TI Designs: TIDA-01374

EMC-Compliant, Automotive Stop Light and Tail Light Reference Design

TEXAS INSTRUMENTS

Description

This automotive reference design details a solution for a stop light and a tail light. The automotive battery directly supplies the TPS92830-Q1 linear light-emitting-diode (LED) controller of the TPS92830-Q1 used in this design, which allows the designer to use the same LEDs for both functions. This reference design also features robust electromagnetic compatibility (EMC) performance, full protection, and diagnostics.

Resources

TIDA-01374	Design Folder
TPS92830-Q1	Product Folder

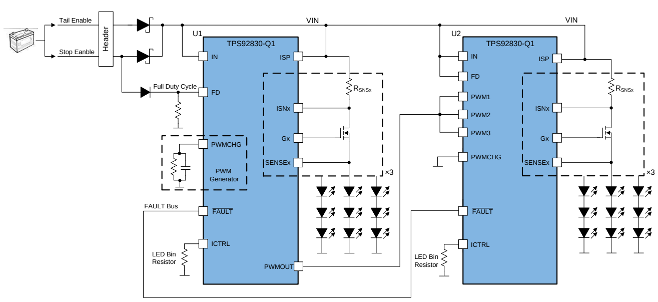
TI E2E™ Community — ASK Our E2E Experts

Features

- Automotive Battery Supply
- Meets CISPR 25 Conducted and Radiated Emission Standards and Passes ISO11452-4 Bulk Current Injection (BCI) Test
- Stop Light and Tail Light LED Reuse Using Device Internal Pulse Width Modulation (PWM) Generator
- 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
- LED Binning Function Using Analog Dimming Input Pin

Applications

- Automotive Rear Light (Stop and Tail Light)



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

Automotive stop lights and tail lights often reuse the same LEDs with two levels of brightness. This reference design offers a dual-brightness solution for stop- and tail-light reuse applications, using the integrated PWM generator of the TPS92830-Q1 controller. Two devices are cascaded by a synchronization PWMOUT output.

Using linear devices, 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 the LEDs and devices with protection 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, the designer can configure the system as one-fails–all-fail or only-failed-channel-off.

In the design, by using bin-setting resistors for analog dimming, the device can realize LED-bin brightness correction. 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 (tail light)	150 mA/CH with 20% duty cycle
Output current (stop light)	150 mA/CH
LED number	3s6p
LED type	LR H9GP, OSRAM

2 System Overview

2.1 Block Diagram

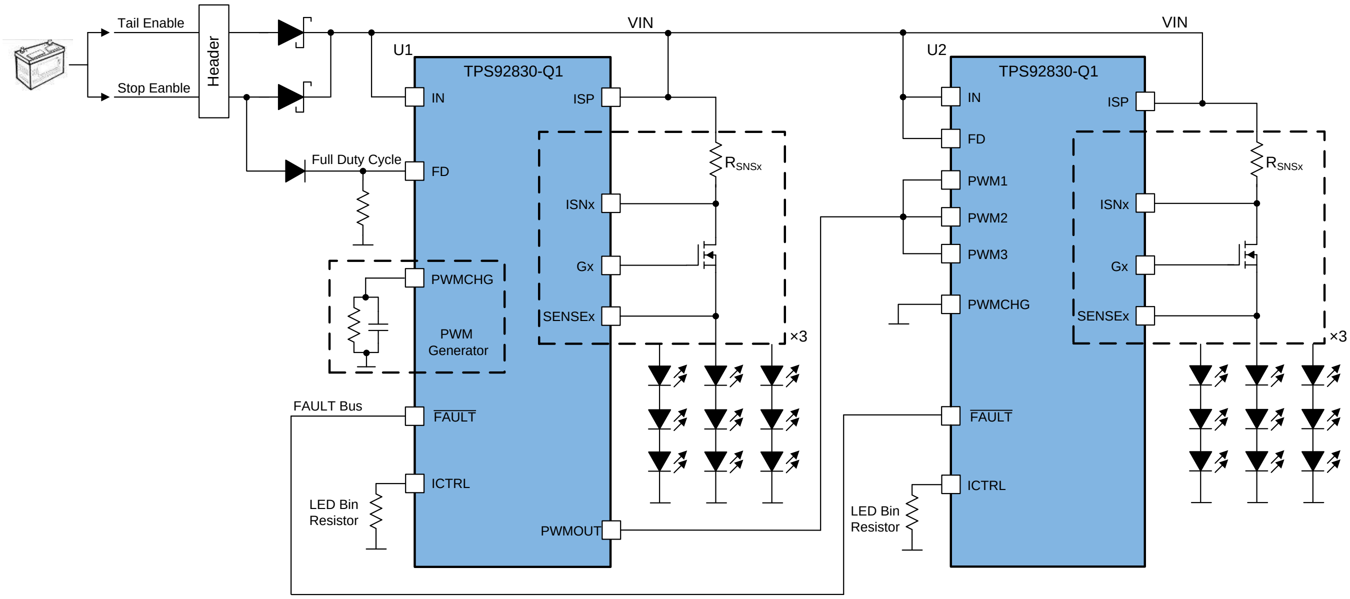


Figure 1. TIDA-01374 Block Diagram

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, which 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 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 TPS92830-Q1 product folder.

3 System Design Theory

This reference design uses two TPS92830-Q1, linear LED controllers to drive six red LED strings. The TPS92830-Q1 device provides a precision PWM generator to realize the dual-brightness output control for automotive stop and tail light applications. Two devices are cascaded by a synchronization PWMOUT output. With a full set of features from the TPS92830-Q1, the design can realize various functions with simple external circuits. Figure 2 shows the schematic of the design. The following subsections provide details on the design.

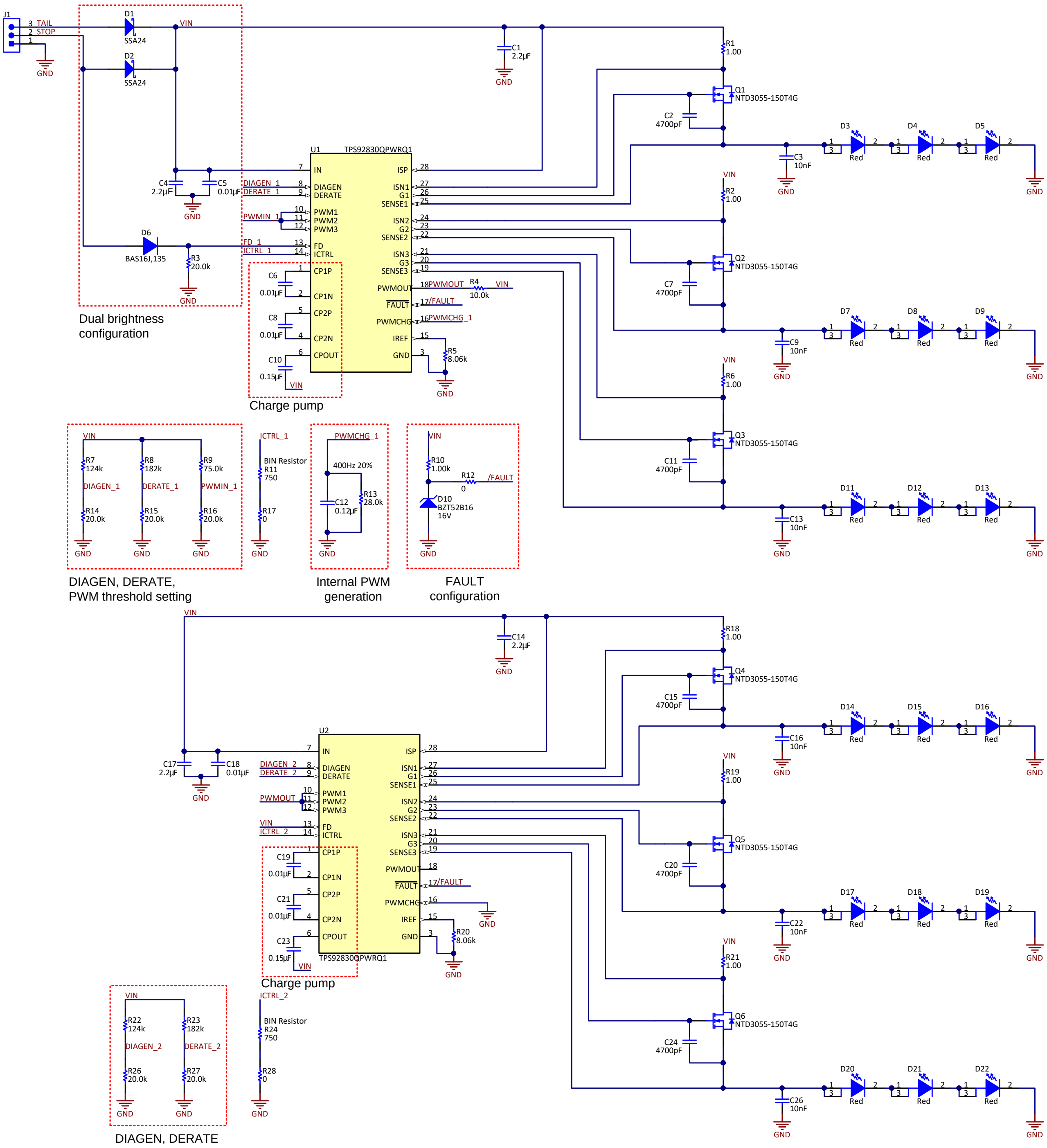


Figure 2. TIDA-01374 Schematic

3.1 Dual-Brightness Design

3.1.1 Dual-Brightness Control

This reference design uses the same set of LEDs to illuminate both automotive stop and tail lights. The LEDs can operate at two different brightness levels. One way to set the brightness level is through analog dimming, which means the LEDs always operate at a 100% duty cycle, and the maximum current through the LEDs varies to the required level of brightness. However, differing levels of LED current may affect the LED color temperature. The other option is to use PWM dimming, which can achieve the desired dimming ratio with the same color temperature.

The TPS92830-Q1 device provides an integrated precision-PWM generator for on-chip PWM dimming. An external RC circuit sets the duty cycle and frequency of the PWM signal, as shown in Figure 2. The device can flexibly switch between the internal PWM modulation mode and the 100% duty cycle mode by using the FD input. When the FD pin is low, the channel PWM depends on the internal PWM generator. When the FD pin is high, the internal PWM generator is bypassed, and the PWM inputs take complete control of the output. Moreover, the device supports open-drain PWMOUT for synchronization between devices. Each device can be connected as a master, which generates PWM, or as a slave, which relies on external PWM sources.

In this design, by connecting PWMOUT of U1 (TPS92830-Q1) to three PWM inputs of U2 (TPS92830-Q1), the two devices are in a master-slave configuration. When the STOP terminal is connected to the battery, the FD input of U1 is high. The output current of U1 is 150 mA per channel at a 100% duty cycle. Also, PWMOUT of U1 is high, so the output current of U2 is also at full duty cycle. The LED strings work in stop mode. When the TAIL terminal is connected to the battery, the FD input of U1 is low. The output current of U1 and U2 is at a 20% duty cycle and 400 Hz, as the external RC circuit sets. The LED strings work in tail light mode.

3.1.2 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}.

Considering the analog dimming pin, ICTRL, is used for LED-bin brightness correction, the current-sense voltage, $V_{(CS\_REG)}$, is reduced using a dimming ratio, $k_{(ICTRL\_DIM)}$. The voltage across the sense resistor and the output current are reduced if the ICTRL voltage, $V_{(ICTRL)}$, decreases. Figure 3 shows the analog dimming ratio versus the $V_{(ICTRL)}$ voltage. In the linear region, the analog dimming ratio can be calculated using Equation 1.

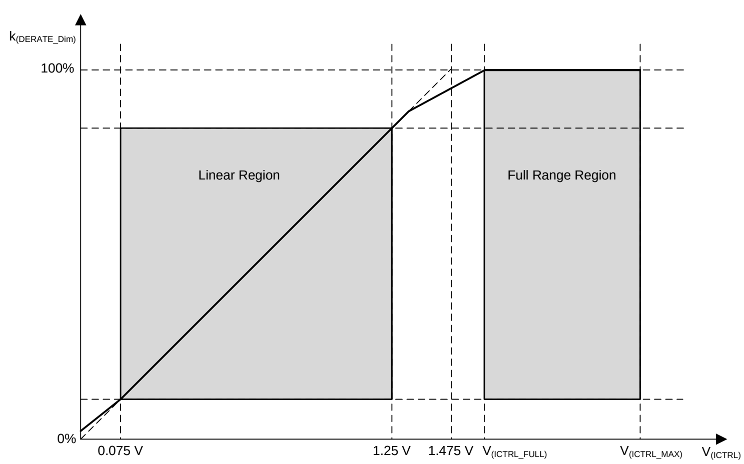


Figure 3. Analog Dimming Ratio

$$k_{(ICTRL\_DIM)} = \frac{V_{(ICTRL)}}{1.475\ V} \times 100\% = \frac{I_{(ICTRL\_pullup)} \times R_{Bin}}{1.475\ V} \times 100\%$$

where

- $I_{(ICTRL\_pullup)}$ is the ICTRL, internal pull-up current (typically 0.985 mA).
- R_{Bin} is the bin-setting resistor connected between ICTRL and GND. (1)

In this design, the current for each LED string is set at 150 mA, so the current-sense resistors can be calculated using Equation 2.

$$R1(R18) = R2(R19) = R6(R21) = \frac{V_{(CS\_REG)} \times k_{(ICTRL\_DIM)}}{I_{(CH)}} = \frac{0.295 \times 0.985 \times R_{Bin}}{150 \times 1.475}$$

where

- $V_{(CS\_REG)}$ is the current-sense resistor-regulation voltage (typically 295 mV).
- $I_{(CH)}$ is the channel current. (2)

In this design, use 750-Ω resistors for R_{Bin}, R11 and R24. Use 1.0-Ω resistors for R1 (R18), R2 (R19) and R6 (R21). Designers can use bin-setting resistors of different value to adjust the output current if using LEDs from different bins, while the current-sense resistors can remain unchanged.

3.1.3 PWM Generator Design

As Section 3.1.1 describes, the designer must generate a 20% duty cycle and 400-Hz frequency PWM output to implement the tail light function. The PWM generator uses reference current 2 × $I_{(IREF)}$ as the internal charge current, $I_{(PWMCHG)}$. The recommended value of the reference resistors R5 and R20 in Figure 2 is 8 kΩ. Select 8.06-kΩ resistors in this design.

Use external resistor R13 and C12 to set the PWM cycle time and duty cycle as required (see Equation 3 and Equation 4).

$$D_{(Tail)} = \frac{\ln\left(\frac{V_{(PWMCHG\_th\_falling)} - I_{(PWMCHG)} \times R13}{V_{(PWMCHG\_th\_rising)} - I_{(PWMCHG)} \times R13}\right)}{\ln\left(\frac{V_{(PWMCHG\_th\_falling)} - I_{(PWMCHG)} \times R13}{V_{(PWMCHG\_th\_rising)} - I_{(PWMCHG)} \times R13}\right) + \ln\left(\frac{V_{(PWMCHG\_th\_rising)}}{V_{(PWMCHG\_th\_falling)}}\right)} \quad (3)$$

$$f_{(Tail)} = \frac{1}{R13 \times C12 \times \left[\ln\left(\frac{V_{(PWMCHG\_th\_falling)} - I_{(PWMCHG)} \times R13}{V_{(PWMCHG\_th\_rising)} - I_{(PWMCHG)} \times R13}\right) + \ln\left(\frac{V_{(PWMCHG\_th\_rising)}}{V_{(PWMCHG\_th\_falling)}}\right)\right]} \quad (4)$$

R13 can be derived as follows in Equation 5.

$$R13 = \frac{V_{(PWMCHG\_th\_falling)} \times \left(\frac{V_{(PWMCHG\_th\_falling)}}{V_{(PWMCHG\_th\_rising)}}\right)^{\frac{D_{(Tail)}}{1-D_{(Tail)}}} - V_{(PWMCHG\_th\_rising)}}{I_{(PWMCHG)}\left[\left(\frac{V_{(PWMCHG\_th\_falling)}}{V_{(PWMCHG\_th\_rising)}}\right)^{\frac{D_{(Tail)}}{1-D_{(Tail)}}} - 1\right]}$$

where

- D ($_{Tail}$) = 0.2
- f ($_{Tail}$) = 400
- $V_{(PWMCHG\_th\_rising)}$ is typically 1.48 V.
- $V_{(PWMCHG\_th\_falling)}$ is typically 0.8 V (1).
- $I_{(PWMCHG)}$ is typically 200 µA (1).

(1) Data sheet value; see the data sheet for a detailed calculation description. (5)

C12 can be derived as follows in Equation 6.

$$C12 = \frac{1 - D_{(Tail)}}{R13 \times f_{(Tail)} \times \ln\left(\frac{V_{(PWMCHG\_th\_rising)}}{V_{(PWMCHG\_th\_falling)}}\right)} \quad (6)$$

Equation 3 shows that the duty cycle is only dependent on R13 and has nothing to do with C12, so the capacitance variation of C12 has no impact on the precision of the duty cycle.

According to the calculation, use R13 = 28 kΩ and C12 = 0.12 µF in the design.

Because U2 is connected as a slave, the PWM input of U2 is connected to PWMOUT of U1 for synchronization. FD of U2 is pulled up to VIN and the PWM-generator oscillation stops. PWMCHG of U2 is connected to ground directly.

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 using external flying capacitors C6 (C19) and C8 (C21) and storage capacitor C10 (C23). The charge-pump voltage is high enough to support a wide selection of N-channel MOSFETs. Recommended capacitance for C6 (C19) and C8 (C21) and C10 (C23) is 10 nF, 10 nF and 150 nF.

3.3 MOSFET Driving Circuits

To ensure control-loop stability, the drive circuit requires sufficient gate-to-source capacitance (C_{GS}) on the MOSFETs. TI recommends the minimum total gate-to-source capacitance on the MOSFETs is 4 nF. For the NVD3055-150 MOSFET, TI recommends placing additional capacitors across the gate and source terminals, because C_{GS} is smaller than 1 nF. Use C2 (C15) = C7 (C20) = C11 (C24) = 4.7 nF.

3.4 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 resistor R12 enables and disables the one-fails–all-fail function.

In Figure 4, when R12 is not mounted, the $\overline{FAULT}$ pin is floating. During normal operation, an internal pull-up current source weakly pulls up the $\overline{FAULT}$ pin. If any fault scenario occurs, an internal pulldown current source strongly pulls the $\overline{FAULT}$ 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 R12 is mounted, the $\overline{FAULT}$ pin 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 (D10) is used to prevent the $\overline{FAULT}$ pin from overvoltage, because the recommended maximum operating voltage for the $\overline{FAULT}$ pin is 20 V.

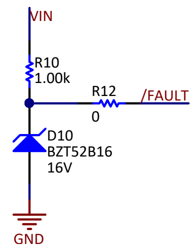


Figure 4. Fault Bus Configuration of TPS92830-Q1

3.5 DIAGEN, DERATE, and PWM Threshold Setting

Figure 5 shows a schematic of the DIAGEN, DERATE, and PWM threshold setting.

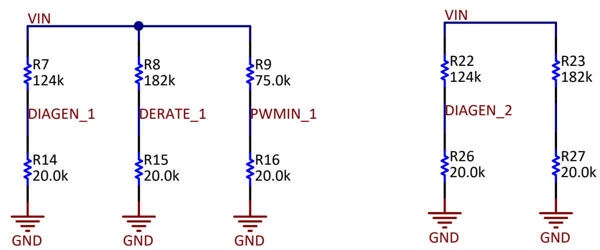


Figure 5. DIAGEN, DERATE, and PWM Threshold Setting

3.5.1 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 low-dropout mode, the LED open-circuit detection must be disabled through 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 7 to set the resistor dividers R7 (R22) and R14 (R26).

$$K_{(RES\_DIAGEN)} = \frac{R14(R26)}{R7(R22) + R14(R26)} = \frac{V_{IH(DIAGEN,\ max)}}{9} \tag{7}$$

where

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

Set R7 (R22) = 124 kΩ and R14 (R26) = 20 kΩ.

3.5.2 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 6 shows the output-current derating profile.

With an external resistor divider, R8 (R23) and R15 (R27), connected from V_{IN} to set the $V_{(DERATE)}$ voltage, as shown in Figure 5, 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 a high-input voltage.

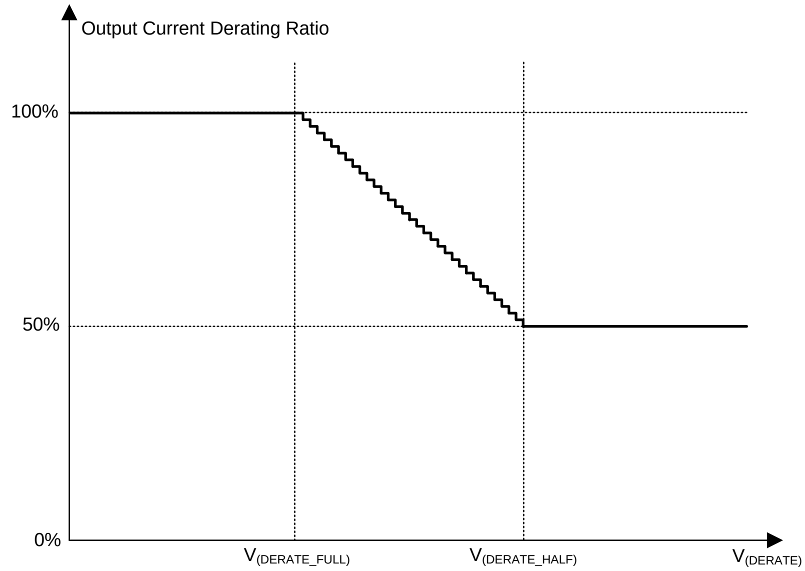


Figure 6. Output-Current Derating Profile

In this design, the output current is configured to be reduced when V_{IN} > 18 V, with the output-current derating feature. Use Equation 8 to set the resistor divider ratio.

$$K_{(RES\_DERATE)} = \frac{R15(R27)}{R8(R23) + R15(R27)} = \frac{V_{(DERATE\_FULL)}}{18} \quad (8)$$

where

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

Set R8 (R23) = 182 kΩ and R15 (R27) = 20 kΩ.

3.5.3 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, R9 and R16. Use Equation 9 to set the resistor-divider ratio.

$$K_{(RES\_PWM)} = \frac{R16}{R9 + R16} = \frac{V_{IH(PWMx,\ max)}}{6} \quad (9)$$

where

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

Set R9 = 75 kΩ and R16 = 20 kΩ.

4 Getting Started Hardware

The following steps outline the hardware setup (see Figure 7).

1. Connect a 12-V DC power supply across terminals TAIL and GND, to enable the tail-light function.
2. Connect a 12-V DC power supply across terminals STOP and GND, to enable the stop-light function.

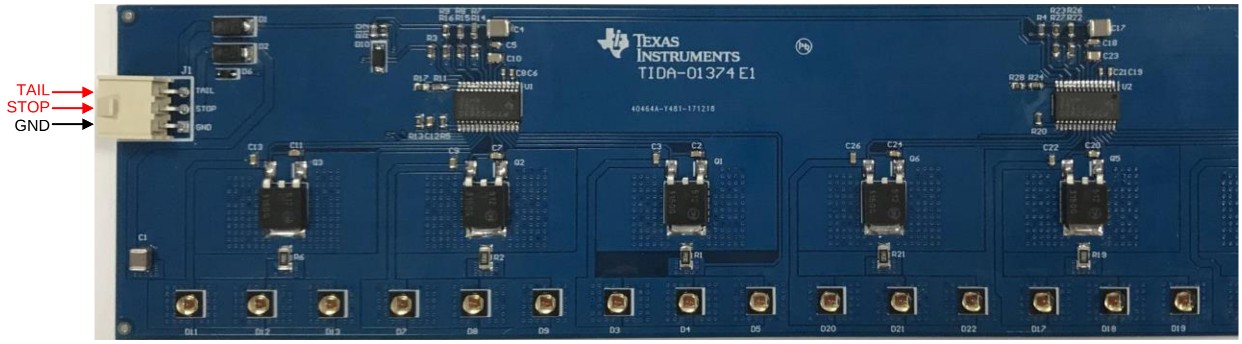


Figure 7. TIDA-01374 Board

5 Testing and Results

5.1 System-Input Current Tested Under Different Brightness Levels

With supply voltage applied to stop light input and tail light input, the device operates at 100% duty cycle and 20% duty cycle, respectively, achieving different brightness levels. Table 2 lists the system-input currents tested under two different brightness levels.

Table 2. System Input Current

FUNCTION	BRIGHTNESS	INPUT VOLTAGE	INPUT AVERAGE CURRENT
Stop light	100%	9 V	903 mA
		12 V	903 mA
		16 V	902 mA
Tail light	20%	9 V	188 mA
		12 V	188 mA
		16 V	188 mA

5.2 Waveforms

Figure 8 and Figure 9 show the input voltage and input-current waveforms for the stop and tail light function, respectively.

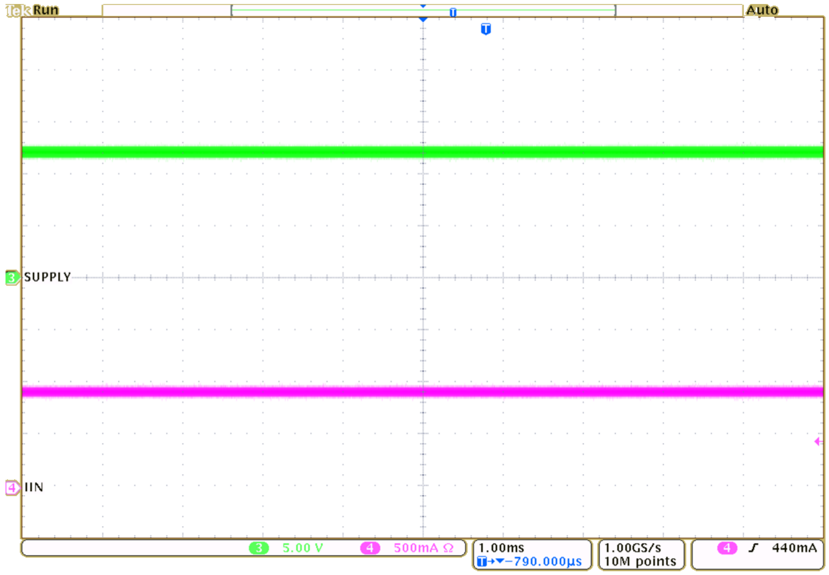


Figure 8. Stop-Function Waveform CH3: Supply Voltage and CH4: Input Current

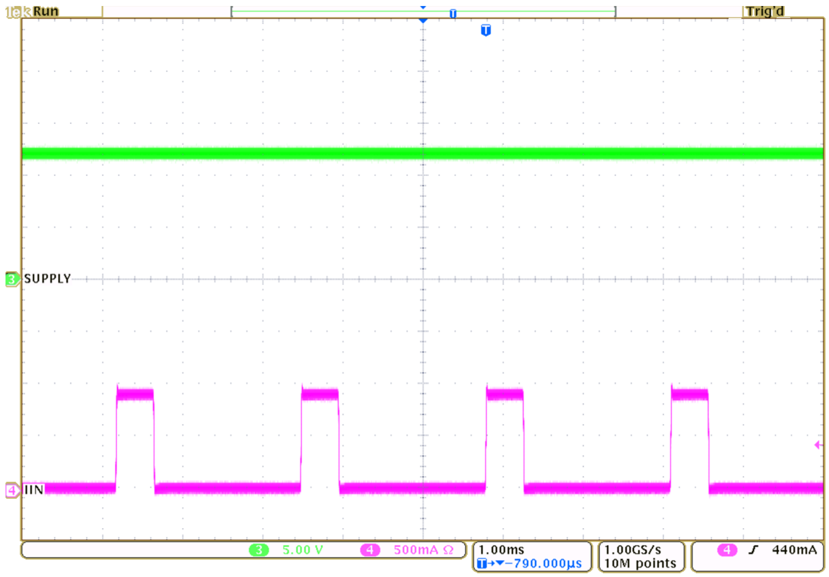


Figure 9. Tail-Light Function Waveform CH3: Supply Voltage and CH4: Input Current

5.3 Thermal Results

Figure 10 and Figure 11 show the infrared thermal images of the design when operating as a stop and tail light, respectively. The input voltage is 12 V. The ambient temperature is 25°C.

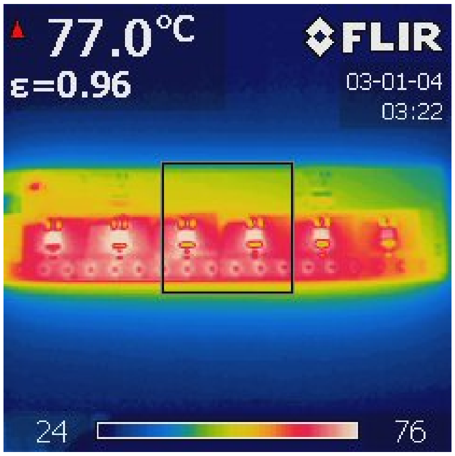


Figure 10. Thermal Image of Stop-Light Function at 25°C, 12-V Input Voltage

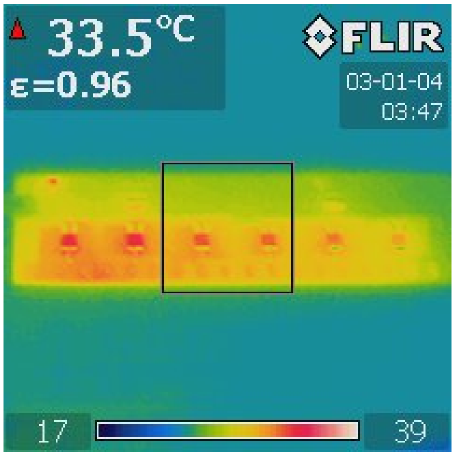


Figure 11. Thermal Image of Tail-Light Function at 25°C, 12-V Input Voltage

5.4 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 ISO11452-4 BCI standard at a qualified third-party facility. The following subsections provide the test results.

5.4.1 Conducted and Radiated Emissions Test

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 when operating at the stop function mode.

Table 3 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-01374.

Table 3. 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 RESULT 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

5.4.2 BCI Test

The BCI test for this design was conducted against the ISO11452-4 standard and at a 13.5-V input when operating in stop mode. Table 4 and Table 5 list the test requirement and acceptance criteria of the BCI test. Table 6 summarizes the test results. For the test setup, test equipment, limits, and detailed test results, see the official test report at TIDA-01374.

Table 4. 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 5. BCI Test Acceptance Criteria

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

Table 6. 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-01374.

6.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-01374.

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-01374.

6.4 Altium Project

To download the Altium project files, see the design files at TIDA-01374.

6.5 Gerber Files

To download the Gerber files, see the design files at TIDA-01374.

6.6 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-01374.

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.