Design Guide: TIDA-020009

Automotive Dual Stage (SEPIC + Linear) Static LED Driver Module Reference Design for Rear Lights

Description

This reference design details a solution for driving LEDs in an automotive, rear-light application such as a rear combination lamp (RCL) . This design features the TPS9261x-Q1 linear LED driver family powered by the LM5155-Q1 voltage regulator which is configured in a single-ended, primary inductance converter (SEPIC). The SEPIC provides a regulated voltage from the automotive battery. This design can operate through cold crank conditions and also optimizes the solution efficiency.

Resources

TIDA-020009	Design Folder
LM5155-Q1	Product Folder
TPS92610-Q1	Product Folder
TPS92611-Q1	Product Folder

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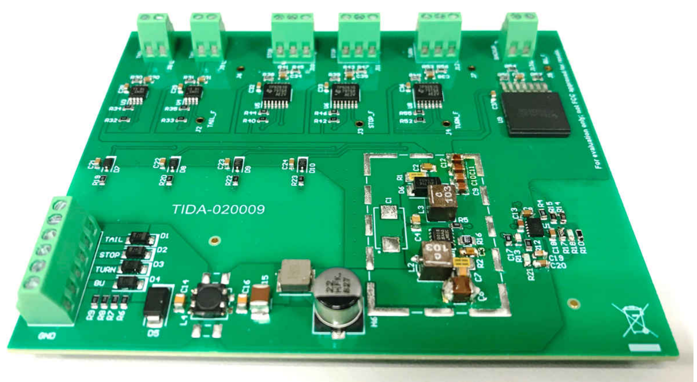
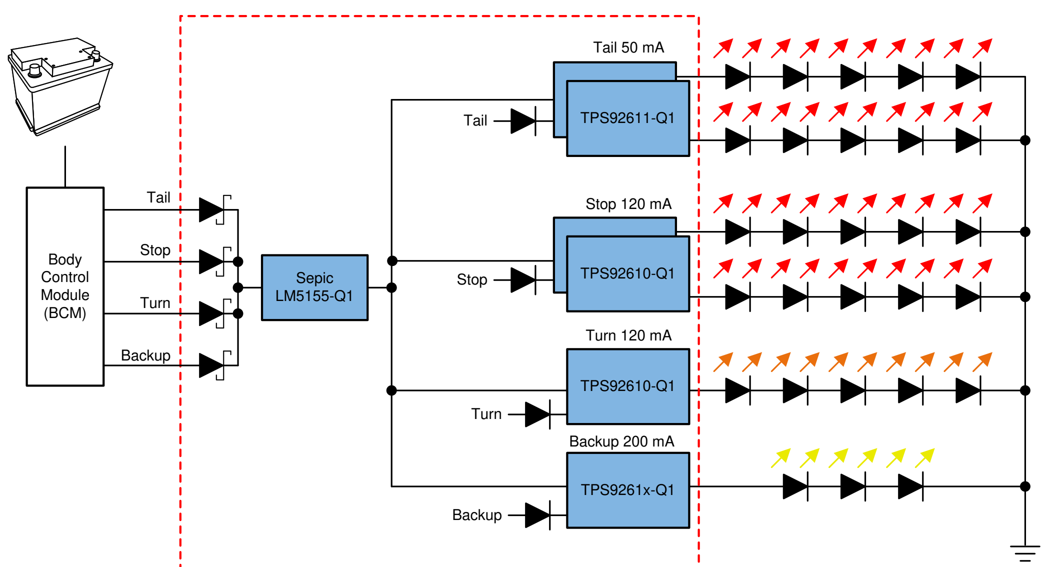
Features

- Operation through cold crank
- Buck-boost operation
- Open and short detection
- Single LED short detection (stop and turn light)
- CISPR25 class 5 compliant

Applications

- Exterior Lighting - Rear Light





1 System Description

The main light source in new rear-light applications, such as a rear combination lamp (RCL), is based on LEDs. Since the LED currents in such an application are not very high, linear LED drivers are mainly used to achieve a cost effective solution. The simplest way is to supply the linear LED drivers directly from the battery which brings some drawbacks. The power dissipation varies with changing battery voltage and the LED string voltage is limited to minimum operating voltage where the system must operate.

This reference design details a solution for driving LEDs in an automotive rear-light application such as a rear combination lamp (RCL). It features linear LED drivers for different rear light functions and the LED drivers are powered by a single ended primary inductance converter (SEPIC) LED power supply. The buck boost SEPIC LED power supply enables operation through varying battery voltage including cold crank and the design optimizes solution size and efficiency while meeting CISPR 25 conducted and radiated emissions requirements.

1.1 Key System Specifications

Table 1-1. Key System Specifications

PARAMETER	SPECIFICATIONS
DC input voltage range	6 V to 18 V
SEPIC output voltage	8 V to 16 V, default = 12.5 V
SEPIC switching frequency	460 KHz
LED string current	Tail light = 50 mA, stop light = 120 mA, turn light = 120 mA, backup light = 210 mA
LED string length	Tail, stop, turn light = 5 LEDs, backup light = 3 LEDs
Operating ambient temperature	-40 to 85°C
PCB form factor	88 x 70 mm (2 layers with 1.5 oz)

2 System Overview

2.1 Block Diagram

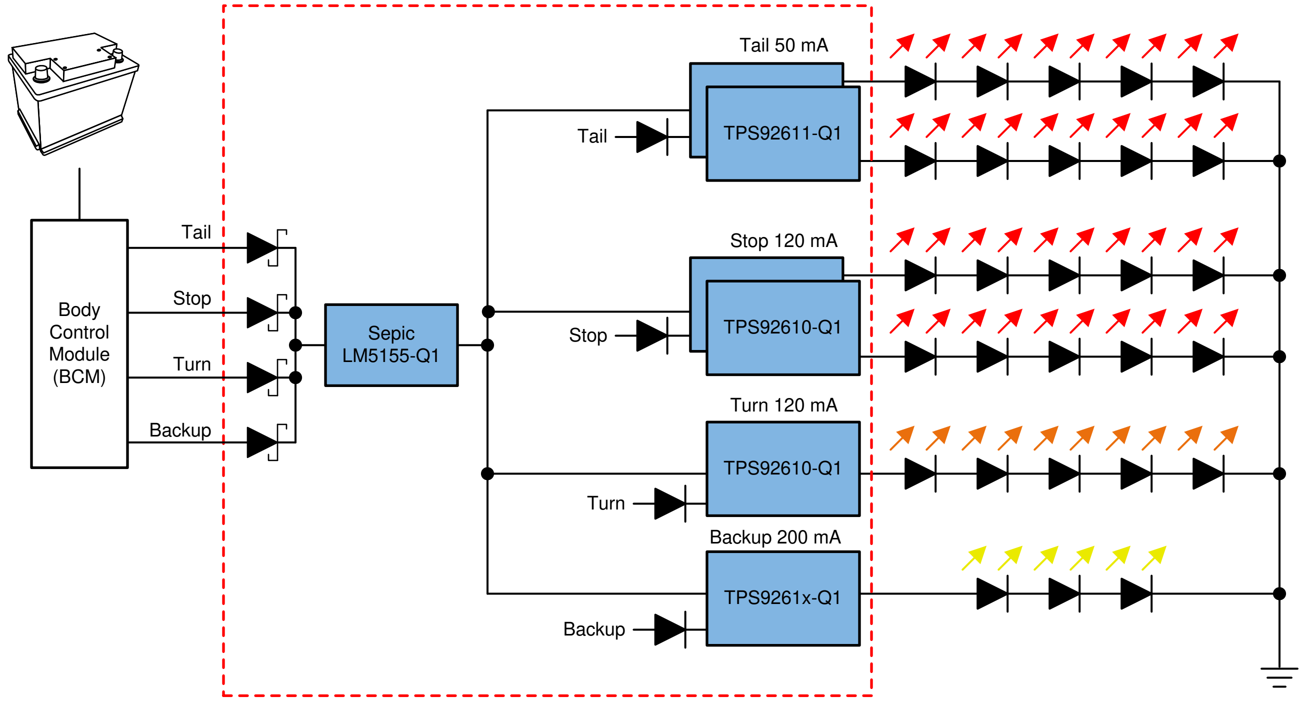


Figure 2-1. TIDA-020009 Block Diagram

2.2 Highlighted Products

2.2.1 LM5155-Q1

The LM5155x device is a wide-input range, non-synchronous boost controller which employs peak current mode control. The device is suitable for use in boost, SEPIC, and flyback topologies.

The wide input range of the device covers automotive cold crank and load dump transient. The device can start up from a 1-cell battery with a minimum 2.97 V. After start-up, the device can operate down to 1.5-V input by supplying the BIAS pin from the boost converter output. The switching frequency is programmed with an external resistor from 100 kHz to 2.2 MHz. Switching at 2.2 MHz minimizes AM band interference and allows for a small solution size and fast transient response.

The device features a 1.5-A standard MOSFET driver and a low, 100-mV current limit threshold. The device supports use of an external VCC supply to improve efficiency. In addition, low operating current and pulse skipping operation improve efficiency at light load.

The device has built-in protection features such as cycle-by-cycle current limit, over voltage protection, line UVLO, thermal shutdown and hiccup mode overload protection (LM51551). Additional features include low shutdown IQ, programmable soft start, programmable slope compensation, precision reference, power good indicator and external clock synchronization.

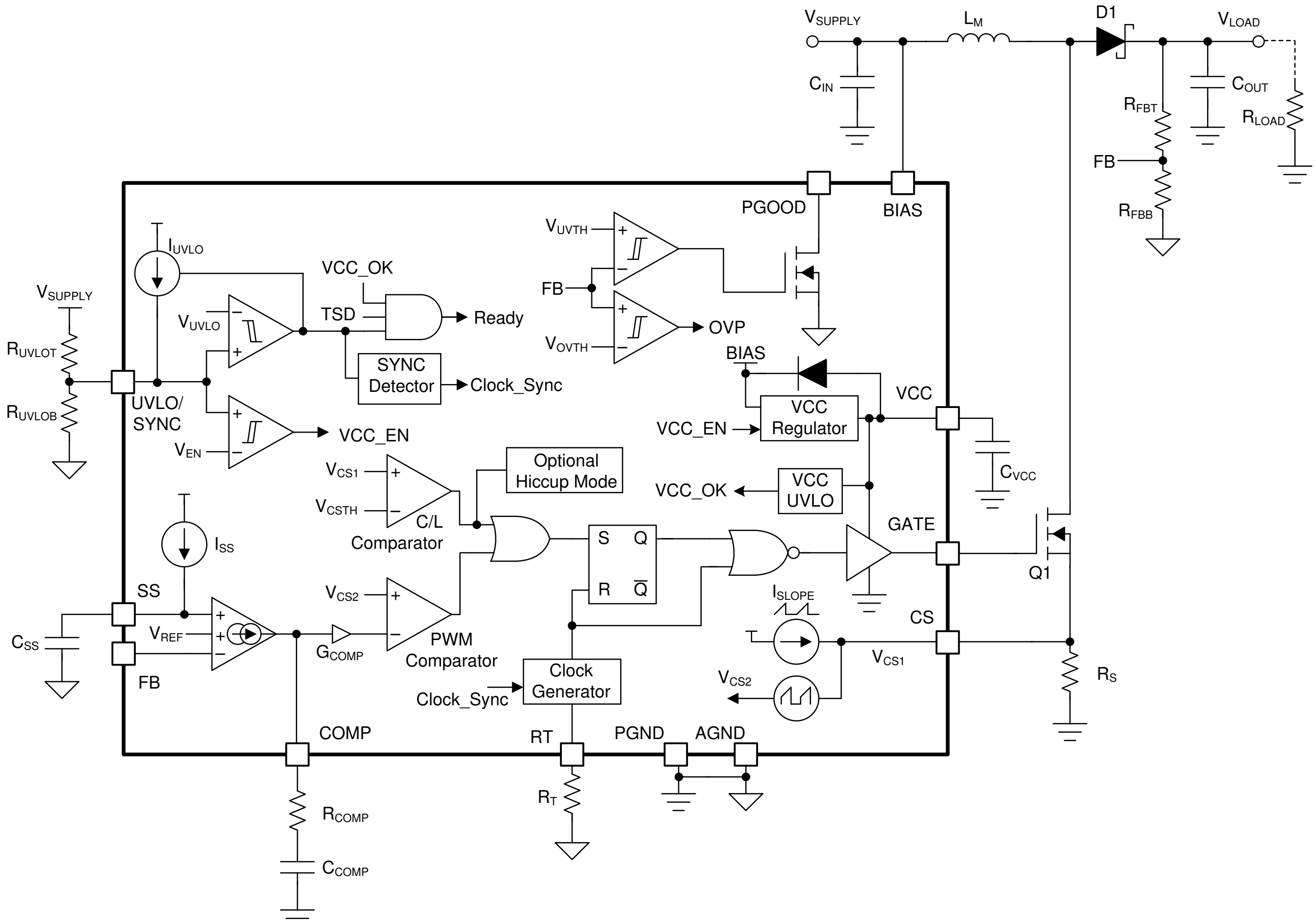


Figure 2-2. Functional Block Diagram of the LM5155-Q1

2.2.2 TPS92610-Q1, TPS92611-Q1

The TPS9261x-Q1 devices are a family of single-channel linear LED drivers. The family provides a simple solution for automotive LED applications. Different package options in the family provide a variety of current ranges and diagnostic options. The TPS92610-Q1 device in an HTSSOP-14 package supports LED open-circuit detection and short-to-ground detection. Unique single-LED-short detection in the TPS92610-Q1 device can help diagnose if one LED within a string is shorted. A one-fails–all-fail fault bus allows the TPS92610-Q1 device to be used together with the TPS9261x-Q1, TPS9263x-Q1, and TPS9283x-Q1 families. The output current can be set by an external R(SNS) resistor. Current flows from the supply through the R(SNS) resistor into the internal current source and to the LEDs.

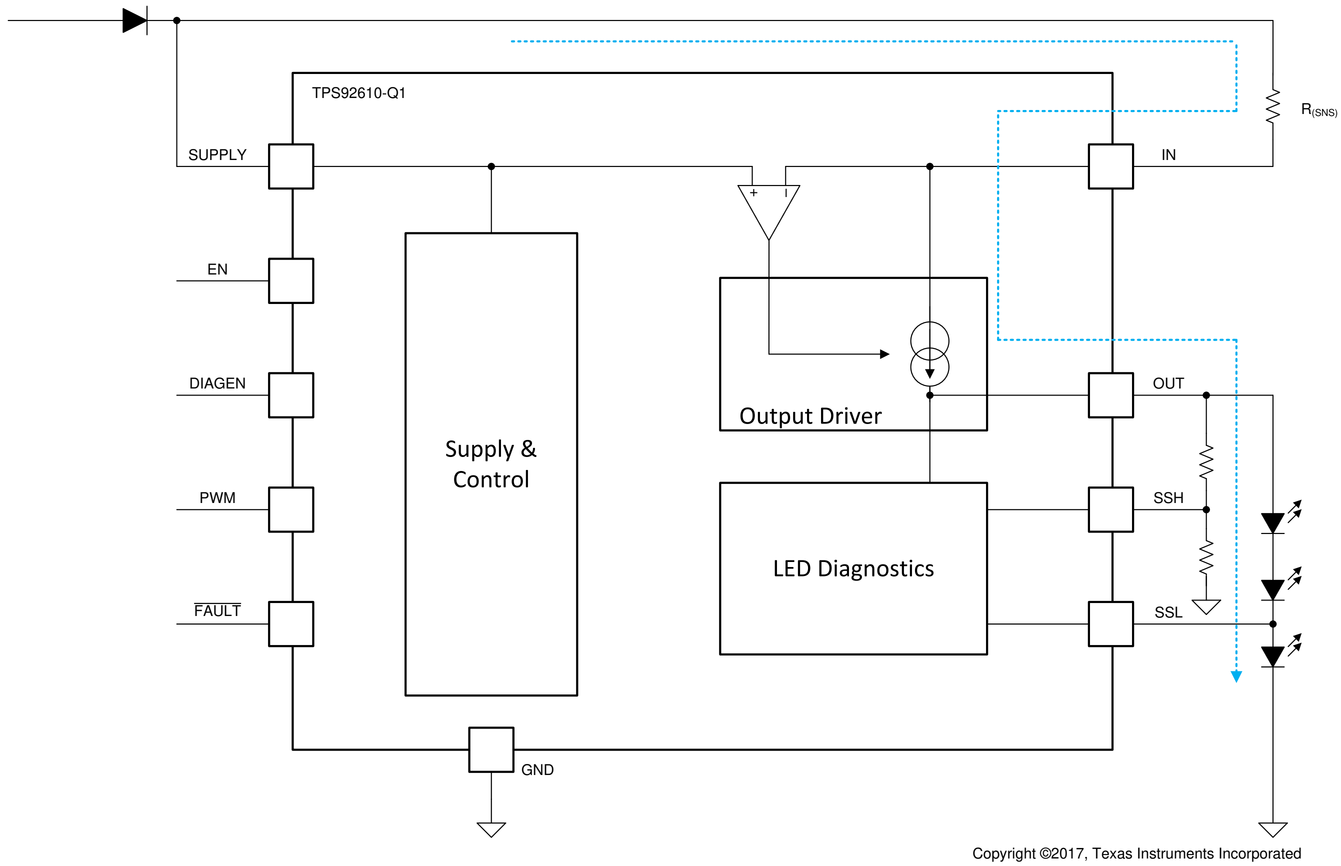


Figure 2-3. Functional Block Diagram of the TPS92610-Q1

2.3 System Design Theory

2.3.1 PCB and Form Factor

This reference design uses a two-layer printed circuit board (PCB) with 1.5 oz of copper where all components are placed on the top layer. The PCB is not intended to fit any particular form factor and has a dimension of 88 mm × 70 mm. The primary objective of the design with regards to the PCB is to make a solution that is compact while still providing a way to test the performance of the board. In a final-production version of this reference design, the size of the solution can be further reduced. Figure 2-4 shows a 3D rendering of the PCB.

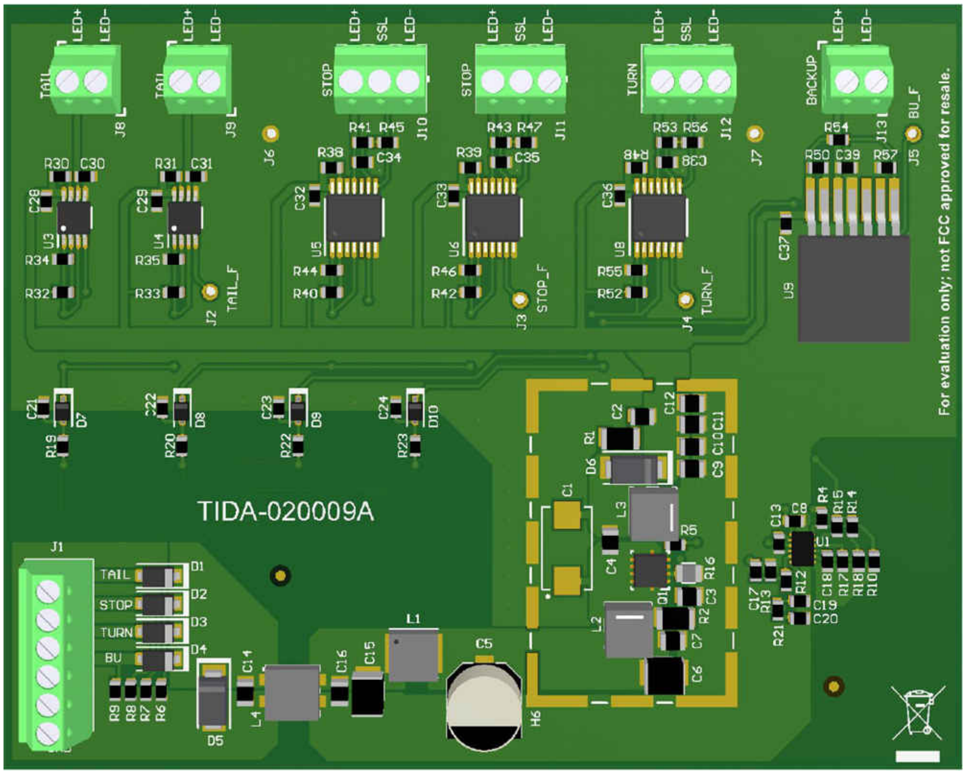


Figure 2-4. 3D Render of TIDA-020009 PCB

2.3.2 Input Protection

In this reference design, reverse polarity protection is implemented by using Schottky diodes D1 through D4 on the input power lines as shown in Figure 2-5. The diodes are acting as an OR-ing circuit, which provides power to the pre-voltage regulator if one or more power rails get active.

For transient protection, a transient voltage suppressor (TVS) diode D5 is placed at the input after the reverse polarity protection to clamp the voltage. However, the LM5155-Q1 supports up to 45-V input voltage.

Resistors R6 through R9 are placed to sink reverse current of the Schottky diodes.

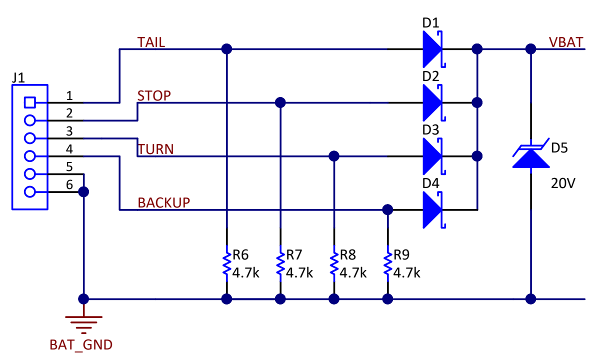


Figure 2-5. Schematic Input Protection

2.3.3 EMI Filter

There are two forms of conducted emissions. Common mode noise and differential mode noise. To attenuate conducted common mode noise a common mode choke is placed on the input whereas a LC filter is used to attenuate differential mode noise. To reduce radiation and near field coupling, place a metal shield on the design to cover all power stage components. The whole filter consists of L4, C14, C15, C16 and L1 as shown in Figure 2-6. For more details, see Simple Success With Conducted EMI From DC-DC Converters and The Engineer's Guide To EMI In DC-DC Converters (Part 2): Noise Propagation And Filtering.

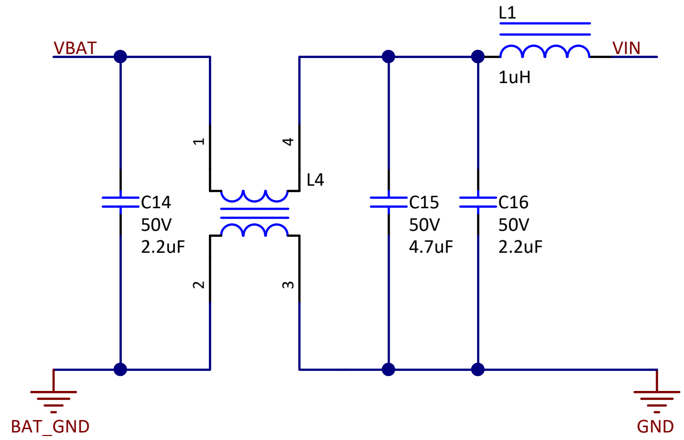


Figure 2-6. Schematic EMI Filter

2.3.4 LM5155-Q1 Voltage Regulator

In this design, the LM5155-Q1 is configured as SEPIC voltage regulator to provide a stable supply to the linear LED drivers. Table 2-1 shows the default design parameters for the LM5155-Q1 voltage regulator.

Table 2-1. Design Parameters of Default Sepic Configuration

DESIGN PARAMETER	VALUE
Output voltage	12.5 V
Output power	10 W
DC input voltage range	6 V to 18 V
Switching frequency	460 kHz

Figure 2-7 shows the default schematic of LM5155-Q1 in SEPIC configuration of this reference design.

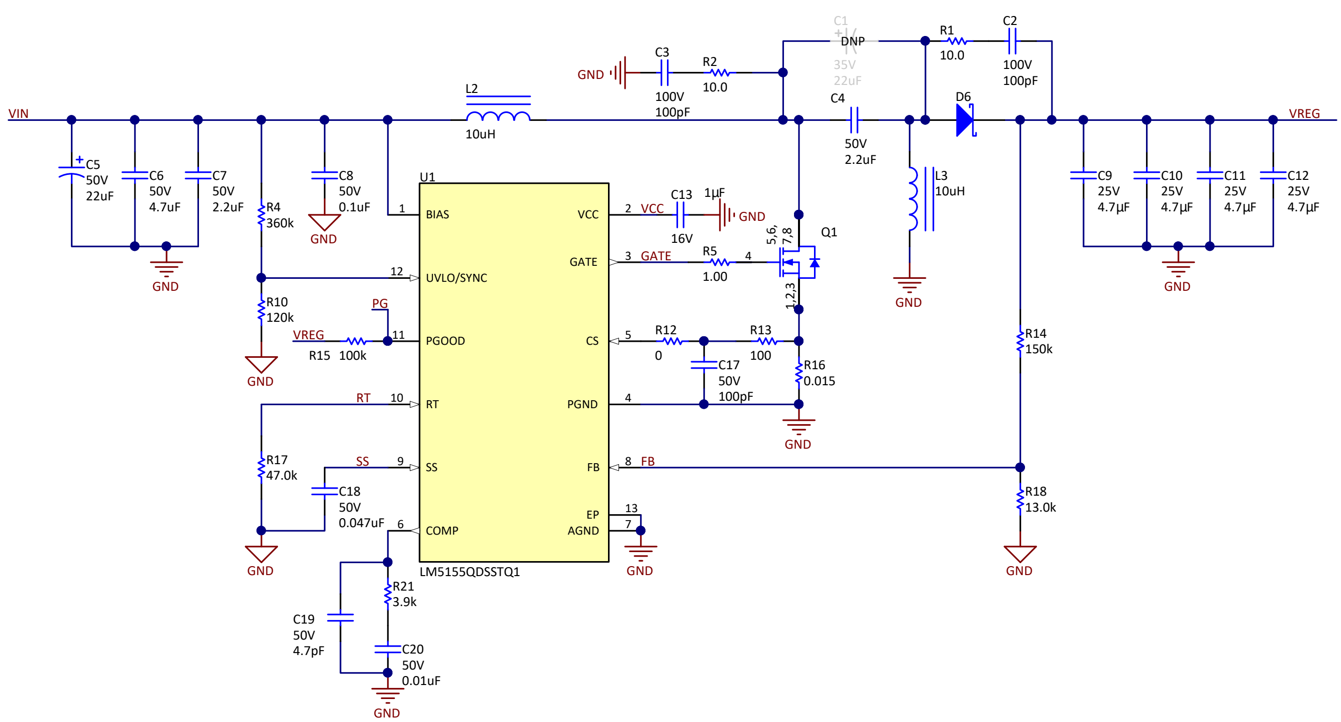


Figure 2-7. Schematic of LM5155-Q1 Controller (SEPIC Configuration)

The main components in the schematic are selected by following the guidelines in the LM5155x-Q1 2.2-MHz Wide Input Non-synchronous Boost/Sepic/Flyback Controller data sheet.

Input capacitors C5, C6, C7 and C8 smooth the input voltage ripple and provide a low impedance supply. The voltage divider resistors R4 and R10 set the desired startup and shutdown voltage level. For this reference design, the startup voltage is 6 V with a hysteresis of 2 V, which results in a 4-V shutdown voltage. Resistor R17 and capacitor C18 are used to set the switching frequency and softstart time. For compensation of the voltage regulator loop C19, R21 and C20 are connected to the comp pin which is the output of the internal transconductance error amplifier. Resistors R14 and R18 adjust the output voltage level. For the internal VCC regulator which supplies the gate driver C13 is required as bypass capacitor. Resistor R13 and capacitor C17 set the slope compensation. A resistor-capacitor snubber network (R2, C3) across the low-side N-channel MOSFET Q1 and (R1, C2) across the requtifier diode reduces ringing and spikes at the switch nodes. For how to calculate these values, see Power Tips: Calculate an R-C snubber in seven steps.

The output capacitors C9, C10, C11 and C12 smooth the output voltage ripple and provide a source of charge during transient loading conditions. The output capacitors also reduce the output voltage overshoot when the load is disconnected suddenly. In a SEPIC regulator, the output is supplied by discontinuous current and the ripple current requirement is usually high, which makes ceramic capacitors a perfect fit. The output voltage ripple is dominated by ESR of the output capacitors. Paralleling the output capacitor is a good choice to minimize effective ESR and split the output ripple current into capacitors. This example uses four 4.7-µF ceramic capacitors with a voltage rating of 25 V. A higher output voltage ripple in this reference design is not a concern for the linear LED drivers, which are connected to the SEPIC output voltage.

The inductors L2 and L3 have a value of 10 µH with a saturation current rating above the maximum expected inductor current of 2 A at a minimum input voltage of 6 V. C4, with a value of 2.2µF, forms the coupling capacitor and D6 the rectifier diode of the SEPIC. The low-side power switch Q1 is a 60-V rated N-channel MOSFETs in a PowerPAK® package. R16 is the current sense resistor to set the current limit.

2.3.5 Tail Light (2x TPS92611-Q1)

For the tail light, two led strings are used where each gets driven by a TPS92611-Q1 linear LED driver. Table 2-2 shows the default design parameters for the tail light.

Table 2-2. Default Design Parameters of Tail Light

DESIGN PARAMETER	VALUE
Input voltage	12.5 V
LED string current	50 mA
Number of LEDs in series	5

Figure 2-8 shows the default schematic of one TPS92611-Q1 linear led driver for tail light of this reference design.

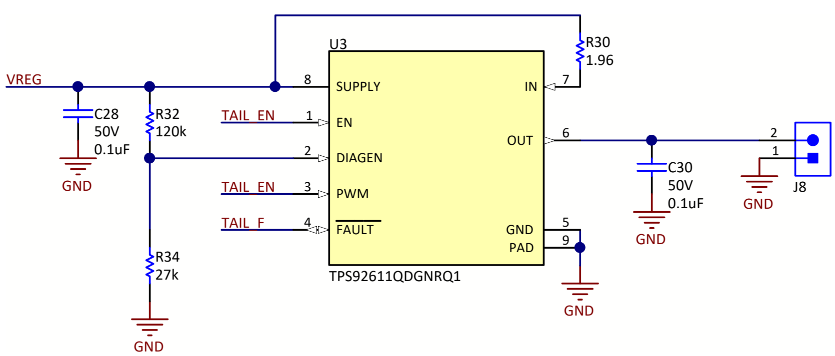


Figure 2-8. Schematic of TPS92611-Q1 Tail Light LED Driver

The main components in the schematic are selected by following the Detailed Design Procedure section in the TPS92611-Q1 Automotive Single-Channel Linear LED Driver data sheet.

With the resistor R30, the LED current is set to 50 mA. Capacitors C26 and C30 are added for noise filtering. Resistor R32 and R34 set the input voltage level where open circuit detection will be active.

2.3.6 Stop Light (2x TPS92610-Q1)

For the stop light, two led strings are used where each gets driven by a TPS92610-Q1 linear LED driver. Table 2-3 shows the default design parameters for the stop light.

Table 2-3. Default Design Parameters of Stop Light

DESIGN PARAMETER	VALUE
Input voltage	12.5 V
LED string current	120 mA
Number of LEDs in series	5

Figure 2-9 shows the default schematic of one TPS92610-Q1 linear led driver for stop light of this reference design.

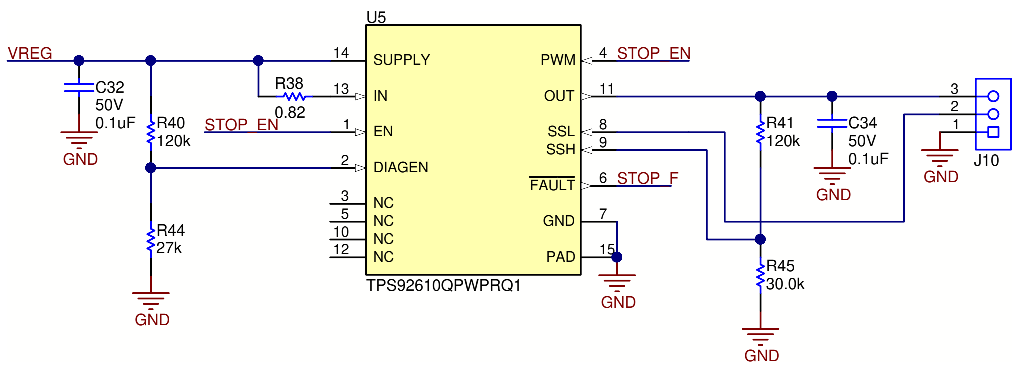


Figure 2-9. Schematic of TPS92610-Q1 Stop Light LED Driver

The main components in the schematic are selected by following the Detailed Design Procedure section in the TPS92610-Q1 Automotive Single-Channel Linear LED Driver data sheet.

With the resistor R38, the LED current is set to 120 mA. Capacitors C32 and C34 are added for noise filtering. Resistor R40 and R44 set the input voltage level where open circuit detection will be active. Resistor divider consisting of R41 and R45 is used to monitor the output voltage for single LED short detection.

2.3.7 Turn Light (TPS92610-Q1)

For the turn light, one LED string is used which gets driven by a TPS92610-Q1 linear LED driver. Table 2-4 shows the default design parameters for the turn light.

Table 2-4. Default Design Parameters of Turn Light

DESIGN PARAMETER	VALUE
Input voltage	12.5 V
LED string current	120 mA
Number of LEDs in series	5

Figure 2-10 shows the default schematic of TPS92610-Q1 linear led driver for turn light of this reference design.

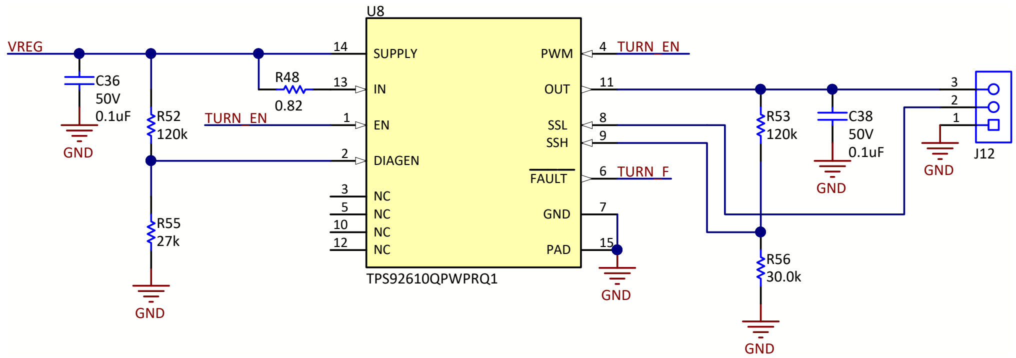


Figure 2-10. Schematic of TPS92610-Q1 Turn Light LED Driver

The main components in the schematic are selected by following the Detailed Design Procedure section in the TPS92610-Q1 Automotive Single-Channel Linear LED Driver data sheet.

With the resistor R48, the LED current is set to 120 mA. Capacitors C36 and C38 are added for noise filtering. Resistor R52 and R55 set the input voltage level where open circuit detection will be active. Resistor divider consisting of R53 and R56 is used to monitor the output voltage for single LED short detection.

2.3.8 Backup Light

For the backup light, one LED string is used which gets driven by a linear LED driver. Table 2-5 shows the default design parameters for the backup light.

Table 2-5. Default Design Parameters of Backup Light

DESIGN PARAMETER	VALUE
Input voltage	12.5 V
LED string current	210 mA
Number of LEDs in series	3

2.3.9 Enabling Light Functions

In most vehicles, the different light functions get activated by providing a power signal coming from the body control module (BCM). The power signals provide power to the system and also control the enable pins of the LED driver ICs which results in independent function of the output channels by applying power to its input supply lines. Figure 2-11 shows the schematic of the circuit. Diodes D7 through D10 are for reverse polarity protection. The resistors and capacitors forms a LC-filter on each channel which creates a short delay for enabling the LED-drivers.

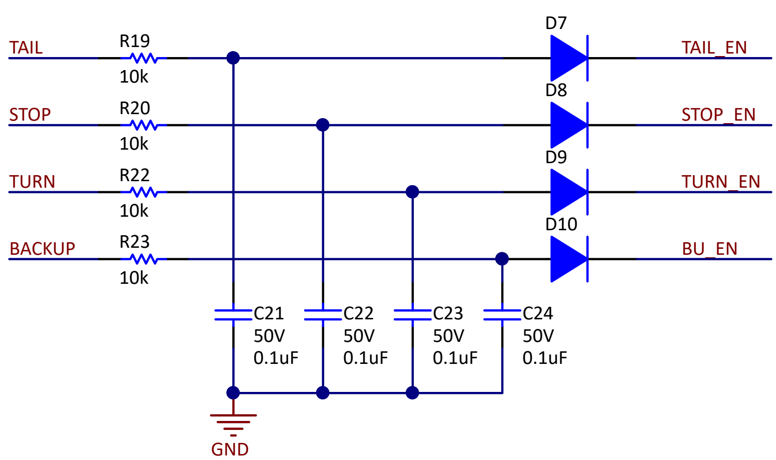


Figure 2-11. Schematic of Enabling Circuit

For systems where CAN or LIN communication is available, one power line from the BCM to the LED driver module is sufficient, and a microcontroller can be used to enable the individual light functions.

2.3.10 Diagnostic

All of the LED drivers used in this reference design provide advanced diagnostics and fault protection features for automotive exterior lighting systems. The devices are able to detect and protect from LED string short-to-GND, LED string open-circuit scenarios. The TPS92610-Q1 supports single-LED-short detection in addition. The LED drivers also support a one-fails–all-fail fault bus that could flexibly fit different legislative requirements. The fault bus can be used to report any failure back to the body control module.

2.3.11 LED Load

For testing the performance of the reference design, a LED load board, as shown in Figure 2-12, was used. The LEDs on the board are OSRAM LR G6SP, LA G6SP and LW G6SP parts.

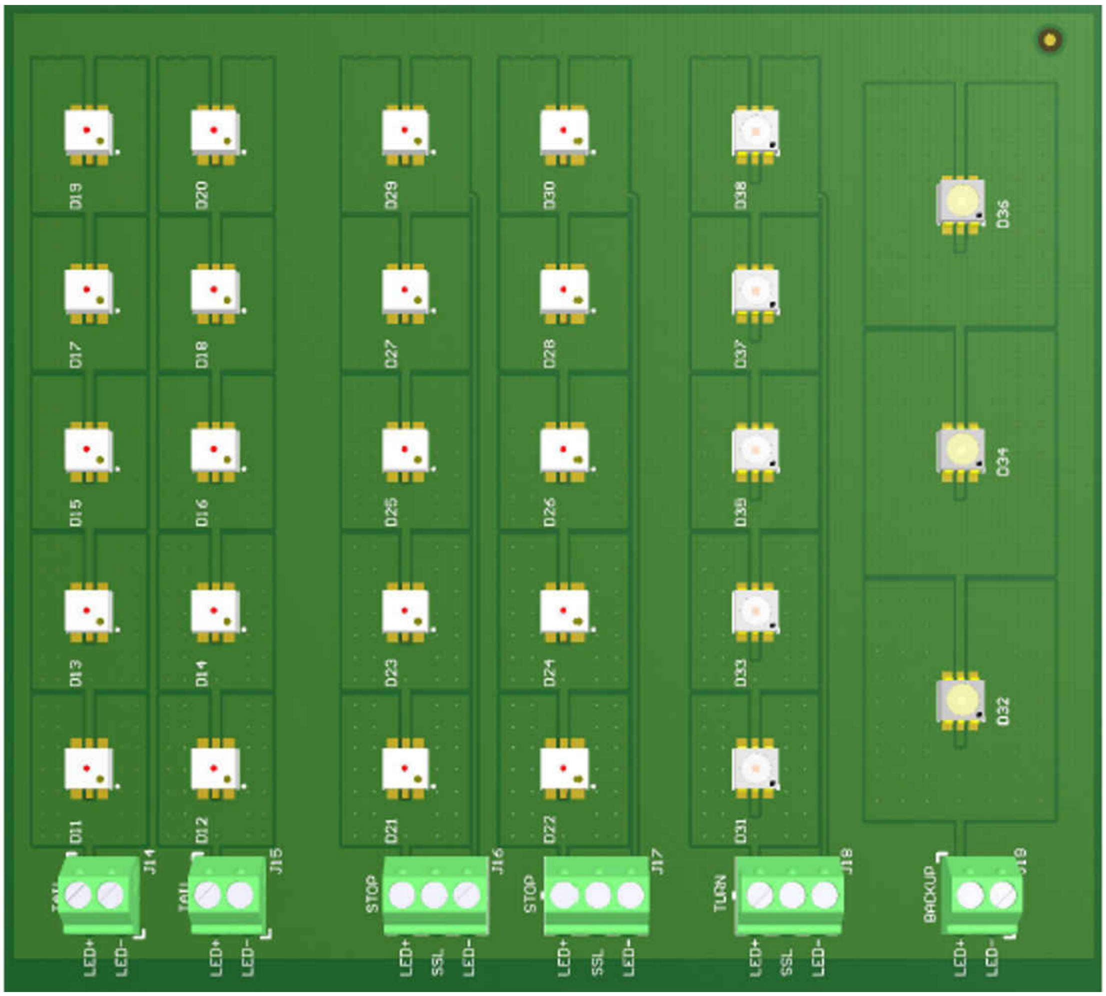


Figure 2-12. 3D Render of LED Load PCB

3 Hardware, Software, Testing Requirements, and Test Results

3.1 Required Hardware

Figure 3-1 shows the default test setup of this reference design.

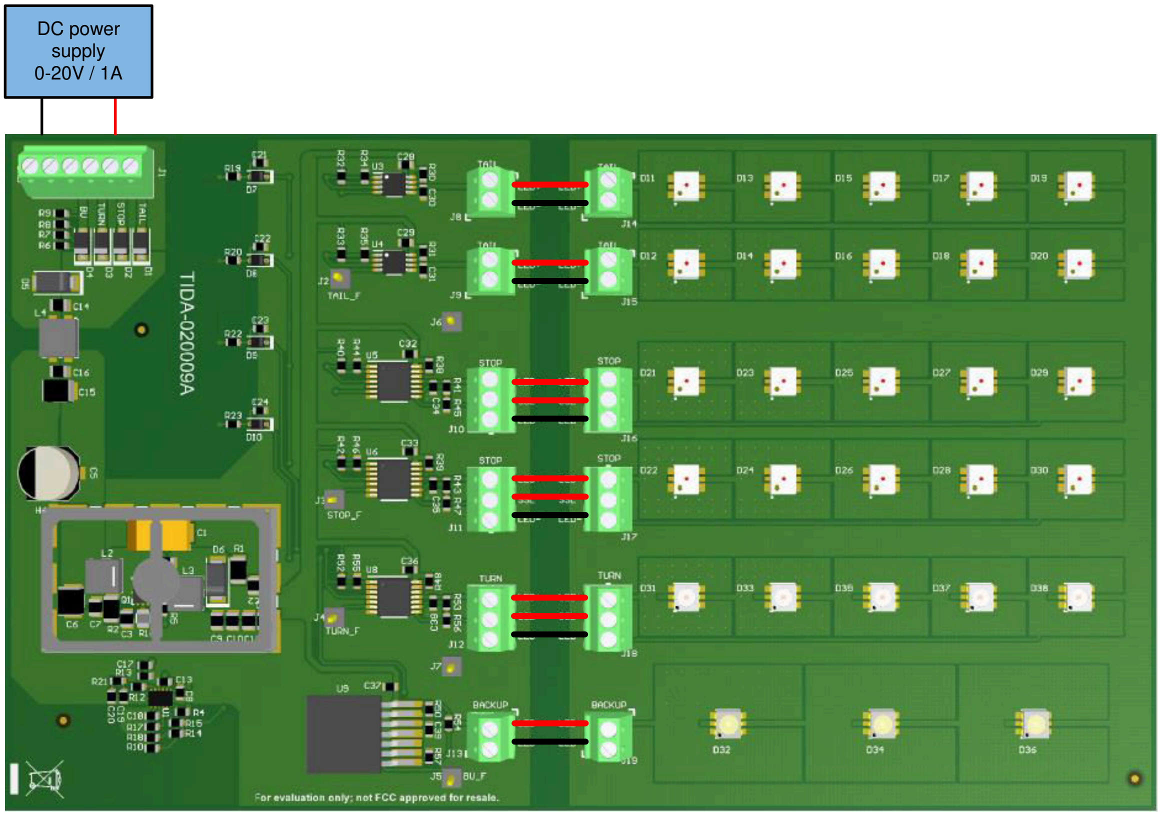


Figure 3-1. Default Hardware Test Setup

Connect a DC power supply to the input terminal J1. By providing power to one of the inputs, the respective output channels get active.

The PCB of this reference design implements several test points, which are described in Table 3-1. Use these test points to measure signals on the reference design.

Table 3-1. Test Point Description

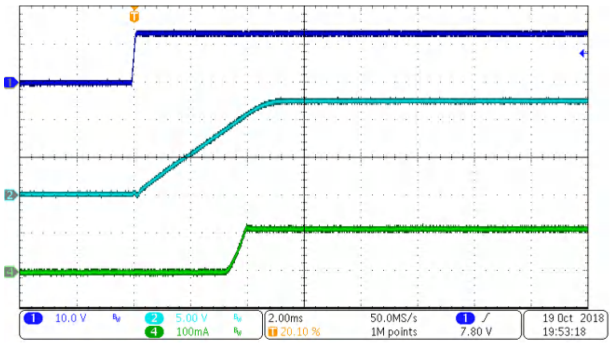
TEST POINT	DESCRIPTION
TP J2	Fault signal of tail light LED drivers
TP J3	Fault signal of stop light LED drivers
TP J4	Fault signal of turn light LED driver
TP J5	Fault signal of backup light LED driver

3.2 Testing and Results

All tests in this section are performed in the default configuration unless otherwise noted.

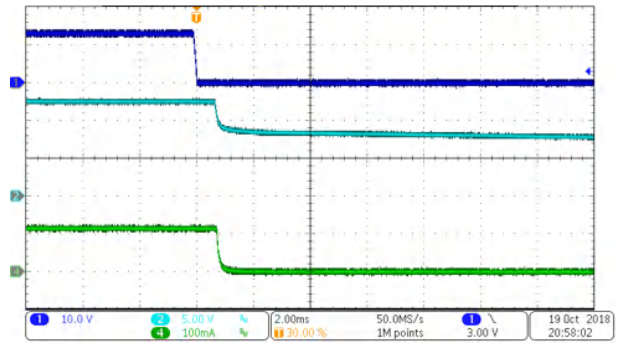
3.2.1 Startup / Shutdown

Figure 3-2 and Figure 3-3 show the startup and shutdown behavior of the reference design. The default softstart time of the SEPIC in this design is 5 ms but can be changed if needed.



CH1: VIN, CH2: VOUT SEPIC, CH4: LED current

Figure 3-2. Startup of Stoplight

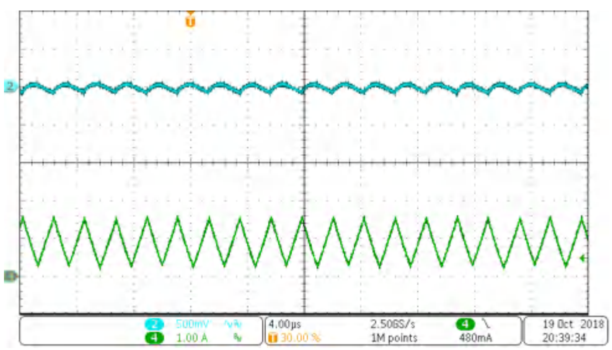


CH1: VIN, CH2: VOUT SEPIC, CH4: LED current

Figure 3-3. Shutdown of Stoplight

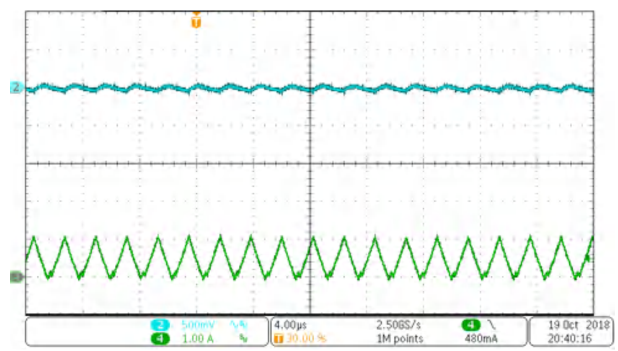
3.2.2 Steady State Operation

Figure 3-4 through Figure 3-7 show the steady state operation of the SEPIC.



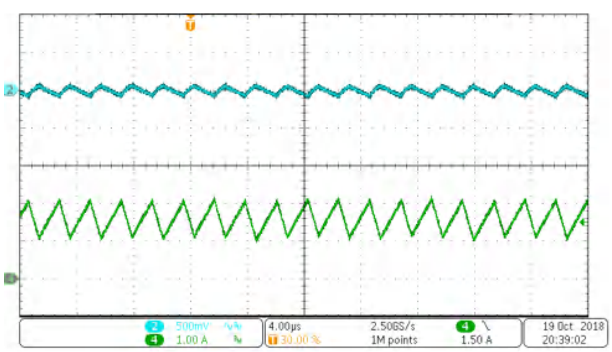
CH2: VOUT SEPIC , CH4: L2 inductor current

Figure 3-4. SEPIC Operation (13.5 V_{in}, 0.8 A)



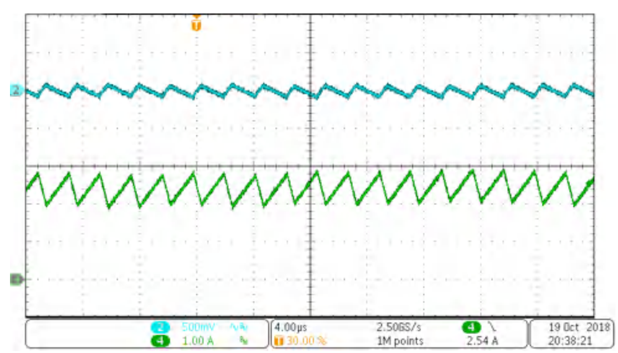
CH2: VOUT SEPIC , CH4: L2 inductor current

Figure 3-5. SEPIC Operation (13.5 V_{in}, 0.4 A)



CH2: VOUT SEPIC , CH4: L2 inductor current

Figure 3-6. SEPIC Operation (8 V_{in}, 0.8 A)

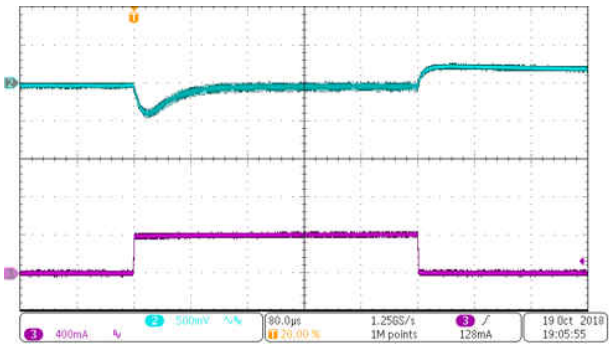


CH2: VOUT SEPIC , CH4: L2 inductor current

Figure 3-7. SEPIC Operation (6 V_{in}, 0.8 A)

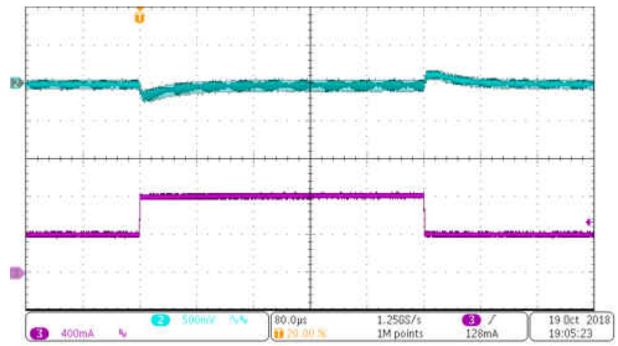
3.2.3 Load Transient Response

Figure 3-8 through Figure 3-13 show the load transient response of the SEPIC voltage regulator in the reference design.



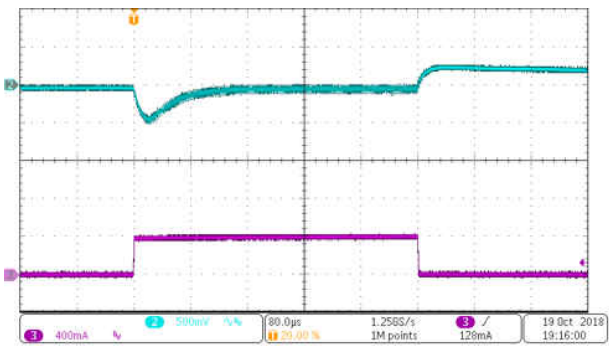
CH2: VOUT SEPIC , CH3: load current

Figure 3-8. Load Transient (13.5 V_{in}, 0-400 mA)



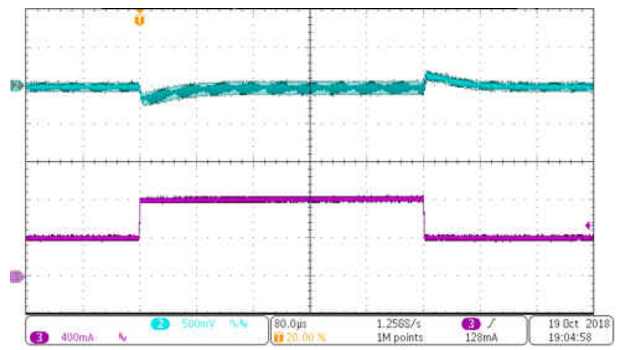
CH2: VOUT SEPIC , CH3: load current

Figure 3-9. Load Transient (13.5 V_{in}, 400-800 mA)



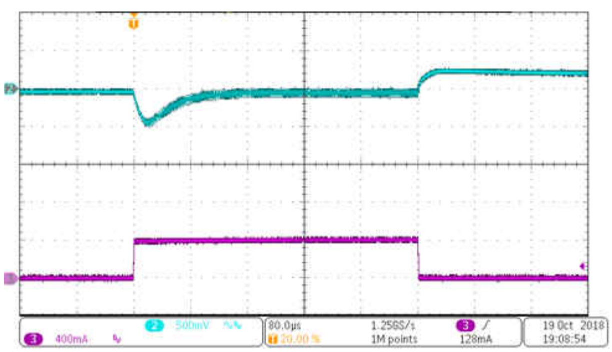
CH2: VOUT SEPIC , CH3: load current

Figure 3-10. Load Transient (8 V_{in}, 0-400 mA)



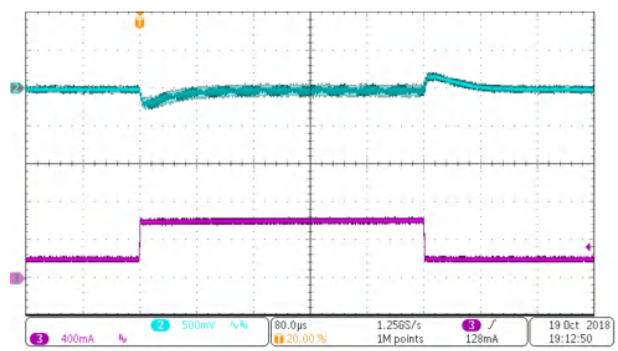
CH2: VOUT SEPIC , CH3: load current

Figure 3-11. Load Transient (8 V_{in}, 400-800 mA)



CH2: VOUT SEPIC , CH3: load current

Figure 3-12. Load Transient (6 V_{in}, 0-400 mA)



CH2: VOUT SEPIC , CH3: load current

Figure 3-13. Load Transient (6 V_{in}, 200-600 mA)

3.2.4 Stability

Figure 3-14 through Figure 3-16 show the bode diagram of the LM5155-Q1 SEPIC voltage regulator in this reference design. All conditions show stable operation with enough phase margin. However, for a stable operation at minimum input voltage at high load current, TI recommends adding more output capacitance or placing an high ESR capacitor (for damping) in parallel to the SEPIC coupling capacitor.

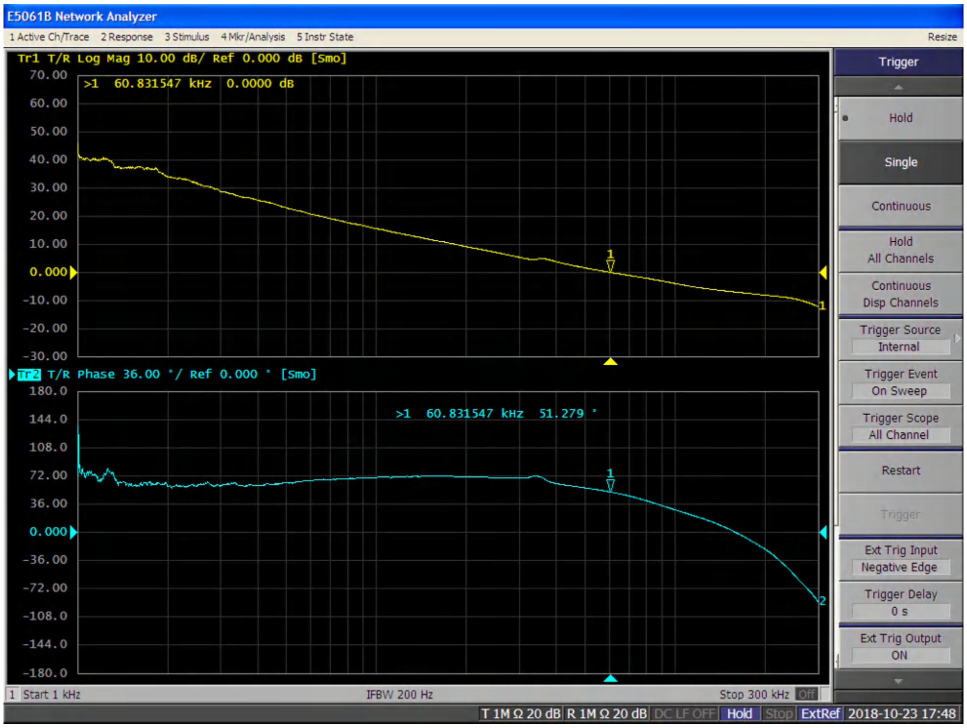


Figure 3-14. Bode Plot: 13.5-V_{in}, 0.8-A Load

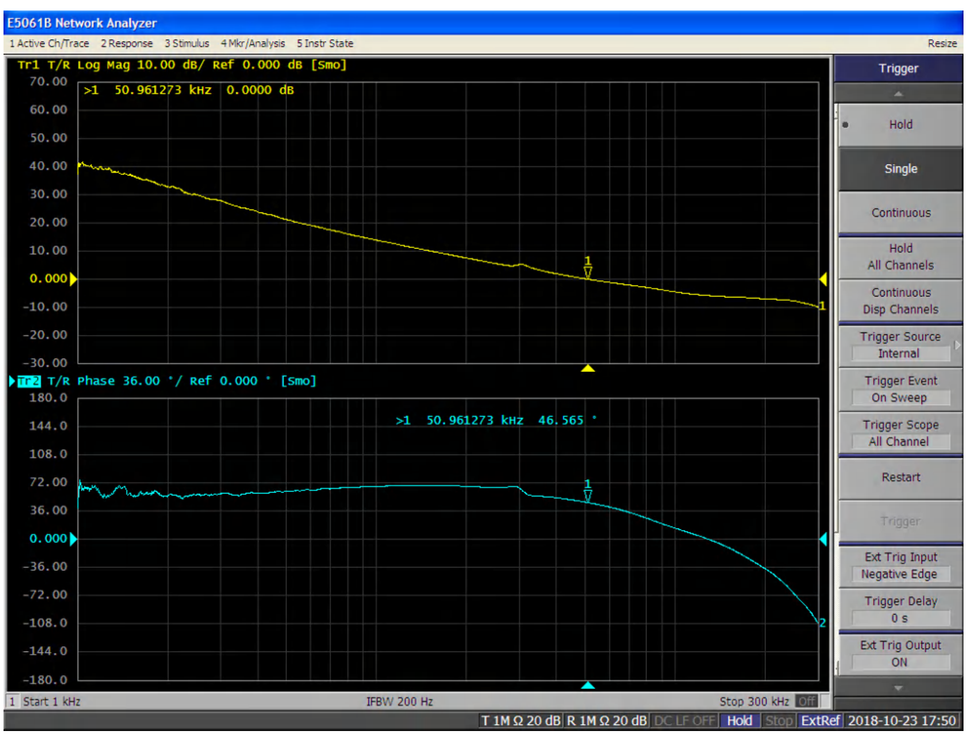


Figure 3-15. Bode Plot: 9-V_{in}, 0.8-A Load

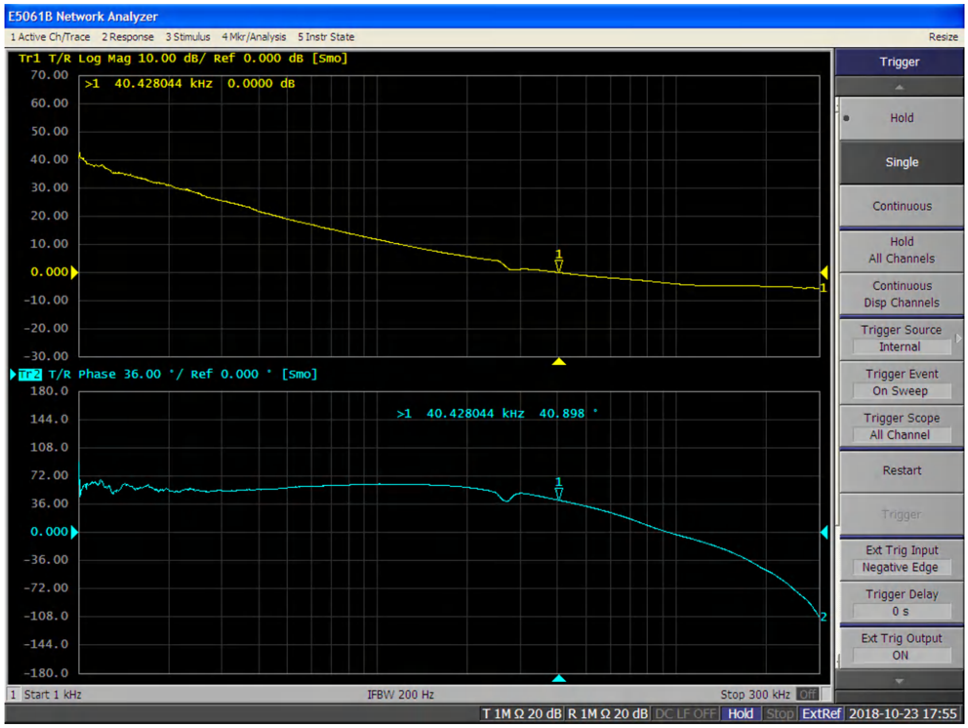


Figure 3-16. Bode Plot: 6-V_{in}, 0.8-A Load

3.2.5 Efficiency

Figure 3-17 shows the efficiency of the SEPIC for 9-V and 13.5-V input voltage.

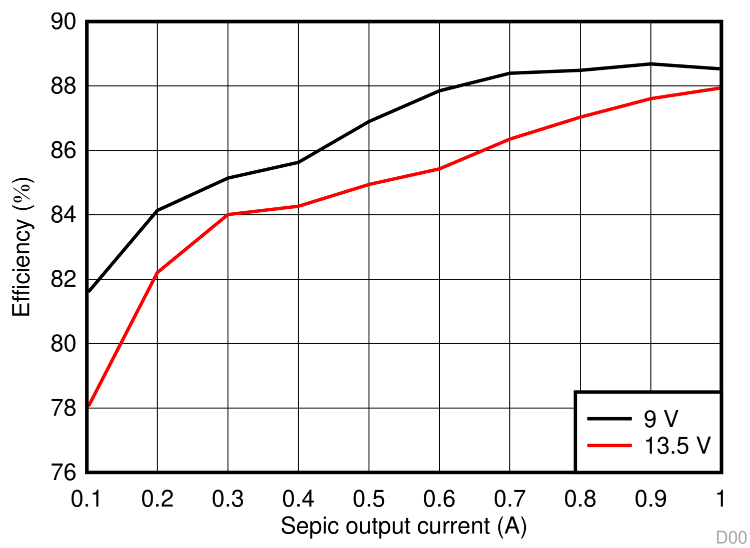


Figure 3-17. Efficiency of SEPIC Voltage Regulator

3.2.6 Electromagnetic Compatibility (EMC)

All tests in this section are performed according to the CISPR 25 standard. During the tests, the LED driver PCB was placed 5 cm above the reference ground plane. With enabled tail, stop, and turn light, the design is CISPR 25 class 5 compliant. The metal shielding, which is covering the power stage components, was populated.

3.2.6.1 Conducted Emissions

Figure 3-18 and Figure 3-19 show the conducted emissions with tail, stop, and turn light enabled.

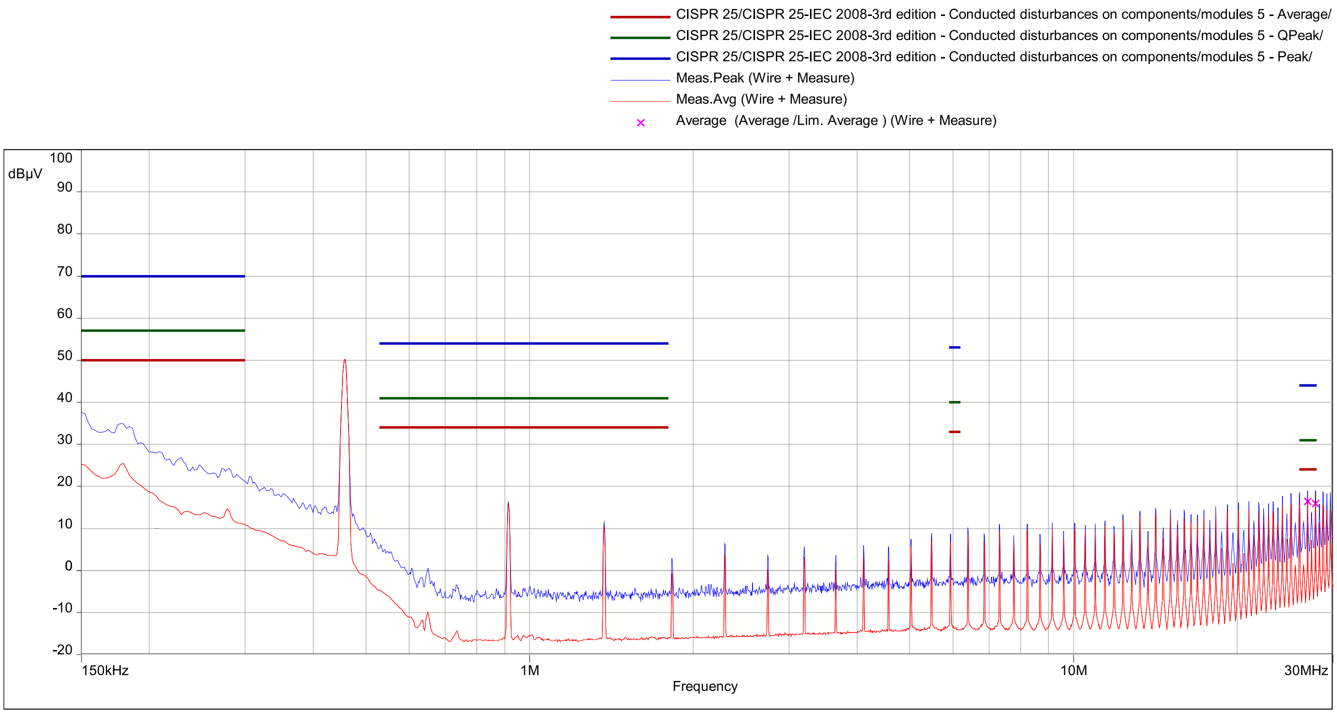


Figure 3-18. Conducted Emissions: 0.15 MHz to 30 MHz: Tail, Stop, Turn Light Enabled (5.75 W)

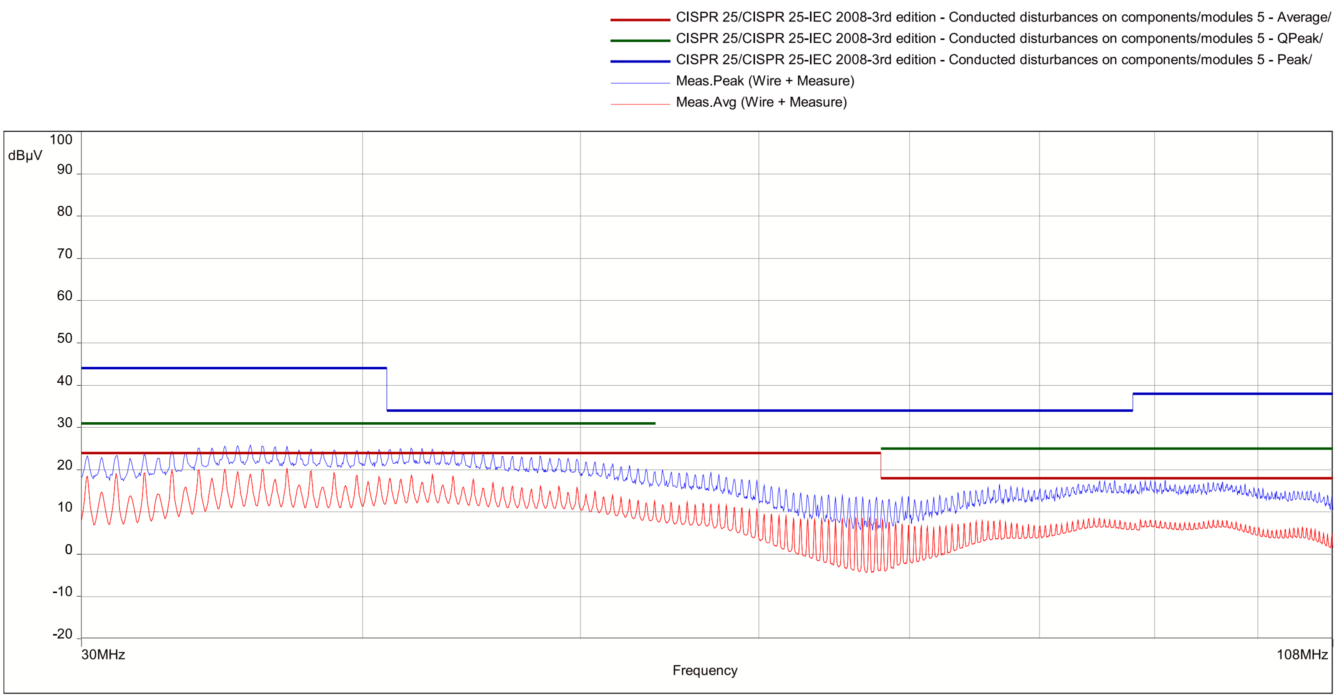


Figure 3-19. Conducted Emissions: 30 MHz to 108 MHz: Tail, Stop, Turn Light Enabled (5.75 W)

Figure 3-20 and Figure 3-21 show the conducted emissions with tail, stop, turn and backup light enabled.

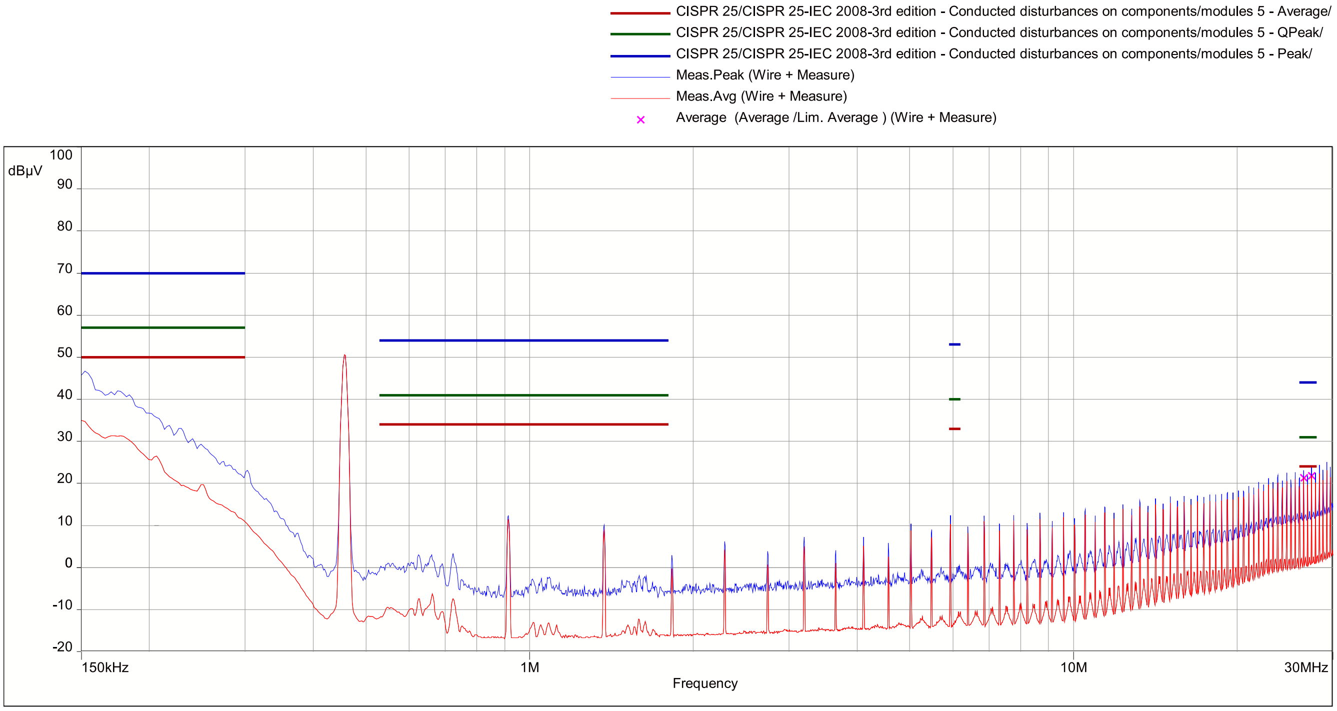


Figure 3-20. Conducted Emissions: 0.15 MHz to 30 MHz: Tail, Stop, Turn, Backup Light Enabled (8.4 W)

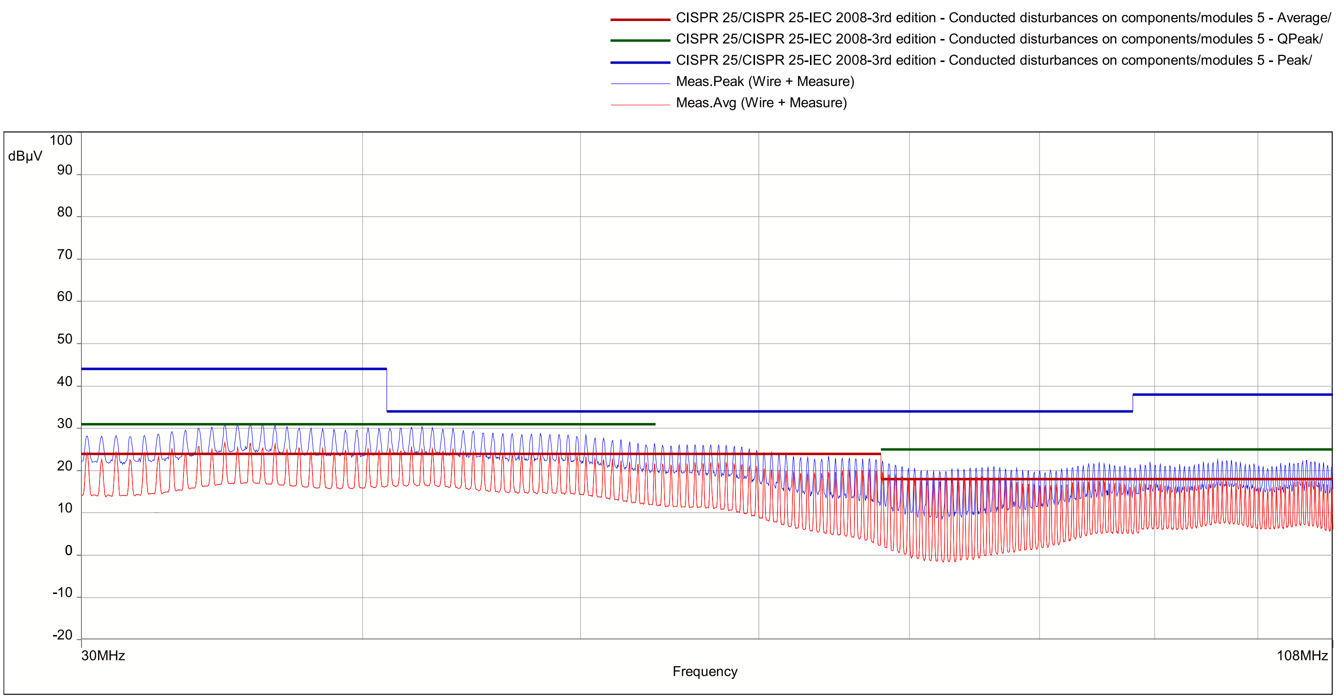


Figure 3-21. Conducted Emissions: 30 MHz to 108 MHz: Tail, Stop, Turn, Backup Light Enabled (8.4 W)

3.2.6.2 Radiated Emissions

Figure 3-22 and Figure 3-23 show the radiated emissions with tail, stop, and turn light enabled.

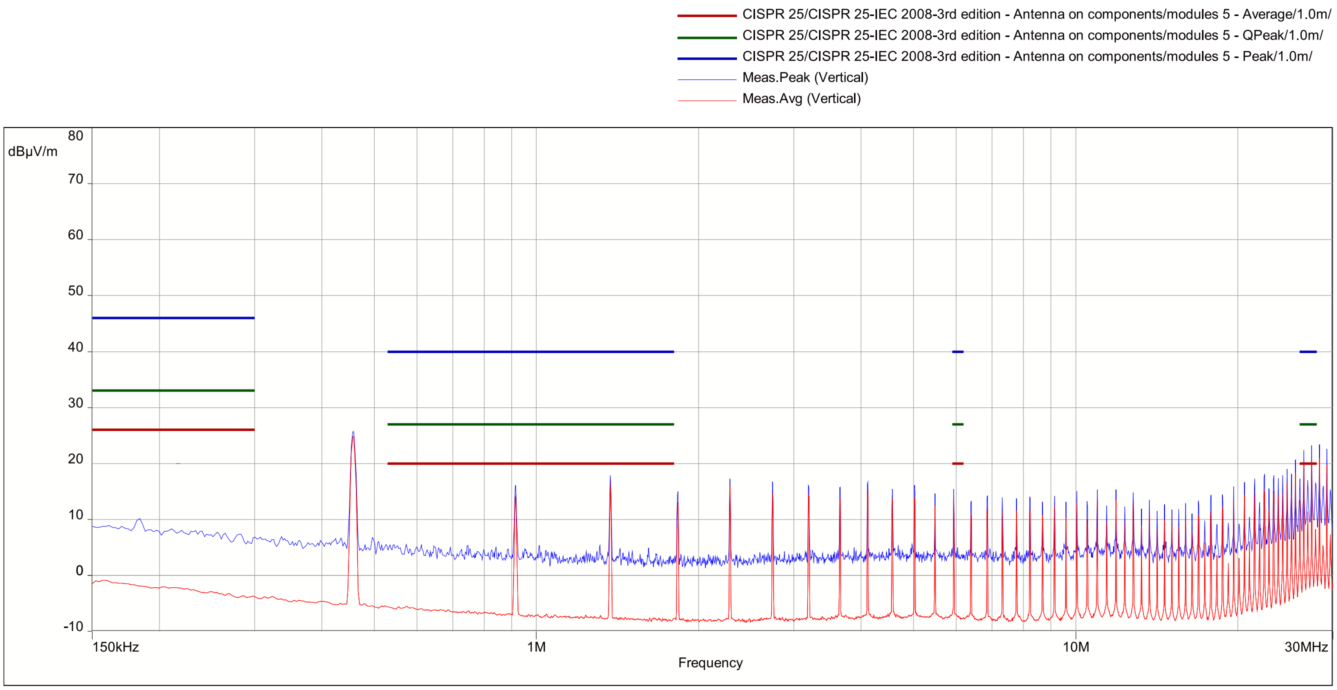


Figure 3-22. Radiated Emissions: 0.15 MHz to 30 MHz: Tail, Stop, Turn Light Enabled (5.75 W)

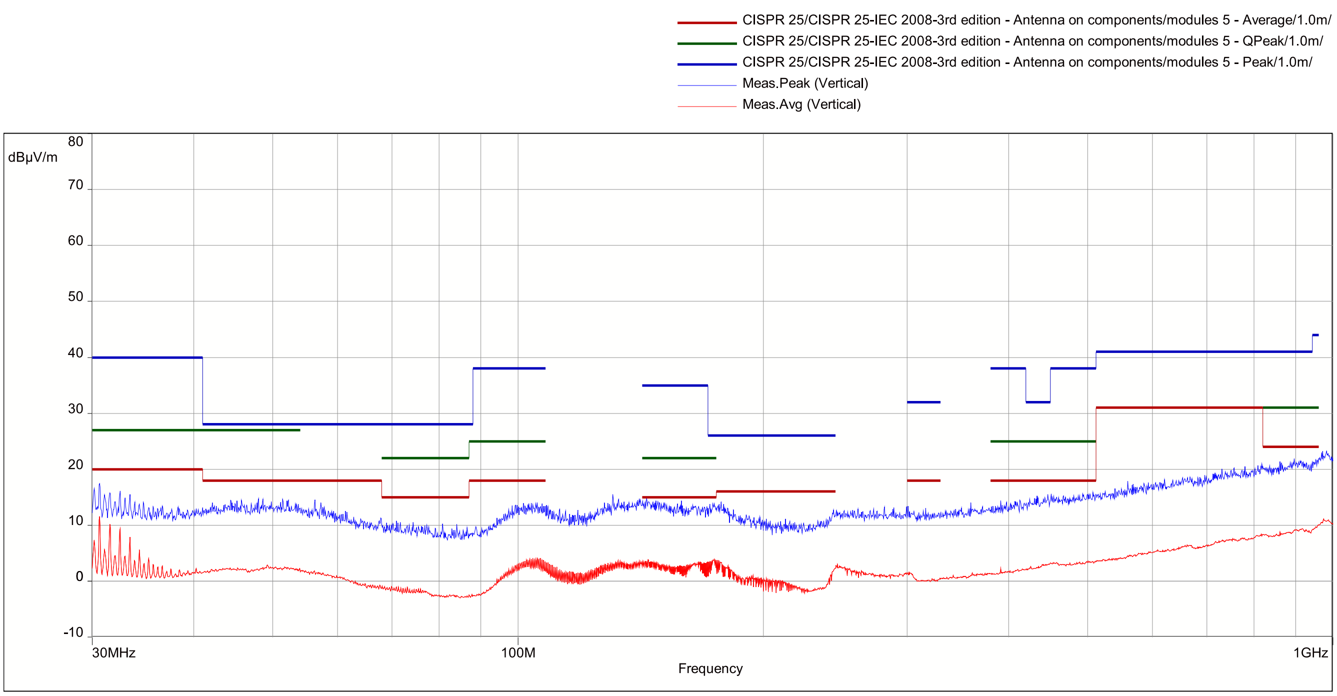


Figure 3-23. Radiated Emissions: 30 MHz to 1 GHz: Tail, Stop, Turn Light Enabled (5.75 W)

Figure 3-24 and Figure 3-25 show the radiated emissions with tail, stop, turn, and backup light enabled.

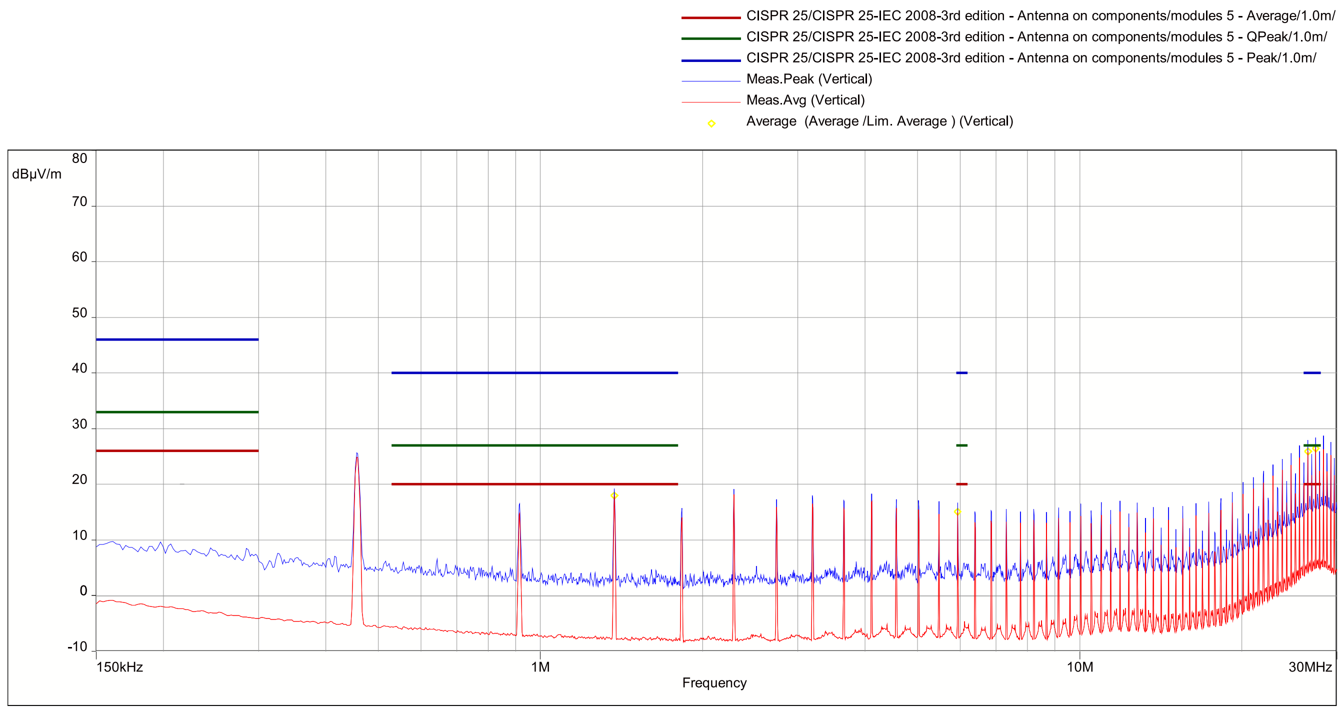


Figure 3-24. Radiated Emissions: 0.15 MHz to 30 MHz: Tail, Stop, Turn, Backup Light Enabled (8.4 W)

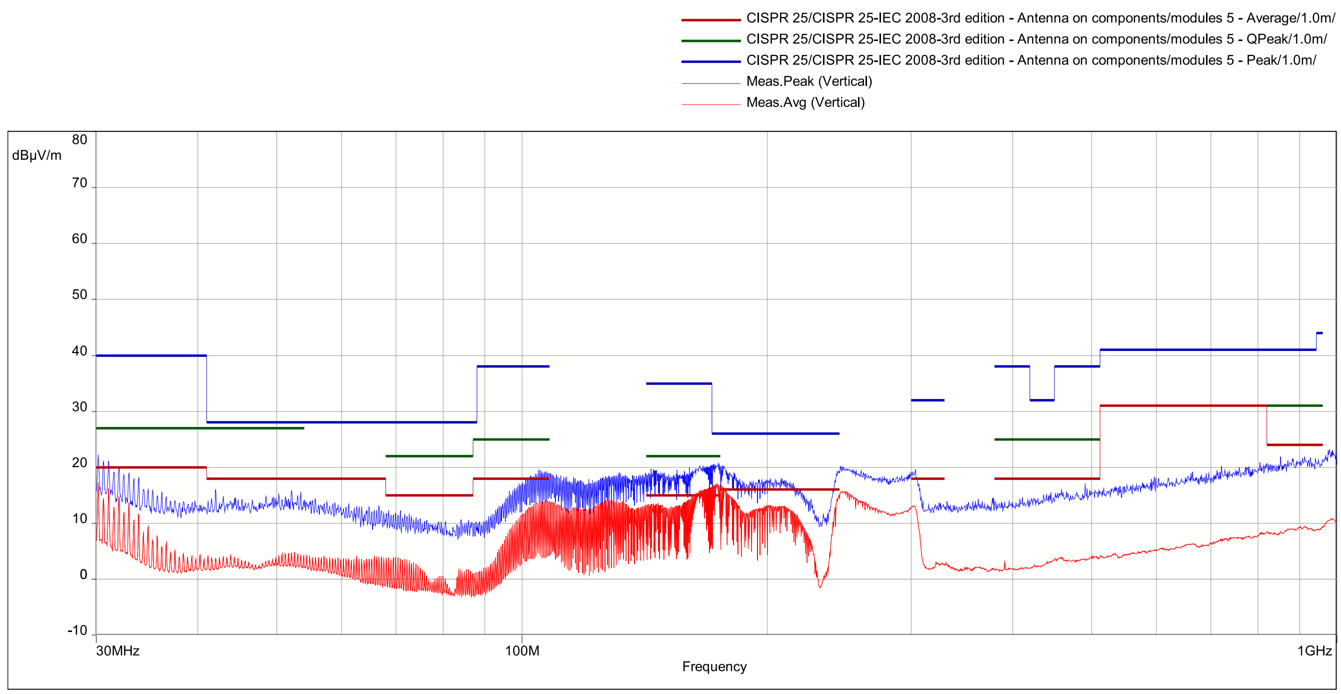


Figure 3-25. Radiated Emissions: 30 MHz to 1 GHz: Tail, Stop, Turn, Backup Light Enabled (8.4 W)

3.2.7 Thermal Performance

Figure 3-26 through Figure 3-28 show the thermal behavior for different load conditions. To improve the thermal performance of the whole board, consider implementing the following items:

- Adding more layers to the PCB
- Increasing the PCB size
- Increasing the copper thickness

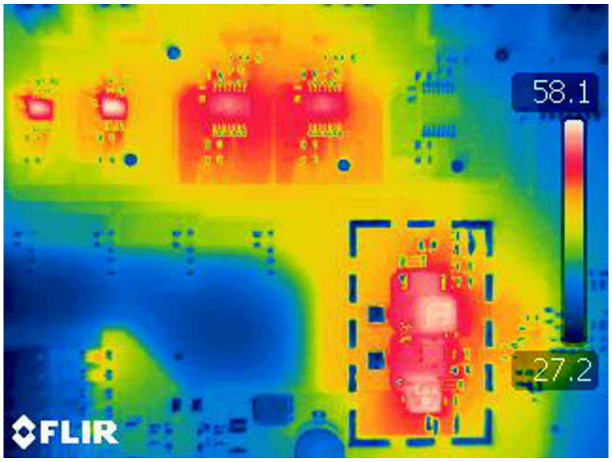


Figure 3-26. Thermal Image: Tail and Stop Light Enabled (4.25 W)

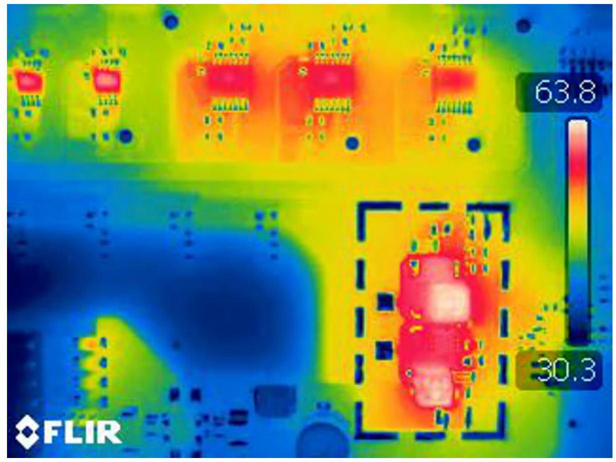


Figure 3-27. Thermal Image: Tail, Stop, Turn Light Enabled (5.75 W)

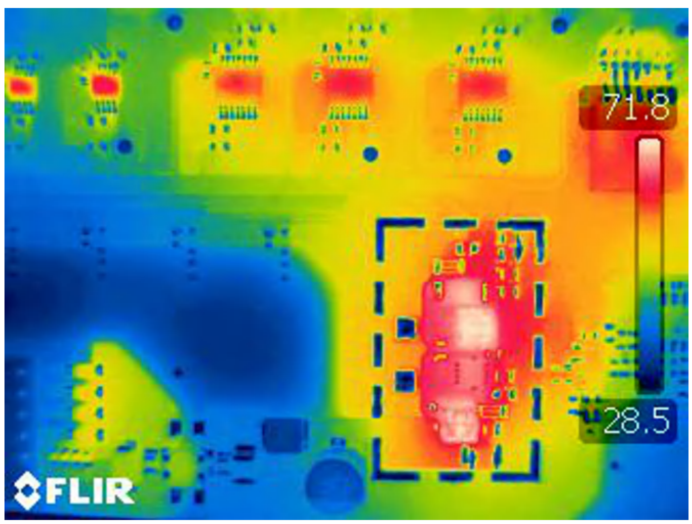


Figure 3-28. Thermal Image: Tail, Stop, Turn, Backup Light Enabled (8.4 W)

4 Design Files

4.1 Schematics

To download the schematics, see the design files at TIDA-020009.

4.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-020009.

4.3 PCB Layout Recommendations

The layout of the reference design is created by following the layout examples and guidelines in the devices DS.

4.3.1 Layout Prints

To download the layer plots, see the design files at TIDA-020009.

4.4 Altium Project

To download the Altium Designer® project files, see the design files at TIDA-020009.

4.5 Gerber Files

To download the Gerber files, see the design files at TIDA-020009.

4.6 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-020009.

5 Related Documentation

1. Texas Instruments, LM5155x-Q1 2.2-MHz Wide Input Non-synchronous Boost/Sepic/Flyback Controller data sheet
2. Texas Instruments, TPS92610-Q1 Automotive Single-Channel Linear LED Driver data sheet
3. Texas Instruments, TPS92611-Q1 Automotive Single-Channel Linear LED Driver data sheet
4. Texas Instruments, Simple Success With Conducted EMI From DC-DC Converters
5. Texas Instruments, The Engineer's Guide To EMI In DC-DC Converters (Part 2): Noise Propagation And Filtering
6. Texas Instruments, Power Tips: Calculate an R-C snubber in seven steps

6 Trademarks

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7 About the Author

MICHAEL HELMLINGER is a systems engineer on the Automotive Body Electronics and Lighting team with 5 years of experience in analog power design. He works on various types of end-equipment in the field of body electronics especially automotive lighting, creating and testing reference designs for automotive manufacturers.

8 Revision History

Changes from Revision * (November 2018) to Revision A (November 2022)	Page
• Updated the numbering format for tables, figures, and cross-references throughout the document	1