(1)	Seat 1 diagnostic enable
TP6	EN(1)	Seat 1 enable
TP7	ST(1)	Seat 1 diagnostic feedback
TP8	SEL1(2)	Seat 2 diagnostics select 1
TP9	SEL2(2)	Seat 2 diagnostics select 2

表 **2. Test Pin Functions (continued)**

TEST POINTS	NAME	DESCRIPTION
TP10	DIA_EN(2)	Seat 2 diagnostics enable
TP11	EN(2)	Seat 2 enable
TP12	ST(2)	Seat 2 diagnostic feedback
TP13	GND_IC	Ground
BLACK TEST POINTS		
TP14-16	TP_GND1-TP_GND3	Ground

3.2 *Button and Knob Functions*

After the board has been powered, each button and knob can be used to control the board. outlines the specific functions of each button or knob.

表 **3. Button and Knob Functions**

BUTTON OR KNOB	FUNCTION
Seat 1 control knob	This knob controls the heat setting for seat 1. When rotated clockwise, the seat cycles through the following heat settings: *OFF – LOW – MEDIUM – HOT – VERY HOT*. The LEDs above this knob (D1 – D4) indicate the current heat setting. The seat is set to the *OFF* position when all LEDs are disabled, and is set to the *VERY HOT* position when all LEDs are illuminated.
Seat 2 control knob	This knob controls the heat setting for seat 2. When rotated clockwise, the seat cycles through the following heat settings: *OFF – LOW – MEDIUM – HOT – VERY HOT* The LEDs above this knob (D5 – D8) indicate the current heat setting. The seat is set to the *OFF* position when all LEDs are disabled, and is set to the *VERY HOT* position when all LEDs are illuminated.
Seat 1 fault button	Pushing this button simulates a failure on seat 1, blocking communication on the enable line from the MPS430™ MCU to the TPS1HA08-Q1. Pressing this button again clears the fault and sets the device back to normal operation.
Seat 2 fault button	Pushing this button simulates a failure on seat 2, blocking communication on the enable line from the MPS430™ MCU to the TPS1HA08-Q1. Pressing this button again clears the fault and sets the device back to normal operation.

4   Testing and Results

4.1   Overview

The TIDA-01184 reference design is specifically designed to provide active monitoring and control of a resistive load, which is typically used to conduct heat in a controlled manner for comfort and safety applications. The following subsections detail the procedures, results, and conclusions to verify successful operation of this design under its intended purpose.

4.2   Normal Operation

This section offers the testing procedure and results under normal operating conditions.

4.2.1   Test Setup

Ensure that the heater card is connected to the main board. Connect the power supply to the main board and apply 12 V with a 4-A current limit. In this test, set seat 1 to the *MEDIUM* temperature setting.

4.2.2   Normal Operation Results

Under normal operation, after the *seat 1 control knob* is rotated, the TLC59116-Q1 illuminates the corresponding LEDs, which indicates that the seat is enabled. Additionally, the LCD shows the current temperature of the load.

As current is supplied to the load, the temperature of the heater card increases. The LMT84-Q1 temperature sensor attached to the heater card outputs a voltage that is inversely proportional to the temperature of the board. 図 3 shows this behavior. From this figure, observe that after a period of 30 seconds the temperature sensor voltage decreases by 220 mV, which translates to a temperature increase of approximately 40°C.
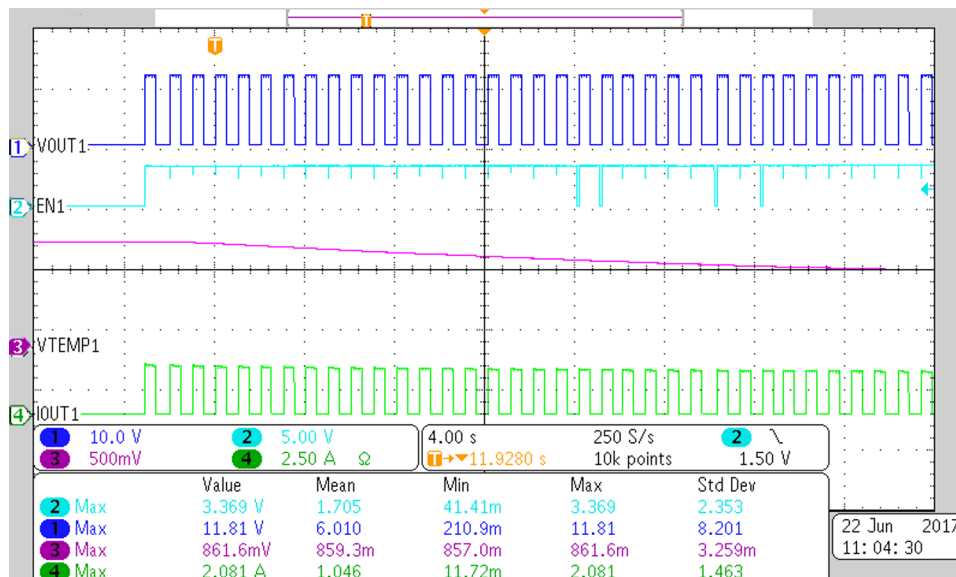

図 3. Normal Operation Test Results

4.3 Open-Load Diagnostics

This subsection offers the detailed testing procedure and results of the open-load diagnostics and indication of the TPS1HA08-Q1. In applications that include conductive loads, it is important for the host system to understand whether the downstream load is connected and operating properly. The TPS1HA08-Q1 smart high-side switch provides the necessary diagnostic information to ensure that the host is aware of any fault, such as the load being disconnected prior to operation and during operation.
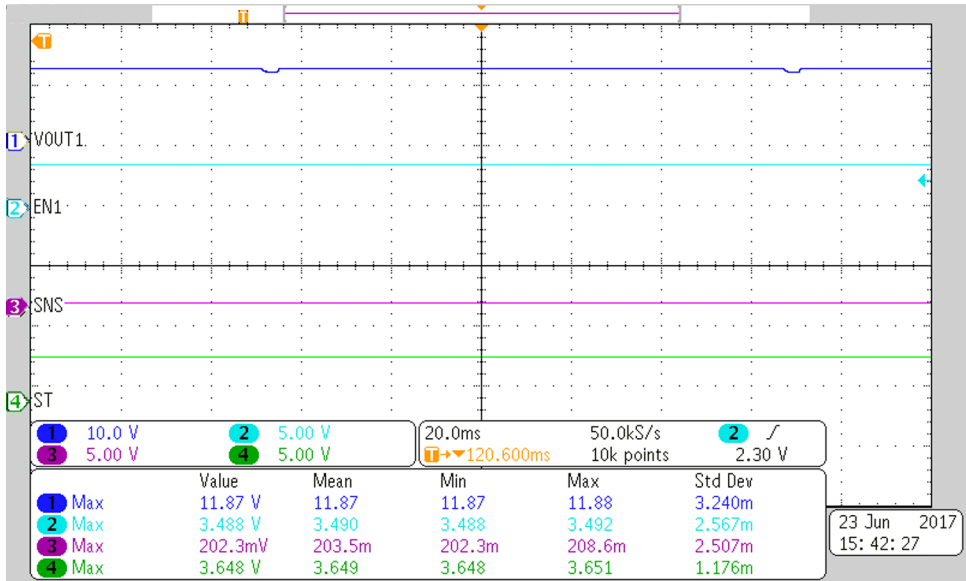
4.3.1 Test Setup

To verify open-load diagnostics is fully operational, two cases must be covered:

1. Open-load while switch is enabled
2. Open-load while switch is disabled

Ensure that the heater card is connected to the main board. Connect the power supply and apply 12 V with a 4-A current limit. In this test, set seat 1 to the *MEDIUM* temperature setting.

4.3.2 Open-Load Diagnostics With Switch-Enabled Results

When the switch is enabled, the open-load condition can be detected through the current sense feature of the TPS1HA08-Q1. If an open-load condition exists, the load current is below the expected value. In this case, the expected load current per TPS1HA08-Q1 device is 2 A. 図 4 shows the behavior of the system when the load card is disconnected while the switch is enabled.
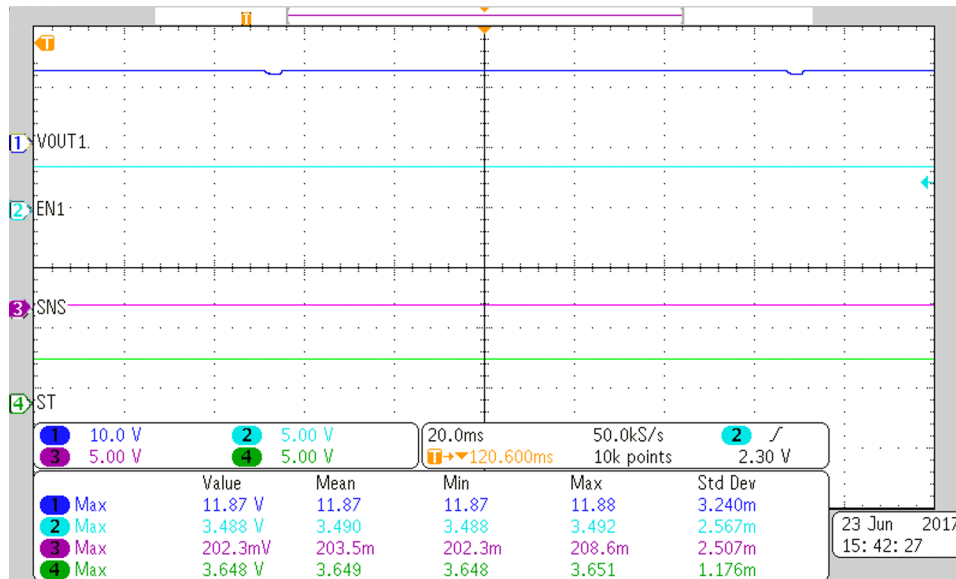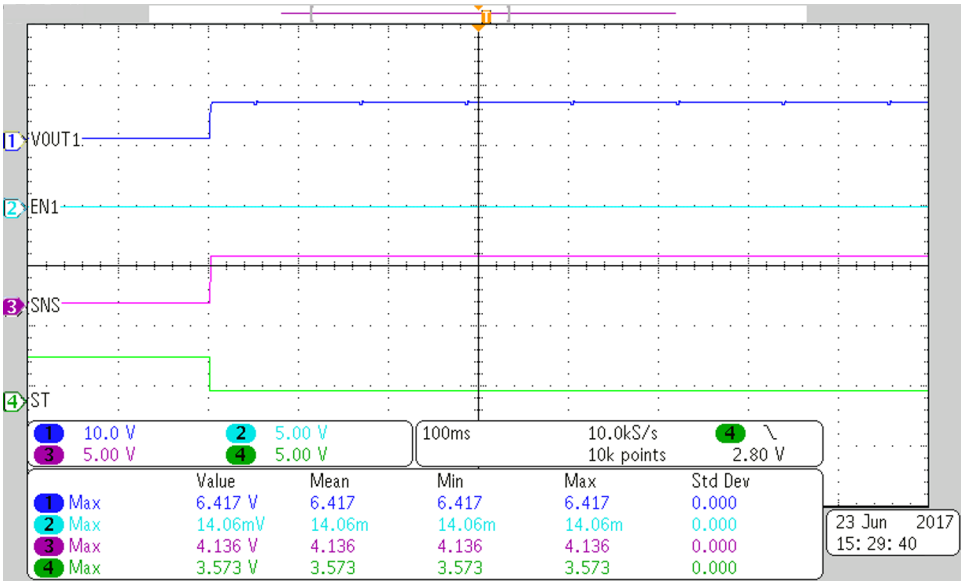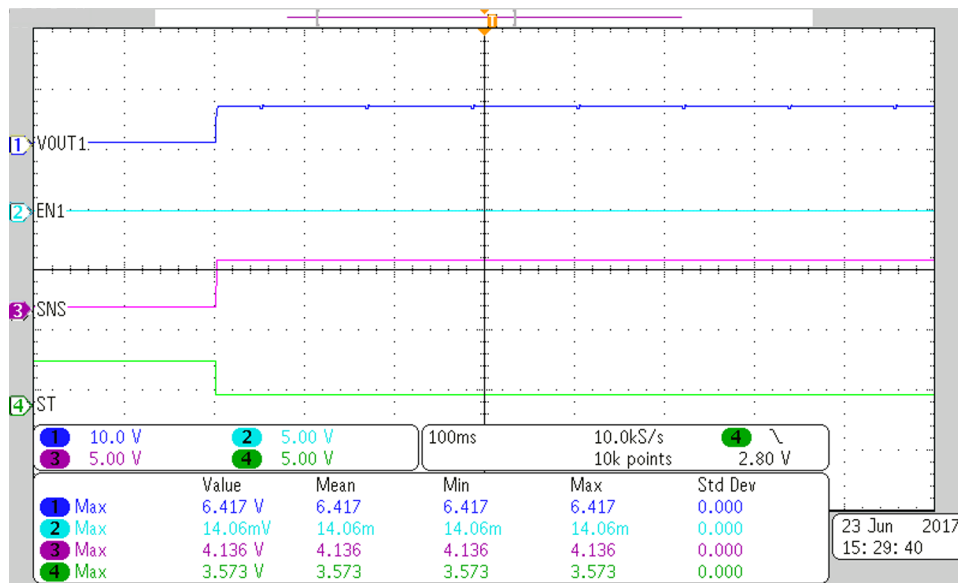

図 **4. Open-Load With Switch-Enabled Test Results**

4.3.3 Open-Load Diagnostics With Switch-Disabled Results

While the TPS1HA08-Q1 switch is disabled (and if DIA_EN(x) is high), an internal comparator detects the condition of V_{OUTx}. The detection circuitry is only enabled when DIA_EN(x) = HIGH and EN(x) = LOW.

If $V_{OUTx} > V_{OL}$ (typically 3 V), the SNS pin moves to the fault level (6 mA < I_{SNSFH} < 8.6 mA) and the ST pin asserts low. If $V_{OUTx} < V_{OL}$, then no fault indication exists.

The fault indication (SNS and ST(x)) only occurs if the SELx pins are selecting the relevant device. 図 5 shows the behavior during an open-load event while the switch is disabled. As the figure shows, when the load is disconnected, SNS rises to I_{SNFSH} and ST is asserted low.

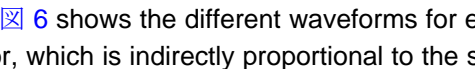**図 5. Open-Load With Switch-Disabled Test Results**

4.4 Independent Control

This section offers the detailed testing procedure and results for the ability to independently control and monitor each connected load.
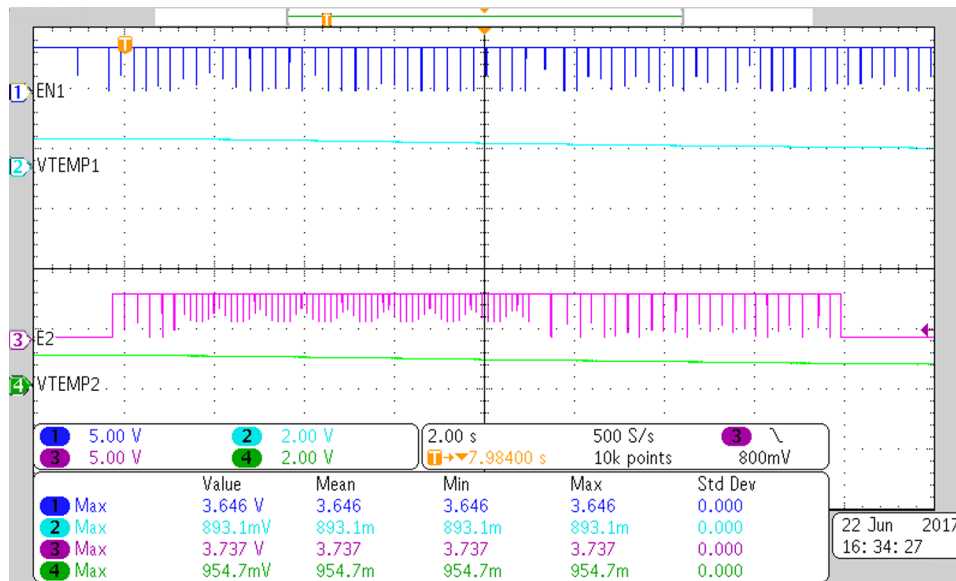
4.4.1 Test Setup

Ensure that the heater card is connected to the main board. Connect the power supply and apply 12 V with a 4-A current limit. In this test, set seat 1 to the *LOW* temperature setting and set seat 2 to the *HIGH* temperature setting.

4.4.2 Independent Control Results

The test results show that each resistive element on the heater card heats up to its corresponding selected temperature setting. 図 6 shows the different waveforms for each seat as well as the voltage for the analog temperature sensor, which is indirectly proportional to the seat temperature.

図 6. Independent Control Test Results

4.5 TPS1HA08-Q1 Thermal Performance

This section offers the detailed testing procedure and results of the thermal performance of the TPS1HA08-Q1 during normal operation.

4.5.1 Test Setup

Ensure that the heater card is connected to the main board. Connect the power supply and apply 12 V with a 4-A current limit. In this test, set both seat 1 and seat 2 to the *VERY HOT* setting.

4.5.2 Thermal Performance Results

図 7 shows the thermal performance of both TPS1HA08-Q1 smart high-side switches. The TPS1HA08-Q1 device does not reach the thermal shutdown limit of 180°C under the maximum seat temperature condition. Observe in 図 7 that minimal heat dissipation occurs during operation, even when both seats are set to the *VERY HOT* setting. In this case, each resistive element is 6 Ω and sinking 2 A. This result translates to each smart high-side switch dissipating about 128 mW of power. Additionally, because this is a resistive load, inrush current is not a concern.
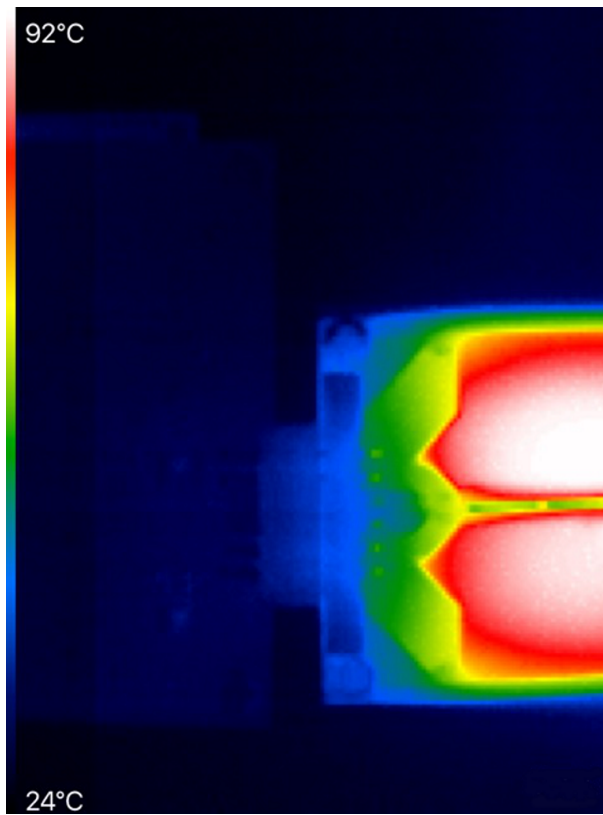
図 7. TPS1HA08-Q1 Thermal Performance Test Results

5 Design Files

5.1 Schematics

To download the schematics, see the design files at TIDA-01184.

5.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-01184.

5.3 PCB Layout Recommendations

Follow the layout recommendations for each device from the data sheets. Make all power traces thick enough to handle the maximum current for each power rail. Place all bypass capacitors as close to each device as possible.

5.3.1 Layout Prints

To download the layer plots, see the design files at TIDA-01184.

5.4 Altium Project

To download the Altium project files, see the design files at TIDA-01184.

5.5 Gerber Files

To download the Gerber files, see the design files at TIDA-01184.

5.6 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-01184.

6 Related Documentation

Texas Instruments, TPS1HA08-Q1 Product Folder

Texas Instruments, TPS1HA08-Q1 Evaluation Module

Texas Instruments, Basics of Power Switches Application Report

Texas Instruments, Adjustable Current Limit of Smart Power Switches Application Report

7 商標

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8 About the Author

MITCHELL KINKEADE is an applications engineer at TI, where he focuses on driving new products and TI designs. He received his Bachelor of Science in Electrical Engineering at Texas A&M University in College Station, TX.

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