# TI Designs
# Linear LED Driver Reference Design for Automotive Lighting Applications

## TI Designs

This TI Design details a solution for an automotive LED tail-light application (tail light, stop light, turn signal, and reverse light). The design features the TPS92630-Q1 linear LED driver powered through a smart-reverse battery diode from the automotive battery. This design guide includes EMI and EMC radiation and pulse tests conducted using CISPR 25 and ISO 7637-2 standards. For a similar design driven by a buck converter, see TIDA-00677. For a similar design driven by a boost converter, see TIDA-00678.

## Design Resources

| | |
|---|---|
| TIDA-00679 | Design Folder |
| TPS92630-Q1 | Product Folder |
| LM74610-Q1 | Product Folder |
| TLC555-Q1 | Product Folder |
| TPS7A1633-Q1 | Product Folder |
| TPS92630EVM | Tools Folder |

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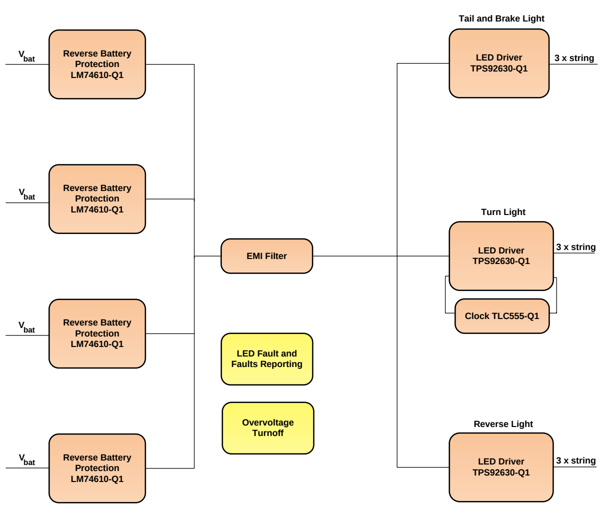
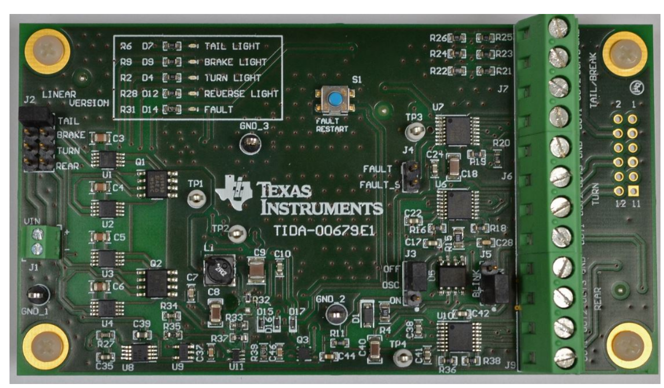
## Design Features

- Efficiency-Optimized Design
- CISPR 25 Tested EMI and EMC
- Load Dump Tolerant
- Operation Through Cold Crank
- Smart-Reverse Battery Protection

## Featured Applications

- Automotive Tail Light
- Automotive Front Lighting
- Automotive Interior Lighting



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# 1 Key System Specifications

Table 1 shows the light-emitting diode (LED) system specifications.

**Table 1. LED Module System Specification**

| PARAMETER | | COMMENTS | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| **System input and output** | | | | | | |
| $V_{IN}$ | Operating-input voltage | Battery-voltage range. Outputs are functional (DC) | 5 | 13.5 | 16 | V |
| $V_{IN\_MAX}$ | Maximum-input voltage | Maximum-battery voltage on the module without device damage (for example: load dump) | | | 45 | V |
| $V_{OUT\_MAX}$ | Output voltage | Maximum output voltage at $V_{IN}$ | | $V_{IN}$ - $V_{DROP}$ | | V |
| $V_{TR}$ | Transient immunity | Load dump (ISO 7637-2) | | | 45 | V |
| $V_{IN\_MIN}$ | Minimum input voltage | Cold crank (ISO 7637-2) | 5 | | | V |
| $V_{Rev}$ | Reverse voltage | Reverse-polarity protection | –42 | | | V |
| $I_{IN\_MAX}$ | Maximum-input current | All outputs at full load (150 mA) | | 1.1 | | A |
| $I_{OUT\_MaxS}$ | Maximum-output current | Maximum current for each string | | | 100 | mA |
| | | Maximum current for brake light | | | 150 | mA |
| $V_{OUT\_OFF}$ | Output off | Turn output off at input over voltage | | 17 | | |
| $LED_{Open\ and\ short\ detect}$ | | LED open and short detection | | Yes | | |
| $LED_{Single\ short\ detect}$ | | LED single-short detection | | Configurable | | |
| **Onboard voltages** | | | | | | |
| $V_{TP1}$ | Voltage at reverse-battery protection output | TP1, LM74610-Q1 | | $V_{IN}$ | | V |
| $V_{TP2}$ | Voltage $\pi$- filter output | TP2 | | $V_{IN}$ | | V |
| $V_{LDO}$ | Output-linear regulator | U8, TPS7A1633-Q1, comparator and clock supply | | 3.3 | | V |
| $f_{OSCTurn}$ | Oscillator frequency | U5, TLC555-Q1, clock generator | | 0.5 | | Hz |
| **Thermal** | | | | | | |
| $T_A$ | Temperature range | Operating-ambient temperature | –40 | | 105 | ºC |
| **Pulse tolerance** | | | | | | |
| Load dump | | Thermal shutdown | | | | |
| Cold crank | | Shutdown dependent on number of LEDs used per string | | | | |
| Jump start | | Thermal shutdown | | | | |
| **EMI tolerance** | | | | | | |
| Meets or exceeds the CISPR 25 class 3 and 5 requirements | | | | | | |
| **Baseboard** | | | | | | |
| Number of layers | | Two layers, double-side populated | | | | |
| Form factor | | 112 mm × 62 mm | | | | |

## 2 System Description

This system was designed as a complete solution for a TPS92630-Q1 automotive-linear LED driver tail-light application and includes reverse-battery protection. Consider the following points:

- Satisfy power requirements for three TPS92630-Q1 devices, each driving three strings of LEDs for tail lights, brake lights, turn lights, and reverse lights.
- Operate over the full range of battery conditions.
  - $V_{IN\_MIN}$ down to 5 V simulating a cold cranking condition (ISO 7637-2:2004 pulse 4)
  - $V_{IN\_MAX}$ up to 16 V simulating the upper range of normal battery operation
- Survive and continue (or switch off depending on the configuration) operation through:
  - Load dump (ISO 7637-2:2004 pulses 5a)
  - Double-battery condition
- Implement a reverse-battery protection scheme with minimal loss for the system.
  - The system must properly respond to a reverse-battery polarity event and shut down appropriately.
- Protect the output against shorts to the battery and GND voltage.
- Optimize the individual blocks for the lowest power dissipation and the highest efficiency.
- Lay out the board to minimize the footprint of the solution while maintaining high performance.
- Provide a flexible-board interface to mate to a custom board through screw terminals or receptacles (J8).
- Provide power for the TLC555-Q1.
- The system must maintain a constant output current over the full DC range of battery conditions or turn off at high and low voltage conditions

Many tail-light applications in vehicles may or may not need to maintain operation during cold crank and load dump, have high efficiency, and be CISPR 25 EMI and EMC compliant. Figure 1 is an example block diagram of the tail-light system.

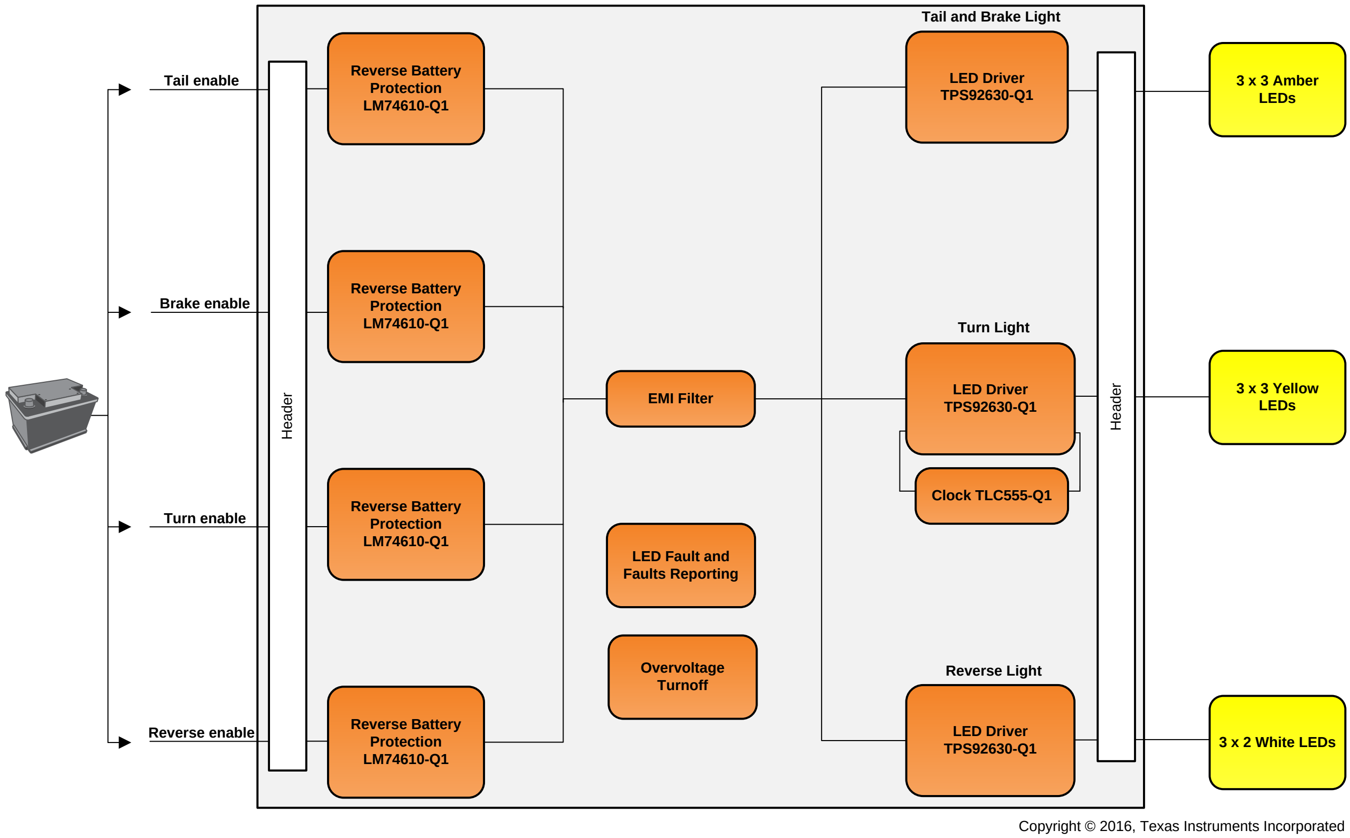



**Figure 1. Tail-Light System Driven From the Car Battery**

The orange blocks are components found on the TIDA-00679 board. The blocks cover most monitoring and power requirements of the example system (see Figure 1).

Figure 1 also features reverse-battery protection, EMC filtering, voltage conditioning, and a linear LED driver. Because length of strings vary from application to application, LEDs are not included.

# 3 Block Diagram

Figure 2 shows the TPS92630-Q1 linear LED driver block diagram.

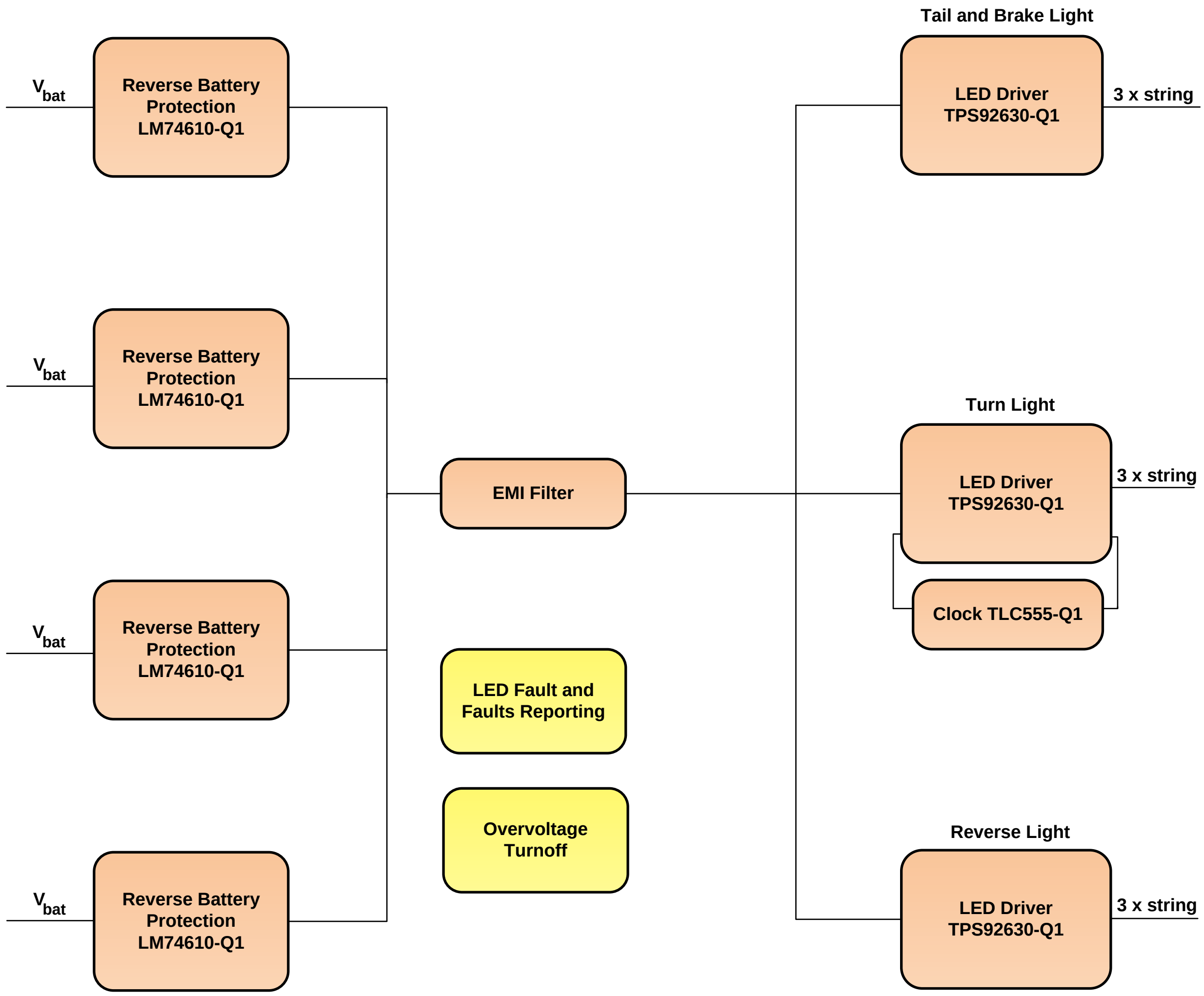



**Figure 2. TPS92630-Q1 Linear LED Driver Block Diagram**

## 3.1 Highlighted Products

This design uses the TI products in Section 3.1.1, Section 3.1.2, Section 3.1.3, and Section 3.1.4. For more information on each of these devices, see the product folders at www.ti.com.

### 3.1.1 TPS92630-Q1

The TPS92630-Q1 device is a linear LED driver that has three channels, analog, and PWM dimming controls. Because the TPS92630-Q1 has full-diagnostic and built-in protection capabilities, it is the ideal device for lighting applications with variable-intensity LEDs up to a medium-power range. Figure 3 is a block diagram of the TPS92630-Q1.

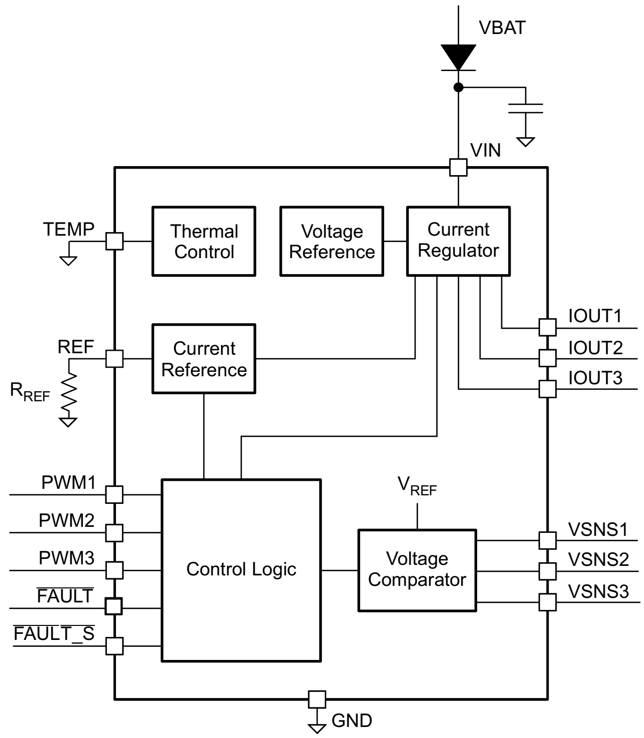



**Figure 3. TPS92630-Q1 Linear LED Block Diagram**

- The TPS92630-Q1 has a 450-mA maximum-output current (150 mA per channel). This design uses a maximum of 100 mA per channel (for IOUT1, IOUT2, IOUT3). If the brake light is turned on, the IOU1 channel delivers 150 mA.
- The PWM1, PWM2, PWM3 inputs for the tail, brake, turn, and reverse lights are tied together and connected to the VIN pin to make the device operate at 100% duty cycle.
- The PWM inputs are tied together for the turn indicator and can be connected through jumper J5 to the low dropout (LDO) output (3.3 V) to enable 100% duty cycle, or to the TLC555-Q1 clock device to enable blinking operation.
- The REF pin is tied through a 1.21-kΩ resistor to GND to set a 100-mA output current per LED string. If the brake light is turned on, a 2.43-kΩ resistor is paralleled to move the current to 150 mA.
- The $\overline{\text{FAULT}}$ pin is used to report general faults as open, short, and thermal shutdown.
- The $\overline{\text{FAULT\_S}}$ pin is not used.
- The TEMP pin is not used and is tied to GND.
- VSNS1, VSNS2, VSNS3 are not used due to long strings.
- Wide-input voltage range (5 V to 16 V and 45-V transients) is required to operate directly from the battery to withstand load dump and operate through cold-crank and start-stop conditions.

### 3.1.2 LM74610-Q1

The LM74610-Q1 is a controller device that can be used with an N-Channel MOSFET in protection circuitry with reverse polarity (see Figure 4). The LM74610-Q1 is designed to drive an external MOSFET to emulate an ideal-diode rectifier when connected in series with a power source. A unique advantage of this scheme is that it is not referenced to the ground and has zero quiescent current ($I_Q$).

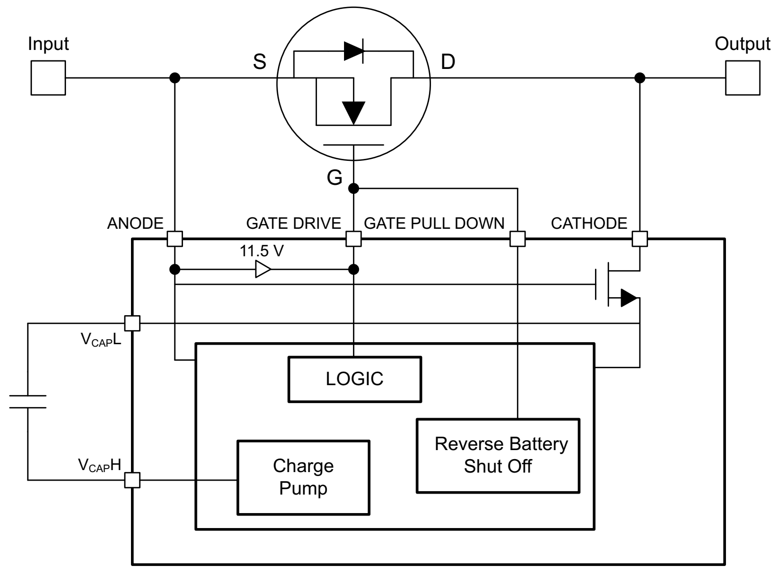



**Figure 4. LM74610-Q1 Zero $I_Q$ Reverse-Polarity Protection Smart-Diode Controller**

The LM74610-Q1:

- Controls an external NFET in series with the battery-supply input to act as an ideal diode, reducing voltage drop and power loss as opposed to a discrete-diode solution
- Quickly turns off the FET when a reverse-battery condition is detected, isolating and protecting downstream circuitry
- Satisfies the requirement for reverse-battery protection down to –42 V
- Has no ground reference, leading to almost a zero $I_Q$ operation. Having no ground reference helps the subsystem draw less standby current from the battery.

The small voltage drop across the FET provides more input-voltage headroom for the wide-$V_{IN}$ buck converter and reduced power dissipation.

### 3.1.3 TLC555-Q1

The TLC555-Q1 is a monolithic timing circuit fabricated using the TI LinCMOS™ process. The timer, shown in Figure 5, is fully compatible with CMOS, TTL, and MOS logic and operates at frequencies of up to 2 MHz. This device uses smaller timing capacitors than the NE555 because it has high-input impedance; more accurate time delays and oscillations are possible. Power consumption is low across the full range of power-supply voltage.

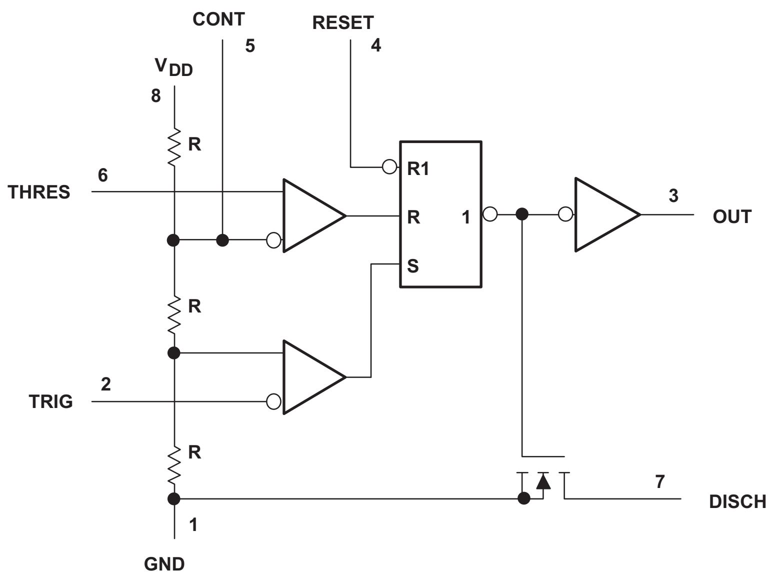





**Figure 5. LinCMOS™ Timer**

The TLC555-Q1:

- Generates a 0.5-Hz clock signal for the turn-indicator LED string
- Has an operating voltage range of 2 V to 15 V
- Is supplied by the 3.3-V LDO to generate a 3.3-V square-wave output.
- Is attached to the PWM input pins of the U7 turn-indicator (TPS92630-Q1)
- Has low power consumption
- Has low supply currents that reduce spikes during output transitions

The TLC555-Q1 has a trigger level equal to approximately one-third of the supply voltage and a threshold level equal to approximately two-thirds of the supply voltage. These levels can be altered by using the control-voltage terminal (CONT). When the trigger input (TRIG) falls below the trigger level it sets the flip-flop and the output goes high. Having TRIG above the trigger level and the threshold input (THRES) above the threshold level resets the flip-flop, and the output is low. The reset input (RESET) can override all other inputs, and a possible use is to initiate a new timing cycle. RESET going low resets the flip-flop, and the output is low. When the output is low, a low-impedance path exists between the discharge terminal (DISCH) and GND.

### 3.1.4 TPS7A1633-Q1

The TPS7A1633-Q1 device is a wide-$V_{IN}$ linear regulator that produces the supply voltage (3.3 V for the overvoltage-turnoff comparator) for the clock generator and the fault LED indicator.Figure 6 shows the TPS7A1633-Q1 block diagram.

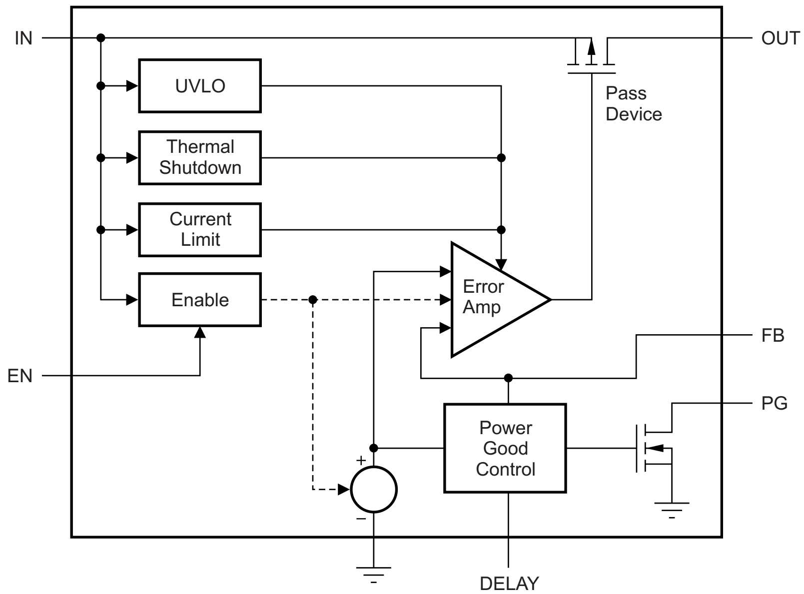



**Figure 6. TPS7A1633-Q1 LDO Voltage Regulator**

This device was chosen because it operates at cold-crank conditions (5 V in this design). Consider the following:

- Add a 22 µF capacitor to the output for stability
- Enable (EN) is tied to IN through a 10-kΩ resistor
- Power good (PG) is not used in this design

# 4 System Design Theory

This TI Design is compliant with EMC and EMI standards that are important to automotive customers. There are many important standards and tests, but the focus is on the standards and tests that are most applicable to off-battery power supplies: ISO 7637-2, ISO 16750-2, and CISPR 25. Auto manufacturers have internal standards for EMC, but these are often based on international ISO and IEC standards. Usually, only a few parameters of different tests or limits are changed, but the essence of the requirements are the same.

## 4.1 ISO 7637-2

ISO 7637 is titled "*Road vehicles – Electrical disturbances from conduction and coupling*," and part two is "*Electrical transient conduction along supply lines only*." Because the design is a subsystem where power comes directly from the supply lines (car battery), ISO 7637 part two is relevant. The standard defines a test procedure, including the description of test pulses, to test the susceptibility of an electrical subsystem to transients that could be harmful to its operation. More details about the pulses used in this design are provided in the following sections.

### 4.1.1 ISO 7637-2 Pulse 5a (Load Dump)

This section is based on the standard, "This test is a simulation of load dump transient, occurring in the event of a discharged battery being disconnected while the alternator is generating charging current and with other loads remaining on the alternator circuit at this moment … Load dump may occur on account of a battery being disconnected as a result of cable corrosion, poor connection or of intentional disconnection with the engine running." This pulse was moved from ISO 7637 to ISO 16750 (detailed in Section 4.2), but for historical reasons it is still grouped with the ISO 7637-2 pulses (see Figure 7).

**NOTE:** The control unit must be able to withstand the high energy and high voltage of the load-dump event.

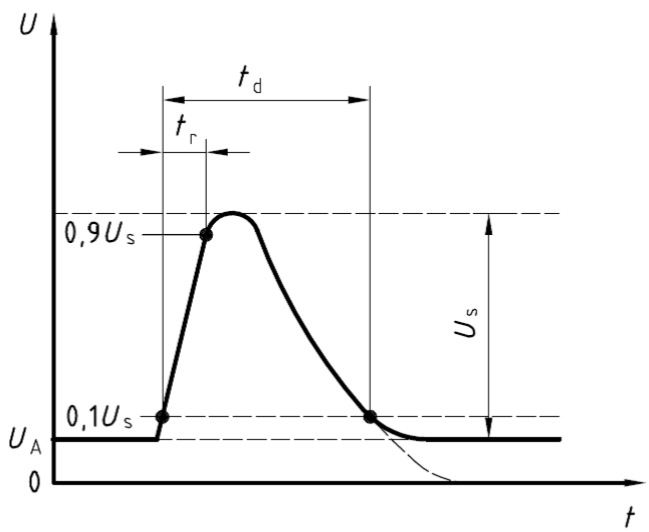



**Figure 7. Load-Dump Pulse**

### 4.1.2 Related Standards

As detailed in Section 4, OEMs (and other standards organizations) maintain versions of these pulses in their standards. Usually, the pulses have different parameters depending on the OEM, but they can be the same.

### 4.2 ISO 16750-2

ISO 16750 is titled “*Road vehicles – Environmental conditions and testing for electrical and electronic equipment*," and part 2 is “*Electrical loads*.” One way to think of this standard is that it defines a series of supply-voltage quality events—variations of the battery-supply voltage under various conditions. These conditions, for the most part, are not harmful to the electrical subsystem, but can affect the state of operation. The tests in this standard are designed to see how the subsystem behaves before, during, and after these events. The required behavior can be classified into multiple functional classes.

- **Functional Class A**
  - All functions of the device or the system perform as designed during and after the test.
- **Functional Class B**
  - All functions of the device or the system perform as designed during the test. However, one or more functions may go beyond the specified tolerance. All functions automatically return within normal limits after the test. Memory functions shall remain Class A.
- **Functional Class C**
  - One or more functions of the device or the system do not perform as designed during the test, but automatically return to normal operation after the test.
- **Functional Class D**
  - One or more functions of the device or the system do not perform as designed during the test and do not return to normal operation after the test until the device or the system is reset by a “operator or use” action.
- **Functional Class E**
  - One or more functions of the device or the system do not perform as designed during and after the test and cannot be returned to proper operation without repairing or replacing the device or the system.

The standards define different tests, but only a small subset of the tests apply to this design. Only the cold-crank, reverse-battery, jump-start, and load-dump results are shown in this document.

### 4.2.1 ISO 16750-2: 4.3.1.2 Jump Start

Figure 8 shows the supply that went through the subsystem during the jump start, where two 12-V batteries are connected to the supply lines in a series. This is an overvoltage condition that is sustained for a period of time.

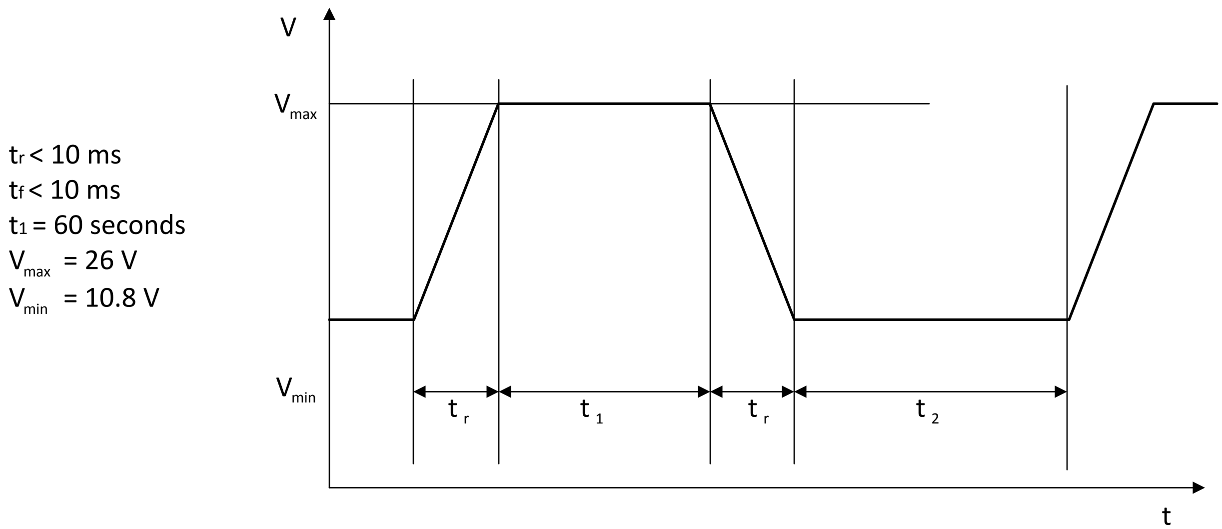



**Figure 8. Jump-Start Profile**

Functional Class C is the requirement for this test.

### 4.2.2 ISO 16750-2: 4.7 Reversed Voltage

This section is based on the standard, “This test checks the ability of a DUT to withstand against the connection of a reversed battery in case of using an auxiliary starting device.” Figure 9 shows the reverse-battery pulse referenced in this section.

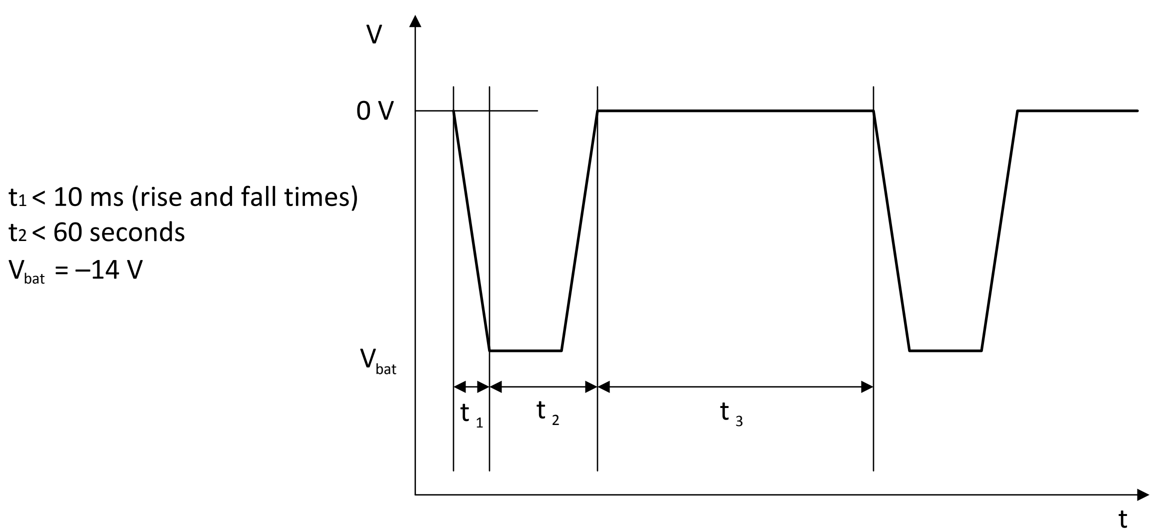



**Figure 9. Reverse-Battery Pulse**

The subsystem does not need to operate during this event, but upon removing the reverse-polarity and re-establishing the normal supply voltage (12 V), the subsystem can satisfy Functional Class A.

### 4.2.3 Cranking Profiles

Cranking tests simulate the drop in supply voltage when the engine is started due to the large current draw of the starter motor. The voltage levels are dependent on the temperature of the car during start-up, with severe cold leading to the largest drop in voltage (*cold crank*). Though the profile looks similar for all OEMs, the voltage levels can vary from standard to standard. Figure 10 shows an example of a cold start, and Table 2 shows the parameters for a cold start.

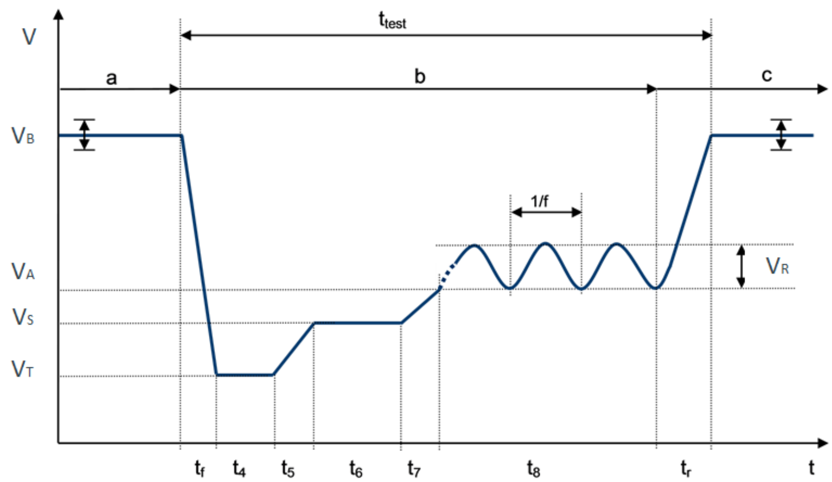



**Figure 10. Example of Cold Start**

**Table 2. Example Parameters for Cold Start**

| PARAMETER | NORMAL TEST PULSE | SEVERE TEST PULSE |
|---|---|---|
| $V_B$ | 11.0 V | 11.0 V |
| $V_T$ | 4.5 V (0%, –4%) | 3.2 V $^{+0.2\ V}$ |
| $V_S$ | 4.5 V (0%, –4%) | 5.0 V (0%, –4%) |
| $V_A$ | 6.5 V (0%, –4%) | 6.0 V (0%, –4%) |
| $V_R$ | 2 V | 2 V |
| $t_f$ | ≤ 1 ms | ≤ 1 ms |
| $t_4$ | 0 ms | 19 ms |
| $t_5$ | 0 ms | ≤ 1 ms |
| $t_6$ | 19 ms | 329 ms |
| $t_7$ | 50 ms | 50 ms |
| $t_8$ | 10 s | 10 s |
| $t_r$ | 100 ms | 100 ms |
| f | 2 Hz | 2 Hz |

## 4.3 CISPR 25

CISPR 25 is the automotive EMI standard that most OEMs reference for requirements. The title of the standard is, "*Vehicles, boats and internal combustion engines – Radio disturbance characteristics – Limits and methods of measurement for the protection of on-board receivers*." The purpose of the standard is to limit the amount of emissions from a subsystem in several frequency bands to ensure it does not interfere with other systems that intentionally operate in those bands.

For example, an AM radio receiver is tuned to a specific frequency (for example 710 kHz), picking up the signal of a radio station on that frequency. The radio receives and amplifies the signals intended for AM radio broadcast on that frequency. However, if another system on the car is unintentionally emitting large quantities of energy (noise) at that frequency, it impedes the ability of the radio to cleanly resolve the signal of the radio station, and the user may hear noise in the signal, or obscure the intentional signal altogether. Standards like CISPR 25 are specifically designed to avoid this by setting acceptable limits on these systems. OEMs will define limits, but CISPR 25 contains examples.

The testing and limits are split into two separate types of emissions: conducted and radiated. Conducted emissions are coupled onto supply lines directly through conductors (such as traces or wires), and radiated emissions are emitted as EM waves and can be picked up by intentional and unintentional antennas on other systems.

The test procedures, relevant-frequency bands, and limits are different for both types of emissions, but the basics are similar: the device under test (DUT) is placed in an isolated room or chamber and set up in a well-defined, reproducible-electrical setup. All other possible emitters are removed from the chamber and the DUT is turned on and then allowed to operate normally. The DUT is powered through an artificial network (line impedance stabilization network [LISN]) and loaded through its normal operation. A spectrum analyzer is used to measure the DUT emissions across different frequencies (through the LISN or from an antenna) and compares the emissions against the CISPR 25 limits. Both the peak and average values of the emissions are measured, and both must pass. Finally, the level of passing falls into several categories, or classes, that have different limits. OEMs define which class a specific subsystem must satisfy.

### 4.3.1 Conducted Emissions

The test setup is outlined in the official CISPR 25 documentation (see the figured titled *Conductied emissions – Test layout for ignition system components* in [1 ]).

Variations of this setup exist and depend on the subsystem that is being tested. See the official documentation for further information about the test setup. Conducted-emissions testing is done only in the lower-frequency bands for the standard. The limits are defined in the CISPR 25 documentation shown in Table 3 and Table 4. $£_r \leq 1.4$

**Table 3. Peak and Quasi Peak Limits**

| SERVICE OR BRAND | FREQUENCY (MHz) | LEVELS IN dV (µV) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CLASS 1 | | CLASS 2 | | CLASS 3 | | CLASS 4 | | CLASS 5 | |
| | | PEAK | QUASI PEAK | PEAK | QUASI PEAK | PEAK | QUASI PEAK | PEAK | QUASI PEAK | PEAK | QUASI PEAK |
| **Broadcast** | | | | | | | | | | | |
| LW | 0.15 to 0.30 | 110 | 97 | 100 | 87 | 90 | 77 | 80 | 67 | 70 | 57 |
| MW | 0.53 to 1.8 | 86 | 73 | 78 | 65 | 70 | 57 | 62 | 49 | 54 | 41 |
| SW | 5.9 to 6.2 | 77 | 64 | 71 | 58 | 65 | 52 | 59 | 46 | 53 | 40 |
| FM | 76 to 108 | 62 | 49 | 56 | 43 | 50 | 37 | 44 | 31 | 38 | 25 |
| TV Band 1 | 41 to 88 | 58 | | 52 | | 46 | | 40 | | 34 | |
| TV Band 3 | 174 to 230 | Conducted emission. Voltage method is not applicable. | | | | | | | | | |
| DAB 3 | 171 to 245 | | | | | | | | | | |
| TV Band 4 and 5 | 468 to 944 | | | | | | | | | | |
| DTTV | 470 to 770 | | | | | | | | | | |
| DAB L Band | 1447 to 1494 | | | | | | | | | | |
| SDARS | 2320 to 2345 | | | | | | | | | | |
| **Mobile services** | | | | | | | | | | | |
| CB | 26 to 28 | 68 | 55 | 62 | 49 | 56 | 43 | 50 | 37 | 44 | 31 |
| VHF | 30 to 54 | 68 | 56 | 62 | 49 | 56 | 43 | 50 | 37 | 44 | 31 |
| VHF | 68 to 87 | 62 | 49 | 56 | 43 | 50 | 37 | 44 | 31 | 38 | 25 |

**Table 4. Average Limits**

| SERVICE OR BAND | FREQUENCY (MHz) | LEVELS IN dV (µV) | | | | |
|---|---|---|---|---|---|---|
| | | CLASS 1 | CLASS 2 | CLASS 3 | CLASS 4 | CLASS 5 |
| | | AVERAGE | AVERAGE | AVERAGE | AVERAGE | AVERAGE |
| **Broadcast** | | | | | | |
| LW | 0.15 to 0.30 | 90 | 80 | 70 | 60 | 50 |
| MW | 0.53 to 1.8 | 66 | 58 | 50 | 42 | 34 |
| SW | 5.9 to 6.2 | 57 | 51 | 45 | 39 | 33 |
| FM | 76 to 108 | 42 | 36 | 30 | 24 | 18 |
| TV Band 1 | 41 to 88 | 48 | 42 | 36 | 30 | 24 |
| TV Band 3 | 174 to 230 | Conducted emission. Voltage method is not applicable. | | | | |
| DAB 3 | 171 to 245 | | | | | |
| TV Band 4 and 5 | 468 to 944 | | | | | |
| DTTV | 470 to 770 | | | | | |
| DAB L Band | 1447 to 1494 | | | | | |
| SDARS | 2320 to 2345 | | | | | |
| **Mobile services** | | | | | | |
| CB | 26 to 28 | 48 | 42 | 36 | 30 | 24 |
| VHF | 30 to 54 | 48 | 42 | 36 | 30 | 24 |
| VHF | 68 to 87 | 42 | 36 | 30 | 24 | 18 |

The DC-DC regulator in the system is the main source of conducted emissions. The switching action of the input-current waveform emits energy back onto the supply lines, and this must be filtered. The supply lines emit at their fundamental-switching frequency and harmonics.

### 4.3.2 Radiated Emissions

The test setup is outlined in the official CISPR 25 documentation. Three different antennas are used to measure over the full frequency range of the testing, and three different test setups are required (see the figure titled *Example of test set-up – rod antenna* in [1 ]).

See the official documentation for more information about the other test setups. The limits are defined in the CISPR 25 documentation, and cover a wider band than the conducted emissions test. Table 5 and Table 6 show the peak, quasi-peak, and average limits for radiated emissions testing.

**Table 5. Peak and Quasi-Peak Limits for Radiated Emissions Testing**

| SERVICE OR BAND | FREQUENCY (MHz) | LEVELS IN dV (µV per m) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CLASS 1 | | CLASS 2 | | CLASS 3 | | CLASS 4 | | CLASS 5 | |
| | | PEAK | QUASI PEAK | PEAK | QUASI PEAK | PEAK | QUASI PEAK | PEAK | QUASI PEAK | PEAK | QUASI PEAK |
| **Broadcast** | | | | | | | | | | | |
| LW | 0.15 to 0.30 | 86 | 73 | 76 | 63 | 66 | 53 | 56 | 43 | 46 | 33 |
| MW | 0.53 to 1.8 | 72 | 59 | 64 | 51 | 56 | 43 | 48 | 35 | 40 | 27 |
| SW | 5.9 to 6.2 | 64 | 51 | 58 | 45 | 52 | 39 | 46 | 33 | 40 | 27 |
| FM | 76 to 108 | 62 | 49 | 56 | 43 | 50 | 37 | 44 | 31 | 38 | 25 |
| TV Band 1 | 41 to 88 | 52 | | 46 | | 40 | | 34 | | 28 | |
| TV Band 3 | 174 to 230 | 56 | | 50 | | 44 | | 38 | | 32 | |
| DAB 3 | 171 to 245 | 50 | | 44 | | 38 | | 32 | | 26 | |
| TV Band 4 and 5 | 468 to 944 | 65 | | 59 | | 53 | | 47 | | 41 | |
| DTTV | 470 to 770 | 69 | | 63 | | 57 | | 51 | | 45 | |
| DAB L Band | 1447 to 1494 | 52 | | 46 | | 40 | | 34 | | 28 | |
| SDARS | 2320 to 2345 | 58 | | 52 | | 46 | | 40 | | 34 | |
| **Mobile Services** | | | | | | | | | | | |
| CB | 26 to 28 | 64 | 51 | 58 | 45 | 52 | 39 | 46 | 33 | 40 | 27 |
| VHF | 30 to 54 | 64 | 51 | 58 | 45 | 52 | 39 | 46 | 33 | 40 | 27 |
| VHF | 68 to 87 | 59 | 46 | 53 | 40 | 47 | 34 | 41 | 28 | 35 | 22 |
| VHF | 142 to 175 | 59 | 46 | 53 | 40 | 47 | 34 | 41 | 28 | 35 | 22 |
| Analog UHF | 380 to 512 | 62 | 49 | 56 | 43 | 50 | 37 | 44 | 31 | 38 | 25 |
| RKE | 300 to 330 | 56 | | 50 | | 44 | | 38 | | 32 | |
| RKE | 420 to 450 | 56 | | 50 | | 44 | | 38 | | 32 | |
| Analog UHF | 820 to 960 | 68 | 55 | 62 | 49 | 56 | 43 | 50 | 37 | 44 | 31 |
| GSM 800 | 860 to 895 | 68 | | 62 | | 56 | | 50 | | 44 | |
| EGSM and GSM 900 | 925 to 960 | 68 | | 62 | | 56 | | 50 | | 44 | |
| GPS L1 civil | 1567 to 1583 | | | | | | | | | | |
| GSM 1800 (PCN) | 1803 to 1882 | 68 | | 62 | | 56 | | 50 | | 44 | |
| GSM 1900 | 1850 to 1990 | 68 | | 62 | | 56 | | 50 | | 44 | |
| 3G and IMT 2000 | 1900 to 1992 | 68 | | 62 | | 56 | | 50 | | 44 | |
| 3G and IMT 2000 | 2010 to 2025 | 68 | | 62 | | 56 | | 50 | | 44 | |
| 3G and IMT 2000 | 2108 to 2172 | 68 | | 62 | | 56 | | 50 | | 44 | |
| *Bluetooth* and 802.11 | 2400 to 2500 | 68 | | 62 | | 56 | | 50 | | 44 | |

**Table 6. Average Limits for Radiated Emissions Testing**

| SERVICE OR BAND | FREQUENCY (MHz) | LEVELS IN dV (µV per m) | | | | |
|---|---|---|---|---|---|---|
| | | CLASS 1 | CLASS 2 | CLASS 3 | CLASS 4 | CLASS 5 |
| | | AVERAGE | AVERAGE | AVERAGE | AVERAGE | AVERAGE |
| **Broadcast** | | | | | | |
| LW | 0.15 to 0.30 | 66 | 56 | 46 | 36 | 26 |
| MW | 0.53 to 1.8 | 52 | 44 | 36 | 28 | 20 |
| SW | 5.9 to 6.2 | 44 | 38 | 32 | 26 | 20 |
| FM | 76 to 108 | 42 | 36 | 30 | 24 | 18 |
| TV Band 1 | 41 to 88 | 42 | 36 | 30 | 24 | 18 |
| TV Band 3 | 174 to 230 | 46 | 40 | 34 | 28 | 22 |
| DAB 3 | 171 to 245 | 40 | 34 | 28 | 22 | 16 |
| TV Band 4 and 5 | 468 to 944 | 55 | 49 | 43 | 37 | 31 |
| DTTV | 470 to 770 | 59 | 53 | 47 | 41 | 35 |
| DAB L Band | 1447 to 1494 | 42 | 36 | 30 | 24 | 18 |
| SDARS | 2320 to 2345 | 48 | 42 | 36 | 30 | 24 |
| **Mobile Services** | | | | | | |
| CB | 26 to 28 | 44 | 38 | 32 | 26 | 20 |
| VHF | 30 to 54 | 44 | 38 | 32 | 26 | 20 |
| VHF | 68 to 87 | 39 | 33 | 27 | 21 | 15 |
| VHF | 142 to 175 | 39 | 33 | 27 | 21 | 15 |
| Analog UHF | 380 to 512 | 42 | 36 | 30 | 24 | 18 |
| RKE | 300 to 330 | 42 | 36 | 30 | 24 | 18 |
| RKE | 420 to 450 | 42 | 36 | 30 | 24 | 18 |
| Analog UHF | 820 to 960 | 48 | 42 | 36 | 30 | 24 |
| GSM 800 | 860 to 895 | 48 | 42 | 36 | 30 | 24 |
| EGSM and GSM 900 | 925 to 960 | 48 | 42 | 36 | 30 | 24 |
| GPS L1 civil | 1567 to 1583 | 34 | 28 | 22 | 16 | 10 |
| GSM 1800 (PCN) | 1803 to 1882 | 48 | 42 | 36 | 30 | 24 |
| GSM 1900 | 1850 to 1990 | 48 | 42 | 36 | 30 | 24 |
| 3G and IMT 2000 | 1900 to 1992 | 48 | 42 | 36 | 30 | 24 |
| 3G and IMT 2000 | 2010 to 2025 | 48 | 42 | 36 | 30 | 24 |
| 3G and IMT 2000 | 2108 to 2172 | 48 | 42 | 36 | 30 | 24 |
| *Bluetooth* and 802.11 | 2400 to 2500 | 48 | 42 | 36 | 30 | 24 |

# 5 Getting Started Hardware

## 5.1 PCB and Form Factor

This design is not intended to fit any particular form factor. The only goal 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. Figure 11 is a 3D rendering of the board.

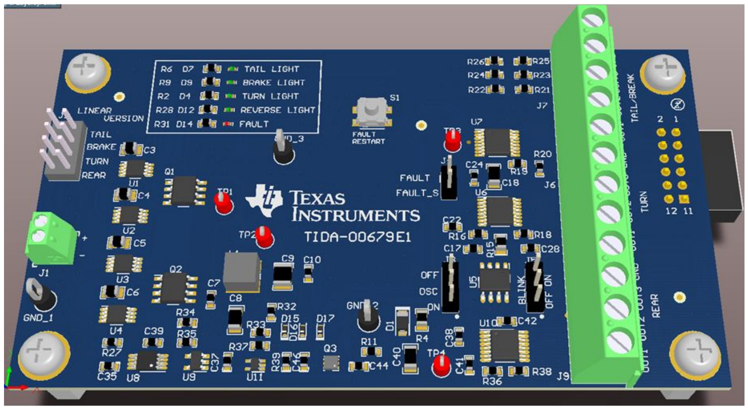



**Figure 11. 3D Rendering of the TIDA-00679 Board**

In a final-production version of this design, several techniques can reduce the size of the solution.

- Test points, headers, sockets, standoffs, and banana plugs can be removed.
- The overvoltage turnoff block can be removed if this function is not required in an application. These blocks can be removed because they do not service a direct function for the board.
- The number, size, and value of capacitors in the system can be optimized.
- Four times a reverse-battery ORing controller might not be needed in the application.

## 5.2 Circuit Design Block Description

### 5.2.1 Reverse-Battery Protection

Reverse-battery protection is required in nearly every electronic subsystem of a vehicle following OEM and ISO 16750-2 standards. The goal is to prevent reverse-biasing components that are sensitive to polarity, such as polarized capacitors and integrated circuits. Figure 12 shows reverse-battery protection with the LM74610-Q1.

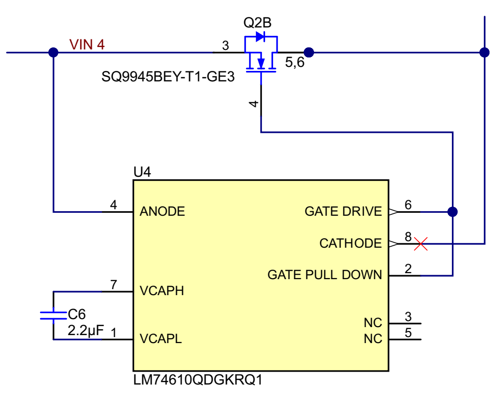



**Figure 12. Reverse-Battery Protection Using the LM74610-Q1**

Instead of using a traditional-diode rectifier for reverse-battery protection, Figure 12 uses an N-channel MOSFET driven by the LM74610-Q1 smart-diode controller. The power dissipation of the traditional-diode solution can be significant because of the 600- to 700-mV forward drop (P = I × V). Using an N-channel MOSFET results in loss because of the $R_{DS(ON)}$ of the FET, but results in greater efficiency and requires less thermal dissipation.

The LM74610-Q1 team provides recommendations and a tool that can be used to help select a FET for the application. Important considerations follow:

- Ensure that the continuous-current rating is sufficient for the application
- The $V_{GS}$ threshold should be 2.5-V maximum
- The $V_{DS}$ should be at least 0.48 V at 1 A and 125°C (in off-state of the FET)

For this design, the FET must be rated at least as high as the clamped-input voltage. A 45-V FET is acceptable, but a 60-V FET allows for additional headroom.

The hiccup behavior of the LM74610-Q1 causes the voltage to drop by approximately 0.5 V every few seconds. Picking a 2.2-µF capacitor for C9 allows for an approximate FET turnon time of 2 s.

### 5.2.2 Input Capacitors Exposed to Battery Inputs

A final consideration for the front-end protection is the input capacitor. Because of the flexion of the PCB, it is possible for a ceramic capacitor to mechanically fail short. If the capacitor mechanically fails short while it is connected directly to the battery, a hard short may occur at the battery terminals. To avoid a ceramic capacitor failing short, two ceramic capacitors are used in series – if one fails, there is another to avoid a short. Align the capacitors at 90° with respect to each other on the layout to provide a chance that a flexion in one direction may only affect the capacitor aligned in that direction. See C1 and C2 in Figure 11.

### 5.2.3 General Power Supply Design Considerations

Choose all device actives and passives that have temperature ratings that are appropriate for an automotive application (typically 40.5°C to 105°C for lighting applications).

Use X7R-dielectric material for lighting applications to ensure a minimum-capacitance variation over the full-temperature range. The voltage rating of the capacitors must be greater than the maximum-possible voltage, and two times the voltage to avoid DC-bias effects.

Low ESR ceramic capacitors may reduce ripple in this design. ICs must be qualified according to AECQ100 standards. The part numbers of TI parts that are qualified typically end with the characters Q1.

## *5.3 Input-Voltage Noise Filtering*

Figure 13 shows the input-voltage noise filter.

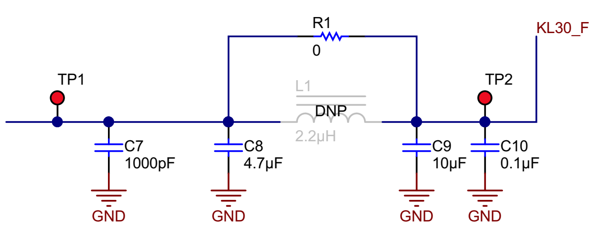



**Figure 13. Input-Voltage Noise Filter**

The noise filter is optional and can be used if the application must be tolerant of high frequency disturbances that come from the wiring harness. The filter protects the LED drivers and LEDs from malfunctioning and from destruction during pulses. Placing the low-pass π filter between the input of the module and the LED driver can attenuate noise.

A landing pad for a 0-Ω resistor to bypass inductor L1 is provided if the filter is not required for the application.

## 5.4 Three-Channel Linear LED Driver

### 5.4.1 Tail Light and Brake Light

Figure 14 shows the schematic for the tail light and the brake light.

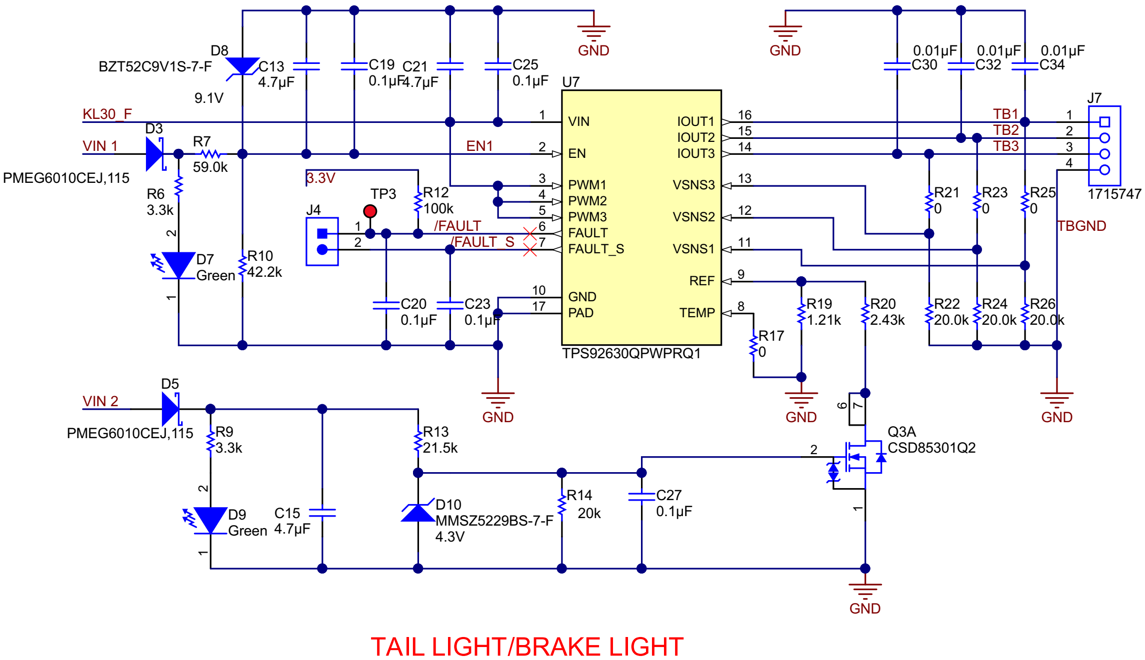





**Figure 14. TPS92630-Q1 3-Channel LED Driver**

Dim by pulse-width modulation (PWM) to achieve different brightness. With this dimming method, the LEDs are dimmed by using a PWM signal with a different duty cycle. Dimming the LEDs by using a PWM signal has switching currents as the LEDs are turned on and off, causing electromagnetic interference.

The other option is to dim linearly, which means the LEDs always operates at 100% duty cycle and the maximum current through the LEDs varies to the brightness needed. TI recommends this approach to have the application with regards to EMI as quiet as possible. The maximum current that passes through the LEDs is programmable by the sense resistor $R_{(REF)}$ (R19, R20). This design has a 100-mA current ($I_{(tail)}$) per LED string for the tail light, turn indicator, and the reverse light. See Equation 1 for the $R_{REF}$ calculation.

$$R_{REF} = \frac{V_{REF} \times K_{(I)}}{I_{tail}} = \frac{1.22\ \text{V} \times 100}{0.1\ \text{A}} \times 1.222\ \text{k}\Omega$$

Where:

- $V_{REF}$ = 1.222 V and $K_{(1)}$ = 100 (both $V_{REF}$ and $K_{(1)}$ are data sheet values). (1)

For many automobiles, the same set of LEDs illuminates both tail lights and stop lights. Thus, the LEDs must operate at two different brightness levels. The dimming level is set with a parallel resistor in REF through an external MOS (Q3A). See Equation 2.

$$R_{tail} = \left( \frac{I_{stop}}{V_{REF} \times K_{(I)}} - 1/R_{stop} \right)^{-1} = \left( \frac{0.15}{1.22\ \text{V} \times 100} - 1/1.21\,\text{k}\Omega \right)^{-1} = 2.49\ \text{k}\Omega \tag{2}$$

Use a 2.43-kΩ resistor. $R_{tail}$ = R20 in Figure 14.

VSNS1 to VSNS3 are not used in this design and are tied to OUT1 to OUT3 through 0-Ω resistors.

Because the gate of the brake-light MOSFET Q4A is directly attached to jumper J2 through the net VIN2, which is connected directly to the car-battery input voltage, the gate must be protected against the highest voltage it can conduct. In this design the load-dump voltage is 45 V.

A resistor divider (R13 and R14) in combination with a 4.3-V Zener diode is used to prevent the gate from high voltage transients. Two debounce capacitors (C15 and C27) prevent toggling. Additional reverse-battery protection is required for the gate of FET Q3A and the EN path of the device because the nets VIN 1 and VIN 2 are directly connected to the car battery. Two LEDs (green) indicate the operating mode of the tail light on (D7) or the brake light on (D9). R6 and R9 limit the current of the indicator LEDs. R7 and R10 help to divide the maximum-input voltage and help D8 and the 4.3-V Zener diode protect the EN pin from external disturbances.

The included temperature monitor reduces the LED drive current if the IC junction temperature exceeds a thermal threshold. This feature is disabled in this design by using a 0-Ω resistor (R17) to GND.

The TPS92630-Q1 device monitors fault conditions on the output and reports the status on the $\overline{\text{FAULT}}$ and FAULT_S pins. The device features single-shorted-LED detection, output short-to-ground detection, open-load detection, and thermal shutdown.

The TPS92630-Q1 device has two fault pins, $\overline{\text{FAULT}}$ and $\overline{\text{FAULT\_S}}$. $\overline{\text{FAULT\_S}}$ is a dedicated fault pin for single-LED short failure, and $\overline{\text{FAULT}}$ is for general faults (for example: short, open, and thermal shutdown). The dual pins allow maximum flexibility based on all requirements and application conditions. The device fault pins can be connected to an MCU for fault reporting. Both fault pins are open-drain transistors with a weak internal pullup. In this design, the $\overline{\text{FAULT}}$ pin is tied with a 100-kΩ resistor to the LDO 3.3-V output to have a defined state. $\overline{\text{FAULT\_S}}$ can be connected through a jumper to $\overline{\text{FAULT}}$. Both pins feature a capacitor-debounce protection (C20 and C23 [100 nF each]).Input VIN is decoupled with a 4.7-µF capacitor and a 100-nF capacitor (C21 and C26).

The outputs IOUT1 to IOUT3 are connected to a header to allow different lengths of LED strings to be attached per channel. C31, C32, and C33 are ESD capacitors for protection of the device from high-voltage transients generated by people touching the connector interface.

### 5.4.2 Reverse Light

The reverse light is set up the same as the tail light and brake light. However, the outputs are not dimmable. The REF input is only tied to GND through the 1.21-kΩ resistor and the parallel path is omitted in Figure 15. Refer to Figure 14 for a detailed description of the device dimensioning and features of the reverse light.

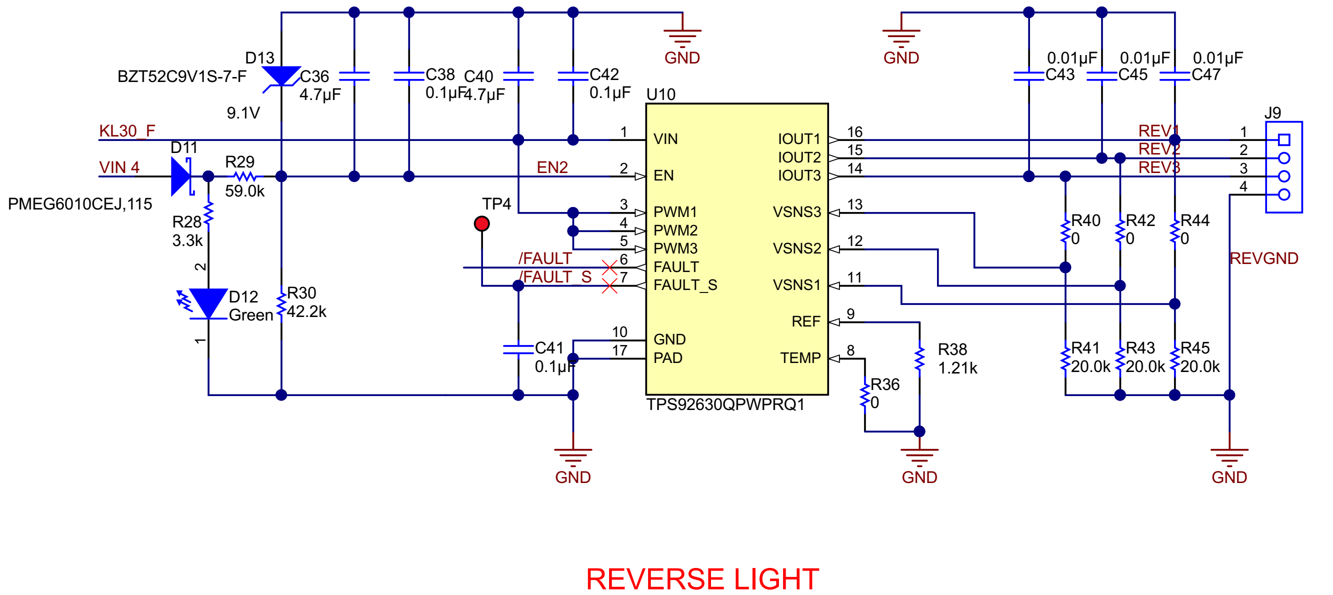





**Figure 15. TPS92630-Q1 3-Channel LED Driver**

### 5.4.3 Turn Light

In Figure 16, the PWM1 to PWM3 inputs are tied together and connected to jumper J6, which lets the user select between permanent on or the LED-blinking function. Setting jumper J5 enables and disables the TLC555-Q1 oscillation.

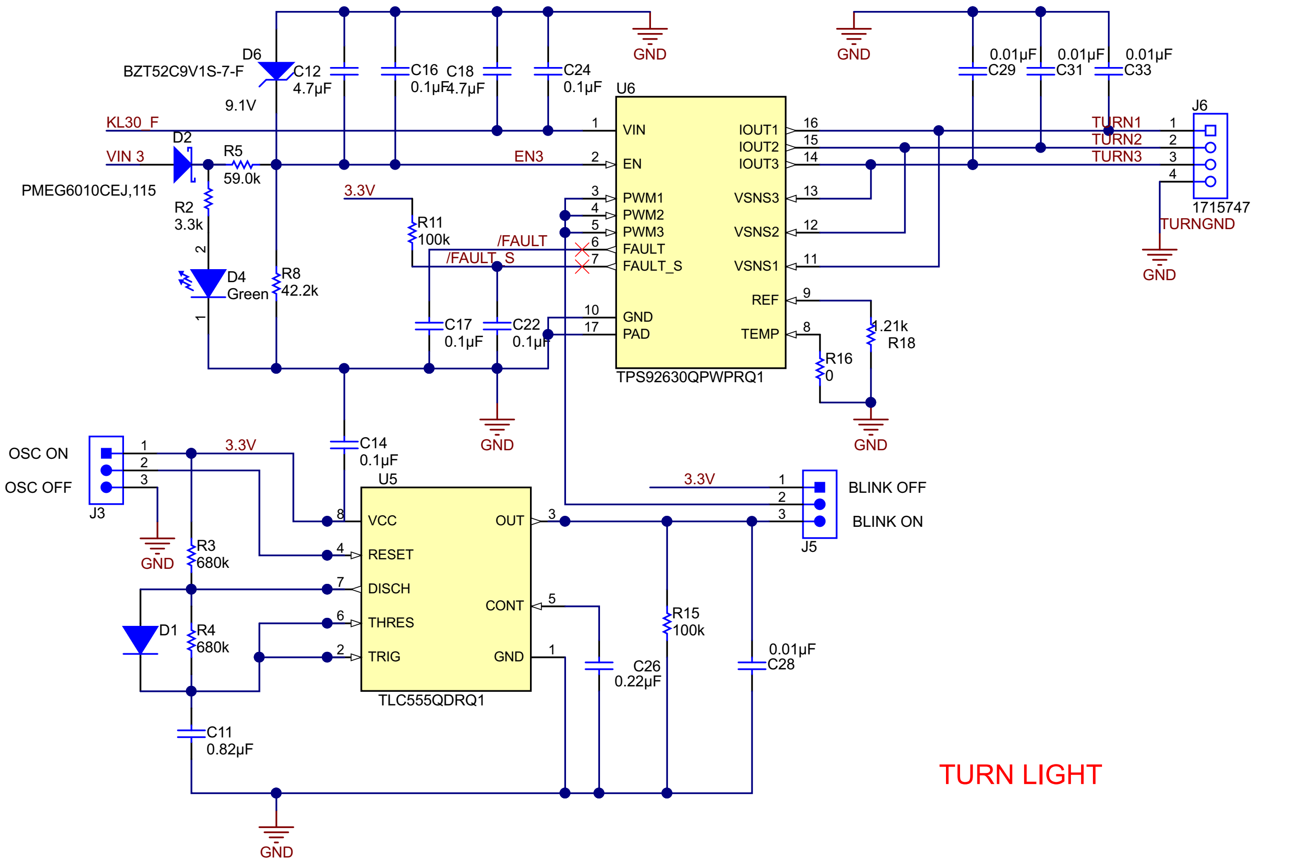





**Figure 16. TPS92630-Q1 Three-Chanel LED Driver**

In Figure 16, connecting TRIG to THRES of the TLC555-Q1 causes the timer to run as a multivibrator, generating a square-wave output voltage. Capacitor C11 charges through R3 and R4 to the threshold-voltage level (approximately 0.67 $V_{DD}$), then discharges through R4 to the value of the trigger-voltage level (approximately 0.33 $V_{DD}$). The output is high during the charging cycle ($t_{C(H)}$) and low during the discharge cycle ($t_{C(L)}$). The values of R3, R4, and C11 control the duty cycle as shown in Equation 3 and Equation 4.

$$t_{C(H)} \approx C_T \left(R13 + R14\right) \times \text{ln2} \approx 0.82\ \mu\text{F} \times \left(680\ \text{k}\Omega + 680\ \text{k}\Omega\right) \times \text{ln2} \approx 0.77\ \text{s} \tag{3}$$

$$t_{C(L)} \approx C_T \times R14 \times \text{Ln2} \approx 0.82\ \mu\text{F} \times 680\ \text{k}\Omega \times \text{Ln2} \approx 0.4\ \text{s} \tag{4}$$

In the previous two equations, use R3 and R4 = 680 kΩ. To get a symmetric duty cycle, diode D9 is paralleled to R23. This approach helps to eliminate one resistor during the charging phase. The capacitors at CONT, C25, and C28 are used for debouncing reasons.

### 5.4.4 Voltage Supervision

Figure 17 shows a supporting block. The circuitry in this block turns off the LED drivers if the battery voltage exceeds 17 V and it will signal open and short failures by turning on the red LED (D15) under normal- and high-voltage conditions.

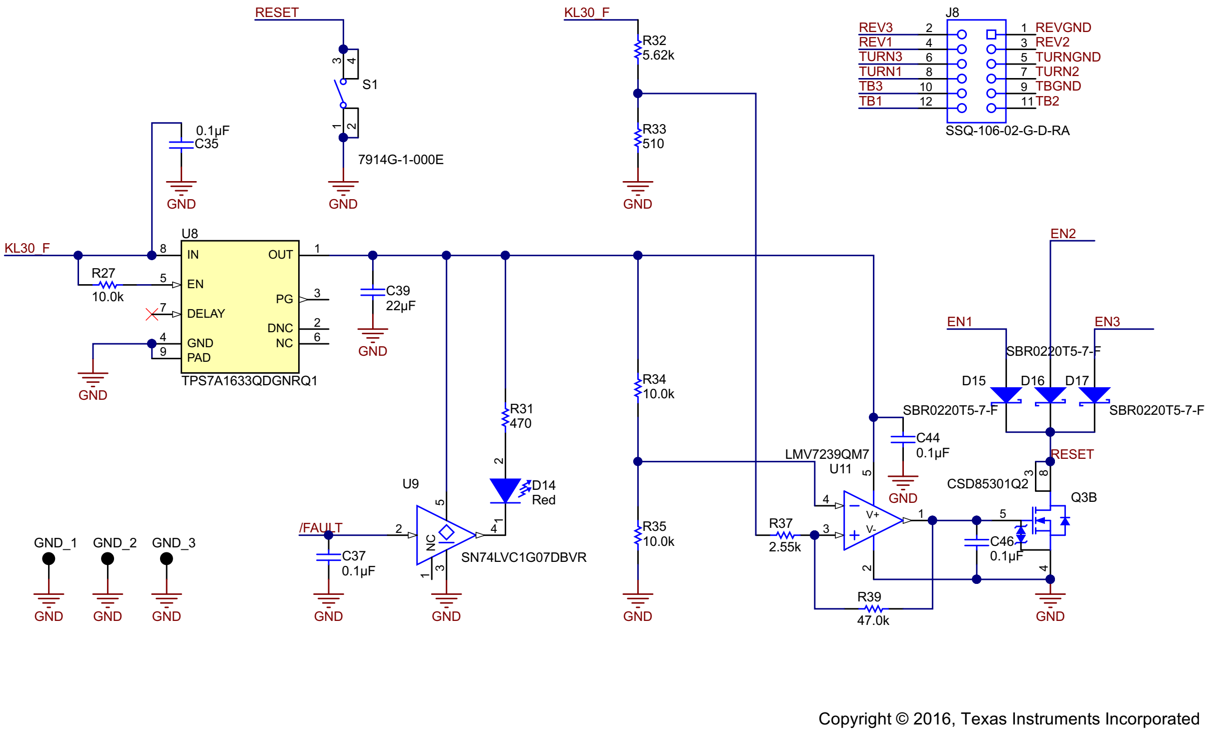



**Figure 17. Voltage Supervision**

Two 3.3-V linear regulators (LDO and U8) supply the little-logic buffer SN74LVC1G07 (U10). If the $\overline{\text{FAULT}}$ signal from the LED drivers is pulled low, the output of the SN74 is also pulled low and enables the red LED. R31 limits the current through the LED. C37 is a debounce capacitor. C39 at the LDO is used for stability, and a 22-µF capacitor is used according to the data sheet recommendation. EN is pulled high with a 10-k resistor so it remains on. For the overvoltage turnoff, an op amp noninverting circuitry is used. This circuitry activates a FET (Q3B) that pulls the cathode of the three diodes (D15, D16, D17) low, disabling the three LED drivers through the signals EN1, EN2, and EN3.

To set the threshold for the >17-V turnoff, R37 and R38 provide a 1.65-V reverence (50% of the 3.3-V LDO) to the negative input of the op amp. If the voltage at the signal KL30_F exceeds 17 V, the resistor dividers (R35 and R36) are dimensioned so the output of the comparator goes high and activates the downstream FET. C46 is used as a debounce capacitor, and C44 is the decoupling capacitor for the op amp. R37 and R39 are set according to the data sheet recommendation.

## 6 Getting Started Hardware

Connect the desired number of LEDs per string at the output screw terminals or at the receptacle to get started with the TIDA-00679 board. The ouputs are grouped in four terminals according to the type of light. Group 1 is labeled with TAIL/BRAKE for the tail light and brake light function. Group 2 is labeled TURN for the turn light. The third group is labeled REAR, and is for the reverse light. All outputs are labeled OUT1, OUT2, OUT3, and GND per group. One string of LEDs can be connected for every output. The maximum output voltage the board supports is approximately 16.5 V. Nine strings of LEDs up to this voltage can be connected for all terminals. As detailed in Section 3.1.1, the output current is set to 100 mA nominal. The appropriate jumper setting is 150 mA for the brake light. The turn and rear light is 100 mA and cannot be dimmed.

Loads can be connected to each output through the screw terminals along the bottom of the board, labeled in Figure 18.

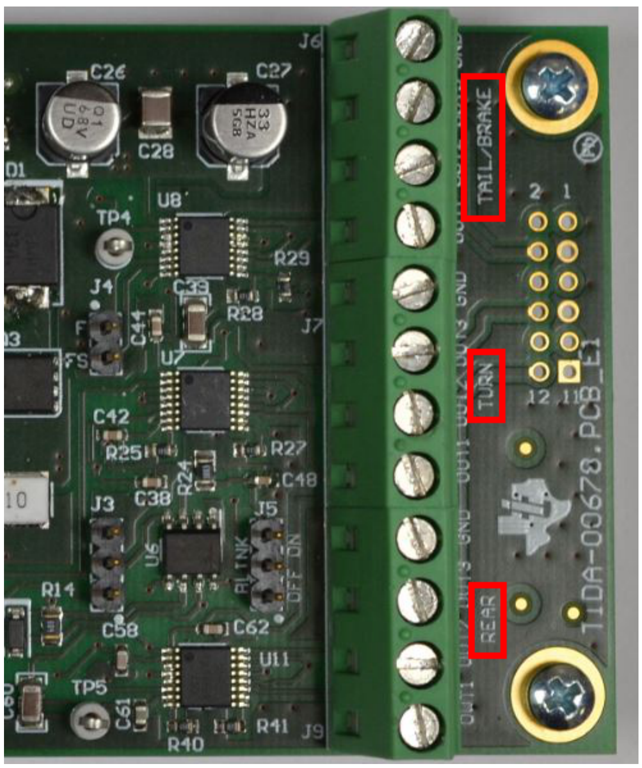



**Figure 18. Screw Terminals for LED-String Outputs (100 mA and 150 mA, Maximum of 9 Strings, Maximum Output Voltage of 16.5 V)**

Set the header on jumper J2 in Figure 19 for the desired type of light (tail, brake, turn, or reverse light).


**Figure 19. Jumper J2 for Setting the Type of Light**

To enable an active turn light (blinking), set jumpers J3 and J5 as shown in Figure 20.

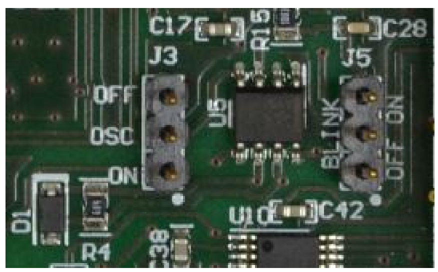



**Figure 20. Turn-Indicator Setting**

Connect the 2-port screw terminal on the left side of the board. The screw terminal is labeled VIN (+) and (–) to indicate the proper polarity of the supply. Connect a power supply capable of at least 12 V and 2 A to the leads, then turn it on.

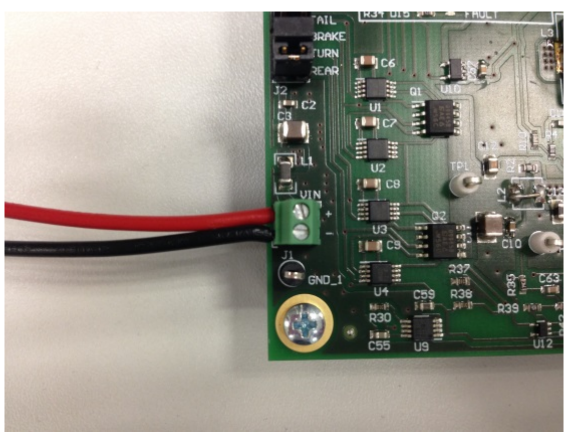


**Figure 21. Board Supply-Input Terminal**

Figure 22 shows the LEDs that indicate on lights and failures.

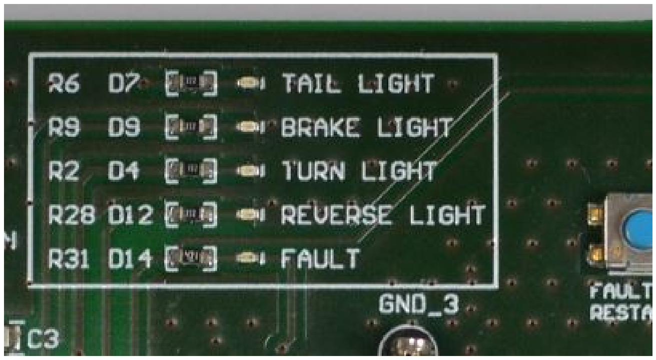



**Figure 22. LEDs Indicating Failures and On Lights**

A 0-Ω resistor (R2) is available on the board to bridge the input filter if desired. To disable the overvoltage-turnoff function, remove resistor R32 (see Figure 23).


**Figure 23. Resistor R32**

# 7 Test Setup

Figure 24, Figure 25, Figure 26, and Figure 27 show how to set up for various tests.

## 7.1 Load-Transient Test Setup

Figure 24 shows the test setup for load dump, cold crank, jump start, and reverse battery.

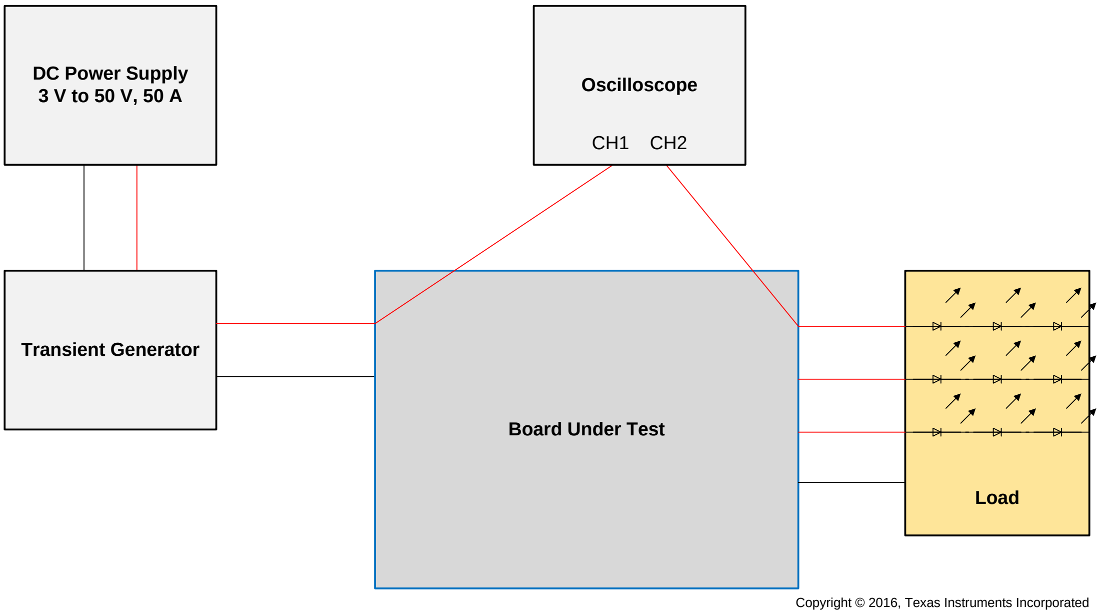



**Figure 24. Test Setup for Load Dump, Cold Crank, Jump Start, and Reverse Battery**

The NSG is used for transient generation. Users need the Teseq AutoStar software to work with the NSG 5500. The software has predefined pulses that the user can adjust to meet specific requirements. See Figure 25.

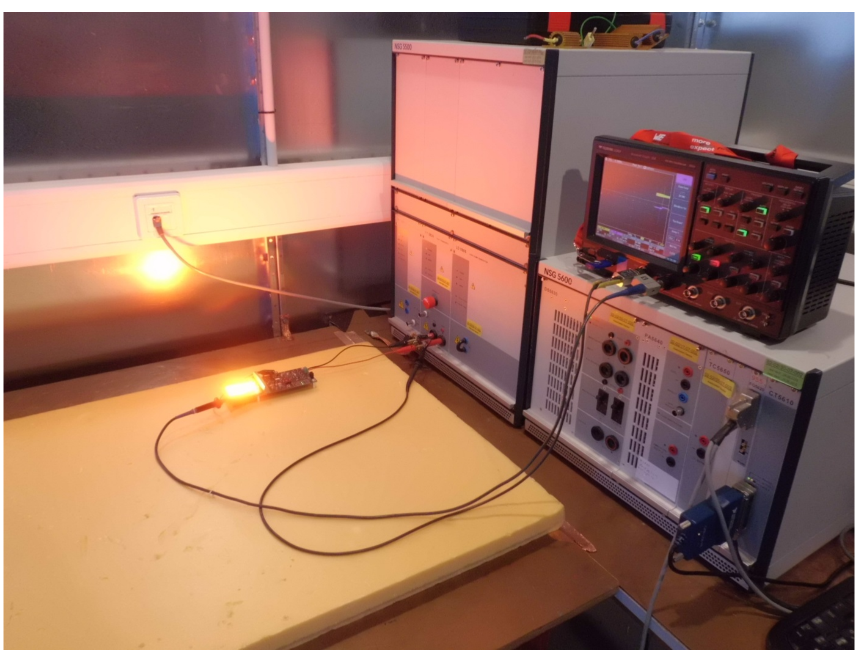


**Figure 25. Setup for Transient Tests With LED Board and NSG 5500 Transient Generator**

### 7.2 Thermal Image-Test Setup

The diagram in Figure 26 shows the setup to measure thermal behavior.

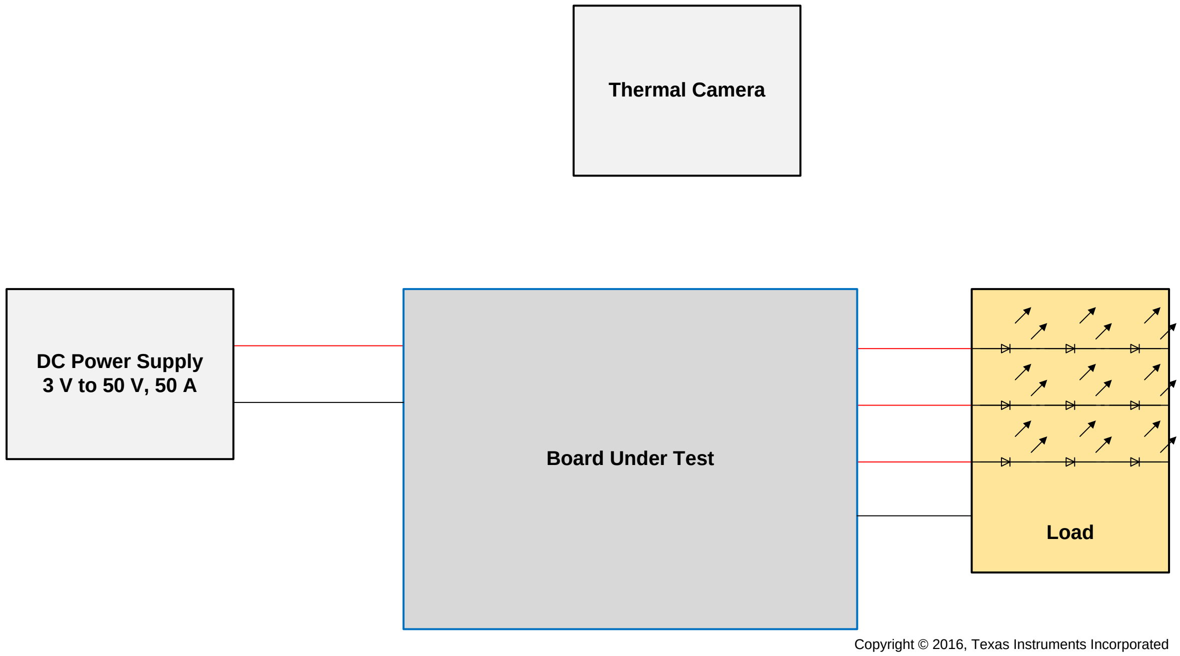



**Figure 26. Setup to Measure Thermal Behavior of the Board**

### 7.3 Efficiency-Measurement Setup

The diagram in Figure 27 shows how to set up an efficiency test.

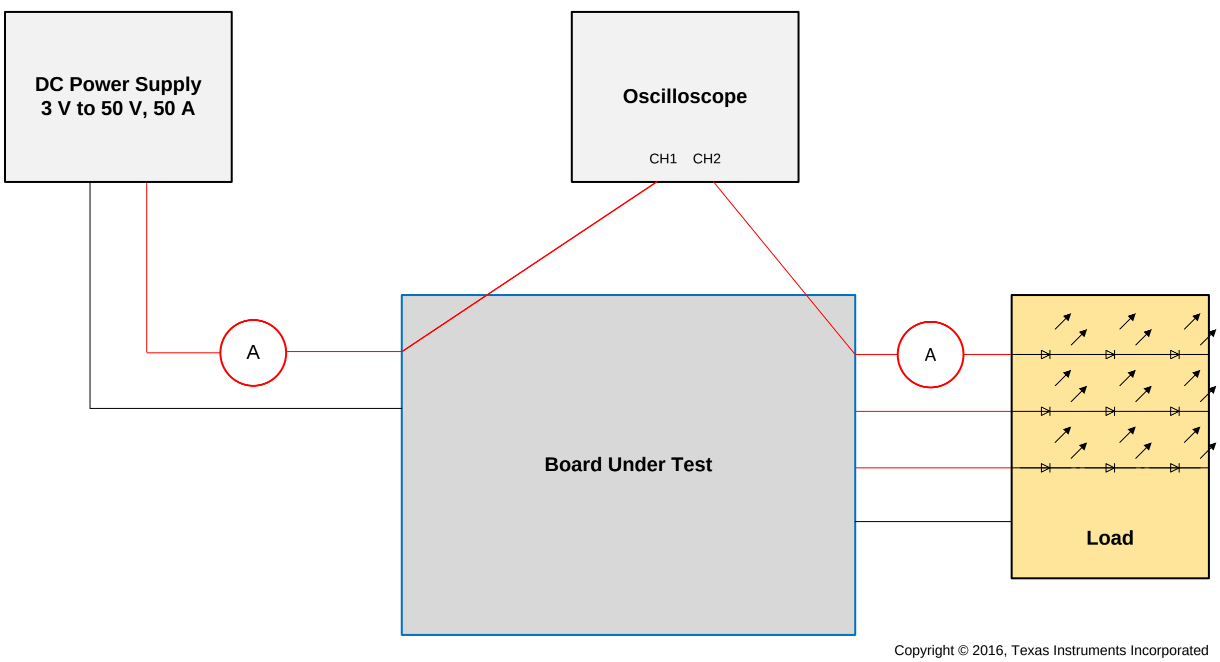



**Figure 27. Efficiency-Test Setup**

# 8 Test Data

## 8.1 Thermal Images

The following subsections show data from Section 7.

Figure 28 and Figure 29 show the temperature rise of the different components at room temperature.


**Figure 28. TPS92630-Q1 Linear LED Driver-Temperature at Three Strings of 100-mA LEDs**

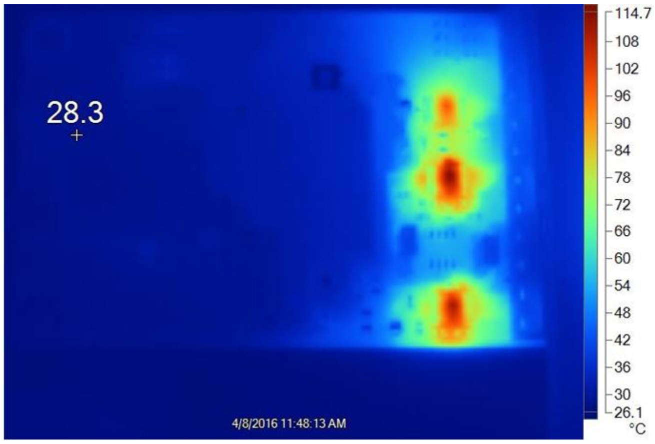



**Figure 29. TPS40210 Smart-Reverse Battery Diode Temperature at 12 V Input Voltage**

## 8.2 Efficiency Testing

Figure 30 shows the results of the efficiency test on the system. The $V_{IN}$ that is given is what is applied to the board inputs, not the voltage at the input of the linear LED driver. This implies that this is a measure of the total-system efficiency taking all losses into account, and not simply that of the TPS92630-Q1 LED driver.

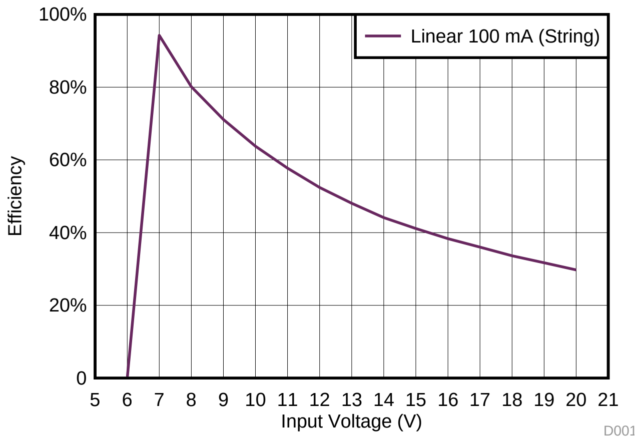



**Figure 30. Efficiency Versus Input Voltage at $I_{LED}$ = 100 mA per String**

## 8.3 Electrical-Transient Testing

Four electrical transient tests with standardized pulses were performed to show the behavior of the LED driver-buck combination. Pulses from ISO 7637-2:2004 Pulse 4, 5a (cold crank and load dump), jump start, and reverse battery were used. The test voltage is 13.5 V.

The LED board also has an overvoltage-turnoff circuitry that can turn off the LED driver once the input voltage exceeds 17 V, and it turns on if the voltage is lower than 17 V.

All tests were conducted twice: once without high-voltage turnoff and once with high-voltage turnoff.

### 8.3.1 Load Dump

Figure 31 shows the load-dump test.

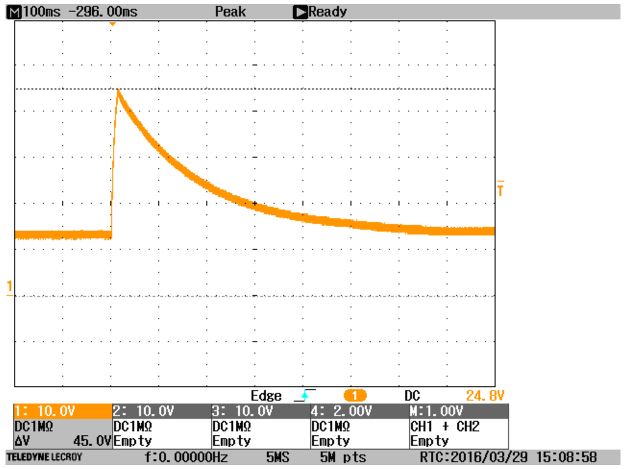


**Figure 31. ISO 7637-2:2004 Pulse 4 Load Dump**

The pulse was verified open circuit. The following parameters were used:

- $V_{min}$ = 45 V
- $R_{source}$ = 2 Ω
- $T_{rise}$ = 10 ms
- $T_{duration}$ = 400 ms

The circuit was subjected to the pulse, and the disturbance to the output of the TPS92630-Q1 was measured, shown in Figure 32 and Figure 33. The orange line is the load dump and the pink line is the output.

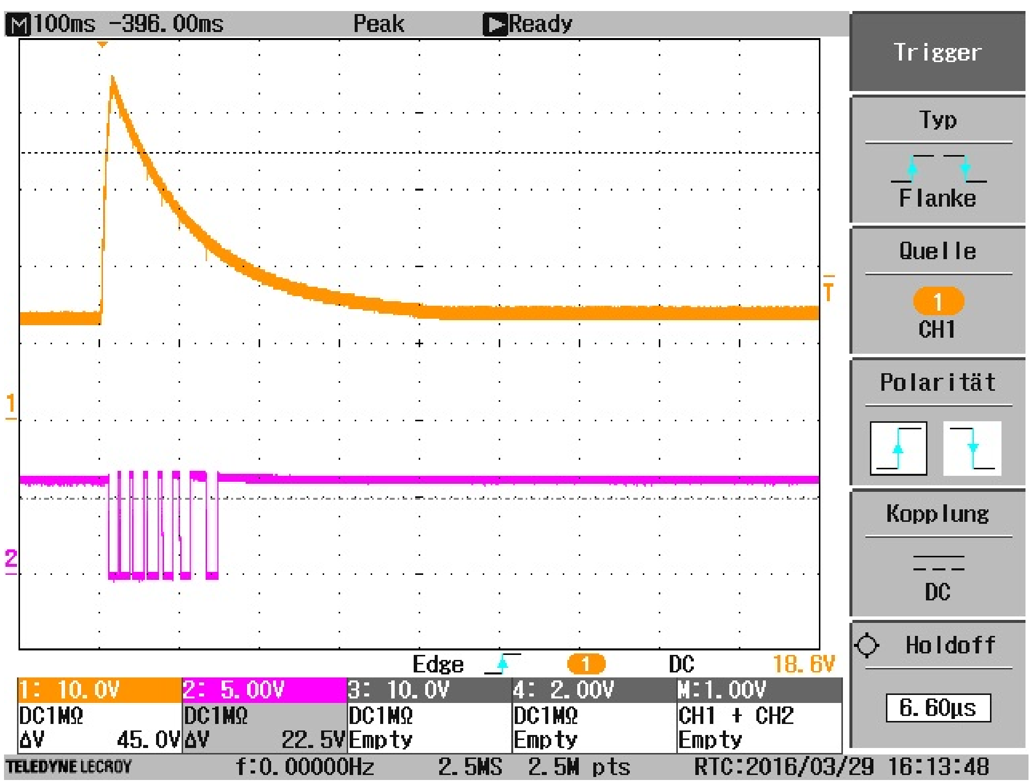



**Figure 32. Load Dump and Output: Thermal Toggling and No Complete Turnoff**

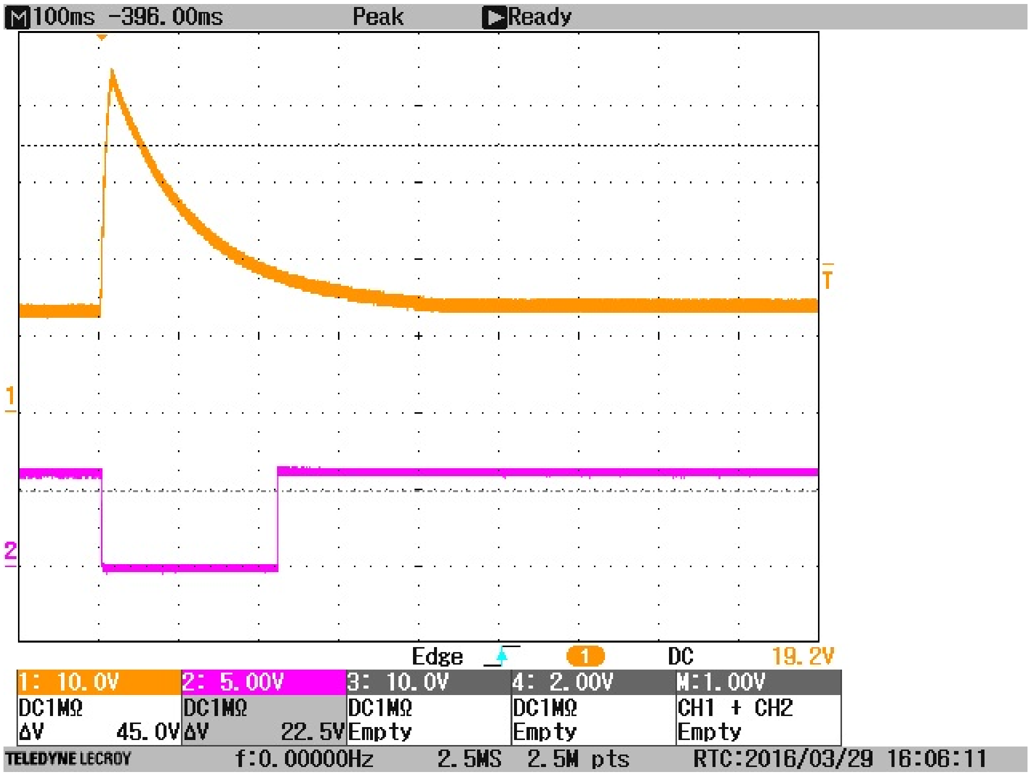



**Figure 33. Load Dump and Output: Turned Off at > 17 V then Turned On**

### 8.3.2 Reverse Battery

Reference the brown trace in Figure 34 on reversing the input voltage. The blue trace decays to 0 V and does not harm any device. The LM74610-Q1 disconnects the circuit from the input within a few µs.

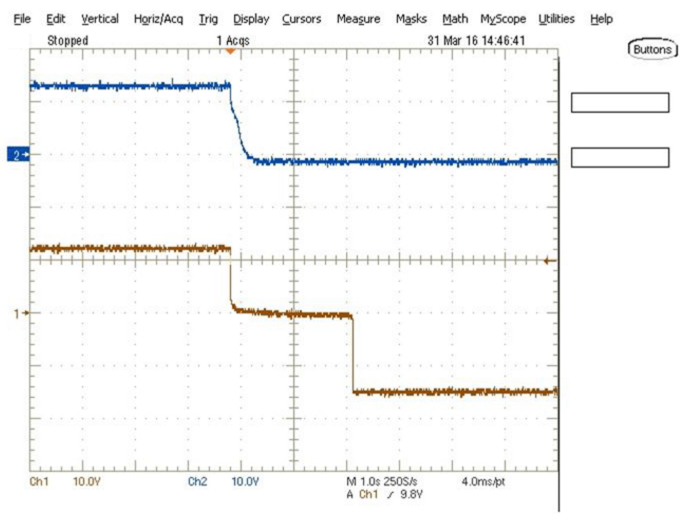



**Figure 34. Reversing the Voltage to 13.5 V**

The brown trace is the voltage at the board input ($V_{IN}$), and the blue trace is the voltage at the LED driver output (OUT1).

### 8.3.3 Double Battery and Jump Start

Figure 35 shows the jump-start test with the output turnoff > 17 V feature enabled. The input voltage of the device rose from 13.5 to 26 V in 60 seconds (orange). The pink line is the output voltage on OUT1. LEDs continue operating during this condition.

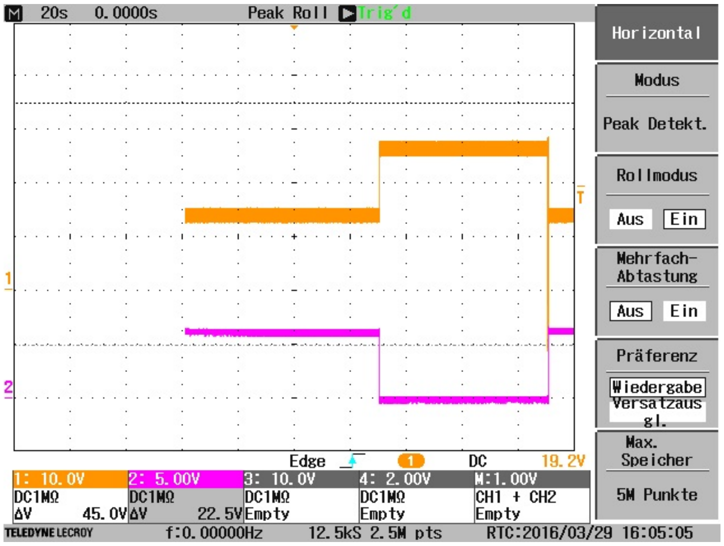



**Figure 35. Jump-Start Condition**

The circuit was tested to the pulse and the disturbance to the output of the TPS92630-Q1 was measured with the output turnoff > 17 V feature disabled (see Figure 36).

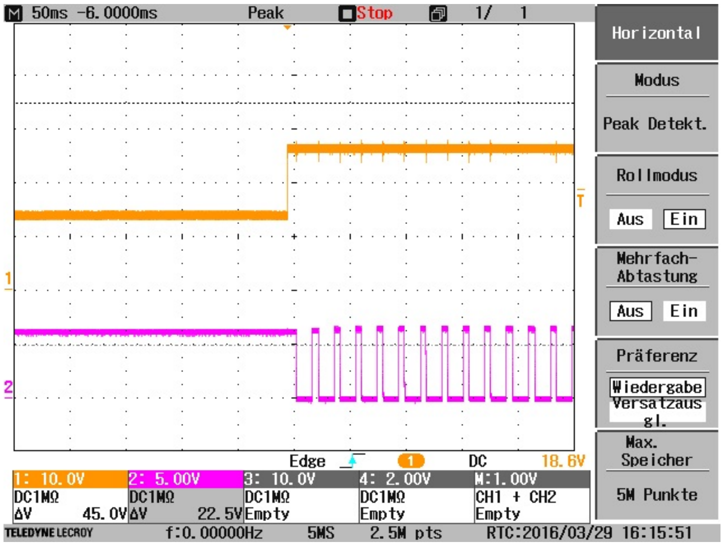



**Figure 36. Jump Start Without High Voltage Turnoff**

### 8.3.4 Cold-Crank Test

Testing the design for operation during a severe cold-crank pulse was an objective of this design. Figure 37 shows the parameters used for this test (only the *Severe* pulse was tested).

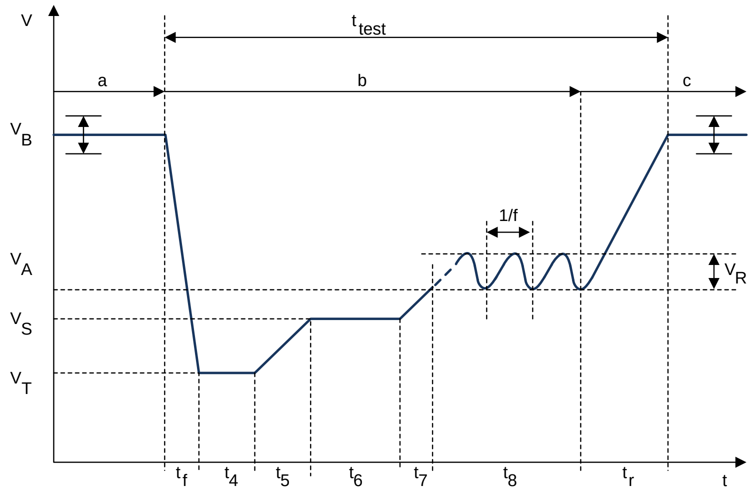



**Figure 37. Cold-Crank Wave Shape**

The lowest voltage ($V_T$) used in Figure 38 is 5 V. In Figure 38, the output (pink) briefly goes to 0 V at the end of the voltage drop (orange); the LEDs will repeatedly turn off during the voltage dip.

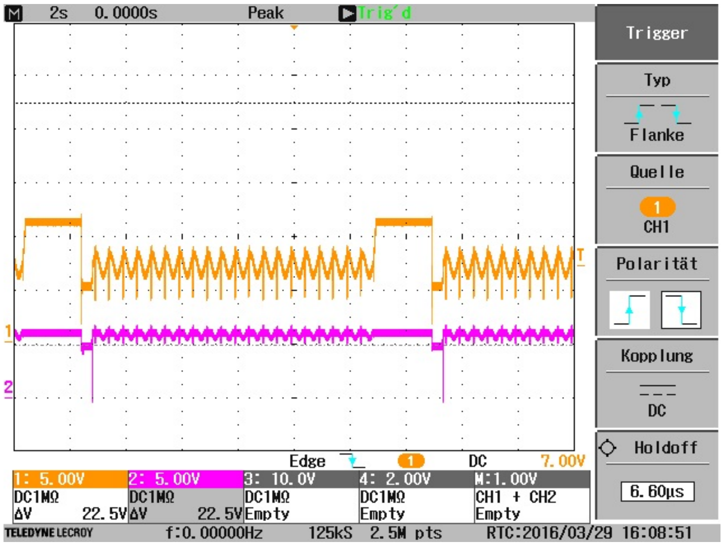



**Figure 38. Cold-Crank Test**

### 8.4 CISPR 25-Emissions Testing

CISPR 25-EMI testing was completed at a third-party facility with compliant ALSE chambers used for emissions testing. Both Conducted and Radiated emissions tests were completed. Background on the standard and the test setup can be found in Section 4.3. When viewing the results, the red lines are Class 5 limits for average emissions, and the blue lines are the peak-emission limits. A table of measurements is available upon request. This report only shows the graphs.

#### 8.4.1 Conducted Emissions

The conducted-emissions setup is shown in Figure 39 (power cable not attached). The LISNs are the gray boxes on the left side, the car battery is behind them, and the DUT is on the insulating material to the right. To test at 13.5 V, a variable voltage supply was fed through the bulkhead from outside of the chamber.

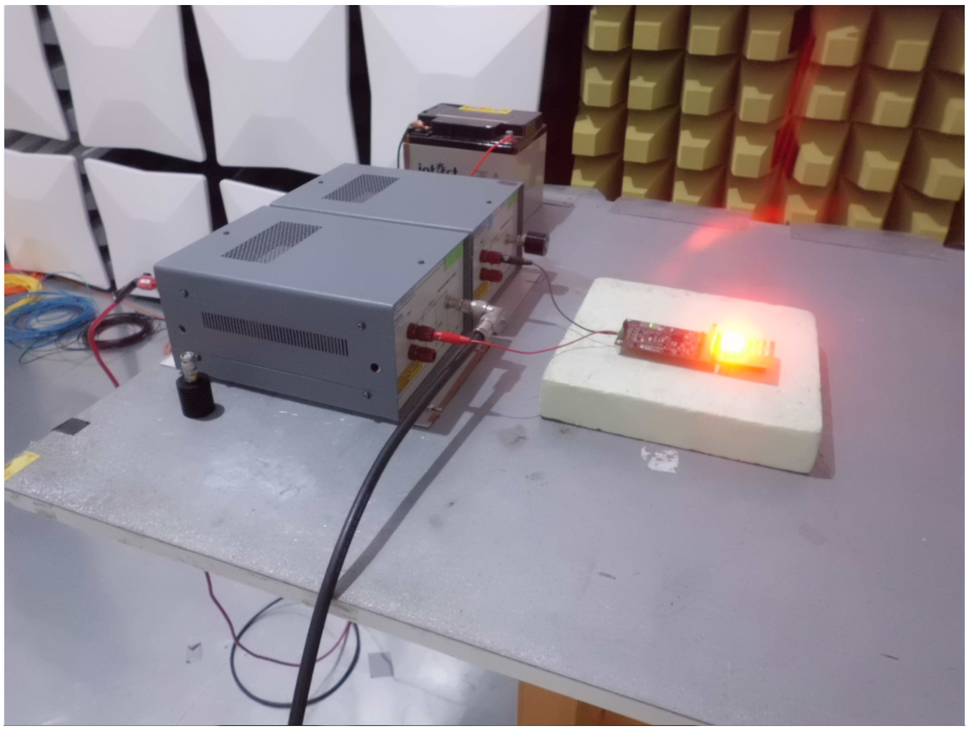


**Figure 39. Conducted-Emissions Setup**

The results are taken on both the return (ground) and line (hot) side through their respective LISNs. The test was conducted at 13.5 V (with the car battery). A load-LED board was connected during operation. Before testing, the noise floor was measured by conducting an ambient measurement with the DUT disconnected. The measurement technique changes above 30 MHz, resulting in the raise of the noise floor, shown in Figure 40 and Figure 41.

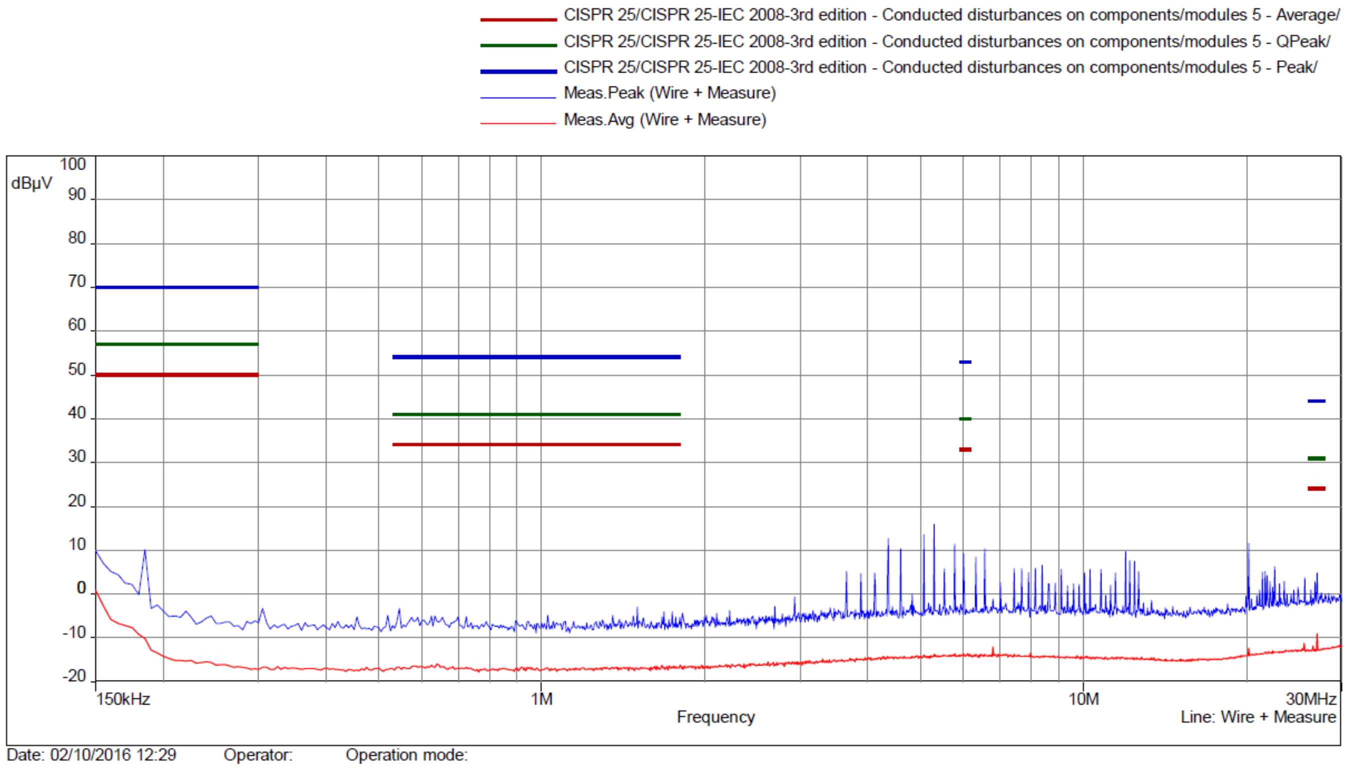



**Figure 40. Ambient-Noise Level: Line Side 150 kHz to 30 MHz**

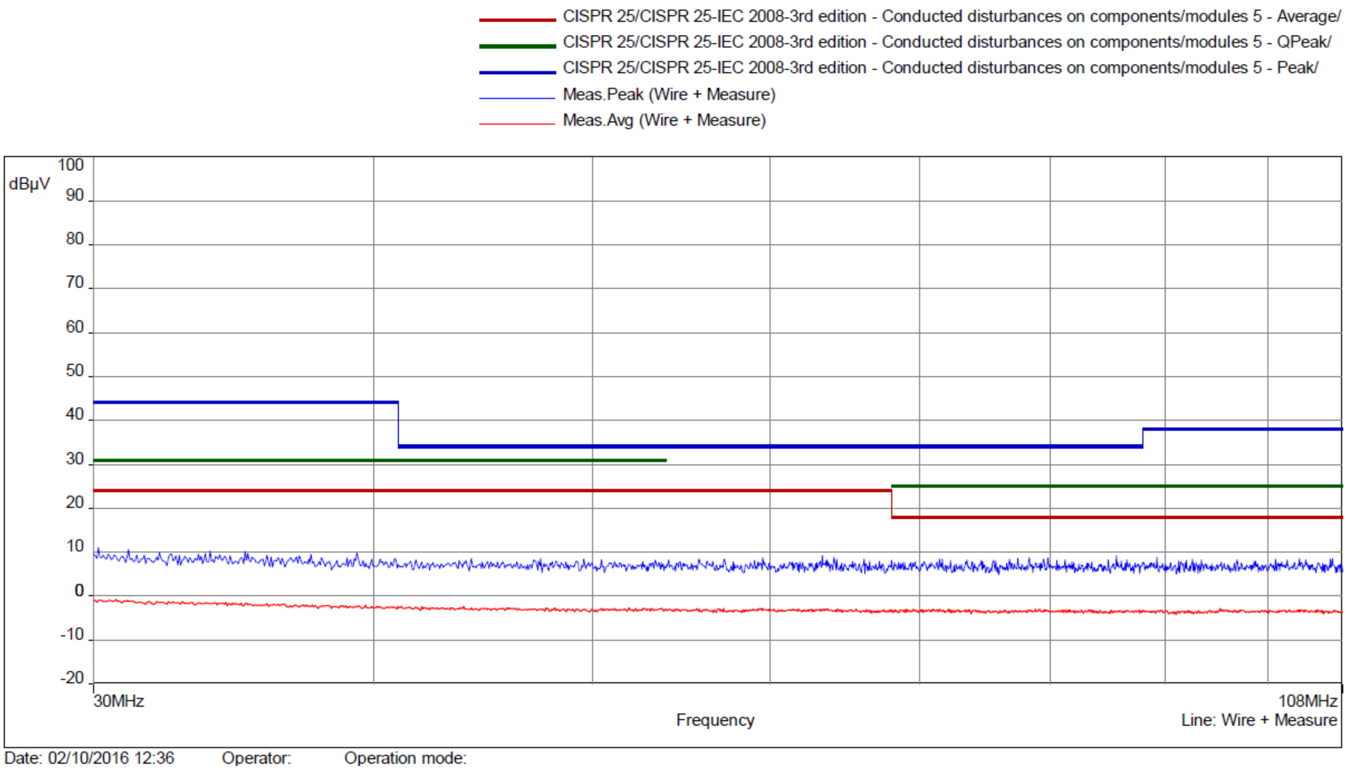



**Figure 41. Ambient-Noise Level 2: Line Side 30 MHz to 108 MHz**

The remainder of the results are shown in Figure 42 and Figure 43 at $V_{IN}$ = 13.5 V. Only the graphs from the line side are shown because the graphs from the return (GND) side are identical.

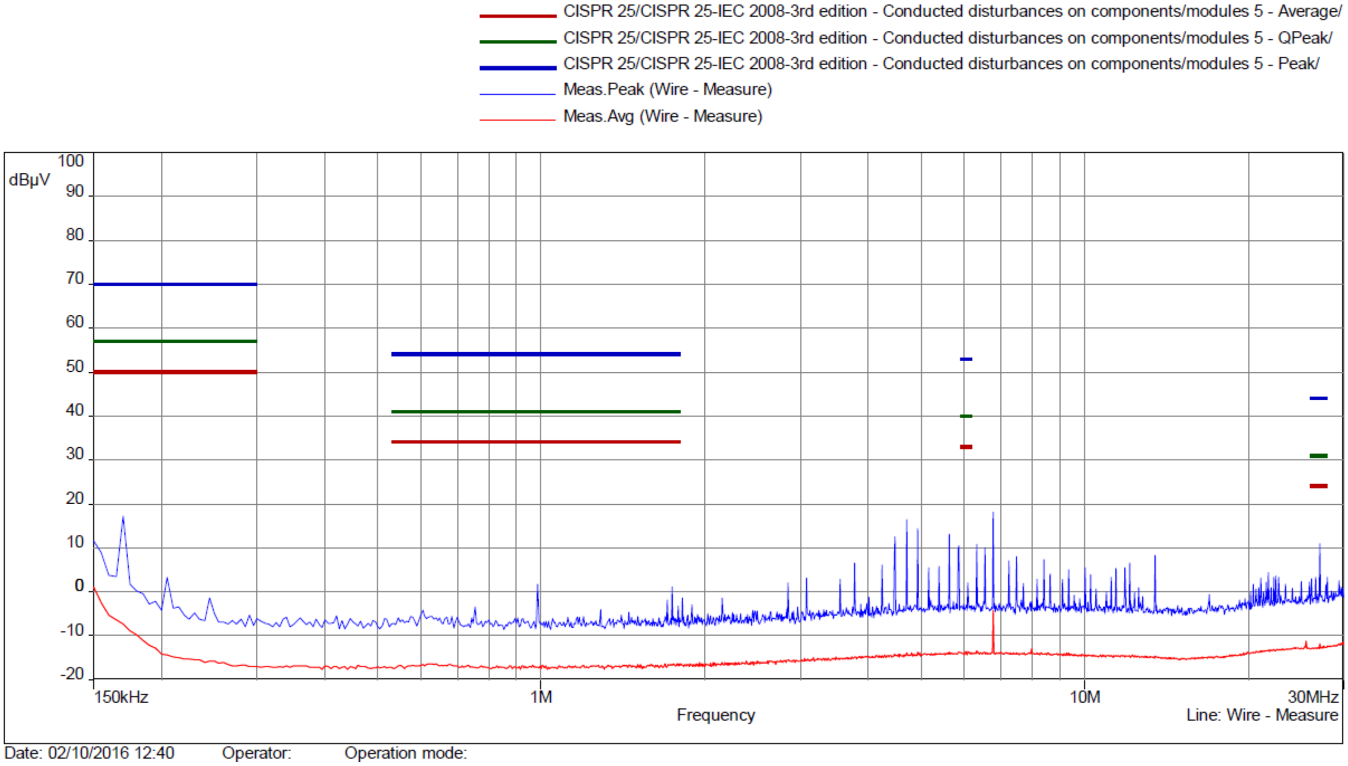



**Figure 42. Conducted Emissions: Line Side 150 kHz to 30 MHz**

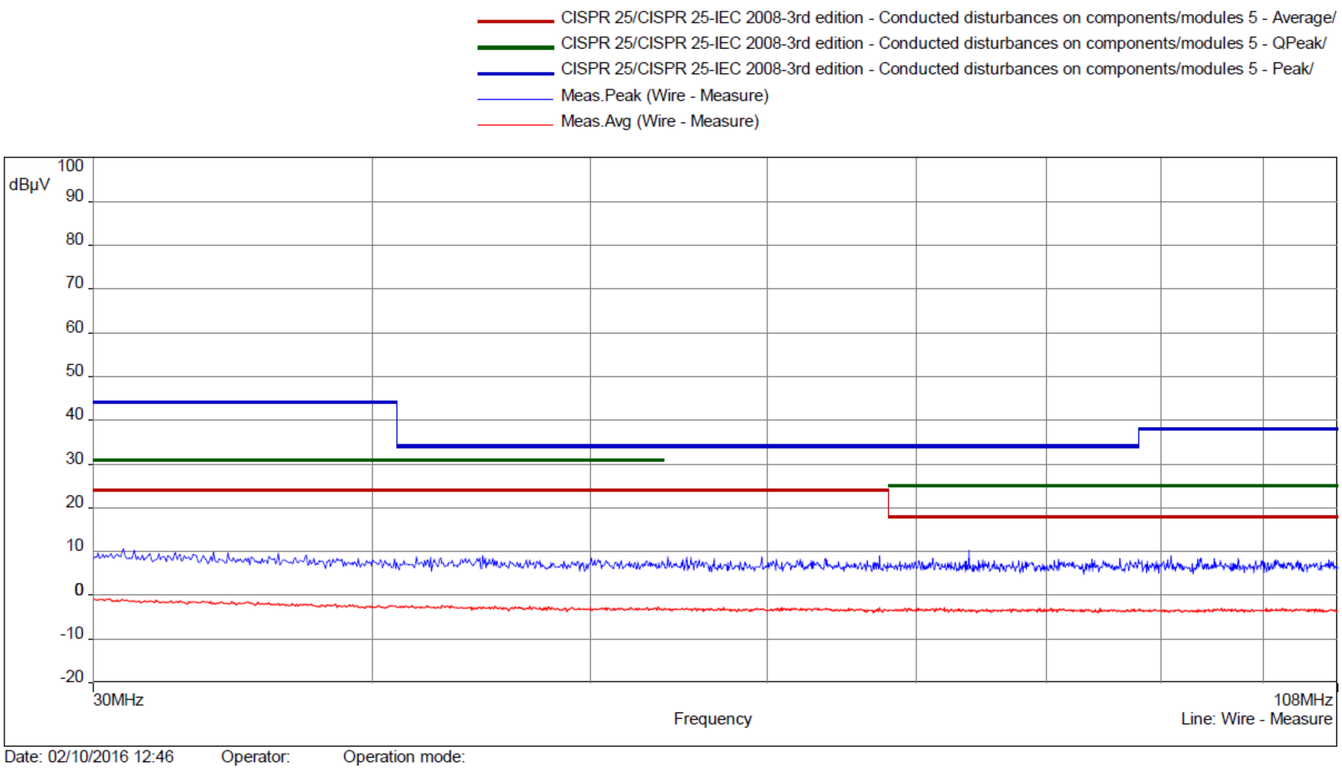



**Figure 43. Conducted Emissions 2: Line Side 30 MHz to 108 MHz**

In Figure 42, the line and return side Peak and Average results are below the Class 5 limits for CISPR 25 conducted emissions.

### 8.4.2 Radiated Emissions

The radiated emissions setup is shown in Figure 44 and Figure 45. The LISNs are the gray boxes on the left side, the car battery is behind them, and the DUT is sitting on the insulating material to the right. To test at 13.5 V, a variable voltage supply was fed through the bulkhead from outside of the chamber. Unlike conducted emissions, the measurements must be divided into different sections, each section tested with a different type of antenna appropriate for that band.

Due to the limitations of the testing facility, the test was only to 1 GHz (a low enough noise floor could not be achieved above this level). There is some ambiguity in the CISPR25 requirement. It is unclear whether the DUT should be grounded to the test-ground plane. The DUT should be connected only if it would be connected in the car. Because the design is not a complete module and is somewhat generic, this connection option was available. This connection will often improve results by several dBµV.

Figure 44 and Figure 45 are images of the test setup for Radiated Emissions. A logarithmic antenna was used to test the lower frequencies.

**Figure 44. Radiated Emissions Setup With a Logarithmic Antenna: 30 MHz to 2.5 GHz**

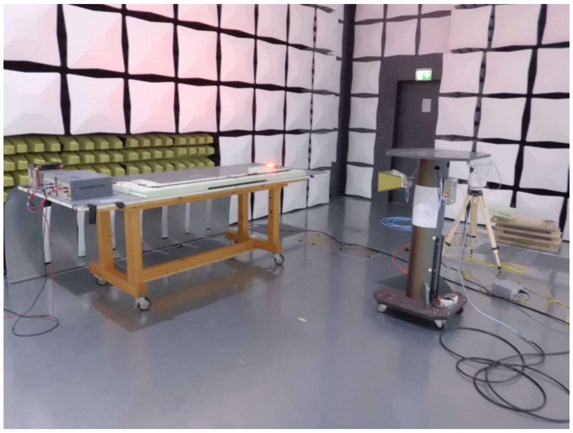


**Figure 45. Radiated Emissions Setup With a Horn Antenna: 1.447 GHz to 1 GHz**

Figure 46 and Figure 47 show the results when testing at 13.5 V.

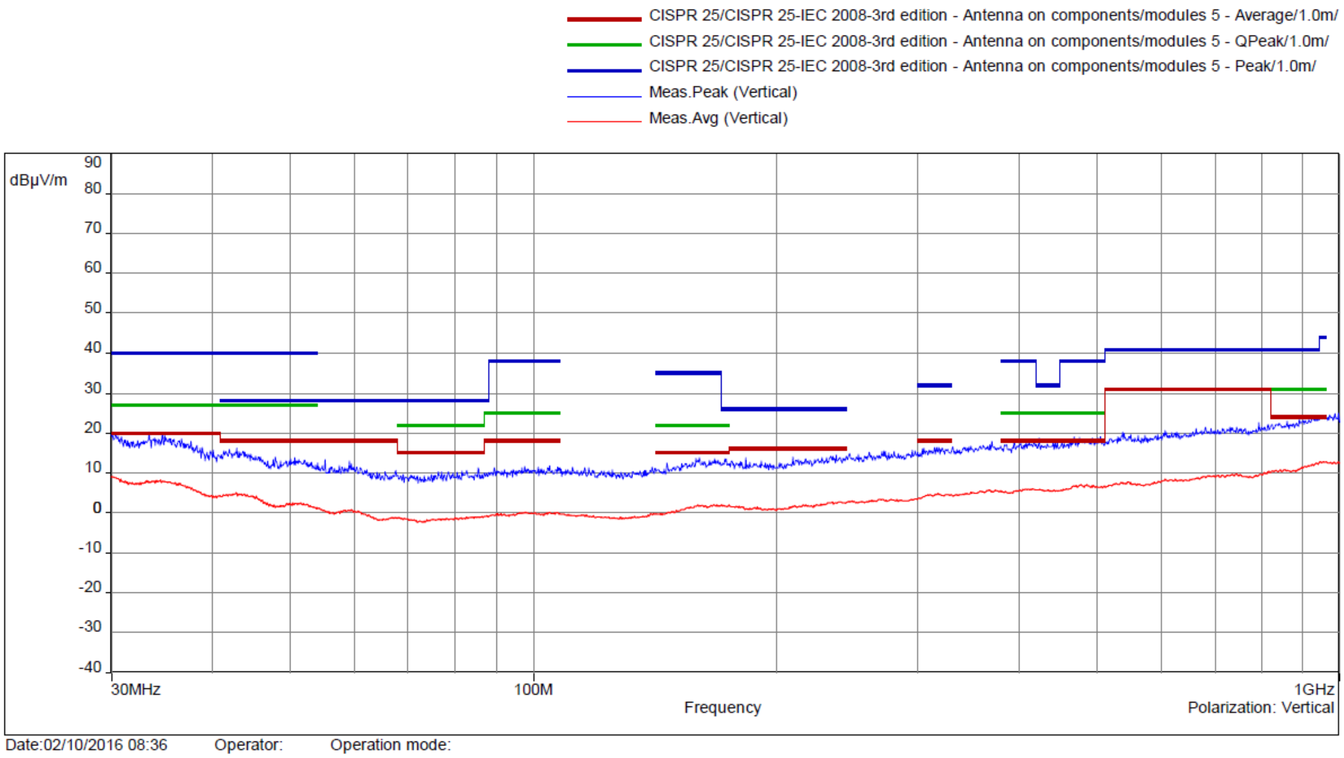



**Figure 46. Radiated Emissions: Line Side 30 MHz to 1 GHz**

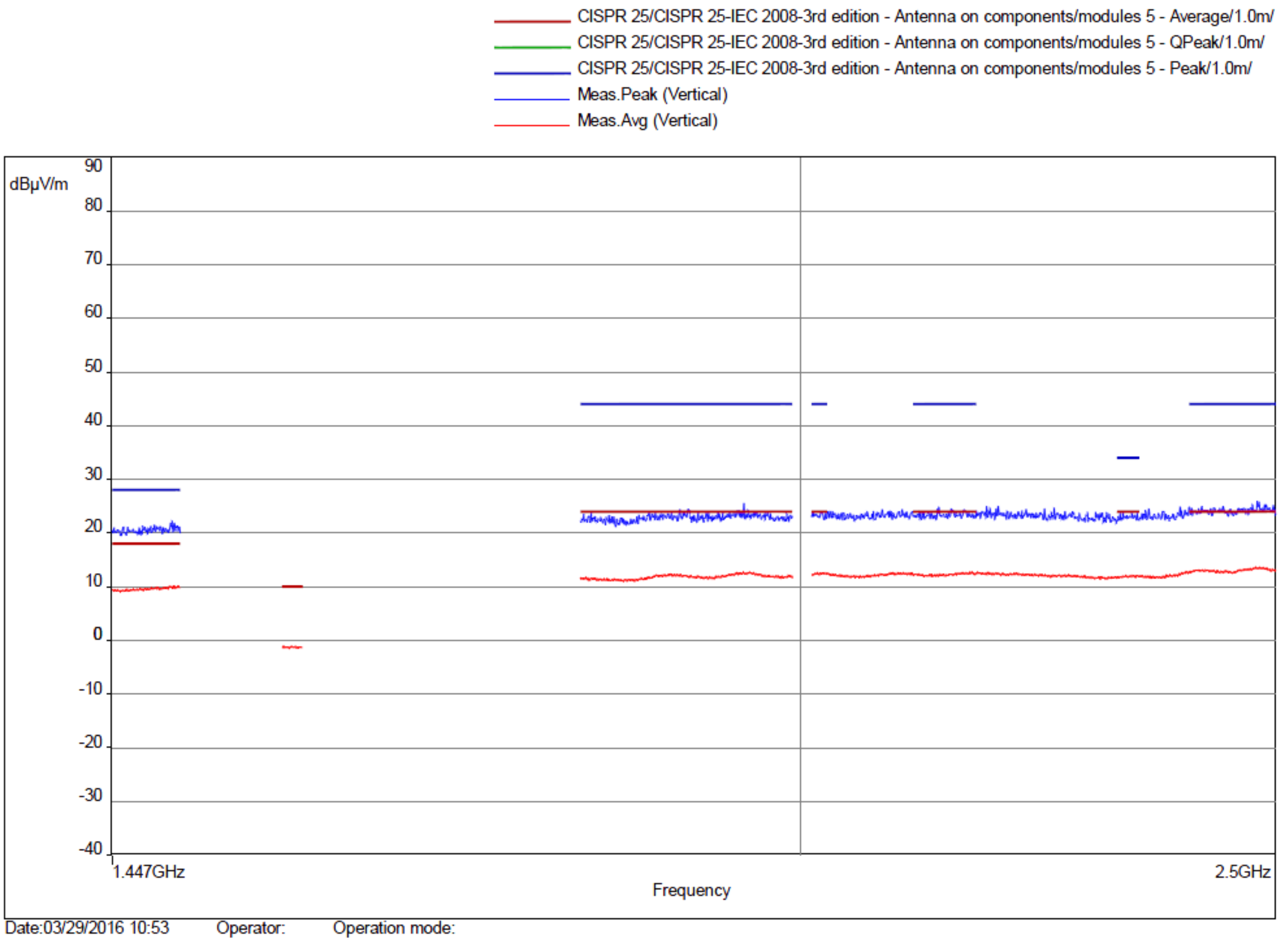



**Figure 47. Radiated Emissions: Line Side 1.44 GHz to 2.5 GHz with Horizontally-Oriented Antenna**

The Peak and Average results (see Figure 46 and Figure 47) are CISPR 25 compliant for 12-V operation.

### 8.4.3 Summary of Results

Table 7 shows the summarized results of both the Conducted and Radiated portions of the tests across different operating points and test conditions.

**Table 7. Summary of Results**

| Conducted Emissions | Conducted Emissions | Class |
|---|---|---|
| 150 kHz to 30 MHz | Peak | Class 5 |
| | Average | Class 5 |
| 30 MHz to 108 MHz | Peak | Class 5 |
| | Average | Class 5 |
| **Radiated emissions** | | |
| 30 MHz to 1 GHz | Peak | Class 5 |
| | Average | Class 5 |
| 1 GHz to 2.5 MHz | Peak | Class 5 |
| | Average | Class 5 |

# 9 Design Files

## 9.1 Schematics

To download the schematics, see the design files at TIDA-00679

## 9.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-00679.

## 9.3 PCB Layout Recommendations

### 9.3.1 TPS92630-Q1 LED Driver

Figure 48 shows the thermal vias under the LED driver.

To download the layer plots, see the design files at TIDA-00679.

To prevent thermal shutdown of the TPS92630-Q1, $T_J$ must be less than 150°C. If the input voltage is high, the power dissipation might be large. The devices are currently available in the TSSOP-EP package, which has good thermal impedance. However, the PCB layout is very important. A good PCB design can optimize heat transfer, which is 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 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.

All thermal vias should be plated shut or plugged and capped on both sides of the board to prevent solder voids. To ensure reliability and performance, the solder coverage should be at least 85 percent.

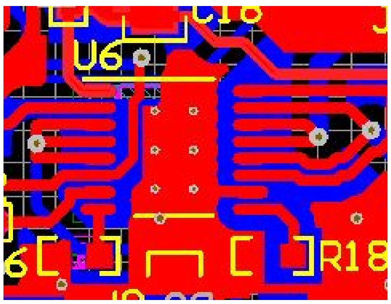



**Figure 48. TPS92630-Q1 Thermal Vias Under LED Driver**

### 9.3.2 LM74610-Q1 Layout Tips

Figure 49 shows the smart-reverse battery-diode layout. The following list contains recommended information about the layout of the LM74610-Q1.

- The VIN terminal must be tied to the source of the MOSFET using a thick trace or polygon.
- Connect the ANODE pin of the LM74610-Q1 to the source of the MOSFET for sensing.
- Connect the CATHODE pin of the LM74610-Q1 to the drain of the MOSFET for sensing.
- The high current path of this design is through the MOSFET, and it is important to use thick traces for source and drain of the MOSFET.
- The charge pump capacitor VCAP must be kept away from the MOSFET to lower the thermal effects on the capacitance value.
- The GATE DRIVE and GATE PULL DOWN pins of the LM74610-Q1 must be connected to the MOSFET gate without using vias, and the trace to the FET should be as short as possible.
- Obtaining acceptable performance with alternate layout schemes is possible, but this layout has produced good results and is intended as a guideline.

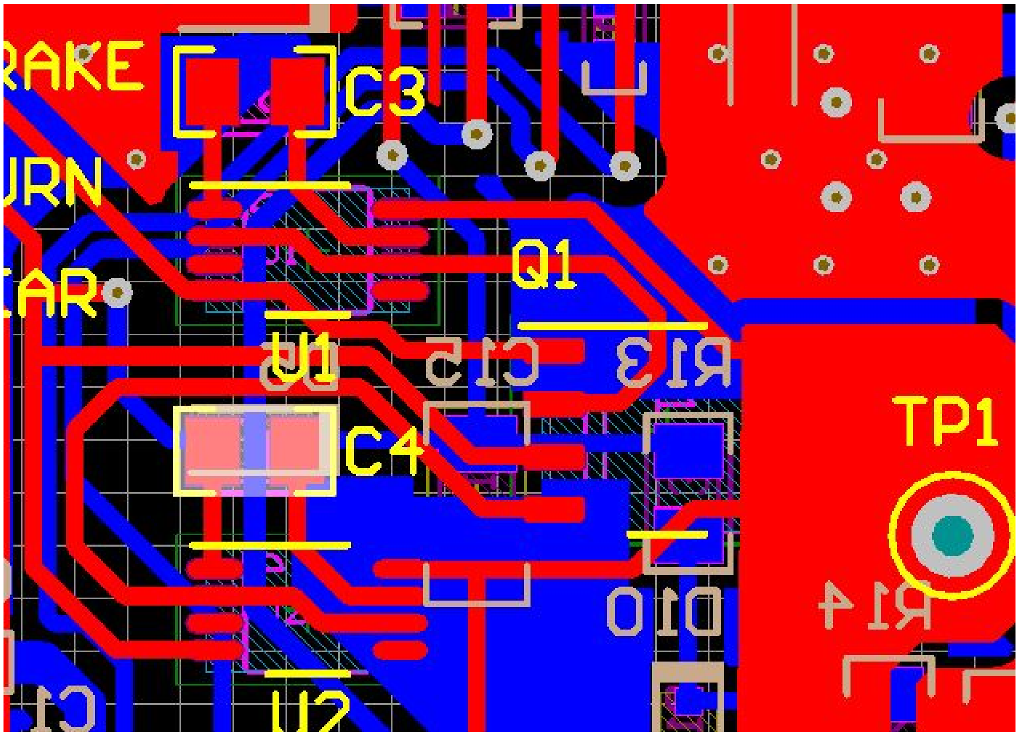
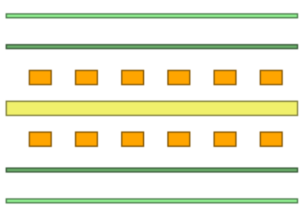



**Figure 49. LM74610-Q1 Smart-Reverse Battery-Diode Layout**

### 9.3.3 PCB Layering Recommendations for 2-Layer Boards

Most LED driver boards in practice are 2-layer boards because of cost. Figure 50 is the stackup used in this board. TI recommends a 1.5-mm 2-layer FR4.



| Layer Name | Type | Material | Thickness (mil) | Dielectric Material | Dielectric Constant | Pullback (mil) | Orientation |
|---|---|---|---|---|---|---|---|
| Top Overlay | Overlay | | | | | | |
| Top Solder | Solder Mask/... | Surface Mat... | 0.4 | Solder Resist | 3.5 | | |
| Top Layer | Signal | Copper | 1.4 | | | | Top |
| Dielectric1 | Dielectric | Core | 59.2 | FR-4 | 4.8 | | |
| Bottom Layer | Signal | Copper | 1.4 | | | | Bottom |
| Bottom Solder | Solder Mask/... | Surface Mat... | 0.4 | Solder Resist | 3.5 | | |
| Bottom Over... | Overlay | | | | | | |

**Figure 50. Layer Stackup of the LED Board**

### 9.3.4 General Power-Supply Considerations

Input capacitors should be placed as close to the IC as possible to reduce the parasitic-series inductance from the capacitor to the device it is supplying. Place the input capacitors in order of ascending size and value, with the smallest capacitor closest to the device input pin (see C24 and C18 in Figure 51.

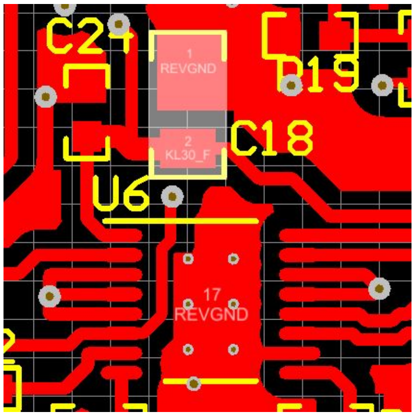



**Figure 51. Input and Output Capacitor Placement**

Place capacitors C1 and C2 perpendicular to each other (see Figure 52).

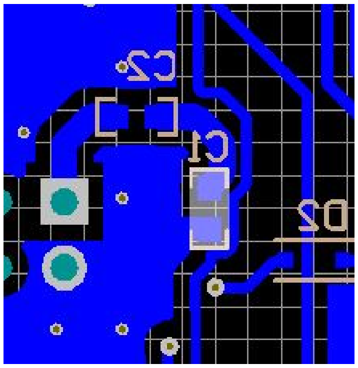


**Figure 52. Arrangement of Capacitors Connected to Battery**

### 9.3.5 GND Pour and Via Stitching

Use a solid GND fill at the top and bottom layer with via stitching to keep current loops as short as possible and to improve thermals (see Figure 53).

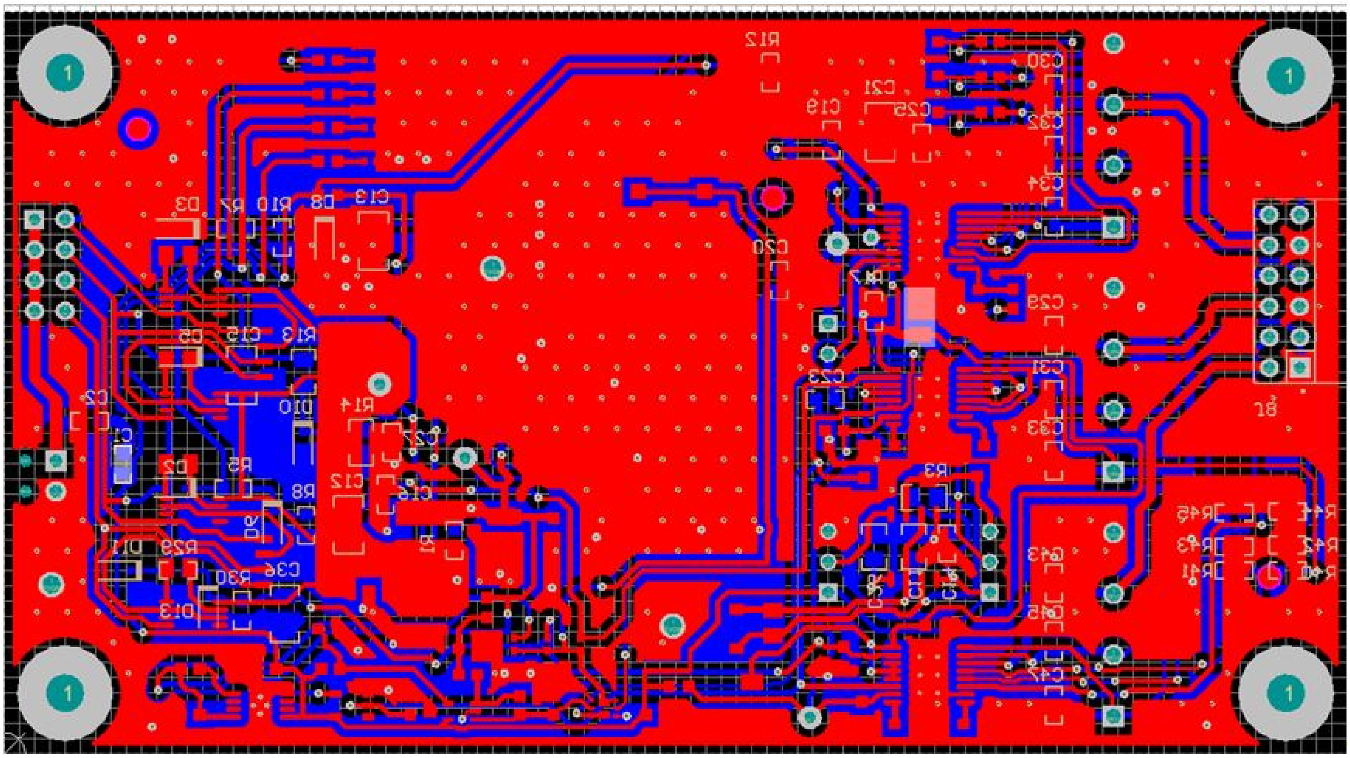


**Figure 53. Solid GND Fill**

## *9.4 Layout Prints*

To download the layer plots, see the design files at TIDA-00679.

## *9.5 Altium Project*

To download the Altium project files, see the design files at TIDA-00679.

## *9.6 Gerber Files*

To download the Gerber files, see the design files at TIDA-00679.

## *9.7 Assembly Drawings*

To download the assembly drawings, see the design files at TIDA-00679.

## 10 Software Files

To download the software files, see the design files at TIDA-00679.

## 11 References


1. CISPR 25, Edition 3.0 2008-03, *Vehicles, Boats and Internal Combustion Engines – Radio Disturbance Characteristics – Limits and Methods of Measurement for the Protection of On-Board Receivers*
2. ISO 16750-2:2010 *Road Vehicles – Environmental Conditions and Testing for Electrical and Electronic Equipment – Part 2: Electrical Loads*, section 4.6
3. ISO 7637-2:2004 *Road Vehicles – Electrical Disturbances From Conduction and Coupling – Part 2: Electrical Transient Conduction Along Supply Lines Only*, section 5.6
4. Texas Instruments, *Three-Channel Linear LED Driver with Analog and PWM Dimming*, Data sheet (SLVSC76)
5. Texas Instruments, *LM74610-Q1 Zero IQ Reverse Polarity Protection Smart Diode Controller*, Data sheet (SNOSCZ1)
6. Texas Instruments, *TLC555-Q1 LinCMOS™ TIMER*, Data sheet (SLFS078)
7. Texas Instruments, *CSD18531Q5A 60 V N-Channel NexFET™ Power MOSFET*, Data sheet (SLPS321)
8. Texas Instruments, *AN-2155 Layout Tips for EMI Reduction in DC / DC Converters*, Application note (SNVA638)
9. Texas Instruments, *AN-2162 Simple Success with Conducted EMI from DC-DC Converters*, Application note (SNVA489)
10. Texas Instruments, *Automotive Wide Vin power frontend with cold crank operation, transient protection, and EMI filter*, Application note (TIDUB49)


## 12 About the Author

**ROBERT REGENSBURGER** is a Systems Architect at Texas Instruments where he is responsible for developing reference design solutions for the Automotive Body and Lighting segment. Robert brings his extensive experience of more than 15 years of automotive analog applications to this role. Robert earned his Engineering Diploma in Electrical Engineering from the Advanced Technical High School in Regensburg, Germany.

# Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

| Changes from Original (July) to A Revision | Page |
|---|---|
| • Updated product-folder links | 1 |
| • Updated TPS92630-Q1 Three-Chanel LED Driver schematic | 24 |

## IMPORTANT NOTICE FOR TI REFERENCE DESIGNS



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