TI Designs
Automotive, High-Side, Dimming Rear Light Reference Design

TEXAS INSTRUMENTS

Design Overview

This TI Design is for the automotive, high-side, dimming rear light, which uses a body control module (BCM) to supply the rear light. In this TI Design a high-side driver TPS1H100-Q1 is used to output a PWM supply with different duty cycles. Linear LED drivers TPS92630-Q1 and TPS92638-Q1 are used to drive the LEDs in constant current.

Design Resources

TIDA-00846	Tool Folder Containing Design Files
TPS92630-Q1	Product Folder
TPS92638-Q1	Product Folder
TPS1H100-Q1	Product Folder
TPS7B6950-Q1	Product Folder
TLC555-Q1	Product Folder

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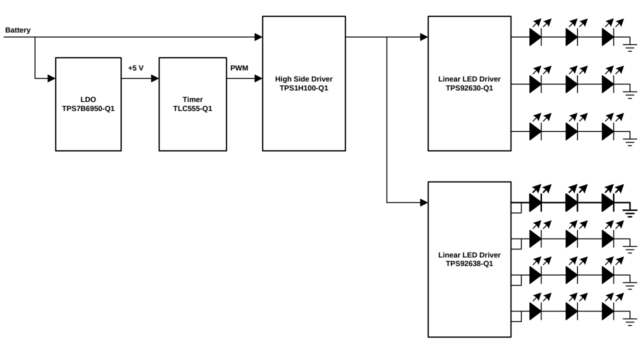
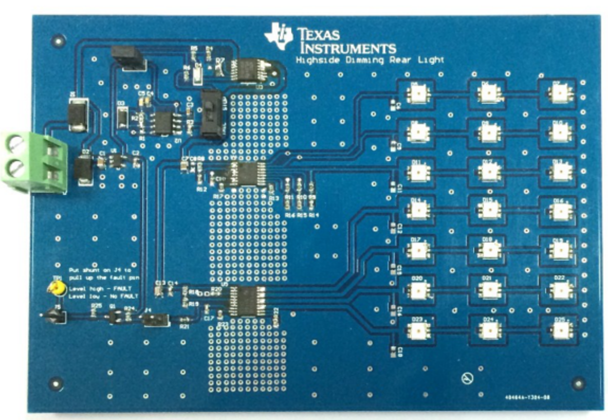
Design Features

- High-Side Dimming
- Wide Input Voltage Range: 12 V (Typical), 9 V to 16 V (Continuous)
- Programmable Current Limit High-Side Driver
- LED Open Circuit, LED Short Circuit, LED Driver Output Short-to-Battery, and Device Thermal Shutdown Protection
- Thermal Foldback Function for LED Driver
- One-Fail-All-Fail (OFAF) Function

Featured Applications

- Automotive Rear Light (Stop Light and Tail Light)





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1 Key System Specifications

Table 1. Key System Specifications

PARAMETERS	SPECIFICATION
Input voltage range	9 V to 16 V
Output current (TAIL)	8 mA/Ch
Output current (STOP)	40 mA/Ch
LED number	3S7P
LED type	LR G6SP, OSRAM

2 System Description

The TIDA-00846 TI Design is for an automotive, high-side, dimming rear light, which uses a body control module (BCM) to supply the rear light system. In this TI Design the high-side driver TPS1H100-Q1 is used to provide a pulse-width modulation (PWM) supply with different duty cycles. Linear light-emitting diode (LED) drivers TPS92630-Q1 and TPS92638-Q1 are used to drive the LEDs with constant current. In the design, TLC555-Q1 is used to generate a 20% duty cycle, 200-Hz PWM input for the high-side driver. The circuit houses a switch to alternate the PWM duty cycle of the TPS1H100-Q1, which can identify different brightness levels of the LED. The LED drivers use 3S7P LEDs as the load. The TPS92630-Q1 device drives three channels of LEDs, while the TPS92638-Q1 device drives four channels of LEDs by placing the two outputs in parallel. The fault pins of the two LED drivers are connected together and implement a one-fail-all-fail (OFAF) function. Adding an external pullup circuit disables the OFAF; however, the fault state can still be detected.

3 Block Diagram

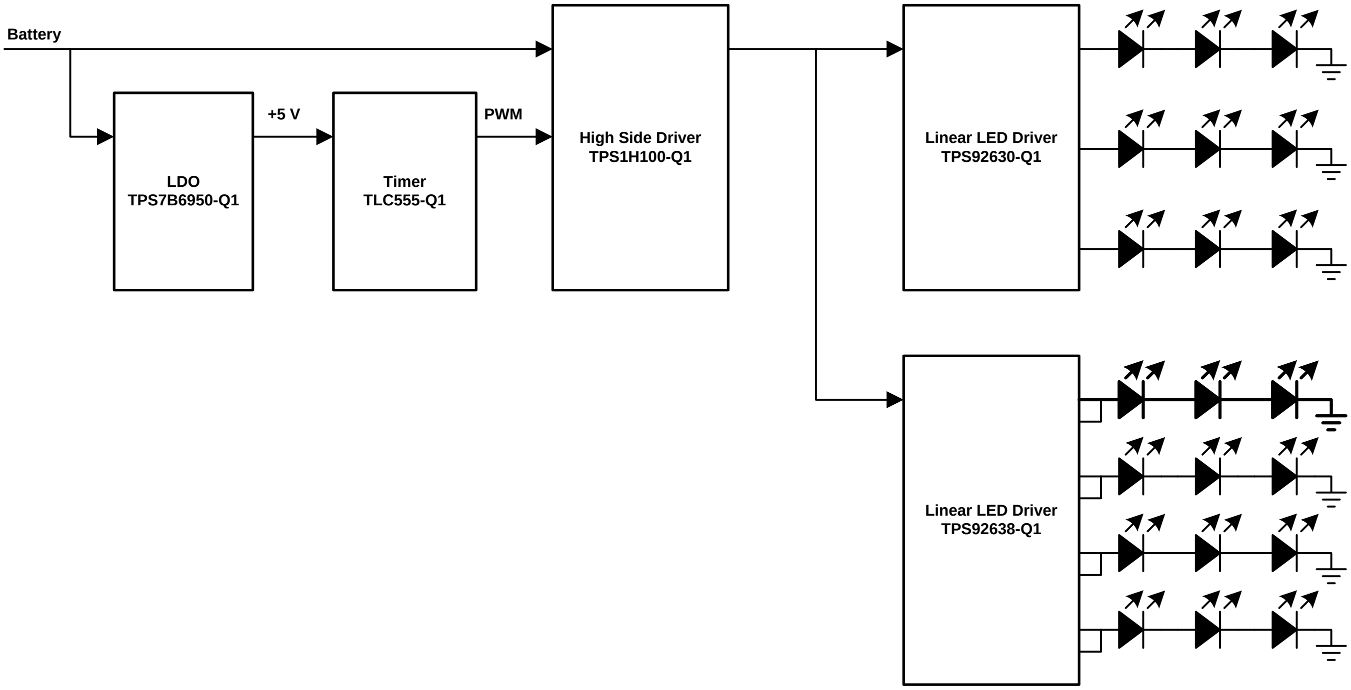

Figure 1. TIDA-00846 System Block Diagram

3.1 Highlighted Products

The following are the highlighted products used in this reference design. The key features for selecting the devices for this reference design are outlined in the following subsections. Refer to the complete details of the highlighted devices in the respective product datasheets.

3.1.1 TPS92630-Q1—Three-Channel Linear LED Driver

Automotive LED rear lights require a constant current LED driver to keep the LED brightness constant during normal operation. The use of linear LED drivers is becoming increasingly popular in automotive LED rear lights because of the advantage in electromagnetic interference (EMI) and electromagnetic compatibility (EMC). The TPS92630-Q1 is a three-channel linear driver with analog and PWM dimming control, which is suitable for automotive LED rear lights. This device can output 150-mA/ch current (maximum) and 450-mA current (maximum) with three outputs in parallel.

The TPS92630-Q1 is suitable for use in automotive LED rear lights such as tail lights and stop lights. The wide input voltage range of 5 V to 40 V allows for a direct connection to a car battery. The TPS92630-Q1 device also has a complete set of system protection features such as LED open, LED short, single LED short, current foldback, and thermal shutdown, which greatly improve reliability and further simplify the design. A 16-pin, thermally-enhanced PWP package (HTSSOP) provides good thermal performance, which allows large output current.

3.1.2 TPS92638-Q1—Eight-Channel Linear LED Driver

The TPS92638-Q1 is also a linear LED driver, which is an eight-channel device with analog and PWM dimming control. This device is very similar to the TPS92630-Q1, but the output current per channel is smaller (70 mA/ch maximum). With the outputs in parallel, the device can output large current (560 mA maximum) with all outputs in parallel. The device is optimized for automotive stop lights and tail lights and the current of these lights can be set by independent resistors. The TPS92638-Q1 contains four PWMs and each PWM controls two output channels. The TPS92638-Q1 also offers complete system protection features such as LED open, LED short, current foldback, and thermal shutdown, which greatly improve reliability and further simplify the design.

3.1.3 TPS1H100-Q1—High-Side Driver

To simulate the BCM output, the TIDA-00846 design uses a high-side driver TPS1H100-Q1. The TPS1H100-Q1 is a fully-protected, high-side power switch with an integrated NMOS power field-effect transistor (FET) and charge pump, which is specified for the intelligent control of a variety of resistive, inductive, and capacitive loads.

A high-accuracy current sense function has been internally implemented in the TPS1H100-Q1 device, which utilizes more efficient real-time monitoring for output current and more accurate diagnostics without requiring further calibration. The TPS1H100-Q1 device also implements a programmable current limit function. The device current limit can be set by an external resistor. This function protects the power supply during short circuit or power up. This programmable current limit function can also save on system costs by reducing printed circuit board (PCB) traces, connector size, and the preceding power stage capacity. The TPS1H100-Q1 also passes the 1 Million Times Short-to-GND test according to AECQ100-12 grade A.

3.1.4 TPS7B6950-Q1—High Voltage LDO

As the automotive industry becomes increasingly concerned with environmental protection, low quiescent current devices also increase in popularity. The TPS7B69xx-Q1 is a low quiescent current linear regulator. With only a 15-µA quiescent current (typical) at light load, the device is suitable for a standby µC system, especially in an automotive application. The TPS7B69xx-Q1 has been designed for an input voltage system up to 40 V. The device can output 150-mA current (maximum) and is stable with a low equivalent-series-resistance (ESR) ceramic output capacitor (2.2 µF to 100 µF). The thermal shutdown and short-circuit protection functions have been integrated for high reliability.

3.1.5 TLC555-Q1—Timer

The TLC555-Q1 device is used to generate a PWM input for the high driver. The TLC555-Q1 is a monolithic timing circuit, which has been fabricated using the TI LinCMOS™ technology process. The timer is fully compatible with complementary metal-oxide semiconductor (CMOS), transistor-transistor logic (TTL), and MOS logic and operates at frequencies up to 2 MHz. This device uses smaller timing capacitors than those used by the NE555 because of its high input impedance. As a result, more accurate time delays and oscillations are possible. Power consumption is low across the full range of power-supply voltage.

4 System Design Theory

The reference design uses one TPS92630-Q1 and one TPS92638-Q1 to drive seven-channel, red LED strings and the current of each string is set at 40 mA. The high-side driver circuit is used to simulate the BCM, which can output a different duty cycle PWM supply to the LED driver. The system houses a switch that can allow the TPS1H100-Q1 device to provide two different outputs, such as a 20% duty cycle, 200-Hz PWM supply and a 100% duty cycle supply. The 20% duty cycle output can be used for a tail light. The 100% duty cycle output can be used for a stop light.

4.1 Linear LED Driver Design

4.1.1 PWM Input Design

When using the TPS92630-Q1 and TPS92638-Q1 devices in the high-side dimming application, TI does not recommend connecting the PWM input directly to the EN and VIN pins because the input voltage may drop below the undervoltage lock out (UVLO) threshold during the PWM off time. This voltage drop can occur as a result of the long turnon time of the output channels, which results in a failure of the fault detection function during high-side dimming and may trigger the open fault during the dropout duration. For these reasons, Texas Instruments (TI) recommends using a resistor divider on the PWM input to turn on and turn off the output at a high input voltage and to choose a proper input capacitor to keep the input voltage higher than the UVLO threshold.

The user can determine the divider ratio based on the turnon and turnoff voltage. The turnon and turnoff voltage must be larger than the forward voltage of the LED in addition to the dropout voltage, which can avoid triggering the open fault of the LED driver.

For example, when using three red LEDs per channel, the forward voltage is 6 V. So an 8-V turnon voltage is a reasonable value. Choose a 56- and 10-kΩ resistor as the resistor divider.

4.1.2 LED Current Design

The user must carefully consider the thermal design when using a linear LED driver. The design is important because, when the input voltage and ambient temperature are high, the junction temperature of the device must be maintained at 150°C to limit the output current.

The following Table 2 outlines a design example.

Table 2. Design Parameters

DESIGN PARAMETERS	EXAMPLE VALUES
V_{IN}	9 V to 16 V
LED	3S3P, OSRAM LED, LR G6SP, VF = 2.1 V
Ambient temperature, $T_{AMBIENT}$	85°C
PCB	Two-layer, 1 oz
θ_{JA}	40°C/W

The following list details the method of calculating the maximum output current of the LED driver:

- Solution with TPS92638
- Total LED forward voltage = 3 × 2.1 = 6.3 V
- Device total power = (150 – $T_{AMBIENT}$) / θ_{JA} = 1.625 W
- Maximum current per channel = 1.625 / (16 – 6.3) / 8 = 20.9 mA, choose 20 mA/ch
- Reference resistor = 1.222 × 200 / 0.02 = 12.22 kΩ

NOTE: θ_{JA} is determined by the PCB material; in this example, the value for θ_{JA} is an estimated value.

4.1.3 LED Fault Design

The fault pin of the TPS92630-Q1 device is compatible with the TPS92638-Q1 device. By connecting the fault pins together, the system can utilize the OFAF function. The OFAF shuts down both of the devices if there is a fault on the TPS92630-Q1 or TPS92638-Q1, as Figure 2 shows.

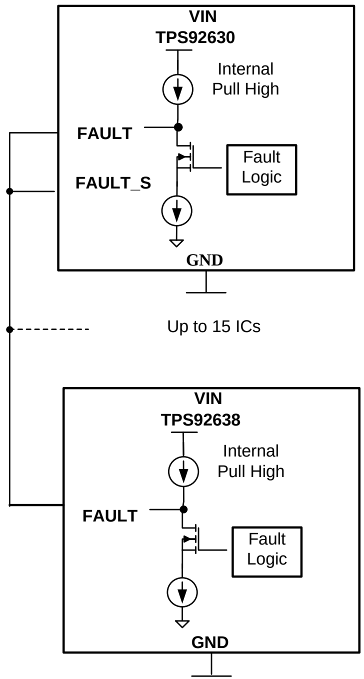

Figure 2. Fault Bus of TPS92630-Q1 and TPS92638-Q1

When one of the channels has a short or an open fault, the remaining channels must continue operating and the fault pin reports the open or short to the microcontroller (MCU). In this case, the Fault pin must be pulled up according to the fault table in the TPS9263x-Q1 datasheet.

Figure 3 shows the circuit that can utilize this function. The fault pin has a pulldown current when a short or open fault occurs on the TPS92630-Q1 or TPS92638-Q1 device. The pulldown current flows through the R1 resistor, the system turns on the PNP transistor, and the connector of the PNP transistor becomes high, which the MCU can detect. During this process, the fault pin voltage is still higher than 2 V, which indicates that the fault pin is in the pullup state. In this case, the remaining channels of the LED driver continue to operate per the fault table.

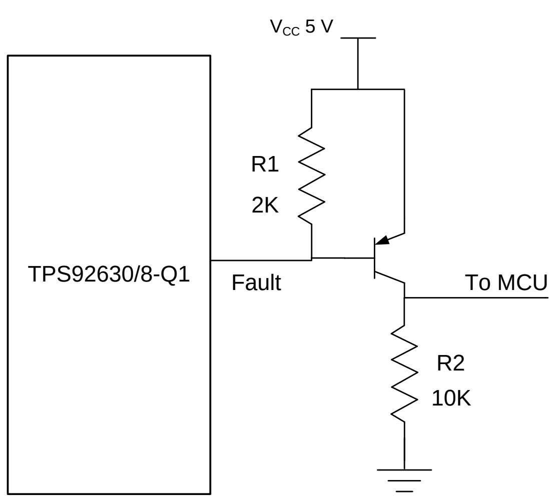

Figure 3. Fault Pin Pullup Circuit

According to the TPS92630-Q1 datasheet, the minimum pulldown current of the fault pin is 500 uA and the maximum pulldown current is 1000 uA. The minimum logic high voltage (V_{IH_MIN}) is 2 V. The V_{BE} of the PNP transistor is typically 0.7 V. Equation 1 and Equation 2 show the requirements for the R1 resistor value.

$$V_{CC} - R1 \times I_{PULLDOWN\_MAX} > V_{IH\_MIN} \quad (1)$$

$$R1 \times I_{PULLDOWN\_MAX} > V_{BE} \quad (2)$$

The range of R1 can be calculated to be from 1.4 kΩ to 3 kΩ. Select a 2 kΩ value for R1.

4.2 PWM Generator Design

To implement the high-side dimming function, the high side driver requires a PWM input signal. In the TIDA-00846 design, the TLC555-Q1 device is used to generate the PWM input signal, as Figure 4 shows. The following paragraphs describe how to set the PWM frequency and duty cycle.

The timing capacitor C5 is filled through R1 and D3 and emptied exclusively through R2. Equation 3 shows the calculation for the output pulse frequency:

$$f = \frac{1.44}{(R1 + R2) \times C5} \quad (3)$$

The following Equation 4 and Equation 5 are used to calculate the high and low times:

$$\text{PWM high time} = 0.69 \times (R1 \times C5) \quad (4)$$

$$\text{PWM low time} = 0.69 \times (R2 \times C5) \quad (5)$$

Using the circuit in Figure 4, the duty cycle can be any value that the user desires. If R1 > R2, the resulting duty cycle is greater than 50% (equivalent to a mark space ratio of more than 1.0). Alternatively, if R1 < R2, the resulting duty cycle is less than 50% (mark space ratio less than 1.0).

In this design, the PWM frequency is 200 Hz and the duty cycle is 20%. So per the calculations in the previous Equation 4 and Equation 5, C5 = 10 nF, R1 = 120 kΩ, and R2 = 600 kΩ.

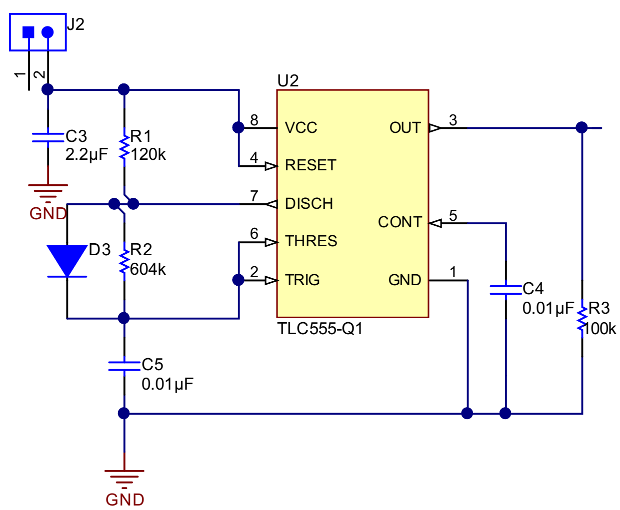

Figure 4. PWM Circuit

5 Getting Started Hardware

Connecting a 12-V DC supply to the onboard input connector (J1) lights up the LED. Switching the J3 connector changes the brightness of the LED which can identify the tail function and stop function.

6 Test Data

6.1 System Input Current Tested Under Different Levels of Brightness

Table 3. System Input Current

FUNCTION	BRIGHTNESS	INPUT VOLTAGE	INPUT CURRENT
Stop light	100%	12 V	283.4 mA
Tail light	20%	12 V	58.7 mA

6.2 Waveforms

Figure 5 and Figure 6 show the input voltage versus input current waveforms for a 100% PWM duty cycle and 20% PWM duty cycle. Channel 1 is the PWM input signal of the high-side driver TPS1H100-Q1, channel 3 is the output voltage of the TPS1H100-Q1, and channel 4 shows the system input current.

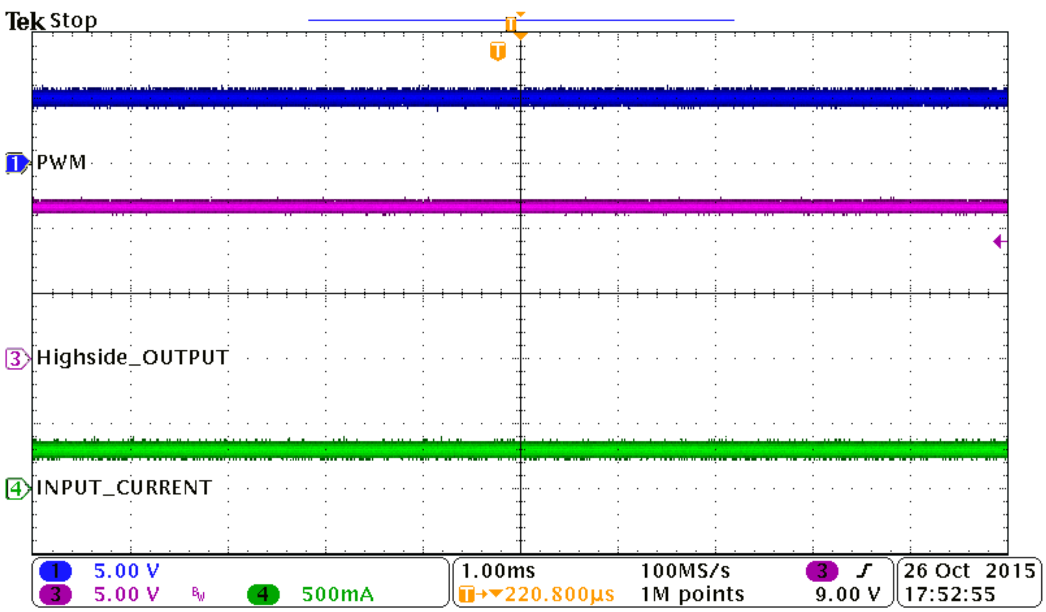

Figure 5. Stop Function Waveform—100% PWM Duty Cycle Input Voltage and Current

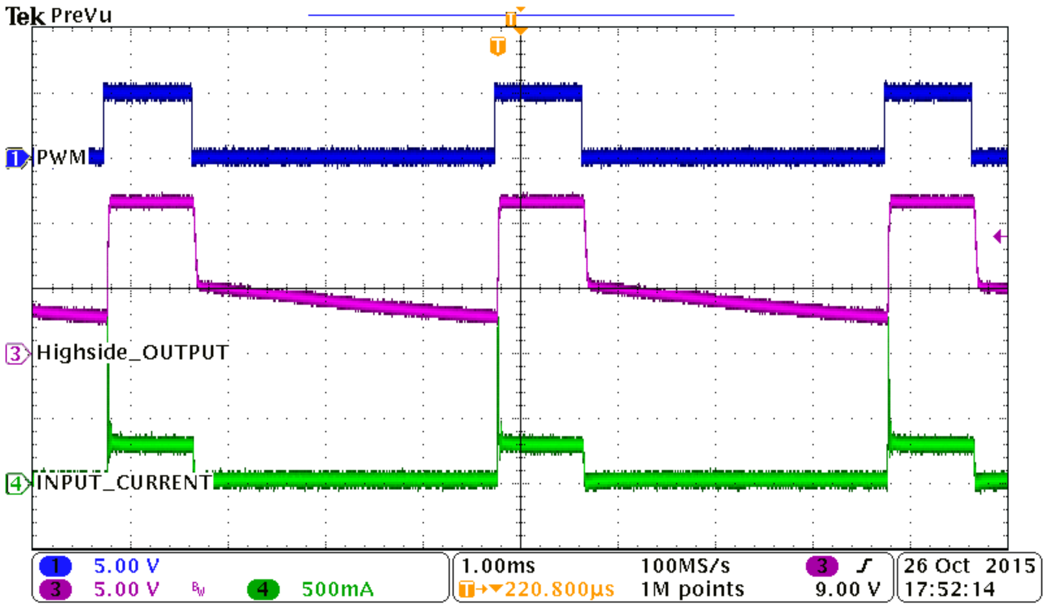

Figure 6. Tail Function Waveform—20% PWM Duty Cycle Input Voltage and Current

The following Figure 7 and Figure 8 show the waveforms of the fault pin pullup circuit during normal operation and in fault mode. Channel 1 shows the output signal of the pullup circuit, which corresponds to the TP1 on the system. Channel 2 shows the signal on the fault pin. In the absence of a fault, the fault pin voltage is high and the TP1 voltage is low. When a fault has occurred, the fault pin voltage is pulled down a little, but is still higher than 2 V, which indicates that the fault pin is still in the pullup state. During this process of a fault occurring, the TP1 voltage becomes high, which the MCU can detect.

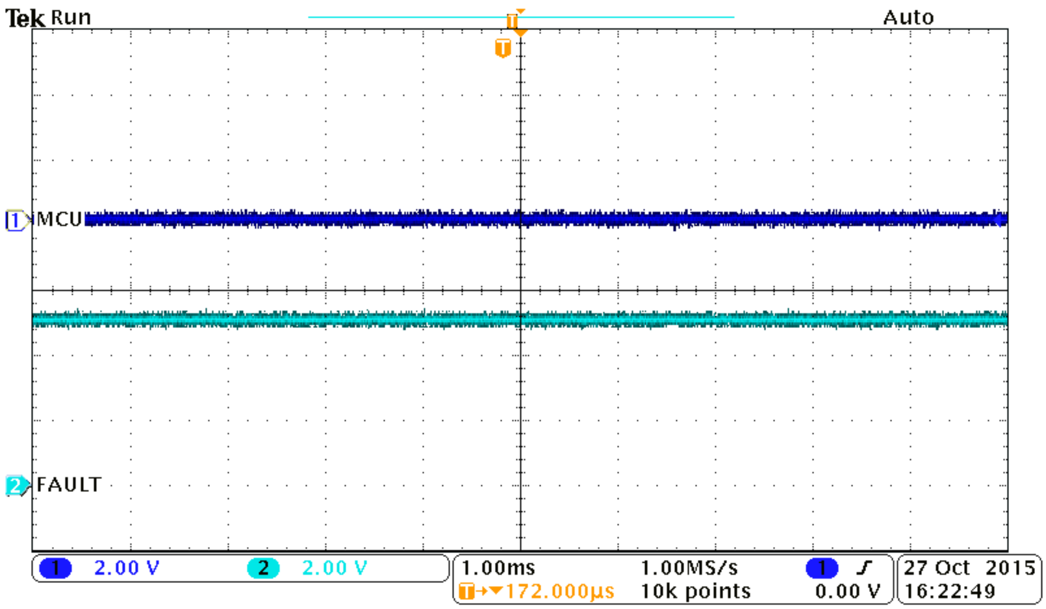

Figure 7. Normal Operation

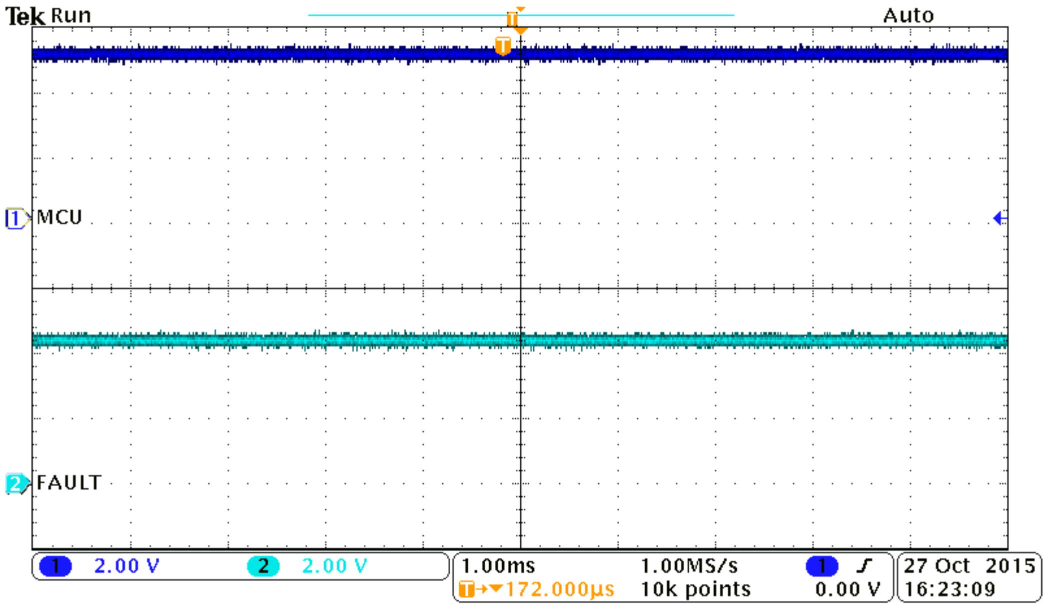

Figure 8. Fault Mode

6.3 Thermal Image

The following figures show the thermal images under two different levels of LED brightness. Figure 9 shows the thermal image when the LED is at the full level of brightness. Figure 10 shows the thermal image when the LED is dimmed under the 20% duty cycle.

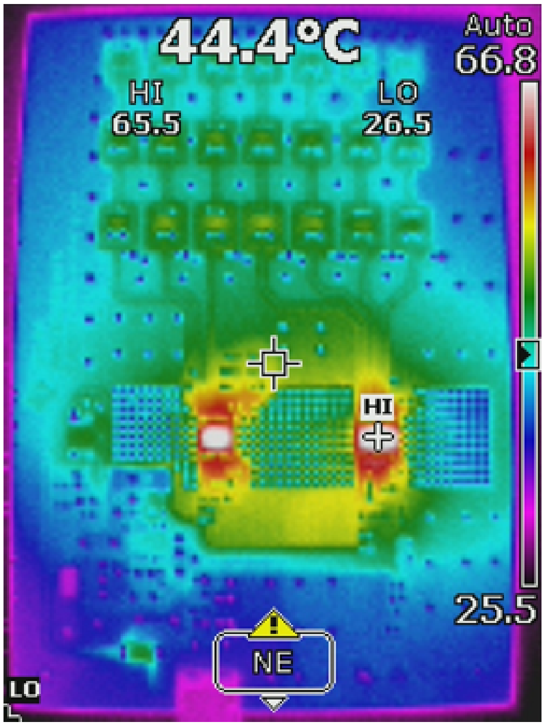

Figure 9. Thermal Image of Stop Function at 25°C, 12-V Input Voltage

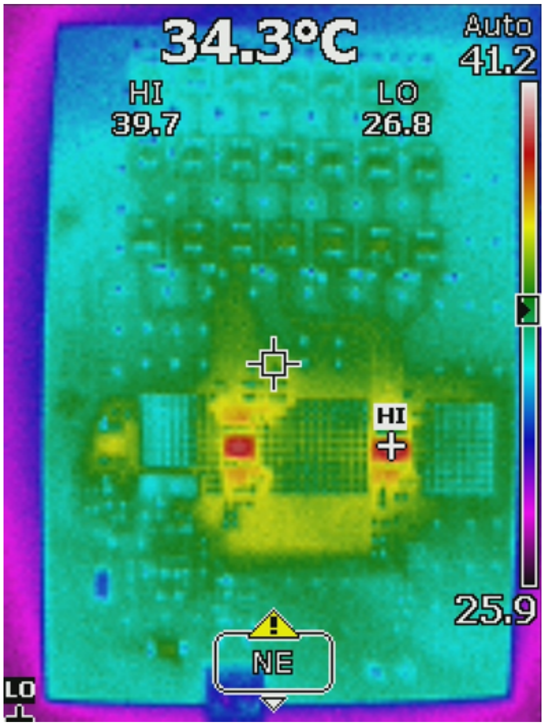

Figure 10. Thermal Image of Tail Function at 25°C, 12-V Input Voltage

7 Design Files

7.1 Schematics

To download the schematics for each board, see the design files at TIDA-00846.

7.2 Bill of Materials

To download the bill of materials (BOM) for each board, see the design files at TIDA-00846.

7.3 PCB Layout Recommendations

The layout process is an important step for the use of a linear LED driver. If the layout is not carefully designed, the driver may not deliver enough output current because of the thermal limitation. To improve the thermal performance of the device and maximize the current output at high ambient temperatures, TI recommends spreading the thermal pad as large as possible and placing a sufficient number of thermal vias on the thermal pad.

7.3.1 Layout Prints

To download the layout prints for each board, see the design files at TIDA-00846.

7.4 Altium Project

To download the Altium project files for each board, see the design files at TIDA-00846.

7.5 Gerber Files

To download the Gerber files for each board, see the design files at TIDA-00846.

7.6 Assembly Drawings

To download the assembly drawings for each board, see the design files at TIDA-00846.

8 References

1. Texas Instruments, *TPS9263x-Q1 Three-Channel Linear LED Driver With Analog and PWM Dimming*, TPS92630-Q1 Datasheet ()
2. Texas Instruments, *TPS92638-Q1 8-Channel Linear LED Driver With PWM Dimming*, TPS92638-Q1 Datasheet (SLVSCK5)
3. Texas Instruments, *TPS1H100-Q1 40-V, 100-mΩ Single-Channel Smart High-Side Power Switch*, TPS1H100 Datasheet ()
4. Texas Instruments, *TPS7B69xx-Q1 High-Voltage Ultra-Low IQ Low-Dropout Regulator*, TPS7B69xx-Q1 Datasheet (SLVSCJ8)
5. Texas Instruments, *TLC555-Q1 LinCMOS™ TIMER*, TLC555-Q1 Datasheet ()

9 About the Author

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