

デザイン・ガイド: TIDA-020012 車載用、車内照明向けピクセル構成天井灯のリファレンス・デザイン



概要

このリファレンス・デザインでは、車載用の車内天井灯用途向けに、30 の LED を別々に駆動および制御するためのソリューションについて詳しく説明します。多数のピクセルを使用して、各種の照明ゾーンや、ウェルカム・ライト・アニメーションを作成できます。このリファレンス・デザインには LED 多重化機能も含まれており、最大 150 の LED を制御できます。降圧型電圧コンバータ、リニア電圧レギュレータ、シリアル・ペリフェラル・インターフェイス (SPI) 付きの 3 つのリニア LED ドライバ、およびマイクロコントローラ LaunchPad™ が使用されています。

リソース

- | | |
|------------------------------|------------|
| TIDA-020012 | デザイン・フォルダ |
| TLC6C5724-Q1 | プロダクト・フォルダ |
| LMR33630-Q1 | プロダクト・フォルダ |
| TPS7B82-Q1 | プロダクト・フォルダ |

特長

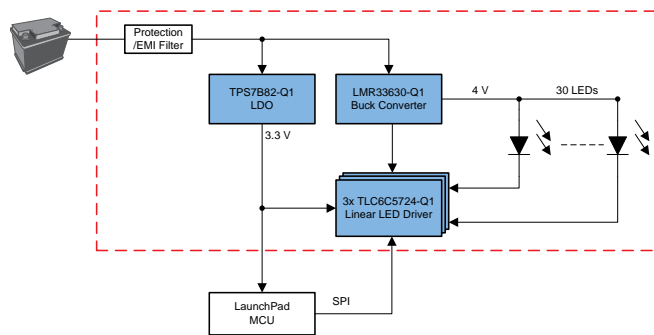
- 多数のピクセル
 - 30 個の LED を直接駆動
 - 150 個の LED を多重化 (5 行) して駆動
- 各 LED チャンネルで完全な機能セットを使用可能
 - 正確な電流設定
 - PWM 調光
 - 診断および保護機能
- CISPR25 準拠

アプリケーション

- 天井灯
- オーバーヘッド・コンソール
- 車内照明



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1 System Description

This reference design details a solution to drive and control 30 LEDs individually for automotive interior dome light applications. The high pixel count can be used to create different light zones or welcome light animations.

If a higher number of LEDs needs to be controlled, use the multiplexing method. This design implements multiplexing functionality to control up to 150 LEDs with 5 rows and 30 columns.

The design uses three linear LED drivers with SPI, a step-down voltage converter which provides a constant voltage for the LED drivers, a linear voltage regulator, and a microcontroller LaunchPad.

1.1 Key System Specifications

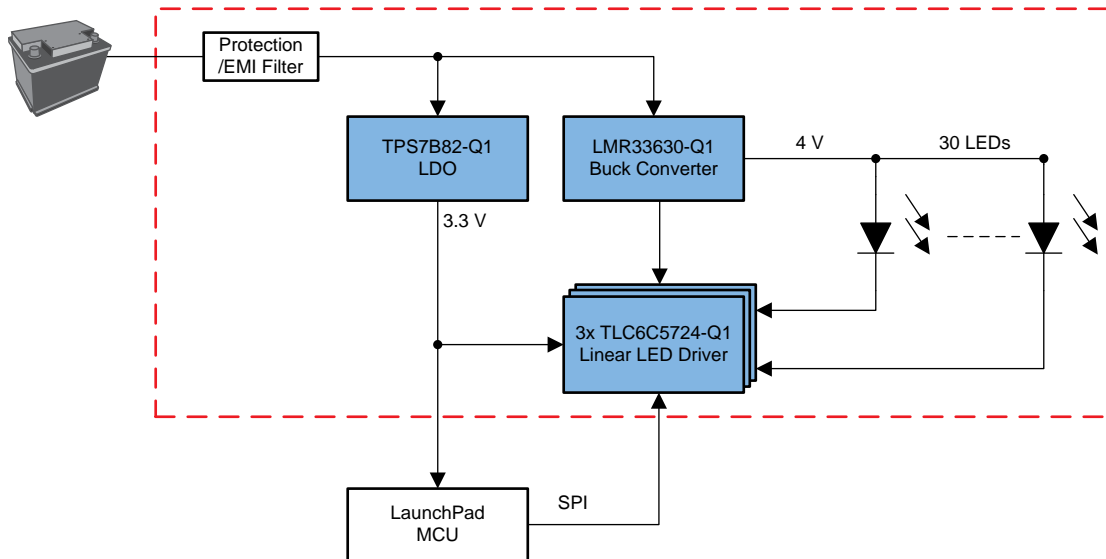
表 1. Key System Specifications

PARAMETER	SPECIFICATIONS
DC input voltage range	6 V to 18 V
Buck regulator output voltage	4 V
Buck regulator switching frequency	400 kHz
LDO output voltage	3.3 V
LED current	60 mA nom, 100 mA max
Operating ambient temperature	-40 to 85°C
PCB form factor	150 x 80 mm (2 layers with 1.5 oz)

2 System Overview

2.1 Block Diagram

図 1. TIDA-020012 Block Diagram



2.2 Design Considerations

To simplify this reference design and make the design more adaptable to a variety of microcontroller units (MCUs), the board is implemented in the BoosterPack™ format. This board format has a simple connector interface to the external LaunchPad MCU board, which allows this reference design to be evaluated with a wide selection of MCUs. The LaunchPad plus BoosterPack implementation also has the advantage that code development and design testing are facilitated with existing tools such as Code Composer Studio™ or Energia, thus speeding up optimization of the design for any specific operating conditions. While the BoosterPack format does allow flexibility in using different MCU boards, the format also creates constraints on the size and layout of the board. In a production version of this design, the MCU would likely be installed on the same board with the chips and other components with a significant reduction in board size.

For ease of testing, the reference design board includes 30 LEDs which can be controlled individually. For driving LEDs with the multiplexing method, an external LED board with 150 LEDs can be connected with a 50-pin header.

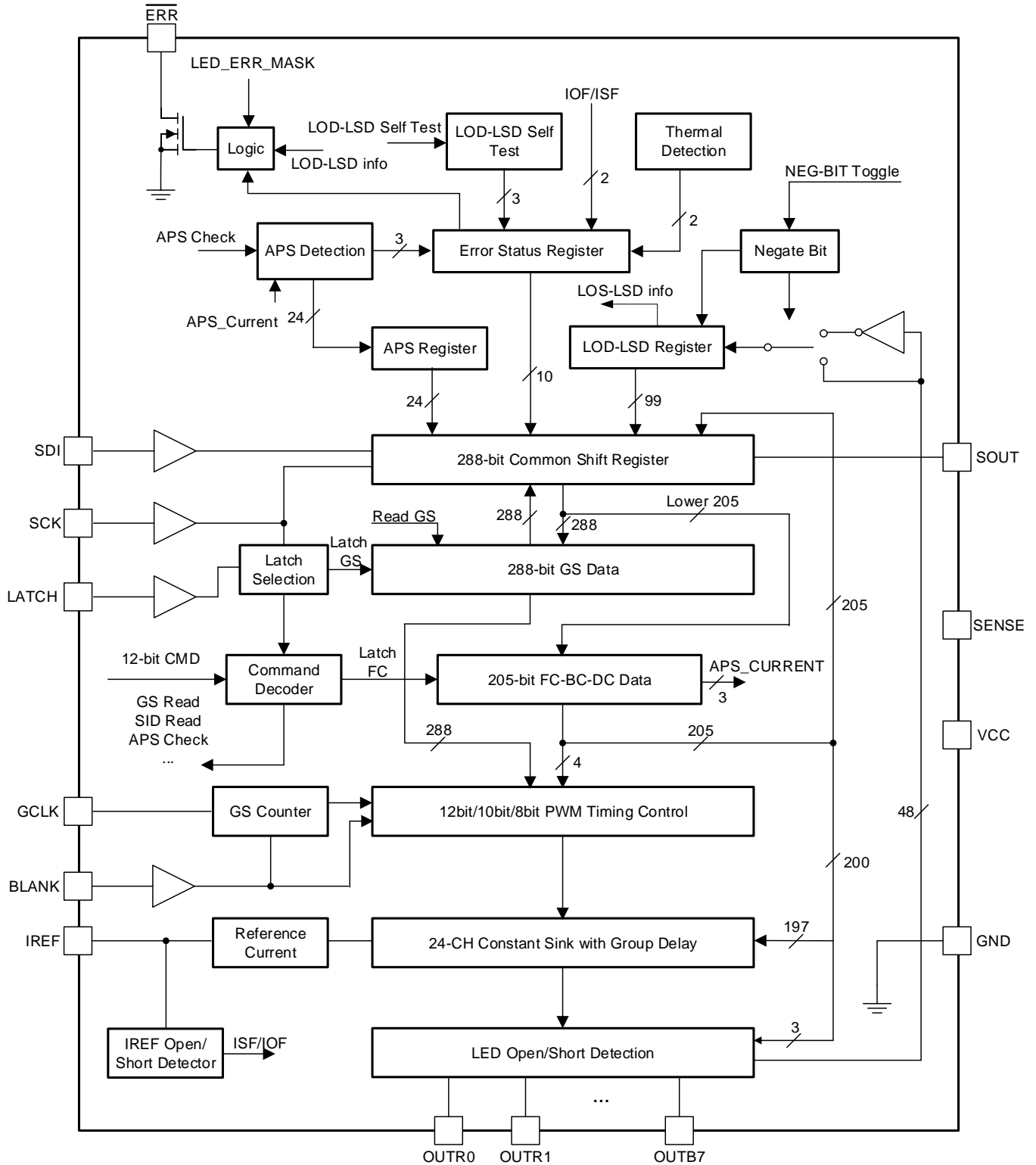
2.3 Highlighted Products

2.3.1 TLC6C5724-Q1

The TLC6C5724-Q1 device is an automotive 24-channel constant-current RGB LED driver that can do tests on the LEDs. The TLC6C5724-Q1 device supplies a maximum of 50-mA output current set by an external resistor. The device has a 7-bit dot correction with two ranges for each output. The device also has an 8-bit intensity control for the outputs of each color group. A 12-, 10-, or 8-bit grayscale control adjusts the intensity of each output. The device has circuits that sense faults in the system, including LED

faults, adjacent-pin short faults, reference-resistor faults, and more. A slew rate control has 2 positions for adjustment to get the largest decrease in system noise. There is an interval between the changes of output level from one LED group to a different one. This interval helps to decrease the starting electrical current. The SDI and SDO pins let more than one device be connected in series for control through one serial interface.

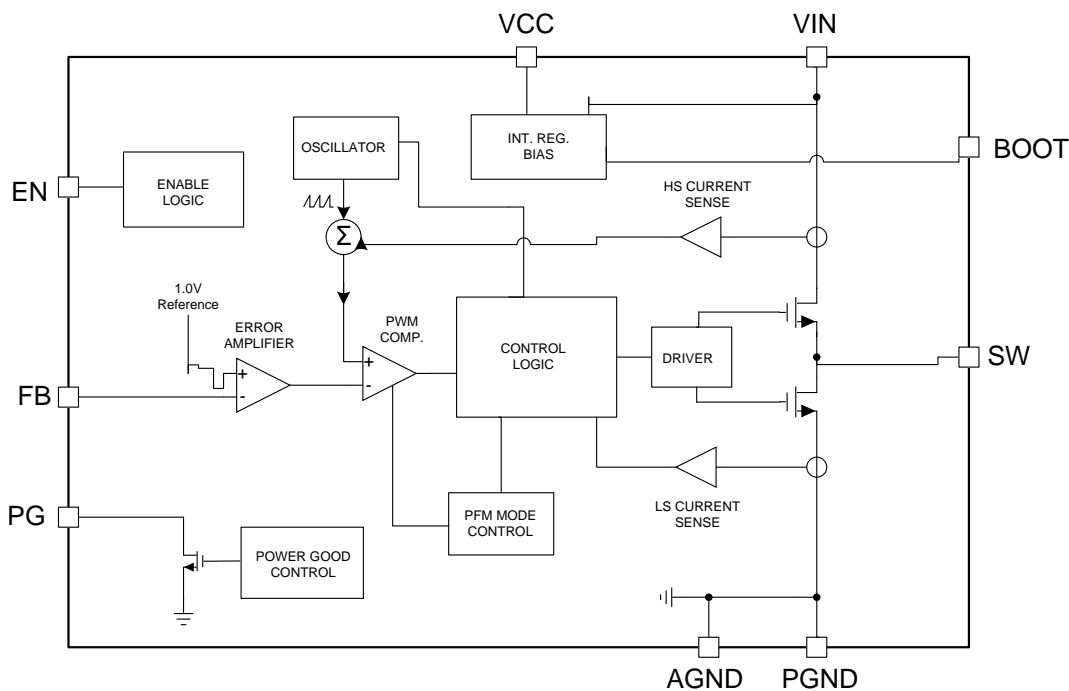
図 2. TLC6C5724-Q1 Functional Block Diagram



2.3.2 LMR33630-Q1

The LMR33630-Q1 voltage regulator is an easy-to-use, synchronous, step-down DC/DC converter that delivers best-in-class efficiency for rugged applications. The LMR33630-Q1 drives up to 3 A of load current from an input of up to 36 V. It provides high light load efficiency and output accuracy in a very small solution size. Features such as a power-good flag and precision enable provide both flexible and easy-to-use solutions for a wide range of applications. The LMR33630-Q1 automatically folds back frequency at light load to improve efficiency. Integration eliminates most external components and provides a pinout designed for simple PCB layout. Protection features include thermal shutdown, input undervoltage lockout, cycle-by-cycle current limit, and hiccup short-circuit protection. The LMR33630-Q1 is available in a 12-pin 3 mm × 2 mm VQFN package with wettable flanks.

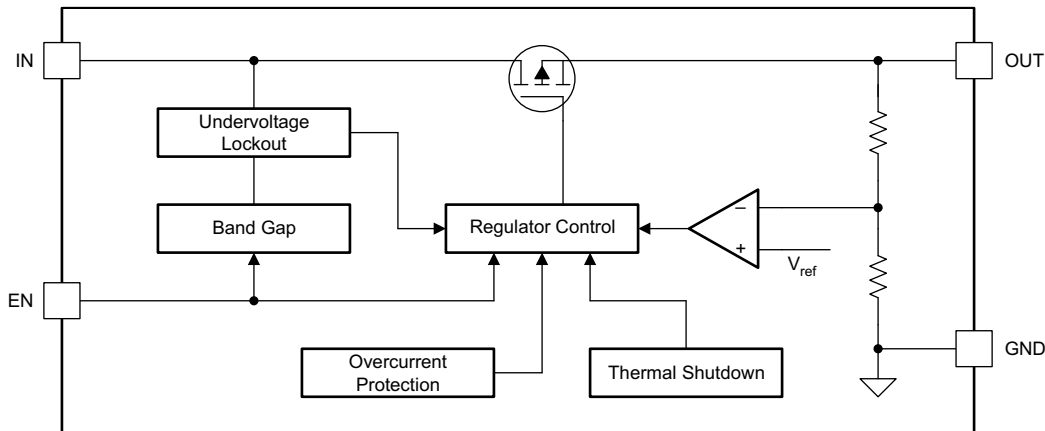
図 3. LMR33630-Q1 Functional Block Diagram



2.3.3 TPS7B82-Q1

The TPS7B82-Q1 device is a low-dropout linear regulator designed to operate with a wide input-voltage range from 3 V to 40 V (45-V load dump protection). Operation down to 3 V allows the TPS7B82-Q1 to continue operating during cold-crank and start stop conditions. With only 2.7- μ A typical quiescent current at light load, this device is an optimal solution for powering microcontrollers (MCUs) and CAN/LIN transceivers in standby systems. The device features integrated short-circuit and overcurrent protection. This device operates in ambient temperatures from -40°C to 125°C and with junction temperatures from -40°C to 150°C . Additionally, this device uses a thermally conductive package to enable sustained operation despite significant dissipation across the device. Because of these features, the device is well suited as a power supply for various automotive applications.

図 4. TPS7B82-Q1 Functional Block Diagram

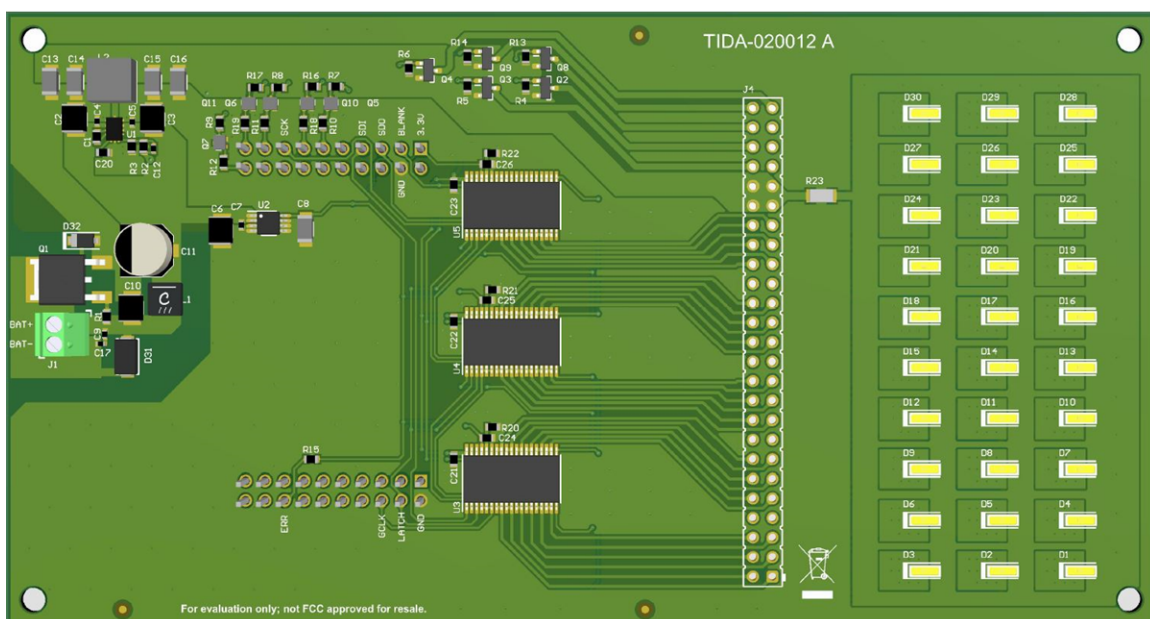


2.4 System Design Theory

2.4.1 PCB and Form Factor

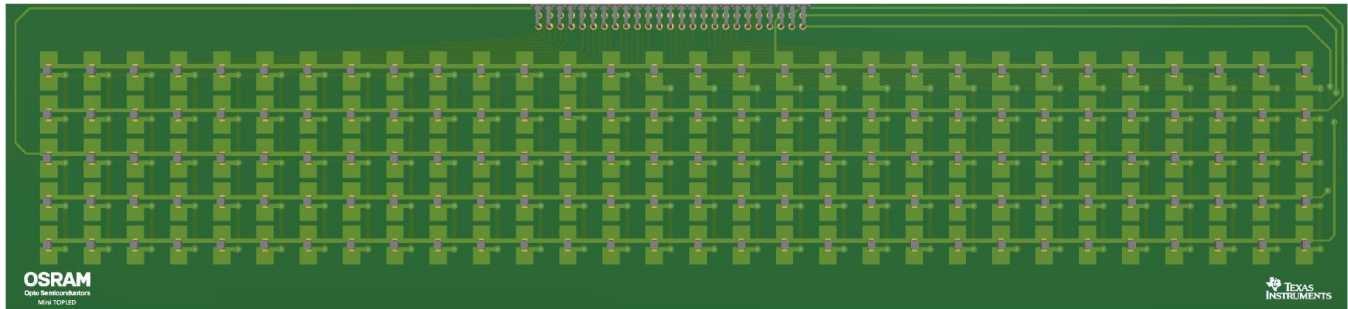
This reference design uses a two-layer printed circuit board (PCB) with 1.5 oz of copper where all components are placed on the top layer. Beside the ICs and passive components, the PCB integrates 30 LEDs which can be individually controlled. The PCB is not intended to fit any particular form factor and has a dimension of 150 mm x 80 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. 図 5 shows a 3D rendering of the PCB.

図 5. 3D Render of TIDA-020012 PCB



There is a second PCB which can be connected to the J4 header of the main PCB. It contains 150 LEDs and allows for the user to drive an LED matrix consisting of five rows and 30 columns of LEDs by using multiplexing method with the control of rows and columns. [Fig 6](#) shows a 3D rendering of the LED PCB.

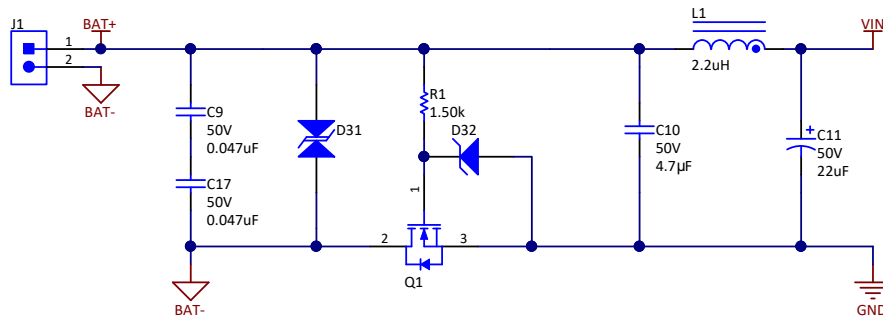
図 6. 3D Render of 150-LED PCB



2.4.2 Input Protection

In this reference design, reverse polarity protection is implemented by using a N-channel MOSFET Q1 in the power return line as shown in [Fig 7](#) where D32 and R1 protect the gate. Under normal operation, Q1 is fully saturated allowing for current to return to the negative terminal of the battery as the gate-source voltage exceeds its threshold. Under a reverse battery condition, the gate-source voltage of Q1 is now negative thus turning off the FET and preventing current flow through the system. D31 is a bidirectional transient voltage suppressor (TVS) diode which clamps the voltage in the case of both positive and negative voltage transients. ESD protection is implemented by series capacitors C9 and C17.

図 7. Input Protection + EMI Filter Schematic



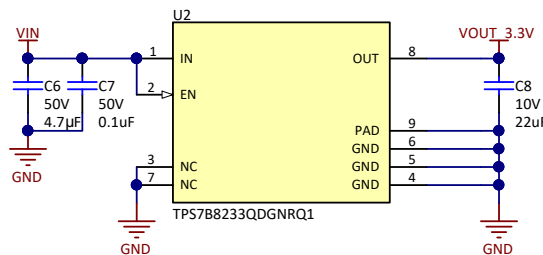
2.4.3 EMI Filter

A LC low-pass filter is placed after the protection circuit to attenuate conducted differential mode noise generated by buck converter. [Fig 7](#) shows that the filter consists of C10, C11, and L1. For more details, see the [AN-2162 Simple Success With Conducted EMI From DC-DC Converters Application Report](#).

2.4.4 TPS7B82-Q1 LDO

The 3.3-V fixed output version of the TPS7B82-Q1 (TPS7B8233-Q1) was used in this reference design to provide 3.3 V to the LED driver VCC. This device only requires input and output capacitors and no additional external components. The components used for the LDO were selected by following the application section in the [TPS7B82-Q1 300-mA High-Voltage Ultra-low-I_Q Low-Dropout Regulator Data Sheet](#).

図 8. TPS7B82-Q1 LDO Schematic



2.4.5 LMR33630-Q1 Buck Converter

In this design, the LMR33630-Q1 device is used to provide a stable supply voltage to the linear LED drivers to reduce power loss. 表 2 shows the default design parameters for the LMR33630-Q1 voltage regulator.

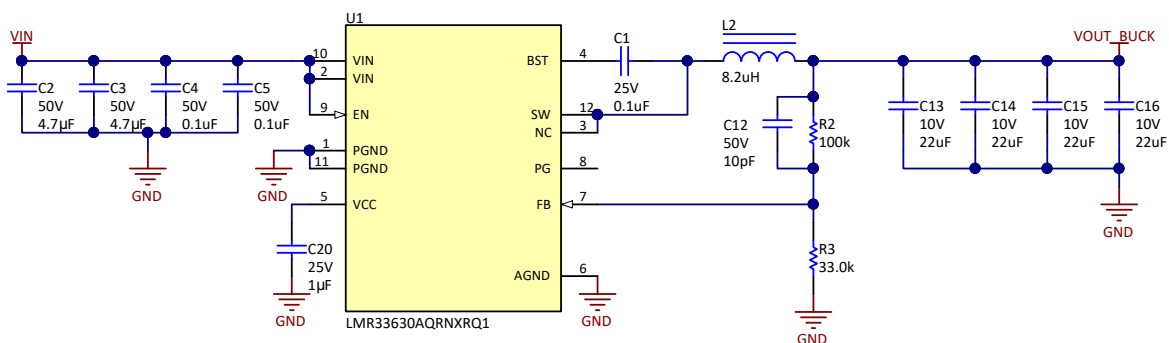
表 2. Design Parameters of Default Buck Converter Configuration

DESIGN PARAMETER	VALUE
Input voltage range	9 V to 36 V
Output voltage	4 V
Output power	12 W max
Switching frequency	400 kHz

The LMR33630-Q1 device is a fully-synchronous converter with integrated switches and is internally compensated. This greatly reduces the number of required external components.

図 9 shows the LMR33630-Q1 buck converter schematic used in this reference design.

図 9. LMR33630-Q1 Buck Converter Schematic



The components used in 図 9 were selected by following the *Detailed Design Procedure* section in the [LMR33630-Q1 3.8-V to 36-V, 3-A Synchronous Step-down Voltage Converter Data Sheet](#).

The ceramic input capacitors C2 and C3 provide a low impedance source to the regulator in addition to supplying the ripple current and isolating switching noise from other circuits. They must be rated for at least the maximum input voltage that the application requires. This capacitance can be increased to help reduce input voltage ripple, maintain the input voltage during load transients, or both. In addition, small case size ceramic capacitors C4 and C5 must be used at the input, as close a possible to the regulator. This provides a high frequency bypass for the control circuits internal to the device.

C20 is the boot-strap capacitor connected between the BOOT pin and the SW pin. This capacitor stores energy that is used to supply the gate drivers for the power MOSFETs. The VCC pin is the output of the internal LDO used to supply the control circuits of the regulator and requires a 1- μ F ceramic capacitor for proper operation. Resistors R2 and R3 adjust the output voltage level to 4 V with an internal reference voltage of 1 V. The inductor L2 has low DCR and a inductance value of 8.2 μ H with a saturation current rating above the expected inductor current at maximum load.

The output capacitors C13, C14, C15, and C16 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. This example uses four 22- μ F ceramic capacitors with a voltage rating of 10 V.

2.4.6 TLC6C5724-Q1 Linear LED Driver


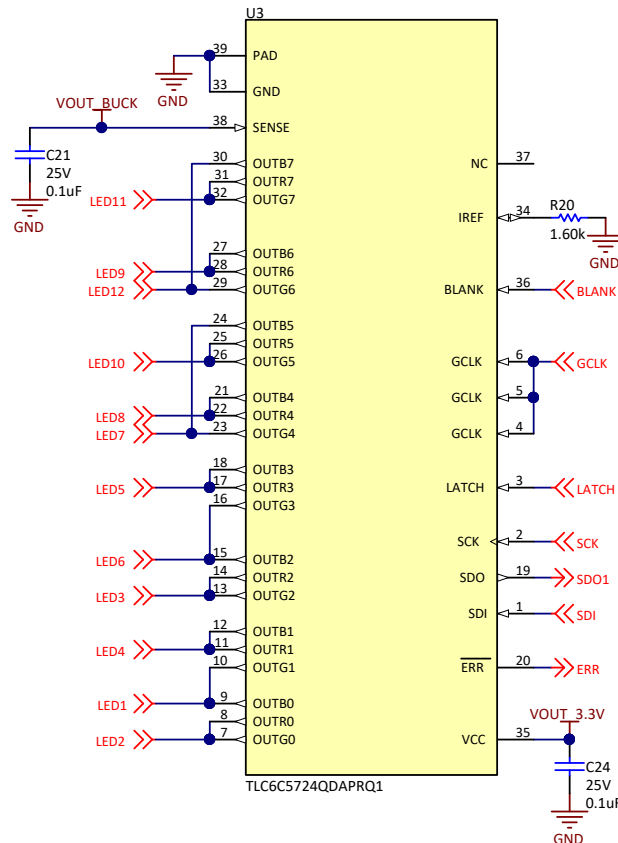
This section describes how to design with the TLC6C5724-Q1 linear LED driver.  10 shows the schematic for one linear LED driver used in this reference design.

図 10. TLC6C5724-Q1 Linear LED Driver Schematic



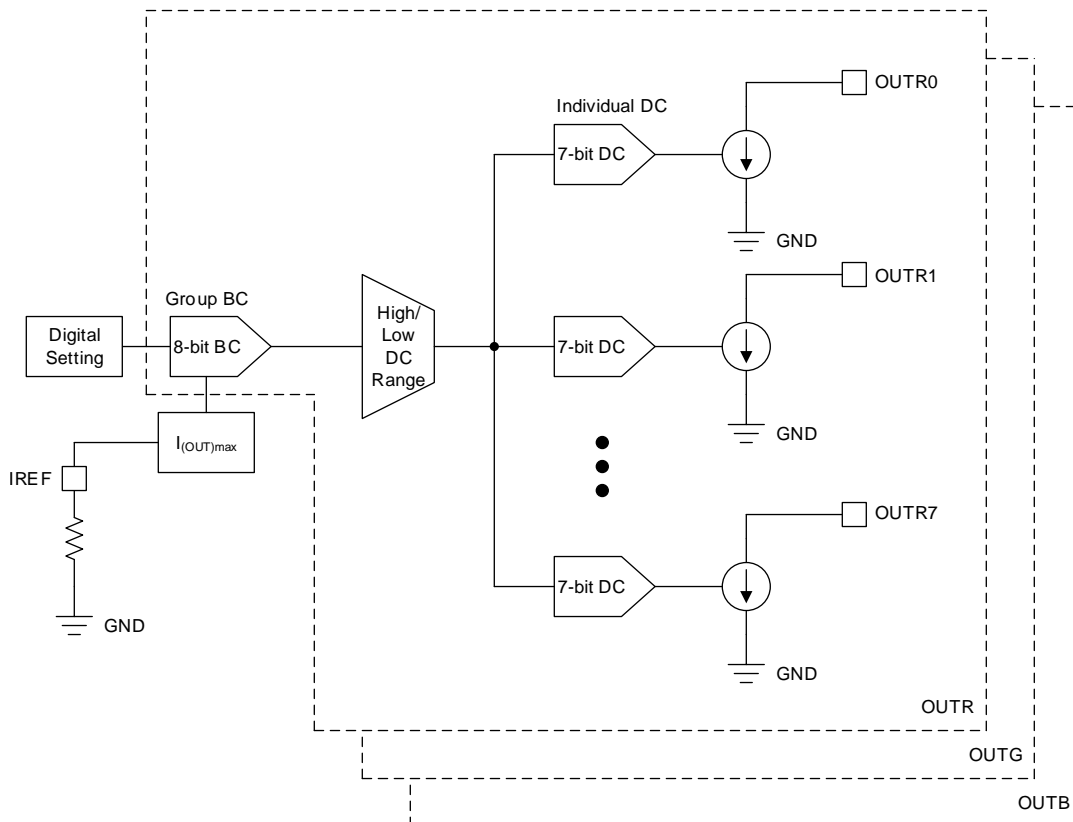
Each channel of the TLC6C5724-Q1 is capable of sinking a maximum of 50 mA. In this reference design two channels are paralleled to achieve higher current through the LEDs. The DC current can be programmed using an external resistor R20 connected between the IREF pin and GND. In this design the current is set to 30 mA which results in a maximum LED current of 60 mA with two combined channels.

In the default configuration the design controls 30 LEDs individually. Since 2 channels are combined for higher current capability 60 channels in total are required. Therefore, three TLC6C5724-Q1 devices are used in the design.

While the LMR33630-Q1 buck converter is capable of supplying 3 A of current, it is advised to keep the total LED current below 2 A to prevent thermal issues on the LED drivers.

Figure 11 shows how the TLC6C5724-Q1 device implements an 8-bit group brightness control (BC) and 7-bit individual dot correction (DC) to calibrate the output current.

Figure 11. Brightness Control and Dot Correction Block Diagram in TLC6C5724-Q1



Furthermore, the LED driver implements a grayscale configuration function to realize the individual PWM dimming function for the output channels. The grayscale has three global configuration modes, 12-bit, 10-bit, and 8-bit where the GCLK input provides the clock source for the internal PWM generator.

The TLC6C5724-Q1 device is programmable via serial interface. It contains a 288-bit common shift register to shift data from SDI into the device. The register LSB connects to SDI and the MSB connects to SDO. On each SCK rising edge, the data on SDI shifts into the register LSB and all 288 data bits shift towards the MSB. The data appears on SDO when the 288-bit common shift register overflows. The SDI and SDO pins allow more than one device to be connected in a daisy chain for control through one serial interface. In this design three LED drivers are connected in daisy chain.

See the [TLC6C5724-Q1 Automotive 24-Channel, Full Diagnostics, Constant-Current RGB LED Driver Data Sheet](#) for more details.

2.4.7 Driving 30 LEDs

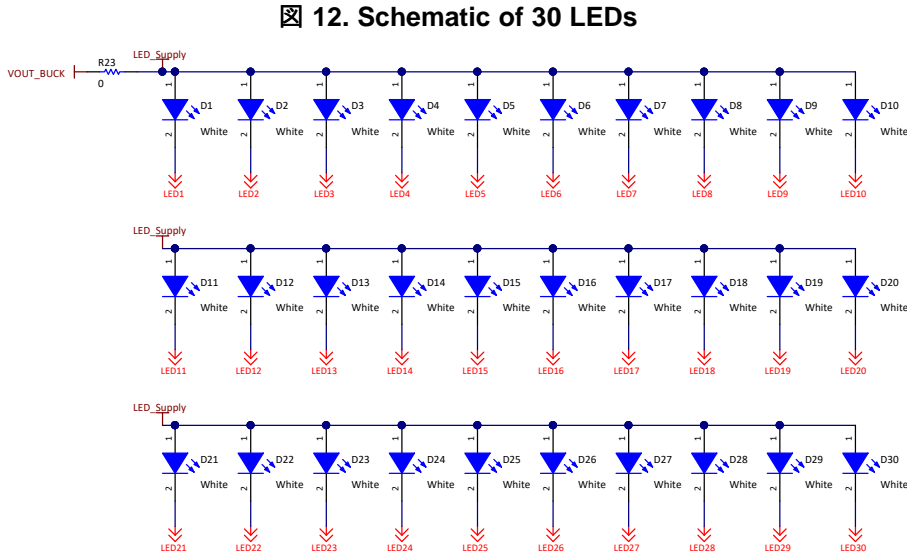
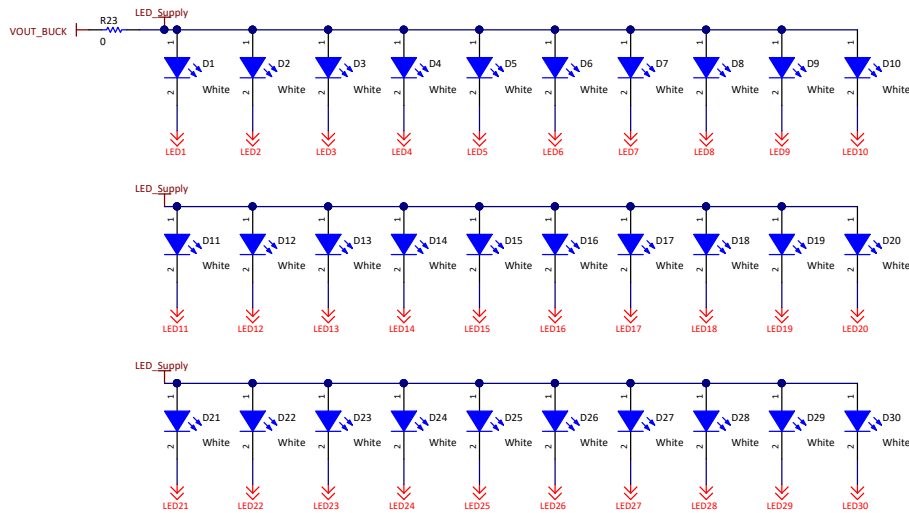
The reference design PCB integrates 30 OSRAM® SYNIOS® E4014 (KWDPLS32.EC) LEDs. These warm white LEDs are a typically used in interior lighting applications.  shows the schematic of the LEDs. The cathode of each LED is connected to the LED drivers current sink. Note that in this design two LED driver channels are paralleled to achieve a higher current through the LED. The anodes are connected to the buck converter output which is providing a 4-V supply.

図 12. Schematic of 30 LEDs



2.4.8 Driving 150 LEDs With Multiplexing Method

To control a higher number of LEDs individually, normally more LED driver channels are required. To save additional channels, LED multiplexing can be used where LEDs are connected in a matrix with control of rows and columns.

This reference design also allows for the user to drive an LED matrix consisting of up to five rows and 30 columns of LEDs (150 LEDs in total). An external LED PCB with 150 OSRAM® Mini TOPLED® (LCW MVSG.EC) LEDs can be connected to the main PCB.

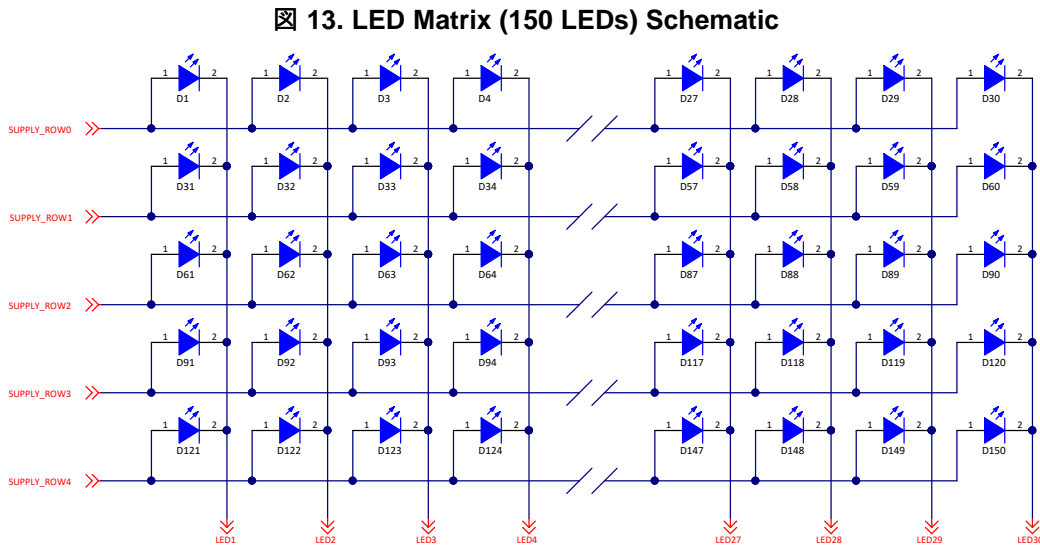
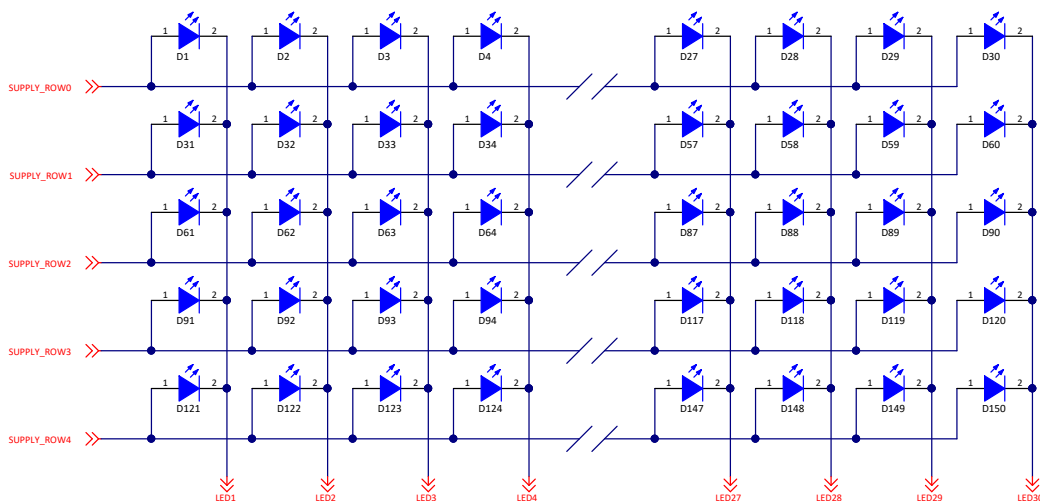

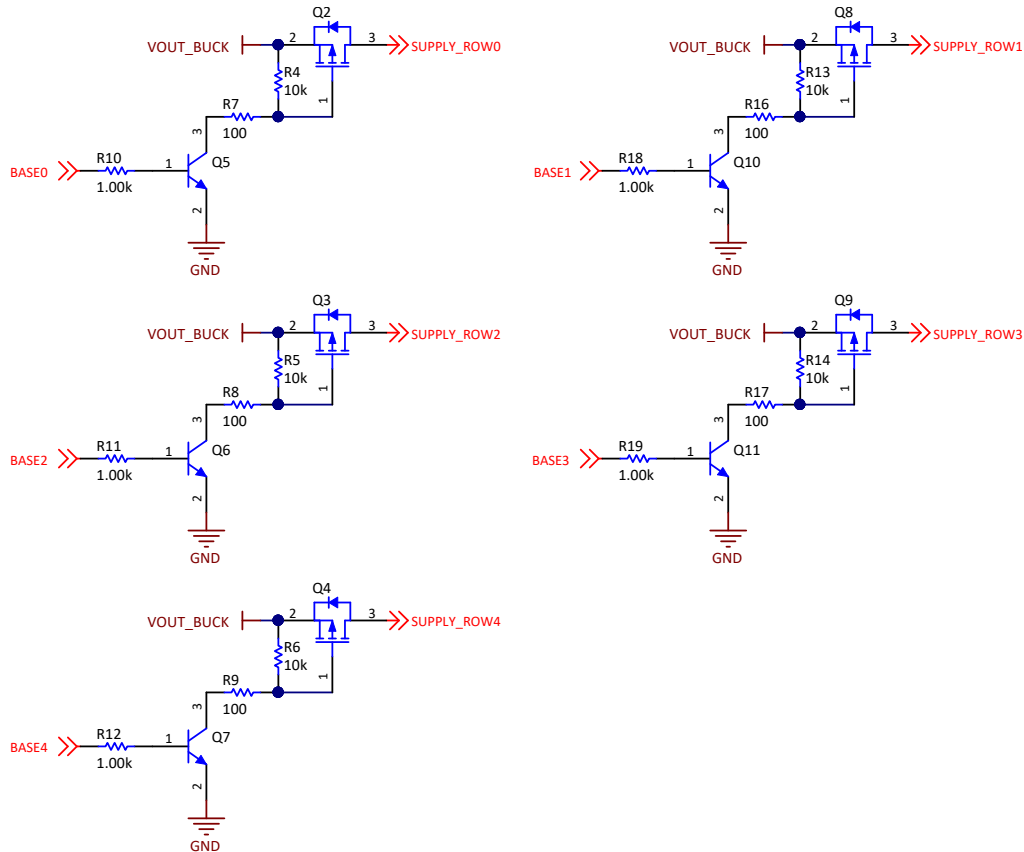
 shows how the 150 LED matrix is configured.

図 13. LED Matrix (150 LEDs) Schematic



Each column gets connected to the LED driver current sinks. To control the five rows a simple PMOS circuit is used.  14 shows the schematic of the circuit to control the rows.

 14. Row Control Circuit Schematic



The signals BASE0 through BASE4 are connected to GPIO pins of the MCU LaunchPad. When the GPIO is pulled HIGH, the NPN transistor conducts and pulls the gate of the P-channel MOSFET low. This, in turn, allows for the MOSFET to conduct and supply the output voltage of the LMR33630-Q1 (VOUT_BUCK) to a row of LEDs.

Following parameters needs to be considered when using LED multiplexing with this reference design:

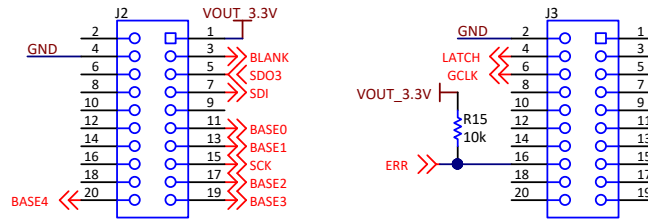
- Refresh rate
- Number of rows
- SPI communication speed
- Number of TLC6C576C-Q1 devices
- PWM Dimming frequency

2.4.9 MCU LaunchPad™

To control the TLC6C5724-Q1 LED drivers a MSP430 LaunchPad is used in this design. The MSP-EXP430F5529LP (or the F5529 LaunchPad) is an inexpensive and simple development kit for the MSP430F5529 USB MCU. It offers an easy way to begin developing on the TI MSP430 MCU, with onboard emulation for programming and debugging.

There are two 20-pin connectors (J2 and J3) on the reference design PCB that allow for connection to the MSP-EXP430F5529LP. 図 15 shows the connectors. The headers allow the connection of any other microcontroller as well to test the reference design.

図 15. Connectors to MCU LaunchPad™

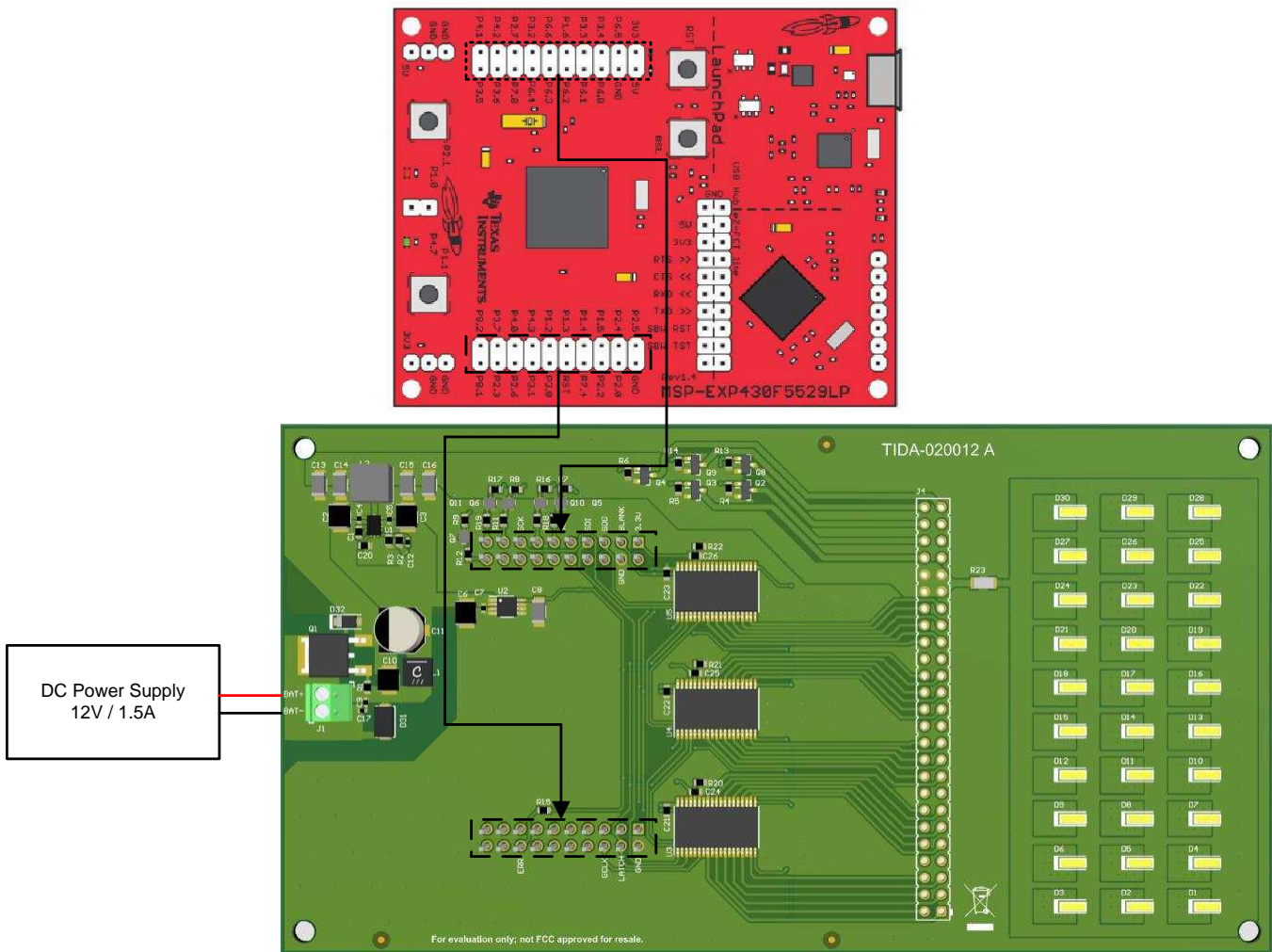


3 Hardware, Software, Testing Requirements, and Test Results

3.1 Required Hardware and Software

☒ 16 shows the default test setup of this reference design.

☒ 16. Hardware Test Setup



The MSP430 LaunchPad can be connected to the PCB using the headers J2 and J3. Connect a DC power supply to the input terminal J1.

A simple code was created for the MSP430F5529 MCU for testing the design. Follow the guidelines in the *Programming* section of the [TLC6C5724-Q1 Automotive 24-Channel, Full Diagnostics, Constant-Current RGB LED Driver Data Sheet](#).

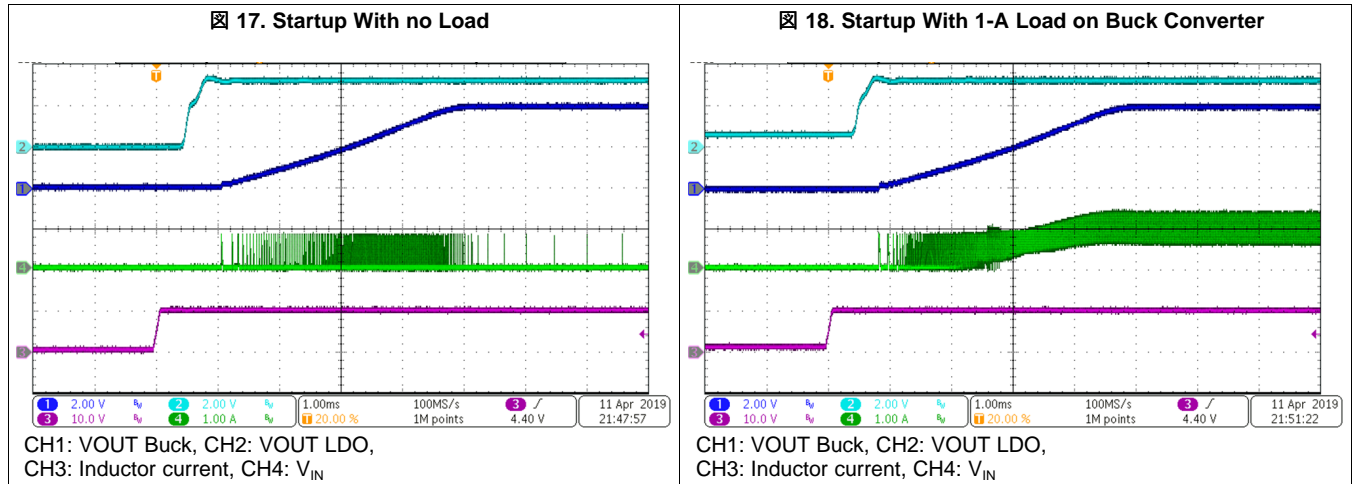
To test the multiplexing method, remove resistor R23 and connect the 150 LED PCB to the header J4.

3.2 Testing and Results

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

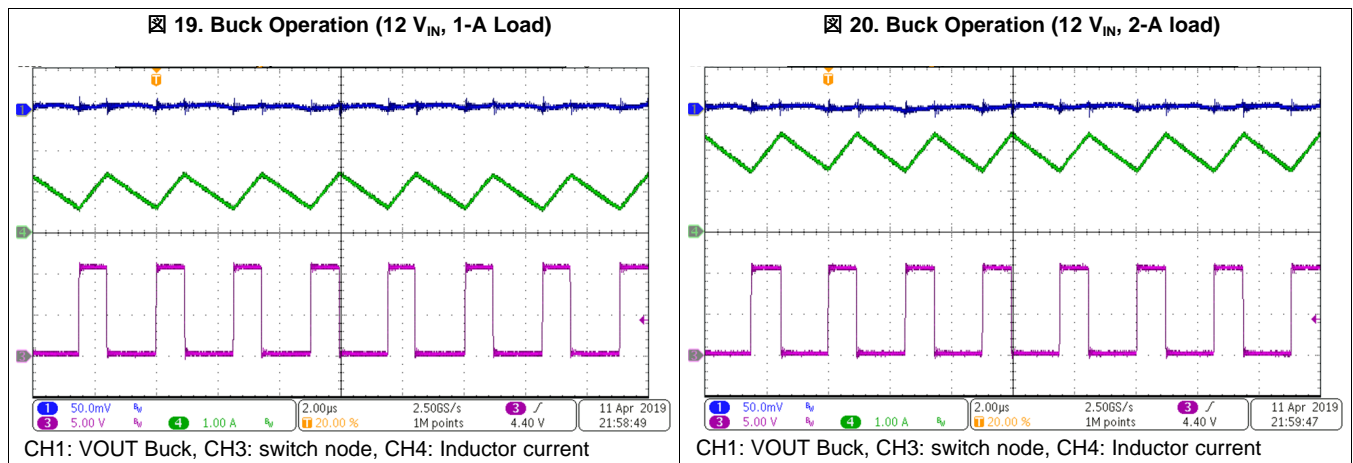
3.2.1 Startup

Figure 17 and Figure 18 show the startup behavior of the reference design.



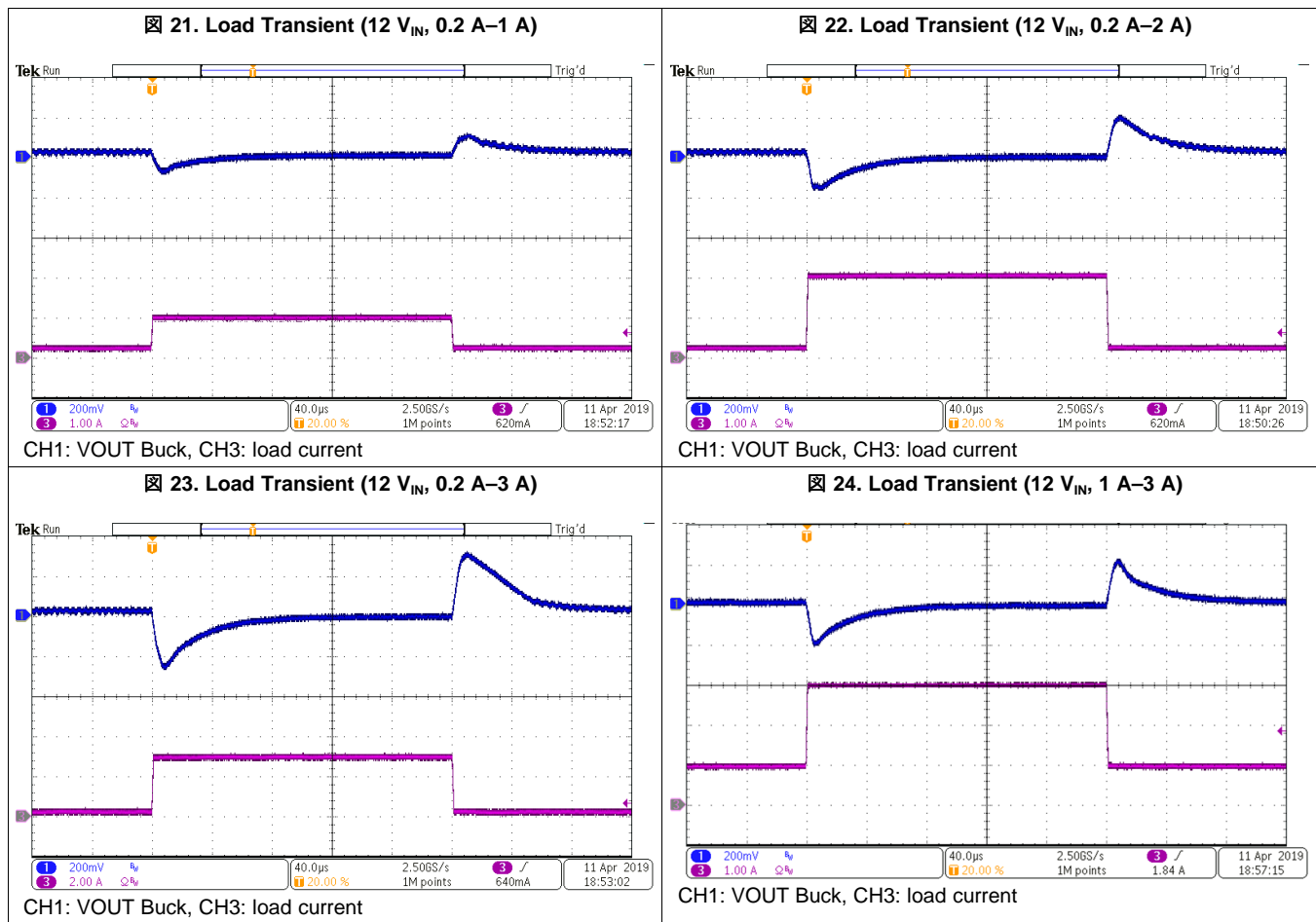
3.2.2 Steady-State Operation Buck Converter

Figure 19 and Figure 20 show the steady state operation of the LMR33630-Q1 buck converter.



3.2.3 Load Transient Response

Figure 21 through Figure 24 show the load transient response of the buck converter in the reference design.



3.2.4 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. [Figure 25](#) through [Figure 30](#) show the conducted emissions of the design with different load conditions. The design is passing CISPR25 class 5 limits up to 90 MHz. From 90–108 MHz, the emissions are violating the class 5 limit lines. By adding a small common-mode choke the design is able to pass in the higher frequency range as well.

Figure 25. Conducted Emissions (0.15 to 30 MHz): 0.6-A Load Current (20-mA LED Current)

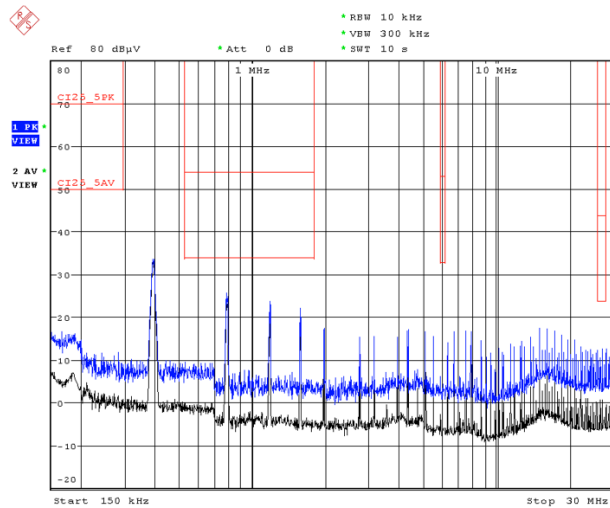


Figure 26. Conducted Emissions (30 to 108 MHz): 0.6-A Load Current (20-mA LED Current)

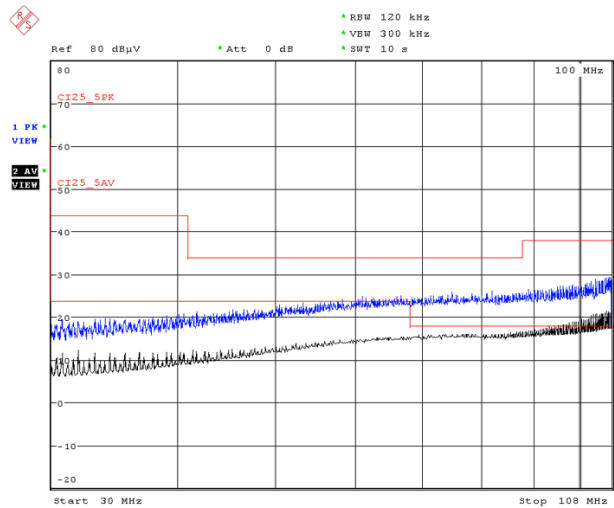


Figure 27. Conducted Emissions (0.15 to 30 MHz): 1.8-A Load Current (60-mA LED Current)

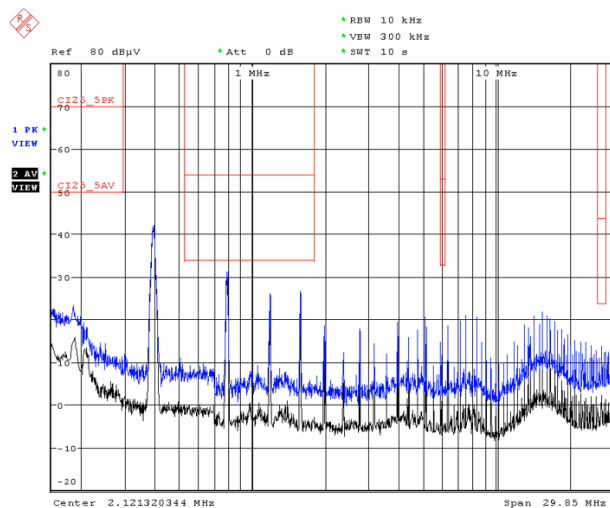


Figure 28. Conducted Emissions (30 to 108 MHz): 1.8-A Load Current (60-mA LED Current)

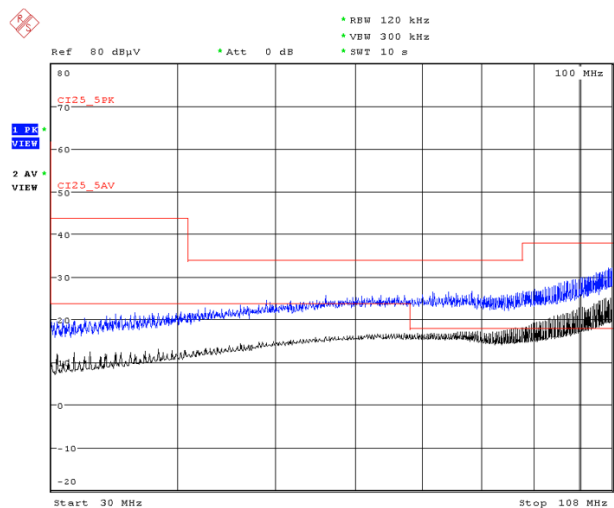
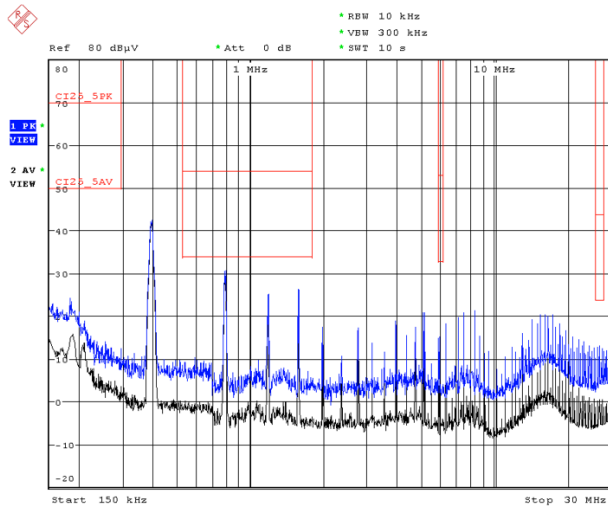
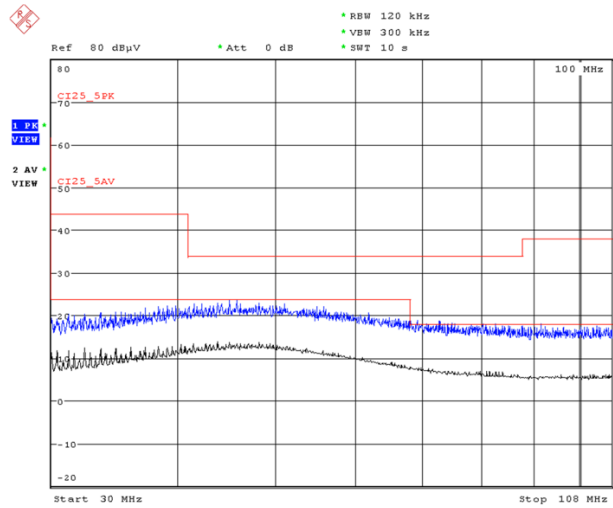


図 29. Conducted Emissions (0.15 to 30 MHz): 1.8-A Load Current (60-mA LED Current) With External Common-Mode Choke



Common-mode choke: TDK ACM4520-421-2P-T000

図 30. Conducted Emissions (0.15 to 30 MHz): 1.8-A Load Current (60-mA LED Current) With External Common-Mode Choke



Common-mode choke: TDK ACM4520-421-2P-T000

3.2.5 Thermal Performance

Figure 31 through Figure 38 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 31. Buck Converter: 0.6-A Load (20-mA LED Current)

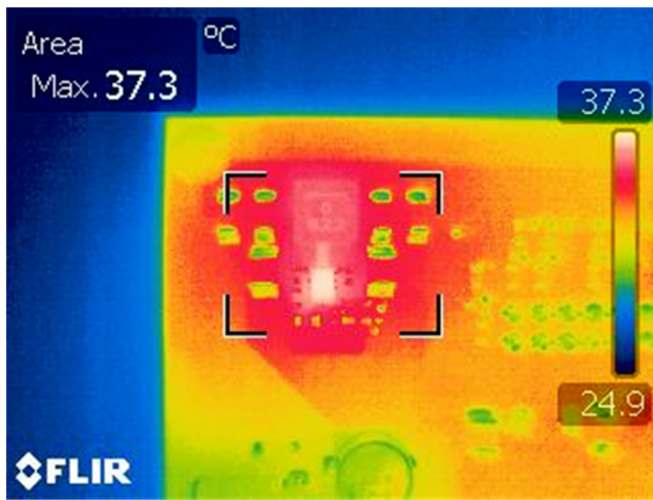


Figure 32. LED Driver: 10-mA Channel Current (20-mA LED Current)

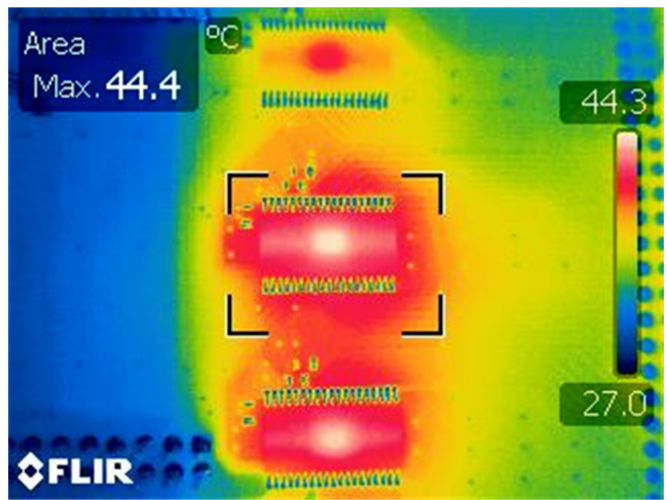


Figure 33. Buck Converter: 1.2-A Load (40-mA LED Current)

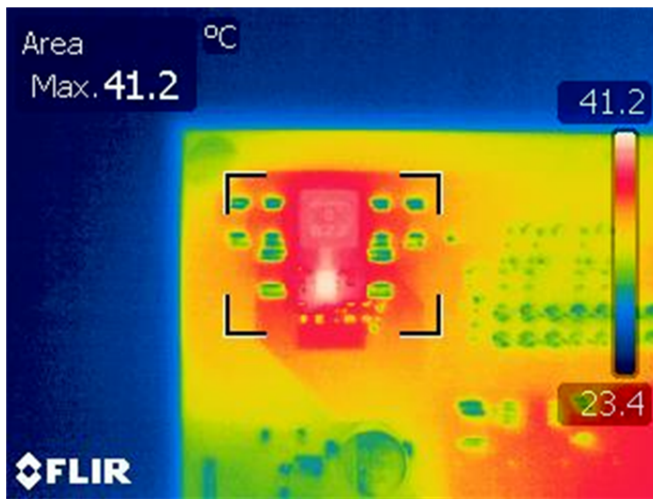


Figure 34. LED Driver: 20-mA Channel Current (40-mA LED Current)

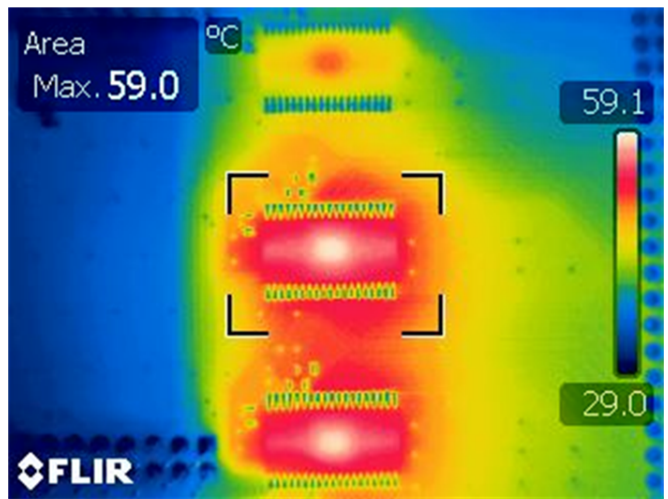


図 35. Buck Converter: 1.8-A Load (60-mA LED Current)

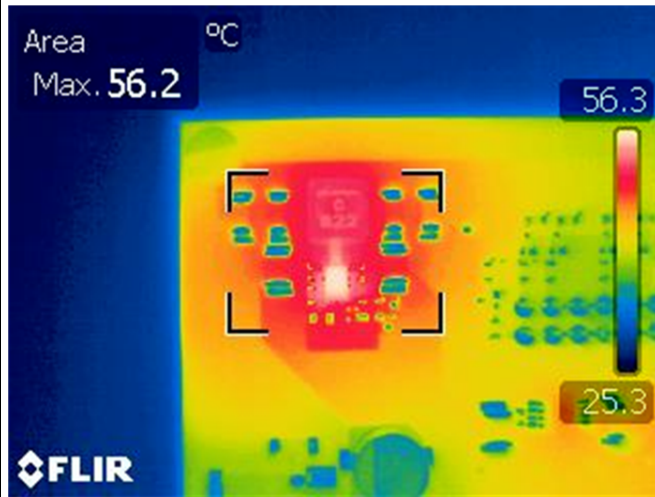


図 36. LED Driver: 30-mA Channel Current (60-mA LED Current)

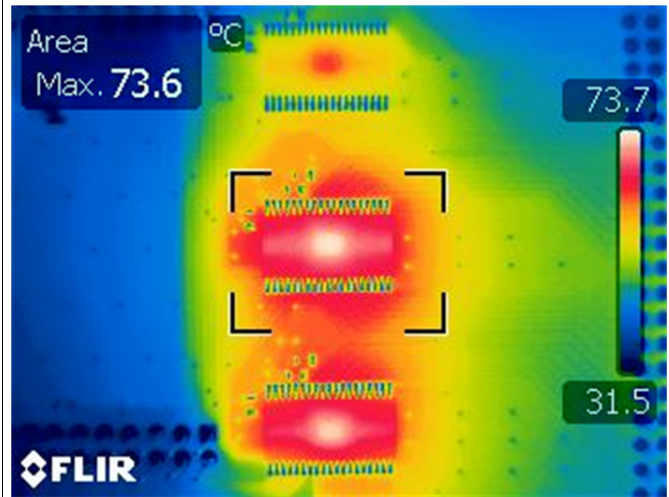


図 37. Buck Converter: 3-A Load

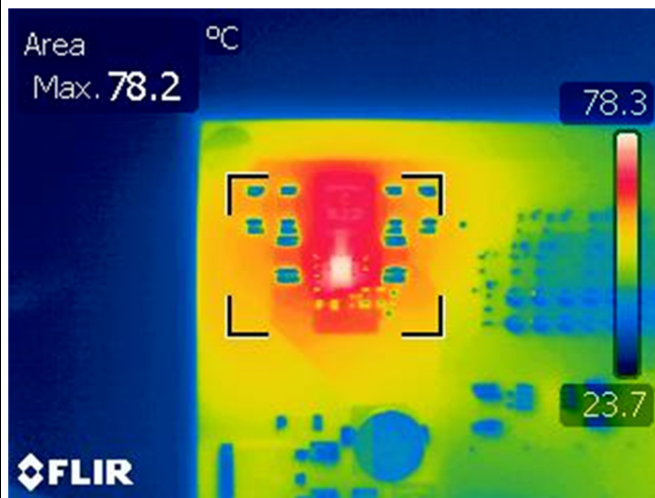
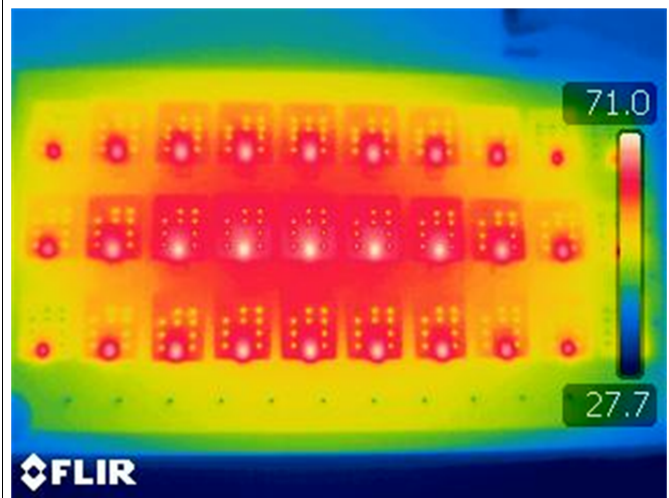


図 38. LEDs at 60-mA LED Current



4 Design Files

4.1 Schematics

To download the schematics, see the design files at [TIDA-020012](#).

4.2 Bill of Materials

To download the bill of materials (BOM), see the design files at [TIDA-020012](#).

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-020012](#).

4.4 Altium Project

To download the Altium Designer® project files, see the design files at [TIDA-020012](#).

4.5 Gerber Files

To download the Gerber files, see the design files at [TIDA-020012](#).

4.6 Assembly Drawings

To download the assembly drawings, see the design files at [TIDA-020012](#).

5 Related Documentation

1. Texas Instruments, [LMR33630-Q1 3.8-V to 36-V, 3-A Synchronous Step-down Voltage Converter Data Sheet](#)
2. Texas Instruments, [TLC6C5724-Q1 Automotive 24-Channel, Full Diagnostics, Constant-Current RGB LED Driver Data Sheet](#)
3. Texas Instruments, [TPS7B82-Q1 300-mA High-Voltage Ultra-low- \$I_Q\$ Low-Dropout Regulator Data Sheet](#)

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6 About the Author

MICHAEL HELMLINGER is a systems engineer on the Automotive Body Electronics and Lighting team with more than 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.

CHRIS SUCHOSKI is an Analog Field Applications Engineer at Texas Instruments supporting customers in the industrial market. Prior to his current role, Chris worked in the Body Electronics and Lighting systems team where he developed collateral specifically targeted towards the automotive market. Chris earned his BS degree in electrical engineering from Virginia Tech in 2017.

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