TI Designs: TIDA-01521
Automotive Linear LED Driver Reference Design for Center High-Mounted Stop Lamp (CHMSL)

Description

This reference design details a highly integrated solution for driving light-emitting diode (LED) strings for a center high-mounted stop lamp (CHMSL), which includes brake and reverse lights. Each light is capable of independent function by applying power to its supply line. The design uses three automotive-rated linear LED drivers (TPS92610-Q1), which results in a low bill of material count and feature-rich solution.

To show the performance, this design guide also includes several test results.

Features

- Low Bill of Materials (BOM) Count
- Wide Input Voltage Range
- High Integrated Solution
- Reverse Battery Protection
- Optional Diagnostic Features
- Precision Current Regulation

Applications

- Exterior Lighting - Rear Light

Resources

TIDA-01521	Design Folder
TPS92610-Q1	Product Folder

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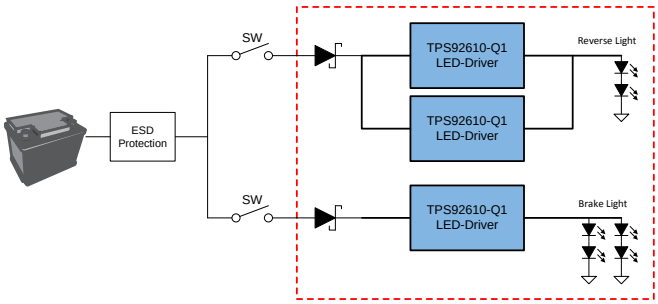

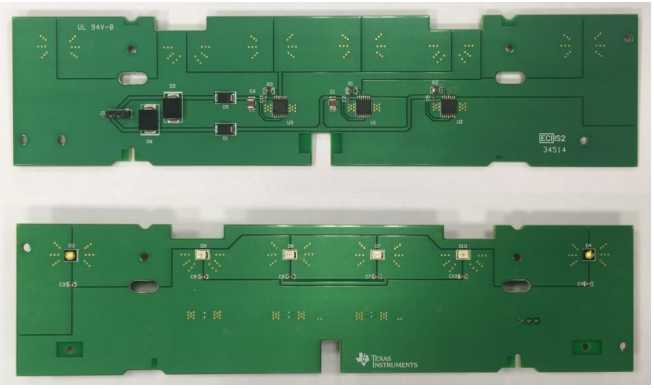

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1 System Description

The center high-mounted stop lamp (CHMSL) is mounted higher than the left and right stop lamps in a vehicle and is essential for providing a warning signal to drivers when their view of the left and right stop lamps is blocked. The CHMSL is similarly known as the "third brake light". The device also provides a redundant stop light signal in the case of a stop lamp malfunction. Some vehicles, such as pick-up trucks, feature a reverse light integrated in the CHMSL in addition to the brake light function.

The drive circuit for the LEDs in a CHMSL application is often realized in a discrete way by using low-side bipolar junction transistor (BJTs) circuits, which results in a high component count.

The TIDA-01521 reference design details a highly integrated solution for driving LEDs in a CHMSL, which includes brake and reverse lights. Each light is capable of independent function by applying power to its supply line. The design uses three automotive-rated linear LED drivers (TPS92610-Q1) to obtain a low BOM count yet feature-rich solution. The design also includes protection features against load dump conditions and reverse battery conditions while simultaneously maintaining a small solution size.

1.1 Key System Specifications

Table 1. Key System Specifications

PARAMETER	SPECIFICATIONS
DC input voltage range	9 V to 16 V
Output current reverse light	240 mA
Output current brake light	90 mA
Maximum ambient temperature	85°C

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2 System Overview

2.1 Block Diagram

Figure 1 shows the block diagram of the TIDA-01521 design that comprises the following main components:

- Two TPS92610-Q1 LED drivers for reverse light
- One TPS92610-Q1 LED driver for brake light
- LEDs for reverse and brake light
- Protection diodes

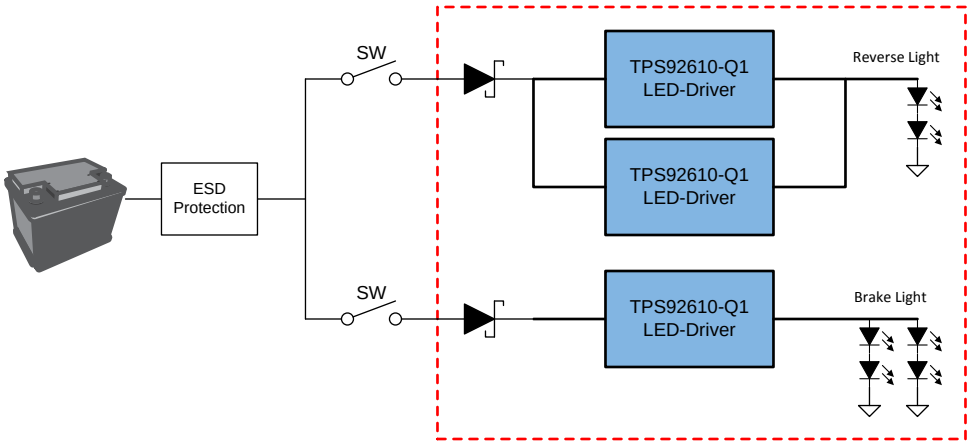

Figure 1. TIDA-01521 Block Diagram

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2.2 Highlighted Products

2.2.1 TPS92610-Q1

The TPS92610-Q1 device is a simple, single-channel, high-side LED driver operating from an automotive car battery. The device is a simple and elegant solution for delivering constant current to a single LED string with a full LED diagnostic. Figure 2 shows the functional block diagram of the TPS92610-Q1.

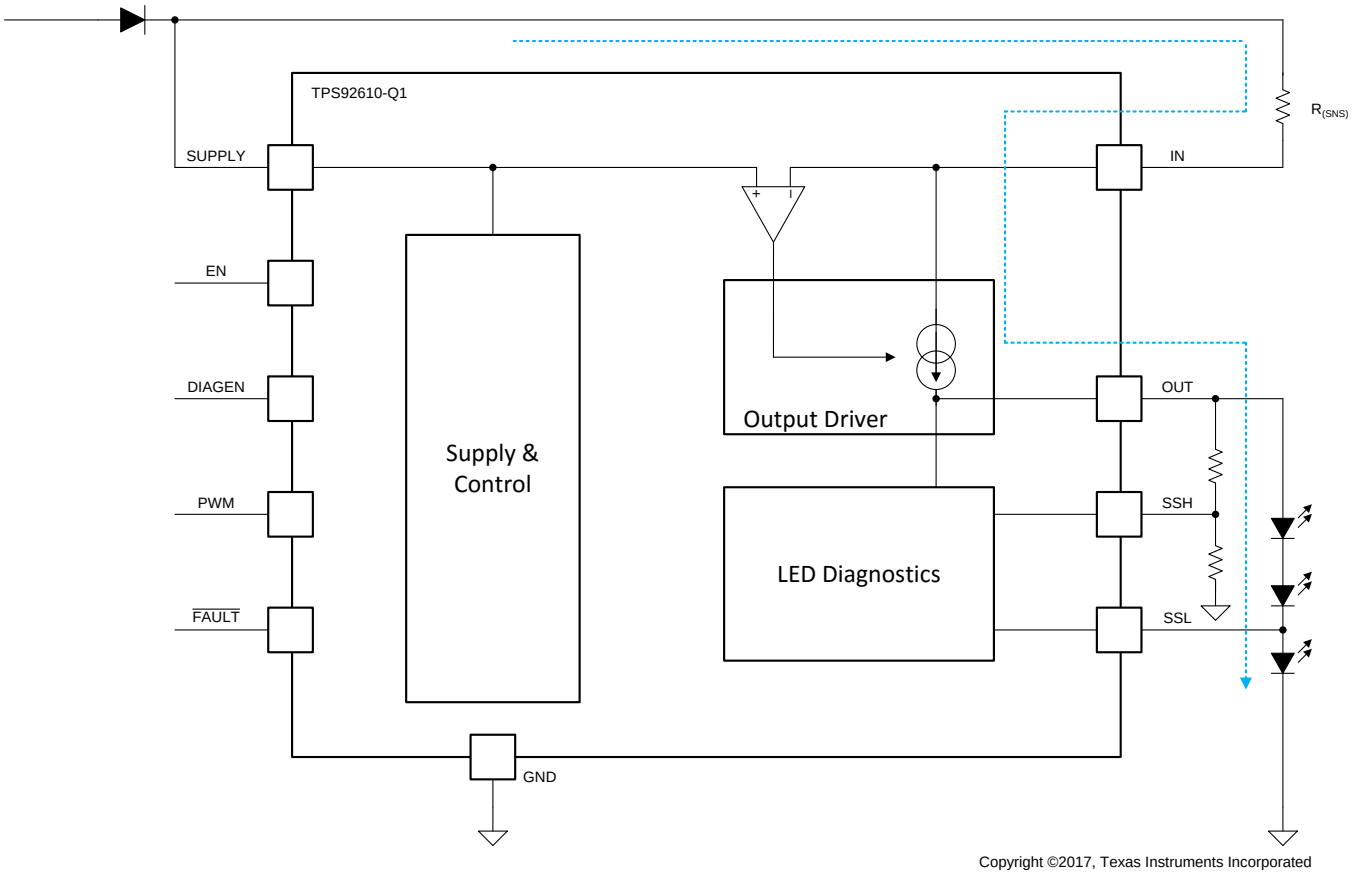

Figure 2. TPS92610-Q1 Functional Block Diagram

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2.3 System Design Theory

One of the more commonplace methods for implementing LED driver circuits in a CHMSL application in a discrete way is to use low-side bipolar junction transistor (BJTs) circuits, which results in a high component count. The primary goal of this reference design is to make a low BOM count, compact solution for driving brake and reverse lights by using three TPS92610-Q1 linear LED drivers. The following subsections provide details on the design process.

Figure 3 shows the physical design in operation after placing it in a CHMSL plastic housing for real applications.

Figure 3. TIDA-01521 Operation in CHSML Housing

2.3.1 PCB and Form Factor

The design uses a two-layer printed-circuit board (PCB) with 1 oz of copper where the integrated circuits (ICs) and diodes are placed on the bottom layer and the LEDs are placed on the top layer. The board dimensions are 210 mm × 51 mm. Figure 4 and Figure 5 show a three-dimensional (3-D) rendering of the PCB.

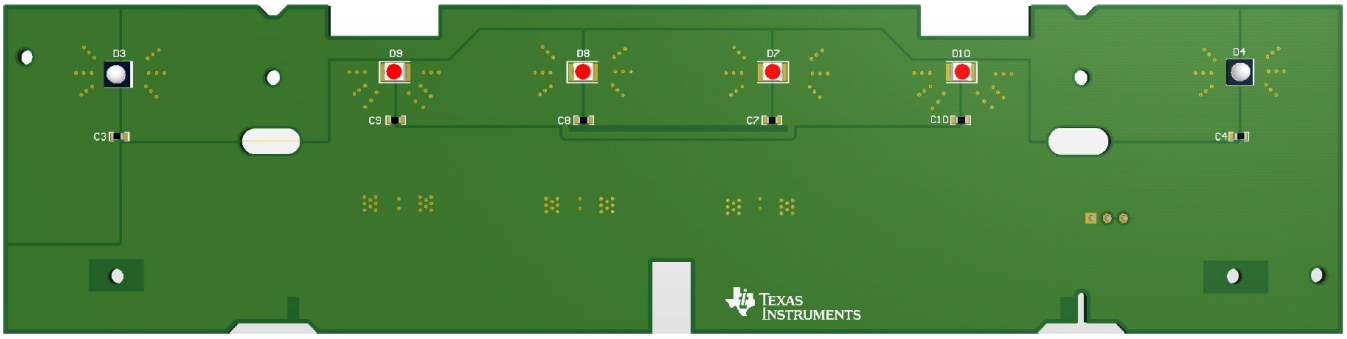

Figure 4. 3-D Render of TIDA-01521 PCB (Top View)

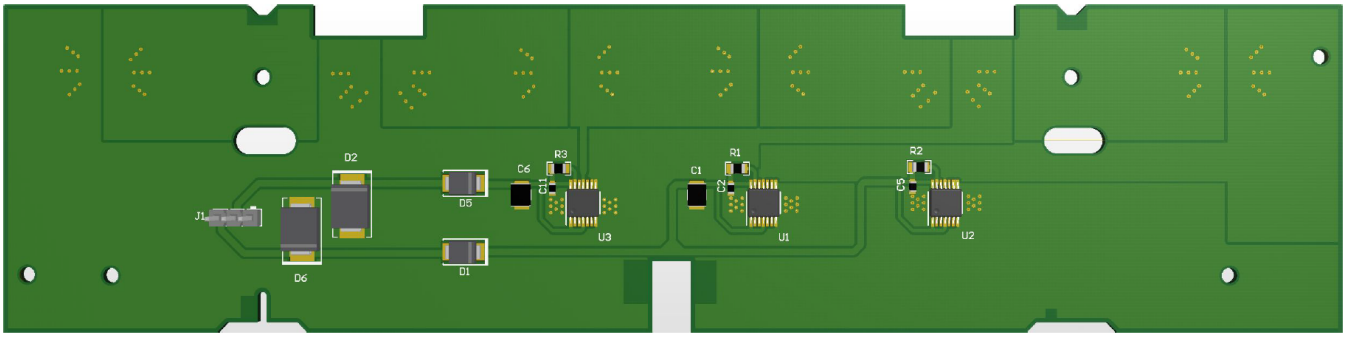

Figure 5. 3-D Render of TIDA-01521 PCB (Bottom View)

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2.3.2 LEDs

This design uses white LEDs from OSRAM (OSLON Black Series - LUW H9GP.CE) for the reverse light with a typical forward voltage of 3 V at a 100-mA forward current. The brake light uses red LEDs (VLMR334BACB) with a typical forward voltage of 2.1 V at a 45-mA forward current.

2.3.3 Input Protection

The design integrates reverse battery protection as well as transient protection. Reverse battery protection is required in the electronic subsystems of a vehicle and is implemented in this design by using Schottky diodes on the inputs. Transient voltage suppression (TVS) diodes are placed on the supply inputs of the system to protect against both positive- and negative-going transients.

2.3.4 Brake Light

The brake light consists of two LED strings where each string is based on two red LEDs in series. To drive these brake light LEDs, this design uses one TPS92610-Q1 LED driver. The total LED driver current is set to 90 mA so that each LED string takes 45 mA.

Table 2 lists the default design specifications for the brake light.

Table 2. Brake Light Design Specifications

DESIGN PARAMETERS	SPECIFICATION
DC input voltage range	9 V to 16 V
Total output current	90 mA
LED strings	Two
LEDs per string	Two

Figure 6 shows the default schematic of the brake light circuit for this reference design.

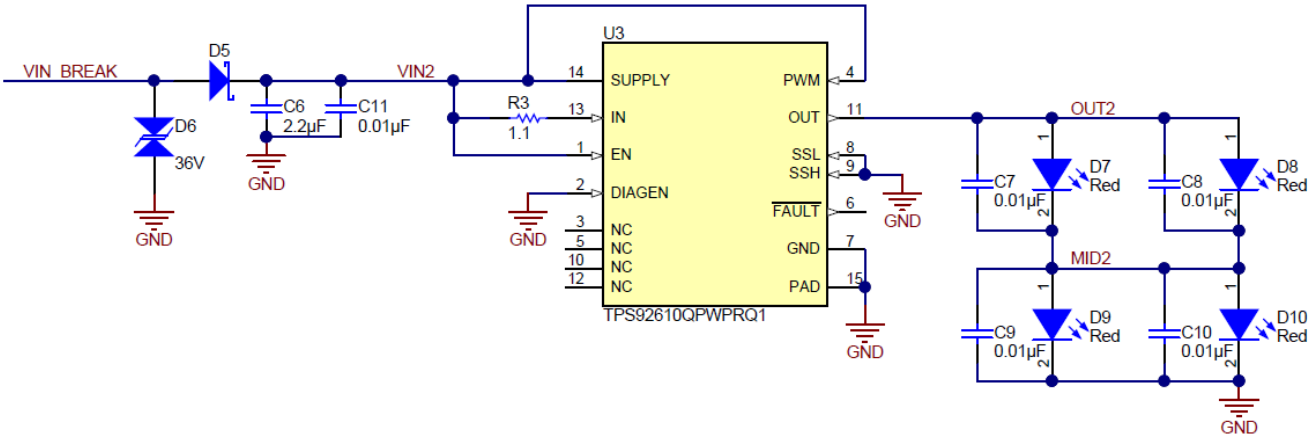

Figure 6. Brake Light Schematic

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Diode D5 is for reverse protection whereas D6 is used for transient protection. Input capacitors C6 and C11 are placed to provide a stable supply voltage. The output current can be set by an external resistor, which the TPS92610-Q1 data sheet describes in further detail. Equation 1 calculates the resistor value to provide the required current level of 90 mA. A resistor value of 1.1 Ω is used.

$$R3 = \frac{V_{CS_REG}}{I_{OUT}} = \frac{98\ mV}{90\ mA} = 1.09\ \Omega \quad (1)$$

where,

- R_3 is the sense resistor to program output current,
- V_{CS_REG} is the sense-resistor regulation voltage (typically 98 mV),
- I_{OUT} is the LED driver output current.

The midpoint of the four LEDs are connected to ensure that three LEDs continue working if one LED fails to open. Capacitors C7, C8, C9, and C10, which are in parallel to the LEDs, are used for noise filtering.

2.3.5 Reverse Light

The reverse light consists of one LED string with two white LEDs in series. To drive these LEDs, this design uses two TPS92610-Q1 LED drivers in parallel to overcome thermal limitations, which Section 2.3.6 addresses further. Each LED driver current is set to 120 mA so the total current through the LED string will be 240 mA.

Table 3 shows the default designs specifications for the reverse light.

Table 3. Reverse Light Design Specifications

DESIGN PARAMETERS	SPECIFICATION
DC input voltage range	9 V to 16 V
LED driver output current	120 mA
Total output current	240 mA
LED strings	One
LEDs per string	Two

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Figure 7 shows the default schematic of the reverse light circuit for this reference design.

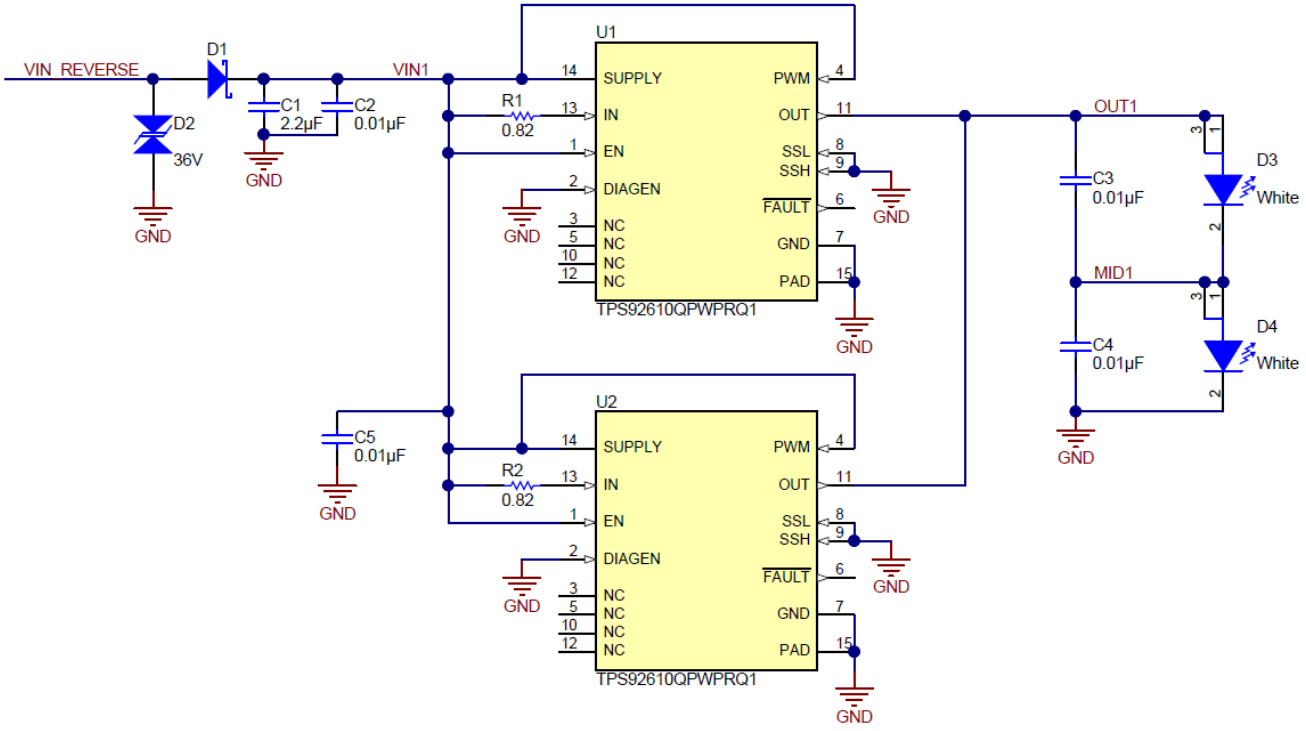

Figure 7. Reverse Light Schematic

Similar to the brake light, the D1 diode is for reverse protection, whereas D2 is used for transient protection. The placement of input capacitors C1, C2, and C5 provide a stable supply voltage. Capacitors C3 and C4 in parallel to the LEDs are used to filter noise. The output current is set using an external resistor.

Equation 1 calculates the resistor values to provide the required current level of 120 mA for each of the two LED drivers. A resistor value of 0.82 Ω is used.

$$R1 = R2 = \frac{V_{CS_REG}}{I_{OUT}} = \frac{98\ mV}{120\ mA} = 0.82\ \Omega \quad (2)$$

where,

- R1/R2 is the sense resistor to program output current,
- V_{CS_REG} is the sense-resistor regulation voltage (typically 98 mV),
- I_{OUT} is the LED driver output current.

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2.3.6 Thermal Considerations

When using the linear LED driver, TPS92610-Q1, thermal performance is one of the most important considerations. Thermal performance limits the power dissipation on the TPS92610-Q1 device in addition to limiting the maximum output current. In linear LED driver applications, the input voltage variation contributes to most of the thermal concerns.

Use Equation 2 to calculate the power dissipation of the device.

$$P_D = (V_{IN} - V_D - Vf_{LED}) \times I_{LED} \quad (3)$$

where,

- P_D is the total power dissipation of the device,
- V_{IN} is the input voltage,
- V_D is the forward voltage of the reverse protection diode (typically 0.3 V),
- Vf_{LED} is the total LED-string forward voltage.

After calculating the power dissipation of the device, use Equation 4 to calculate the junction temperature. To be compliant with the IC specification, T_J must remain lower than 150°C in worst-case conditions.

$$T_J = T_A + P_D \times R_{\Phi JA} \quad (4)$$

where,

- T_J is the junction temperature of the device,
- T_A is the ambient temperature,
- $R_{\Phi JA}$ is the junction-to-ambient thermal resistance.

The $R_{\Phi JA}$ is available for look-up in each data sheet of the device, but note that this value is typically based on the JEDEC standard. $R_{\Phi JA}$ is a measure of the thermal performance of an IC package mounted on a specific PCB. For additional information, see *Semiconductor and IC Package Thermal Metrics* and *How to Calculate TPS92630-Q1 Maximum Output Current for Automotive Exterior Lighting Applications*.

For the purposes of this reference design, the $R_{\Phi JA}$ values listed in Table 4 and Table 5 are based on thermal simulations. The $R_{\Phi JA}$ values of the ICs are slightly different due to how they influence each other on the PCB.

Table 4 shows the calculated results with an input voltage of 12-V and an ambient temperature of 25°C and 85°C.

Table 4. Thermal Calculation Results (V_{IN} = 12 V)

PARAMETER	LED DRIVER U3 (BRAKE LIGHT 90 mA)	LED DRIVER U1 (REVERSE LIGHT 120 mA)	LED DRIVER U2 (REVERSE LIGHT 120 mA)
P_D (12 V_{IN})	0.68 W	0.68 W	0.68 W
T_A = 25°C			
$R_{\Phi JA}$	59.7°C/W	65.2°C/W	58.5°C/W
T_J	65°C	70°C	65°C
T_A = 85°C			
$R_{\Phi JA}$	54.4°C/W	58.9°C/W	52.9°C/W
T_J	122°C	125°C	121°C

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Table 5 shows the calculated results with an input voltage of 16-V and an ambient temperature of 25°C and 85°C. Note that the worst-case condition is with a 16-V input voltage at 85°C ambient temperature.

Table 5. Thermal Calculation Results (V_{IN} = 16 V)

PARAMETER	LED DRIVER U3 (BRAKE LIGHT 90 mA)	LED DRIVER U1 (REVERSE LIGHT 120 mA)	LED DRIVER U2 (REVERSE LIGHT 120 mA)
P_D (16 V_{IN})	1.04 W	1.16 W	1.16 W
T_A = 25°C			
$R_{\Phi JA}$	59.3°C/W	63.1°C/W	57.°C/W
T_J	86°C	99°C	91°C
T_A = 85°C			
$R_{\Phi JA}$	54.3°C/W	57.6°C/W	52.2°C/W
T_J	141°C	152°C	146°C

The calculated worst-case results in Table 5 show that the maximum junction temperature T_J is slightly above 150°C. To further improve the thermal performance of the design, implement the following items:

- Increase copper thickness to 2 oz
- Increase distance between the ICs
- Use a silicon diode to obtain a higher voltage drop
- Decrease the LED current

For calculating the maximum output current under specific conditions, first use Equation 4 to calculate the maximum power dissipation at a specific ambient temperature. Then use the previous Equation 3 to solve for the current. *How to Calculate TPS92630-Q1 Maximum Output Current for Automotive Exterior Lighting Applications* shows an example calculation.

2.3.7 Diagnostic

The TPS92610-Q1 implements full diagnostic features like LED open detection, short detection, single-LED short detection, and fault detection; however, note that this reference design does not implement these functions. For more details, see *TPS92610-Q1 Automotive Single-Channel LED Driver*.

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3 Getting Started Hardware

3.1 Hardware

Connect a 12-V DC power supply to connector J1 to get started with the TIDA-01521 board (see Figure 8).

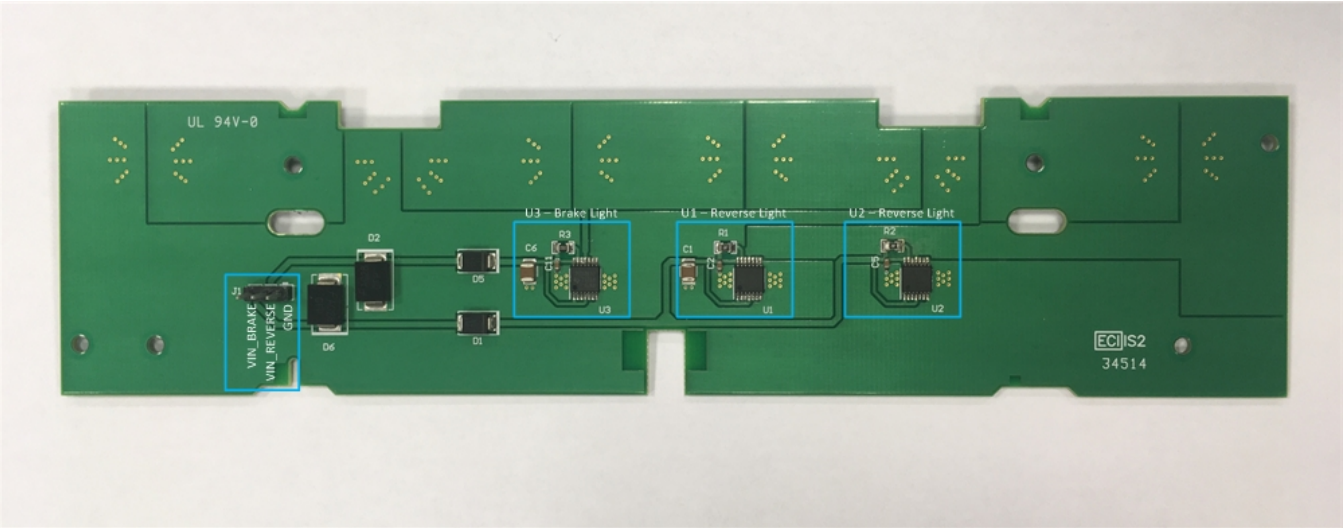

Figure 8. TIDA-01521 Hardware Setup

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4 Testing and Results

4.1 Start-Up

Figure 9 shows the start-up behavior of the brake light LED driver. The Input voltage source is 12 V.

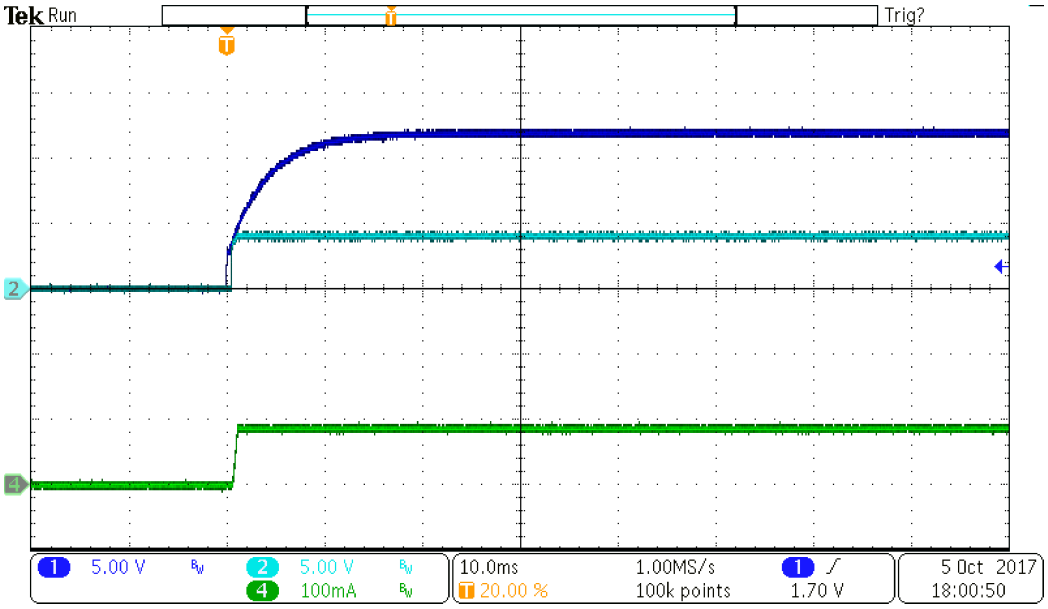

Figure 9. Start-Up Brake Light
Ch1 = V_{IN}, Ch2 = V_{OUT}, Ch4 = I_{OUT}

Figure 10 shows the start-up behavior of the reverse light LED drivers. The input voltage source is 12 V.

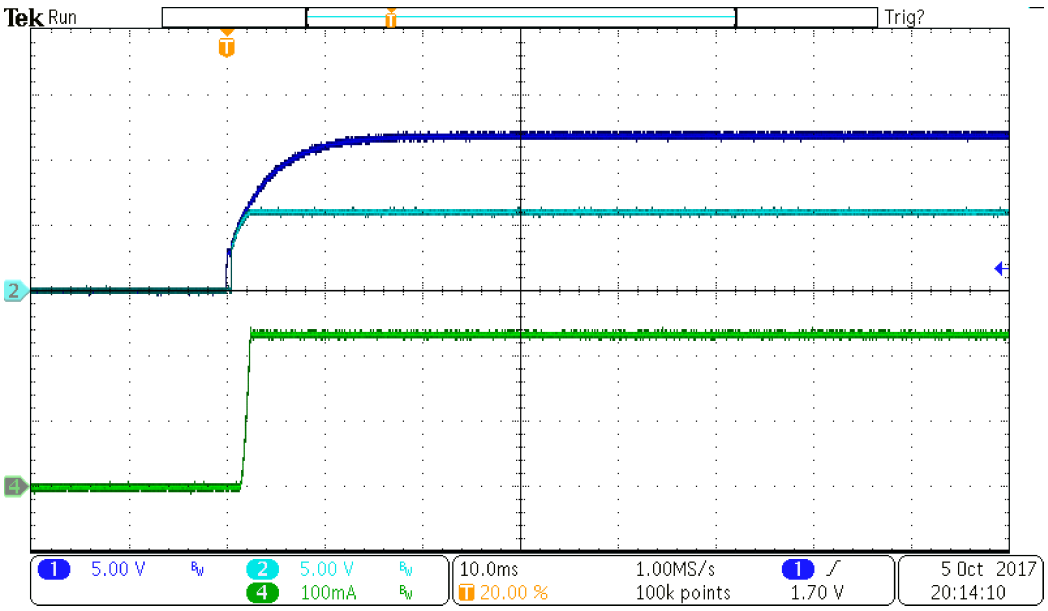

Figure 10. Start-Up Reverse Light
Ch1 = V_{IN}, Ch2 = V_{OUT}, Ch4 = I_{OUT}

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4.2 Thermal Results

The images in this section show the thermal performance of the TIDA-01521 design at an ambient temperature of 25°C. The measured results of the maximum IC temperatures correlate well with the calculated results from Table 4 and Table 5.

Figure 11 through Figure 13 show the maximum temperature at an input voltage of 12 V.

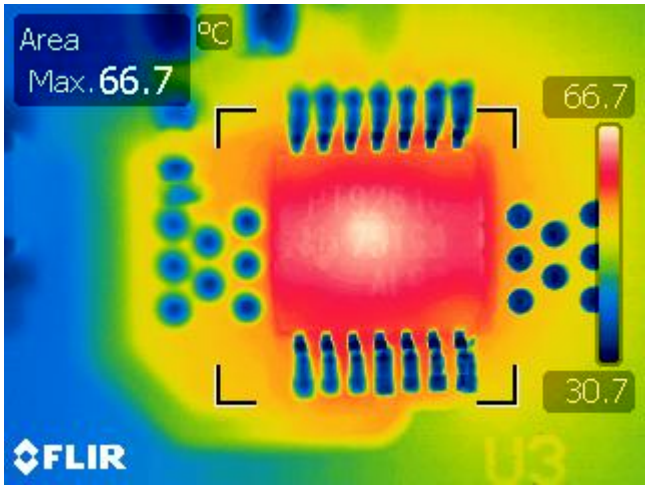

Figure 11. Thermal Image of LED Driver U3 (V_{IN} = 12 V)

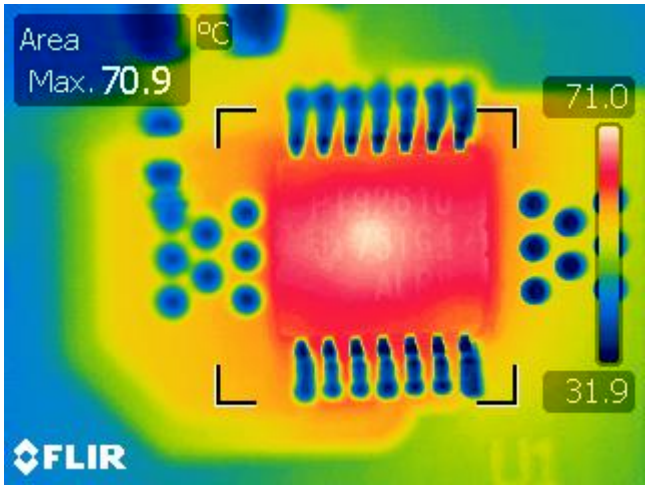

Figure 12. Thermal Image of LED Driver U1 (V_{IN} = 12 V)

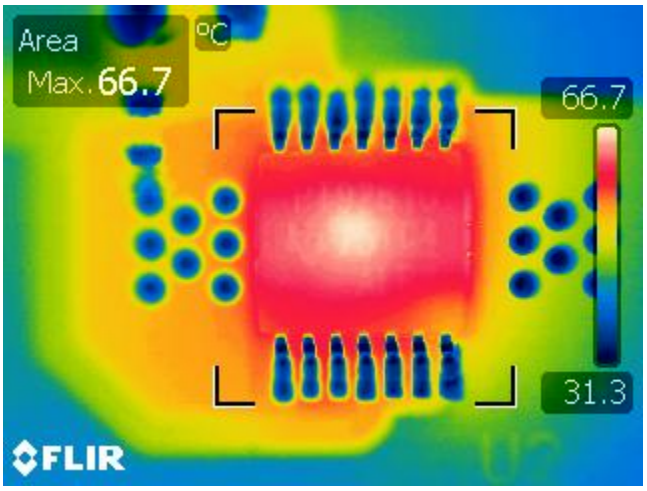

Figure 13. Thermal Image of LED Driver U2 (V_{IN} = 12 V)

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Figure 14 through Figure 16 show the maximum temperature at an input voltage of 16 V.

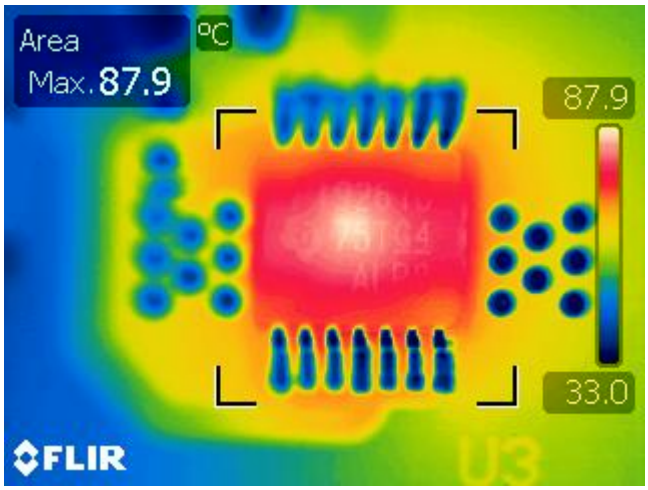

Figure 14. Thermal Image of LED Driver U3 (V_{IN} = 16 V)

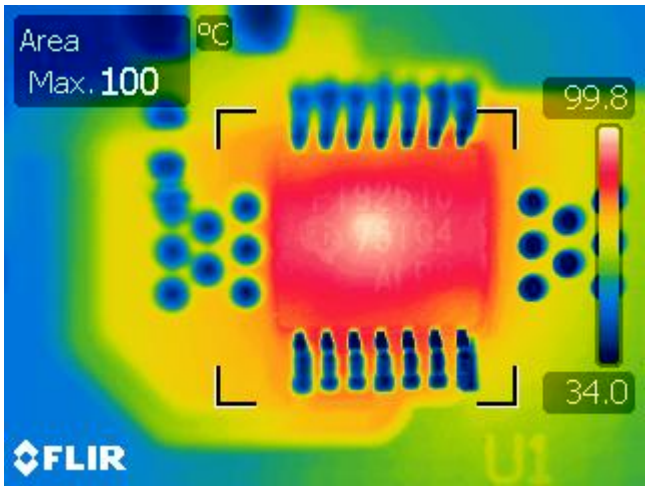

Figure 15. Thermal Image of LED Driver U1 (V_{IN} = 16 V)

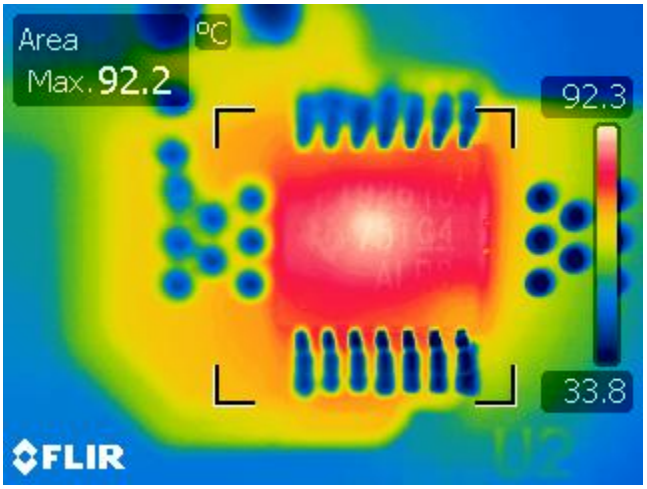

Figure 16. Thermal Image of LED Driver U2 (V_{IN} = 16 V)

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5 Design Files

5.1 Schematics

To download the schematics, see the design files at TIDA-01521.

5.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-01521.

5.3 PCB Layout Recommendations

To stay withing the IC specification and prevent thermal shutdown, T_J must be less than 150°C. If the input voltage is very high, the power dissipation may be large. The TPS92610-Q1 device is available in a 14-pin HTSSOP package, which has good thermal impedance; however, the PCB layout is also very important. A good PCB design is likely to 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. Maximum copper is extremely important when the design does not include heat sinks attached to the PCB 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.

5.3.1 Layout Prints

To download the layer plots, see the design files at TIDA-01521.

5.4 Altium Project

To download the Altium project files, see the design files at TIDA-01521.

5.5 Gerber Files

To download the Gerber files, see the design files at TIDA-01521.

5.6 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-01521.

6 Related Documentation

1. Texas Instruments, *Semiconductor and IC Package Thermal Metrics*
2. Texas Instruments, *How to Calculate TPS92630-Q1 Maximum Output Current for Automotive Exterior Lighting Applications*
3. Texas Instruments, *TPS92610-Q1 Automotive Single-Channel LED Driver*

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