TI Designs: TIDA-01376
EMC-Compliant, Automotive LED Turn Indicator Reference Design

Description

This automotive reference design details a solution for a turn-indicator application. The automotive battery directly supplies the linear light-emitting-diode (LED) controller of the TPS92830-Q1 used in this design. This reference design features robust electromagnetic compatibility (EMC) performance, full protection, diagnostics and MOSFET thermal protection.

Resources

TIDA-01376	Design Folder
TPS92830-Q1	Product Folder

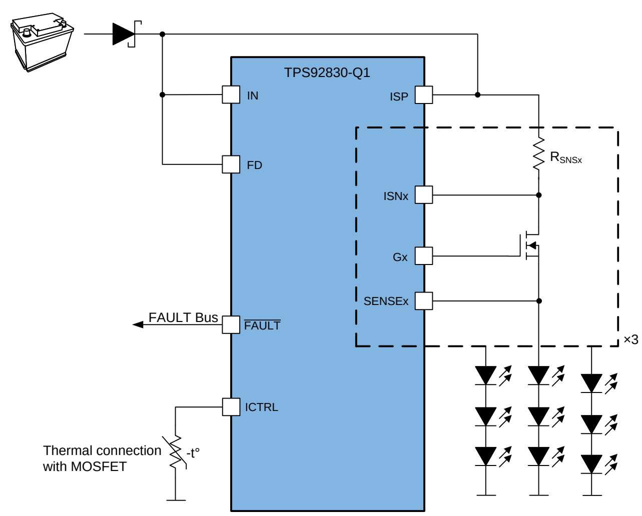
TI E2E™ Community — ASK Our E2E Experts

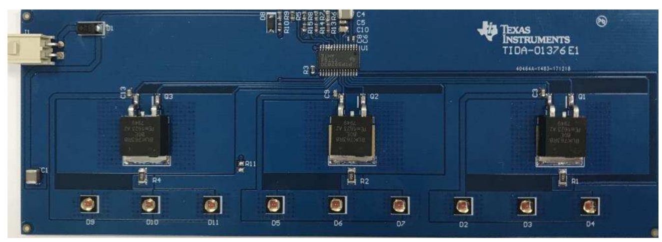
Features

- Automotive Battery Supply
- Meets CISPR 25 Conducted and Radiated Emission Standards and Passes ISO11452-4 Bulk Current Injection (BCI) Test
- LED-String Open-Circuit, Short-to-Ground, and Short-to-Battery Diagnostics, With Auto Recovery
- Fault Bus Configurable as One-Fails-All-Fail or Only-Failed-Channel-Off
- MOSFET Thermal Protection Using Analog Dimming Input Pin

Applications

- Automotive Turn Indicator





An IMPORTANT NOTICE at the end of this TI reference design addresses authorized use, intellectual property matters and other important disclaimers and information.

1 System Description

The TIDA-01376 is intended for an automotive turn-indicator application. The device is supplied directly from the automotive battery. The output current is set by high-side current-sense resistors. Using the linear device TPS92830-Q1, this design has a satisfactory EMC performance that meets CISPR 25 Class-5 conducted emission and radiated emission standards and passes the ISO11452-4 BCI test.

This design provides protection to the LEDs and devices from LED-string short-to-ground and open-circuit faults, with auto recovery. The LED open-circuit detection is disabled to avoid false diagnostics on an output channel resulting from a low supply voltage. By using different FAULT bus configurations, designers can configure the system as one-fails–all-fail or only-failed-channel-off.

In this design, placing an NTC thermistor close to the MOSFET for analog dimming can reduce the MOSFET current when the temperature gets higher than the set threshold. In addition, the LED current can be reduced when the input voltage is higher than 18 V, to protect the MOSFETs from overheating.

1.1 Key System Specifications

Table 1. Key System Specifications

PARAMETER	SPECIFICATION
Input voltage range	9 V to 16 V
Output current	300 mA/CH
LED number	3s3p
LED type	LA H9GP, OSRAM

2 System Overview

2.1 Block Diagram

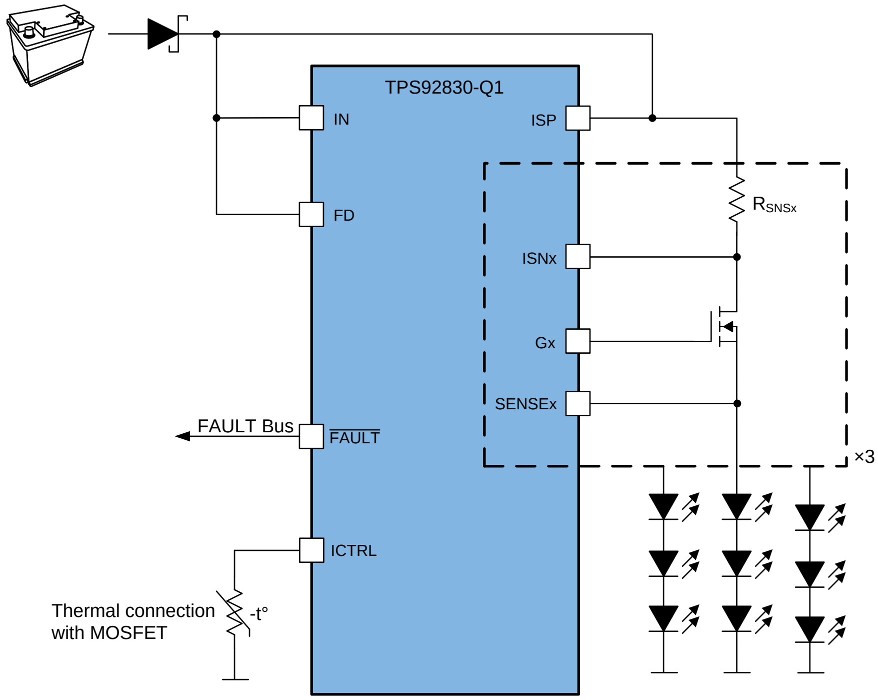


Figure 1. TIDA-01376 Block Diagram

2.2 Highlighted Products

2.2.1 TPS92830-Q1

The TPS92830-Q1 device is an advanced, automotive-grade, high-side, constant-current, linear, LED controller that delivers high current using external N-channel MOSFETs. The device has a full set of features for automotive applications. Each channel of the TPS92830-Q1 device independently sets the channel current using the sense resistor value. An internal, precision, constant-current, regulation loop senses the channel current by the voltage across the sense resistor and controls the gate voltage of the N-channel MOSFET accordingly. The device also integrates a two-stage charge pump for low-dropout operation. The charge-pump voltage is high enough to support a wide selection of N-channel MOSFETs. PWM dimming allows multiple sources for flexibility –internal PWM generator, external PWM inputs, or power-supply dimming. Various diagnostic and protection features specially designed for automotive applications help to improve the system robustness and ease of use. A one-fails–all-fail FAULT bus supports the TPS92830-Q1 operation together with the TPS92630-Q1, TPS92638-Q1, and TPS9261x-Q1 family of devices, to fulfill various fault-handling requirements.

For more information on the TPS92830-Q1 device used in this reference design, see the product folder at www.ti.com.

3 System Design Theory

The TIDA-01376 uses the TPS92830-Q1, a linear-LED controller, to drive 3s3p amber LED strings, which provides easy control for automotive turn-indicator applications. This design uses the TPS92830-Q1 to implement a constant-output current and various flexible functions. Figure 2 shows the schematic of the design. The following subsections provide details on the design.

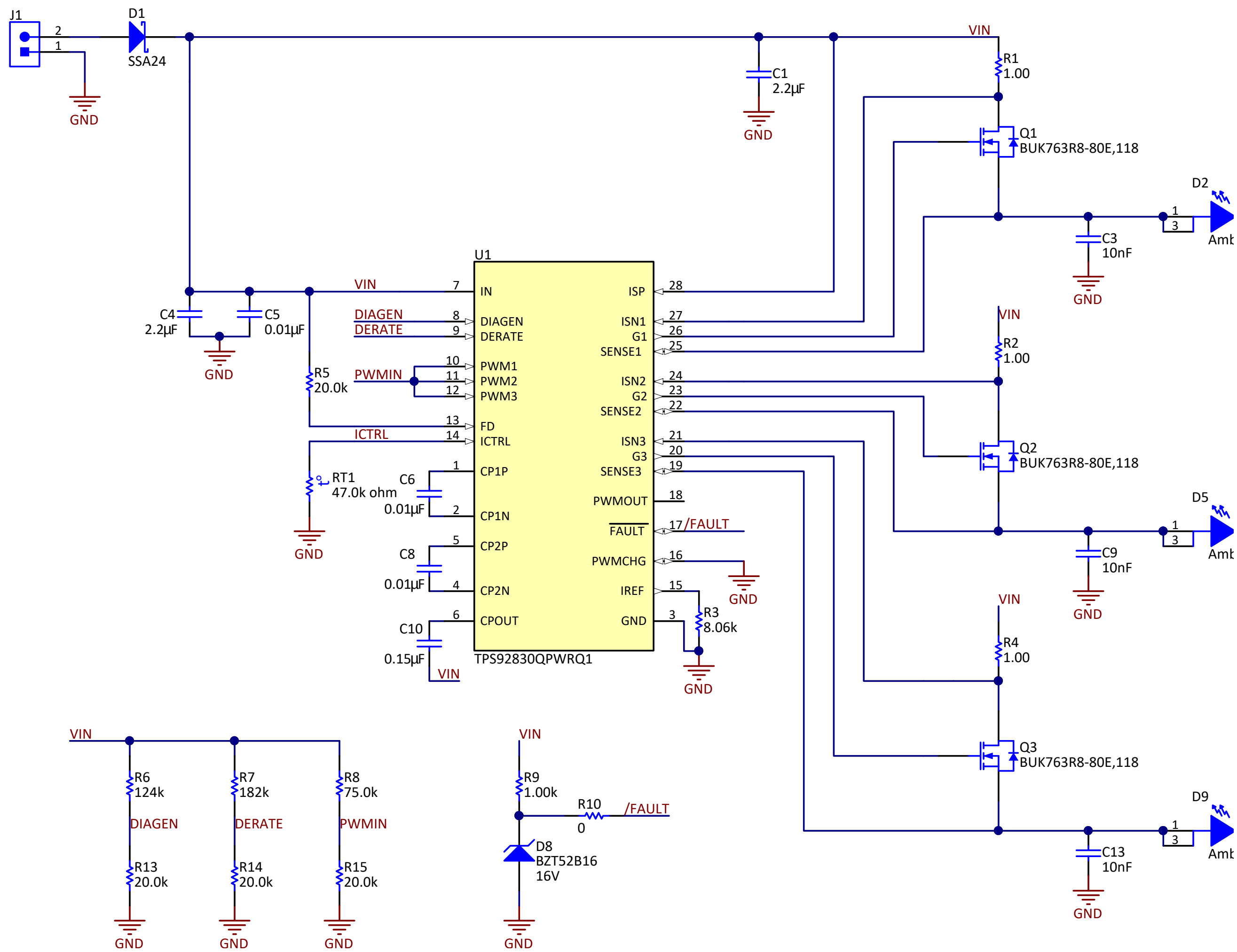


Figure 2. TIDA-01376 Schematic

3.1 LED Current Design

The TPS92830-Q1 device has three, independent, constant-current driving channels. Each channel sets the channel current with an external, high-side, current-sense resistor, R_{SNSx}. The channel current is set as $V_{(CS\_REG)}$ / R_{SNSx}. In this design, the current for each LED string is set at 300 mA, so the current-sense resistors can be calculated using Equation 1.

$$R1 = R2 = R4 = \frac{V_{(CS\_REG)}}{I_{(CH)}} = \frac{295}{300} = 0.985 \quad (1)$$

where

- $V_{(CH\_REG)}$ is the current-sense resistor-regulation voltage (typically 295 mV).
- $I_{(CH)}$ is the channel current.

Use three 1-Ω resistors for R1, R2, and R4.

3.2 Charge Pump Design

The TPS92830-Q1 device uses a two-stage charge pump to generate the high-side gate-drive voltage, as shown in Figure 2. The charge pump is a voltage tripler, which uses external flying capacitors, C6 and C8 and a storage capacitor, C10. The charge-pump voltage is high enough to support a wide selection of N-channel MOSFETs. TI recommends the capacitance for C6 and C8 as well as C10 is 10 nF, 10 nF, and 150 nF.

3.3 LED Fault Design

The TPS92830-Q1 device provides advanced diagnostics and fault protection methods for this design. The device can detect and protect the system from LED output short-to-GND, LED output open-circuit, and device overtemperature scenarios.

The TPS92830-Q1 supports flexible FAULT bus diagnostic, which can be configured as one-fails–all-fail or only-failed-channel-off, based on legislative requirements and application conditions. Setting the resistor R10 enables and disables the one-fails–all-fail function.

In Figure 3, when R10 is not mounted $\overline{\text{FAULT}}$ is floating. During normal operation, an internal pull-up current source weakly pulls up the $\overline{\text{FAULT}}$ pin. If any fault scenario occurs, an internal pull-down current source strongly pulls the $\overline{\text{FAULT}}$ pin low. All outputs shut down for protection, which effectively realizes the one-fails–all-fail function. The faulty channel continually retries until the fault condition is removed. The designer can also connect the FAULT bus to an MCU for fault reporting.

If R10 is mounted, $\overline{\text{FAULT}}$ is externally pulled up. The one-fails–all-fail function is disabled and only the faulty channel is turned off. A 16-V Zener diode (D8) is used to prevent the $\overline{\text{FAULT}}$ pin from overvoltage, because the recommended maximum operating voltage for the $\overline{\text{FAULT}}$ pin is 20 V.

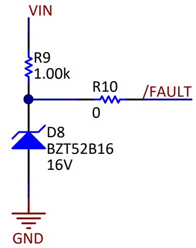


Figure 3. Fault Bus Configuration of TPS92830-Q1

3.4 DIAGEN, DERATE, and PWM Threshold Setting

Figure 4 shows the DIAGEN, DERATE, and PWM threshold setting.

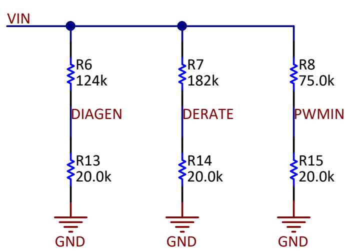


Figure 4. DIAGEN, DERATE and PWM Threshold Setting

3.4.1 DIAGEN Setting

When the input voltage is not high enough to keep the external N-channel MOSFET in the constant-current saturation region, the TPS92830-Q1 device works in low-dropout mode. In dropout mode, LED open-circuit detection must be disabled using the DIAGEN input. Otherwise, the dropout mode would be treated as an LED open-circuit fault.

In this design, LED open detection is enabled when V_{IN} > 9 V. Use Equation 2 to set the resistor divider, R6 and R13.

$$K_{(RES\_DIAGEN)} = \frac{R13}{R6 + R13} = \frac{V_{IH(DIAGEN,\ max)}}{9}$$

where

- $V_{IH(DIAGEN,\ max)}$ is the maximum-input logic-high voltage for the DIAGEN pin in the data sheet (1.255 V). (2)

Set R6 = 124 kΩ and R13 = 20 kΩ.

3.4.2 DERATE Setting

The TPS92830-Q1 device has an integrated output-current derating function. Voltage across the sense resistor is reduced if the DERATE pin voltage ($V_{(DERATE)}$) increases, so that the output current is reduced as well. Figure 5 shows the output-current derating profile.

With an external resistor divider, R7 and R14, connected from V_{IN} to set the $V_{(DERATE)}$ voltage, as shown in Figure 4, the current is reduced when V_{IN} rises above the set level. Therefore, the current derating function can be used to limit power dissipation in external MOSFETs and LEDs, to prevent thermal damage at high input voltage.

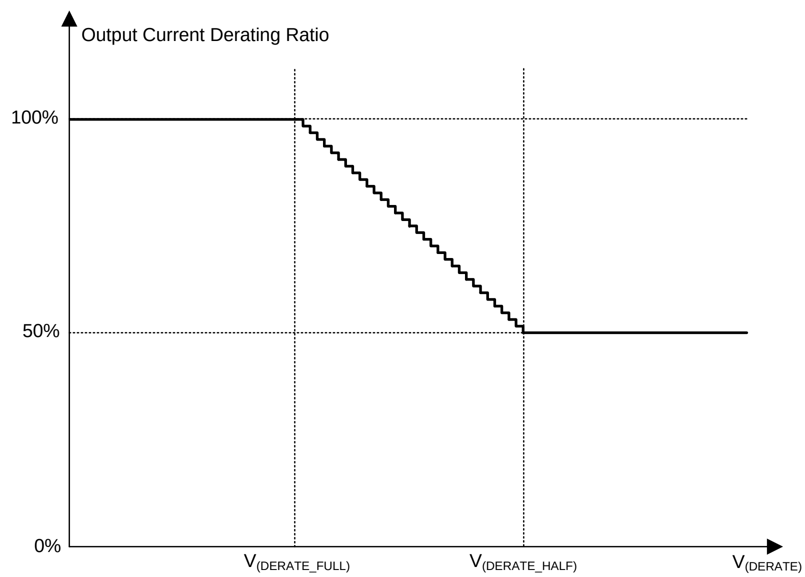


Figure 5. Output-Current Derating Profile

In this design, the output current is configured to be reduced when V_{IN} > 18 V, with the output current derating feature. Use Equation 3 to set the resistor divider ratio.

$$K_{(RES\_DERATE)} = \frac{R14}{R7 + R14} = \frac{V_{(DERATE\_FULL)}}{18}$$

where

- $V_{(DERATE\_FULL)}$ is the full-range DERATE voltage in the data sheet (1.83 V). (3)

Set R7 = 182 kΩ and R14 = 20 kΩ.

3.4.3 PWM Threshold Setting

With the wide range of battery voltages in modern automotive systems, a common requirement among car OEMs is to turn LEDs off when the battery voltage is below the minimal voltage threshold. In this design, the three channels are designed to be enabled when V_{IN} > 6 V. PWM1 to PWM3 are connected together with a resistor divider, R8 and R15. Use Equation 4 to set the resistor-divider ratio.

$$K_{(RES\_PWM)} = \frac{R15}{R8 + R15} = \frac{V_{IH(PWMx,\ max)}}{6} \quad (4)$$

where

- $V_{IH(PWMx,\ max)}$ is the maximum-input logic-high voltage for PWM in the data sheet (1.248 V).

Set R8 = 75 kΩ and R15 = 20 kΩ.

3.5 *MOSFET Thermal Protection*

Thermal is a concern when using linear devices to drive LEDs at high currents in automotive environments. The TPS92830-Q1 device uses external MOSFETs rather than integrated-power transistors. MOSFETs handle most of the power dissipation and get hottest in the system. To enhance MOSFET reliability, it is better to reduce the current going through them when their temperature exceeds a thermal threshold. This reduction is done is by using the analog dimming function of the TPS92830-Q1.

The TPS92830-Q1 device has a linear, analog input pin, ICTRL, with an internal pull-up current, $I_{(ICTRL\_pullup)}$, which is typically 0.985 mA (from the data sheet). The voltage across the sense resistor and the output current is reduced if the ICTRL voltage ($V_{(ICTRL)}$) decreases below $V_{(ICTRL\_FULL)}$. Figure 6 shows the analog dimming ratio versus the $V_{(ICTRL)}$ voltage.

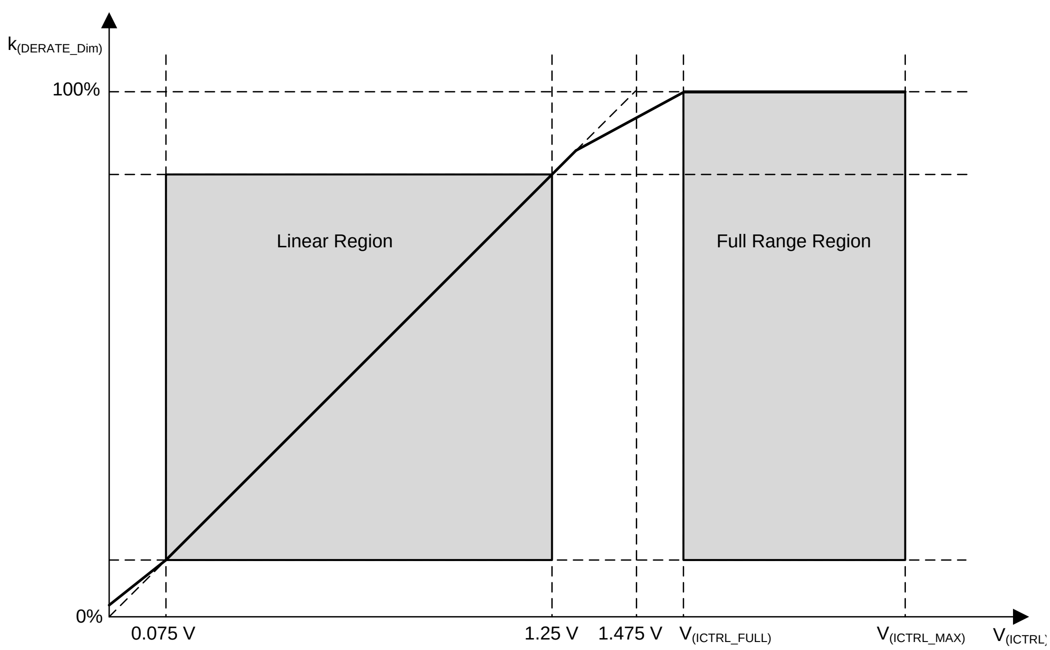


Figure 6. Analog Dimming Ratio

In this design, a negative temperature coefficient (NTC) thermistor connected to the ICTRL pin is placed near the MOSFET, to monitor the temperature of the MOSFET. With the resistance of the NTC thermistor decreasing as the temperature rises, $V_{(ICTRL)}$ decreases accordingly. When the temperature exceeds a desired point and $V_{(ICTRL)}$ decreases below $V_{(ICTRL\_FULL)}$, the output current is reduced. Then the thermistor protects the MOSFET from overheating and enhance the MOSFET reliability.

Selection of the thermistor depends on the required relationship of the MOSFET current versus temperature, and the thermal resistance between the MOSFET junction and the NTC thermistor for a specific connection. In this design, the thermistor selected is the NCP15WB473F0SRC from Murata Electronics. The current starts to derate when the thermistor temperature rises to 126°C and drops to 50% of the full value when the temperature reaches 154°C. Users can also disable the thermal protection feature by leaving the ICTRL pin floating.

4 Getting Started Hardware

Connect a 12-V DC power supply across the SUPPLY and GND terminals to enable the turn indicator function (see Figure 7).

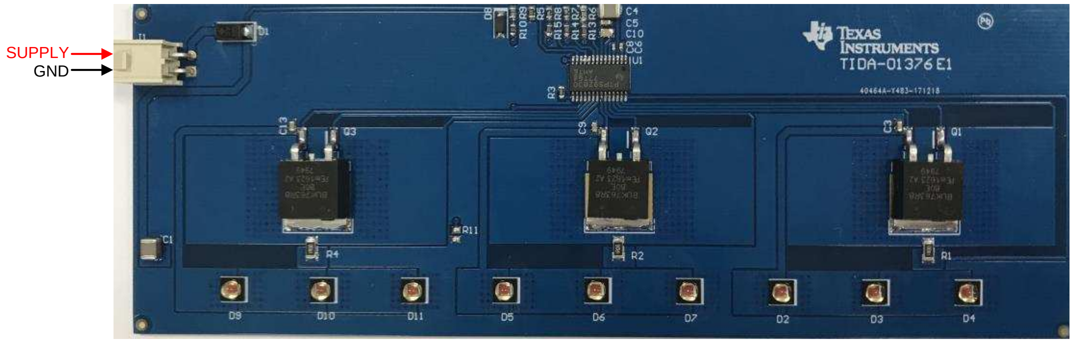


Figure 7. TIDA-01376 Board

5 Testing and Results

5.1 Operating Waveforms

Figure 8, Figure 9,and Figure 10 show the input voltage and input-current waveforms of this design, when the supply voltage is at 9 V, 12 V and 16 V, respectively.

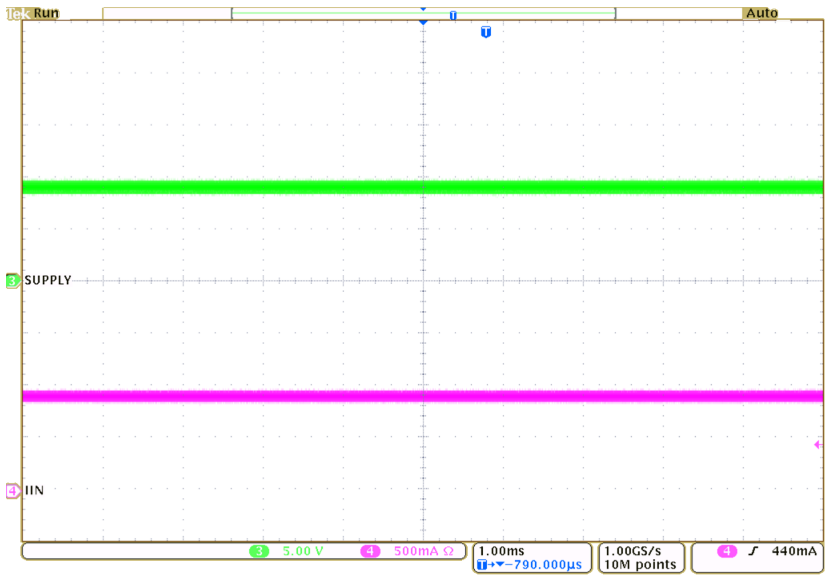


Figure 8. Operating Waveform, V_{IN} = 9 V
CH3: Supply Voltage, CH4: Input Current

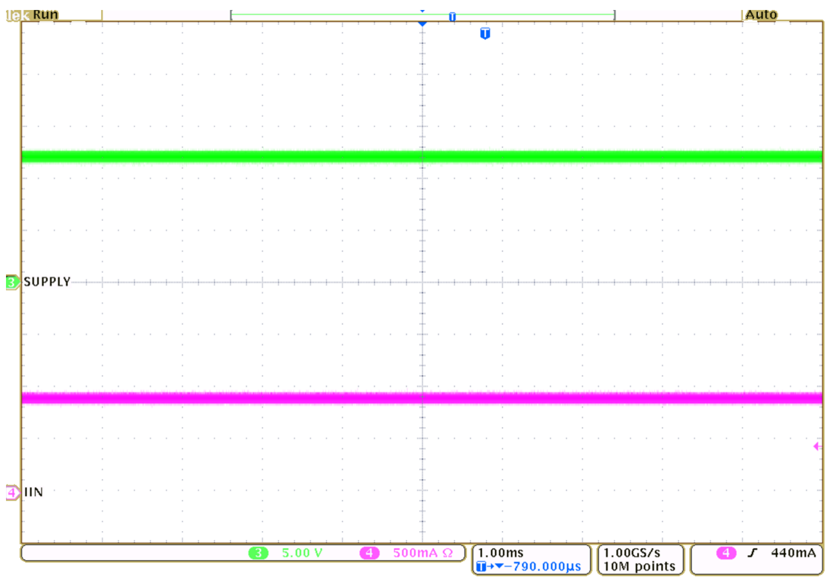


Figure 9. Operating Waveform, V_{IN} = 12 V
CH3: Supply Voltage, CH4: Input Current

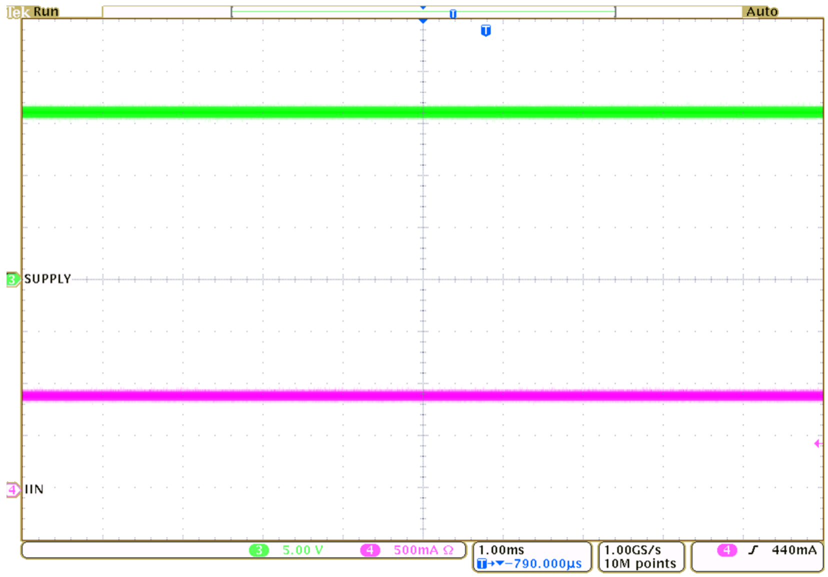


Figure 10. Operating Waveform, V_{IN} = 16 V CH3: Supply Voltage, CH4: Input Current

5.2 Thermal Data

Figure 11 shows the infrared thermal image of the design. The input voltage is 12 V. The ambient temperature is 25°C.

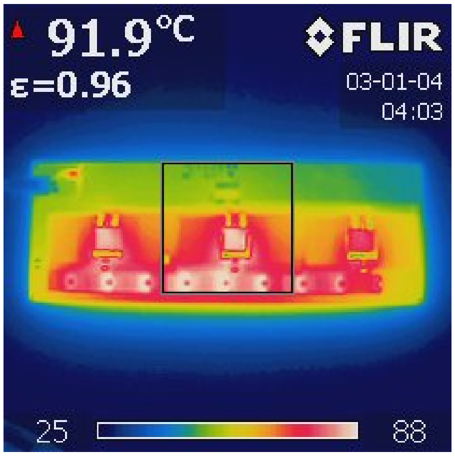


Figure 11. Thermal Image at 25°C, 12-V Input Voltage

5.3 EMC Test Results

This reference design is compliant with several EMC standards that are important for automotive applications. The design has been tested against the CISPR 25 conducted and radiated emissions standard and the ISO11452-4 BCI standard at a qualified third-party facility. The following subsections provide the test results.

5.3.1 Conducted and Radiated Emissions Test

The CISPR 25 is the automotive, EMI standard that most OEMs reference for requirements. Both conducted and radiated emissions tests for this design were completed against the CISPR 25 standards. The test was conducted at 13.5-V input.

Table 2 lists the summarized results of both the conducted and radiated portions of the tests across different operating points and test conditions. For the test setup, test equipment, limits and detailed test results, see the official test report at TIDA-01376.

Table 2. Conducted and Radiated Emissions Test Results Summary

RADIATED EMISSION (ALSE METHOD) - CISPR25: 2008					
FREQUENCY BAND (MHz)	ANTENNA POLARIZATION	MEASUREMENT SYSTEM BANDWIDTH	DETECTION SCHEME	TEST LIMIT	TEST RESULTS DESCRIPTION
0.15 to 30	V	9 kHz	PK/QP/AV	CISPR25: 2008 Class 5	Meets requirement
30 to 200	V	120 kHz	PK/QP/AV		Meets requirement
	H	120 kHz	PK/QP/AV		Meets requirement
200 to 1000	V	120 kHz	PK/QP/AV		Meets requirement
	H	120 kHz	PK/QP/AV		Meets requirement
1000 to 2500	V	9/120 kHz	PK/AV		Meets requirement
	H	9/120 kHz	PK/AV		Meets requirement
CONDUCTED EMISSION (VOLTAGE MODE) - CISPR25: 2008					
FREQUENCY BAND (MHz)	SUPPLY LINE POLARITY	MEASUREMENT SYSTEM BANDWIDTH	DETECTION SCHEME	TEST LIMIT	TEST RESULTS DESCRIPTION
0.15 to approximately 108	Positive	9/120 kHz	PK/QP/AV	CISPR25: 2008 Class 5	Meets requirement
	Negative	9/120 kHz	PK/QP/AV		Meets requirement

5.3.2 BCI Test

The BCI test for this design was conducted against the ISO11452-4 standard and at a 13.5-V input. Table 3 and Table 4 list the test requirements and acceptance criteria of the BCI test.

Table 3. BCI Test Requirement

BULK CURRENT INJECTION-ISO11452-4: 2011			
FREQUENCY (MHz)	FREQUENCY STEP SIZE (MHz)	DWELL TIME (sec)	TEST LEVEL (mA)
1 to 10	1	2	200
10 to 200	5	2	200
200 to 400	10	2	200

Table 4. BCI Test Acceptance Criteria

WORKING MODE	MONITORING PARAMETERS	ACCEPTANCE	TEST LEVEL	STATUS
Mode 1	The brightness of light	No obvious phenomenon	200 mA	Class A

Table 5 lists the test results. For the test setup, test equipment, limits, and detailed test results, see the official test report at TIDA-01376.

Table 5. BCI Test Results Summary

FREQUENCY BAND (MHz)	INJECTION MODE	POSITION (mm)	MODULATION	TEST LEVEL	TEST RESULTS DESCRIPTION
1 to 400	CBCI	150	CW	200 mA	No obvious phenomenon
			AM		No obvious phenomenon
		450	CW		No obvious phenomenon
			AM		No obvious phenomenon
		750	CW		No obvious phenomenon
			AM		No obvious phenomenon

6 Design Files

6.1 Schematics

To download the schematics, see the design files at TIDA-01376.

6.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-01376.

6.3 PCB Layout Recommendations

This design relies on external MOSFETs to dissipate heat. The thermal performance of the design is highly dependent on the cooling conditions of the MOSFETs and LEDs. A good printed-circuit board (PCB) design can optimize heat transfer, which is essential for long-term reliability. Consider the following PCB layout recommendations:

- Increase copper thickness or use metal-based boards if possible. Maximize the copper coverage on the PCB to increase the thermal conductivity of the board. Place thermal vias on the thermal dissipation area to further improve the thermal dissipation capability.
- The current path starts from IN through the sense-resistors, MOSFETs, and LEDs to GND. Wide traces are helpful to reduce parasitic resistance along the current path.
- Place capacitors, especially charge pump capacitors, close to the device to make the current path as short as possible.

6.3.1 Layout Prints

To download the layer plots, see the design files at TIDA-01376.

6.4 Altium Project

To download the Altium project files, see the design files at TIDA-01376.

6.5 Gerber Files

To download the Gerber files, see the design files at TIDA-01376.

6.6 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-01376.

7 Related Documentation

1. CISPR 25, Edition 3.0, 2008-03, *Vehicles, Boats and Internal Combustion Engines – Radio Disturbance Characteristics – Limits and Methods of Measurement for the Protection of On-Board Receivers*
2. ISO11452-4, Edition 4, 2011-12, *Road vehicles — Component test methods for electrical disturbances from narrowband radiated electromagnetic energy — Part 4: Harness excitation methods*
3. Texas Instruments, *TPS92830-Q1 3-Channel High-Current Linear LED Controller*, data sheet

7.1 Trademarks

All trademarks are the property of their respective owners.