TI Designs: TIDA-01500
Automotive Multichannel LED Driver for HVAC HMI Reference Design

Description

This reference design offers a cost-effective solution to drive multiple light-emitting diodes (LEDs) for a heating, ventilation, and air conditioning (HVAC) human-machine interface (HMI). An I^2C interface controls the LED, pulse-width modulation (PWM), blinking, and brightness features on this design. The individual PWM controller in the LED driver allows the designer to set each LED to a specific value of brightness. This design also incorporates TI's ambient light sensor, which measures the intensity of visible light and delivers the digital values through the same I^2C bus. Implement control of the design using a TI LaunchPad™ Development Kit, which adjusts the dimming PWM of the LEDs according to the ambient light intensity.

Resources

TIDA-01500	Design Folder
TPS709-Q1	Product Folder
TLC59116-Q1	Product Folder
OPT3001-Q1	Product Folder

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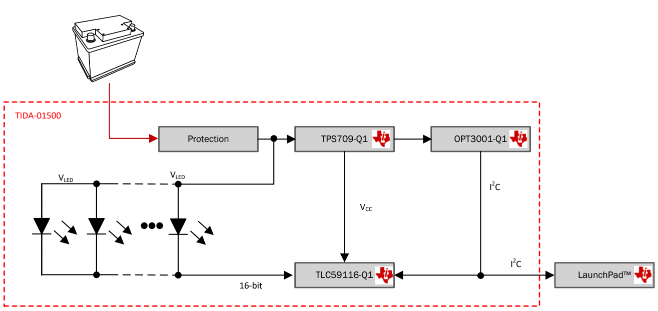
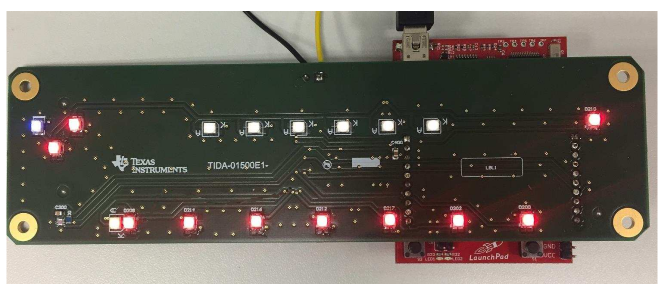
Features

- Withstands Reverse Battery Protection
- One-Chip Solution to Drive up to 18 LEDs With 16 Individual PWM Controllers in LED Driver
- LEDs Do Not Require Current Limiting Resistor for Hassle-Free Resistor Matching
- Simple Circuit and Compact Layout; Does Not Require External BJT or Field-Effect Transistor (FET) to Drive LED
- Automatic LED Dimming Based on Ambient Light Intensity

Applications

- Automotive HVAC HMI





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1 System Description

The displays and buttons in HVAC HMIs are illuminated with a number of LEDs. The drive circuit for these LEDs is typically realized in a discreet way so that the microcontroller (MCU) drives external low-side bipolar junction transistors (BJTs), which sink the LED currents. The LED current is always limited by a series resistor. The designer must adjust the values of the current-limiting resistors to eliminate the difference in the LED light intensity caused by any small deviation between each component. The designer can use a pulse-width modulation (PWM) signal to drive these BJTs and obtain the dimming effect or they can use these BJTs like a switch (on and off). The goal of this reference design is to develop a cost-effective LED driver solution for 18-LEDs that can be driven without using current-limiting resistors. The designer can individually adjust the current, as well as the PWM-dimming signal, in each diode excluding those that are connected in series to one pin. This design includes protection features against load dump conditions and reverse battery conditions while simultaneously maintaining a small solution size and low quiescent current.

The TIDA-01500 has been designed with a focus on the following points:

- Capability to simultaneously drive 18 LEDs without current-limiting resistors
- Capability to survive reverse battery condition
- Low leakage current
- Output current adjustment for all 16 outputs through one external resistor
- LED-dimming based on ambient light intensity

1.1 Key System Specifications

Table 1. Key System Specifications

PARAMETER	SPECIFICATIONS	MIN	TYP	MAX	UNIT
V_{IN}	Operating input voltage	5.5	12	17 (1)	V
V_{REV}	Reverse voltage	—	—	–60	V
I_{IN_MAX}	Maximum input current (all outputs at full preset current level)	—	0.45	—	A
I_{OUT_MAX}	Maximum output current per channel (LED)	—	0.028 (2)	—	A
OPTICAL					
Peak irradiance spectral responsivity	x minute of no motion detected	—	550	—	nm
Resolution (LSB)	Lowest full-scale range	—	0.01	—	lux
TEMPERATURE					
Operating temperature range	Temperature range (limited by CR2032 coin cell operating range)	–40	—	+85	°C

(1) The operating input voltage can be extended if the LEDs are supplied externally (V_{LED}). The supply voltage for this design must be limited up to 17 V in this design because the TLC59116-Q1 device handles voltages on output pins up to 17 V and because the V_{LED} is delivered right after the reverse polarity protection diode.

(2) In this reference design, the current level is set through an external resistor. The current limit for the TLC59116-Q1 device can be extended up to 120 mA per output channel.

2 System Overview

2.1 Block Diagram

Figure 1 shows the block diagram of this TIDA-01500 design, which comprises four main modules:

- Protection Circuit
- Voltage Regulator (LDO)
- Ambient Light Sensor (OPT3001-Q1)
- Constant-Current LED Sink Driver (TLC59116-Q1)

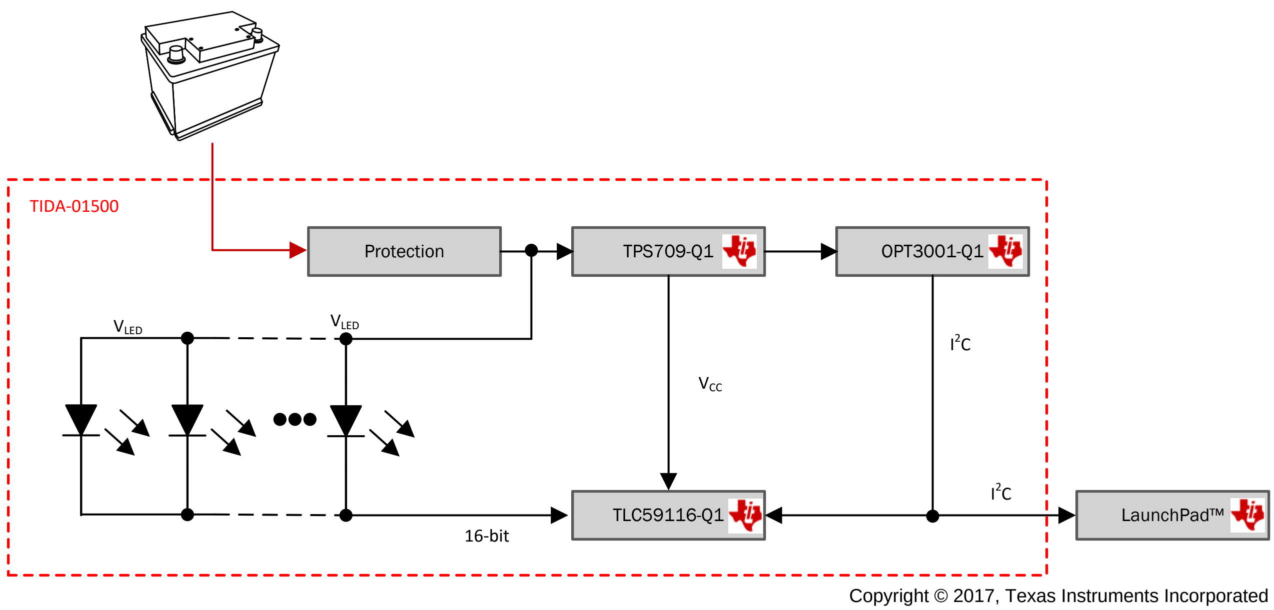

Figure 1. TIDA-01500 Block Diagram

2.2 Highlighted Products

2.2.1 TPS709-Q1

The TPS709-Q1 is an ultra-low-quiescent-current, low-dropout (LDO) linear regulator that offers reverse current protection to block any discharge current from the output into the input. However, in this reference design, the TPS709-Q1 is still used an external Schottky-diode to prevent the reverse current condition for the whole circuit. The device also features current limit and thermal shutdown for reliable operation. Figure 2 shows the block diagram.

The main features of this device are as follows:

- Undervoltage lockout (UVLO)
- Enable and disable pin
- Reverse current protection
- Internal current limit
- Thermal protection

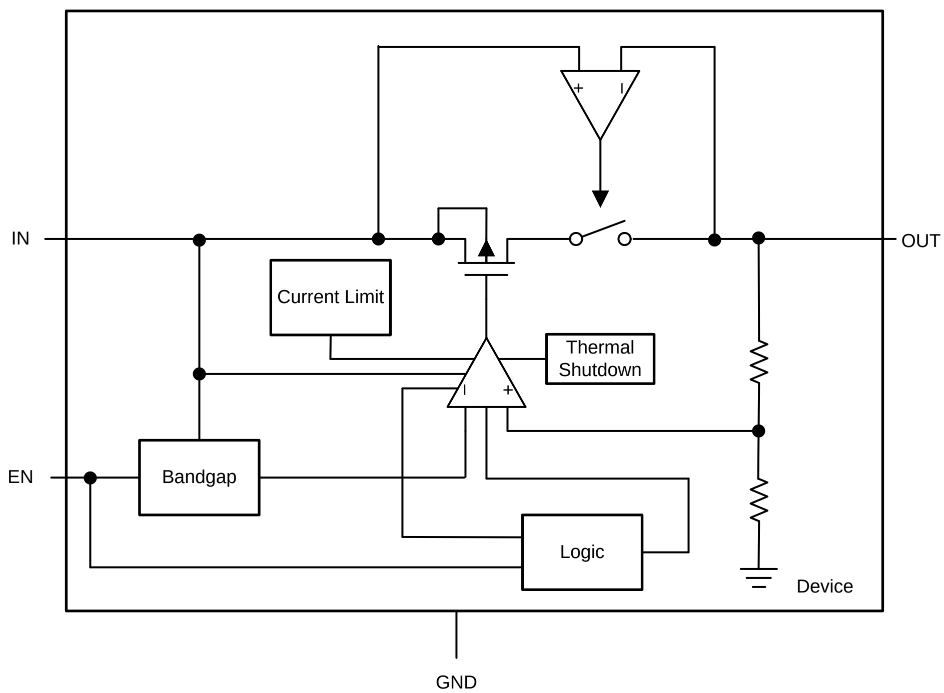

Figure 2. TPS709-Q1 Block Diagram

2.2.2 TLC59116-Q1

The TLC59116-Q1 is an I²C-bus-controlled, 16-channel LED driver. Each LED output has its own 8-bit resolution (256 steps) fixed-frequency individual PWM controller that operates at 97 kHz, with a duty cycle that is adjustable from 0% to 99.6%. The individual PWM controller allows the designer to set each LED to a specific brightness value. An additional 8-bit resolution (256 steps) group PWM controller has both a fixed frequency of 190 Hz and an adjustable frequency between 24 Hz to once every 10.73 s, with a duty cycle that is adjustable from 0% to 99.6%. The group PWM controller dims or blinks all LEDs with the same value. Figure 3 shows the block diagram of the device with 16 constant current sink outputs.

The main features of this device are as follows:

- Open-circuit detection
- Overtemperature detection and shutdown
- Power-on reset (POR)
- Individual brightness control with group dimming and blinking

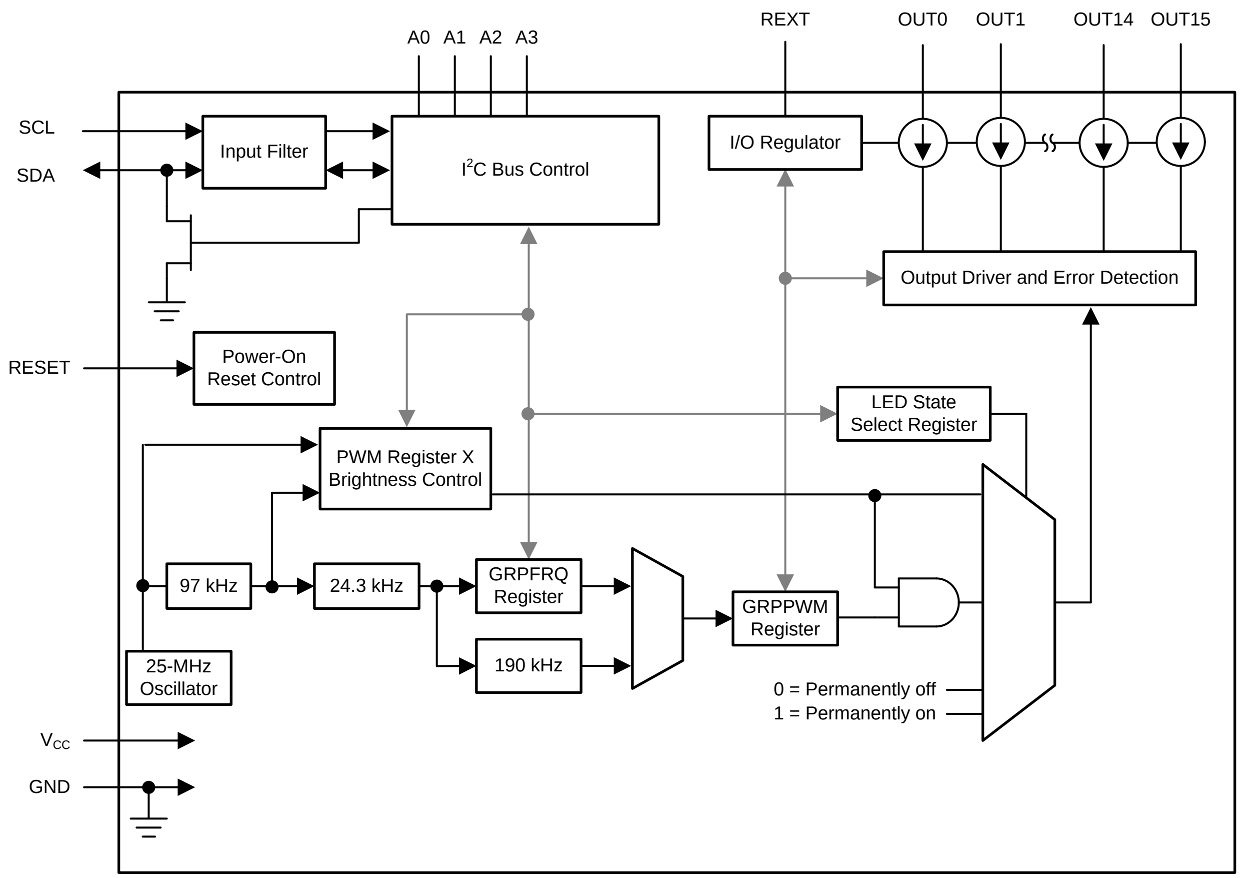

Figure 3. TLC59116-Q1 Block Diagram—OUT0 to OUT15 as Constant Current Sink Outputs

2.2.3 OPT3001-Q1

The OPT3001-Q1 is a single-chip lux meter which measures the intensity of light as visible by the human eye. The spectral response of the sensor tightly matches the photo picture response of the human eye and includes significant infrared (IR) rejection. The precision spectral response and strong IR rejection of the device enables the OPT3001-Q1 device to accurately meter the intensity of light as seen by the human eye, regardless of the light source. The OPT3001-Q1 is an ideal, preferred replacement for photodiodes, photoresistors, or other ambient light sensors with less human eye matching and IR rejection. Users can make measurements from 0.01 lux up to 83 klux without manually selecting full-scale ranges by using the built-in, full-scale setting feature. Measurements can be either continuous or single-shot. The digital output is reported over an I^2C- and SMBus-compatible, two-wire serial interface. The low-power consumption and low-power supply voltage capability of the OPT3001-Q1 device enhance the battery life of battery-powered systems. Figure 4 shows the block diagram of the sensor with digital interface and INT output pin, which can use the result to alert the system and interrupt the processor.

The main features of this device are as follows:

- Precision optical filtering to match the human eye:
  – Rejects > 99% (typical) of IR
- Measurements: 0.01 lux to 83 klux
- 23-bit effective dynamic range with automatic gain ranging
- Low operating current: 1.8 μA (typical)
- Wide power-supply range: 1.6 V to 3.6 V
- Flexible interrupt system
- Small-form factor: 2 mm × 2 mm × 0.65 mm

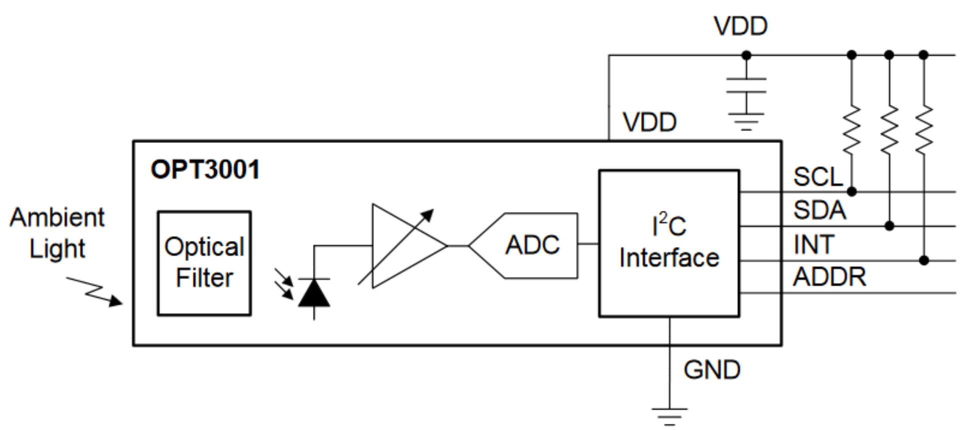

Figure 4. OPT3001 Block Diagram

2.3 System Design Theory

The displays and buttons In HVAC HMIs are illuminated with a number of LEDs. The drive circuit for these LEDs is typically realized in a discreet way using a current-limiting resistor and low-side BJT for each LED (or a couple of them in series) where MCU controls the basis pin of the transistor. Therefore in such topologies controlling of 18 LEDs independently would require same amount of independently driven low side BJTs and PWM-output pins of the MCU.

The primary goal of this reference design, with regards to the printed-circuit board (PCB), is to make a compact solution and still offer the possibility to drive a total of 18 LEDs simultaneously (of which 16 can be driven independently) to provide the LED dimming depending on whether the ambient light intensity is sufficient and whether the circuit avoids any current-limiting resistors for the LEDs. These features are possible through the use of one TLC59116-Q1 and one OPT3001-Q1, which are controlled through the I^2C bus by a TI LaunchPad™ Development Kit (MSP-EXP430G2553), as shown in Figure 5.

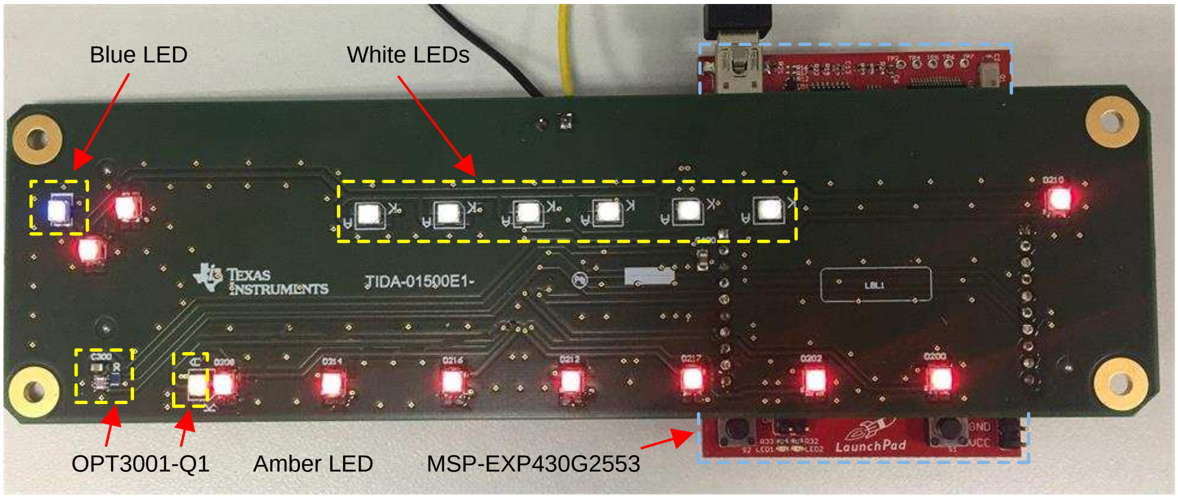

Figure 5. LaunchPad™ Development Kit With TIDA-01500—Top Side

Figure 5 and Figure 6 show the TIDA-01500 board from the top side and bottom side. The top side of the PCB is populated only with LEDs and the ambient light sensor. The TLC59116-Q1, voltage regulator, and the protection circuit are on the bottom side of the PCB. The reason for such a population is the HMI housing (see Figure 7) where the TIDA-01500 is fixed. The yellow dashed box in Figure 7 shows the opening through which the light enters and falls on the sensing surface of the OPT3001-Q1 device.

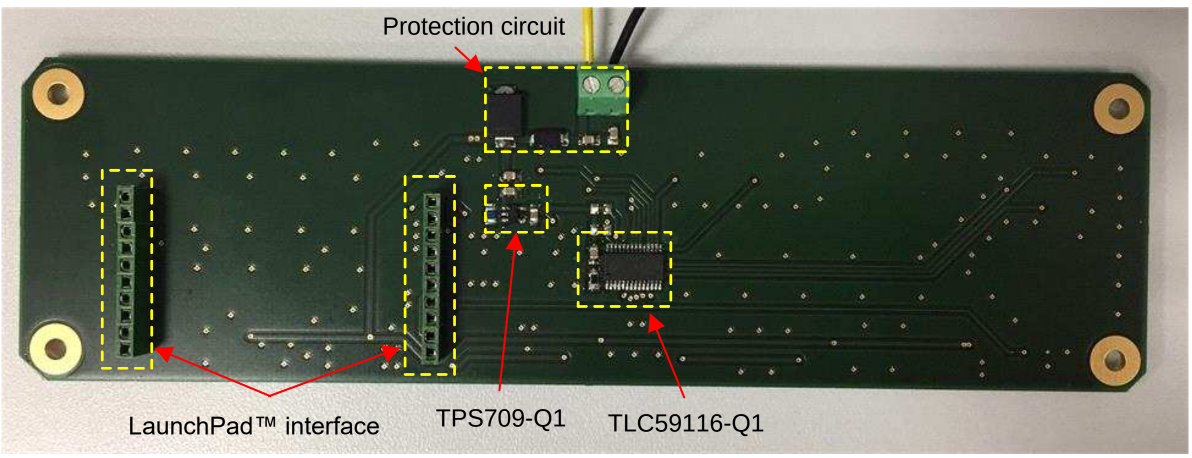

Figure 6. TIDA-01500—Bottom Side

Figure 7. HVAC HMI Housing

2.3.1 Protection Circuit and Power Supply

The protection circuit of the TIDA-01500 design that Figure 8 shows consists of an electrostatic-discharge (ESD) protective part, reverse battery protection diode, transient voltage suppressor (TVS) diode, and two ceramic capacitors for better noise filtering (input capacitors for the voltage regulator).

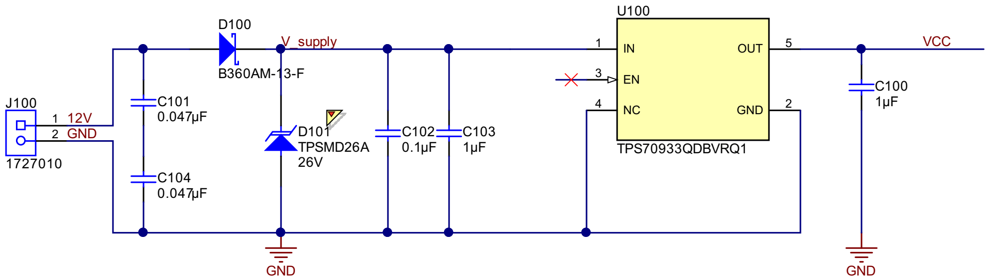

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Figure 8. Protection Circuit and Linear Voltage Regulator

This design incorporates two in-series capacitors with high-voltage rating values (100 V) for ESD protection. These capacitors are populated on the PCB in an L-shape (90° rotated from each other), which is a common technique in automotive applications. This way of arranging the ESD capacitors can prevent short circuit. When PCB bending occurs due to vibrations, the ceramic capacitor is subject to mechanical damage and the inner layers of the capacitor are at the risk of being shorted.

A TVS diode protects the circuit against load dump transient, which occurs in the event of disconnecting a discharged battery while the alternator is generating charging current to the other loads that remain on the alternator circuit. Another important requirement for a TVS diode is the 24-V jump-start (for 12-V systems). In this design, the TVS has been chosen in such a way that the standoff voltage value of the diode is above the voltage level, which can occur at the start of a jump-start event. In other words, below this voltage level, which is called the reverse standoff voltage, the TVS diode is transparent for the rest of the circuit. One important thing to note is that, due to the compact and small PCB in this reference design, the supply voltages for the LEDs are taken directly after the protection circuit and are not delivered separately using some other voltage source. Because the level of the max voltage that can occur on the TLC59116-Q1 output pins is 17 V, TI highly recommends to supply this reference design with a max of 17 V. The designer can use supply voltages for this design that reach up to 30 V by specifying a different voltage source to supply the LEDs .

As Figure 8 shows, the protection circuit is followed by a voltage regulator TPS70933-Q1, which is permanently enabled (EN pin floating). The TPS70933-Q1 is a linear voltage regulator with a fixed output voltage equal to 3.3 V. The device has very-low quiescent current and is able to deliver 200 mA of peak current. This device also has overcurrent protection and thermal shutdown. The voltage regulator supplies the LED driver, ambient light sensor, and is also externally connected to a LaunchPad Development Kit.

2.3.2 LED Driver TLC59116-Q1

This reference design uses a 16-channel constant-current sink driver (TLC59116-Q1) that has an I^2C digital interface. Each (LED) output has its own 8-bit resolution, fixed-frequency PWM controller and the duty cycle is adjustable from 0% to 99.6% (256 steps in total). This feature allows the designer to adjust the light intensity of each LED independently, which allows for equal illumination over the entire illuminated surface regardless of deviations between LEDs. Figure 9 shows the circuit diagram of TLC59116-Q1. This circuit diagram also shows the pullup resistors (4.7 KΩ) required for the I^2C communication. The pins from A0 to A3 are hardware address pins which function to set the address of the device on the I^2C bus. In this reference design, all the Ax pins have been tightened to the ground, which determines 1100000 as an I^2C address of the device. The TLC59116 driver only requires one resistor connected to the REXT-pin to set all the output currents. The goal in this design is to set the currents to 28 mA for all the LEDs. Using Equation 1, calculate the appropriate R_{EXT} to be 665-Ω.

$$I_{OUT} = \left(\frac{1.25\ V}{R_{EXT}}\right) \times 15 \tag{1}$$

Figure 10 shows the 18 LEDs (the colored circles represent the color of each LED). The D241 and D216, as well as D212 and D217, are connected in series—each pair to one output pin on the TLC59116-Q1 driver.

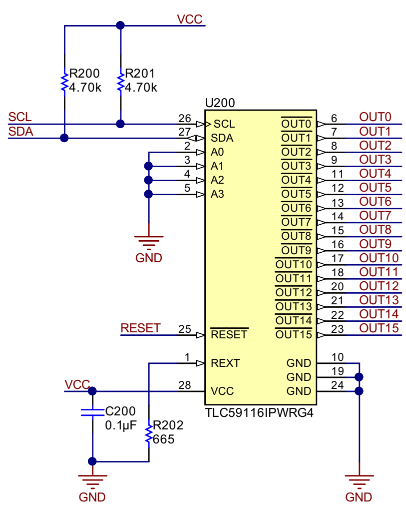

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Figure 9. TLC59116-Q1 16-Channel LED Driver With I^2C Interface

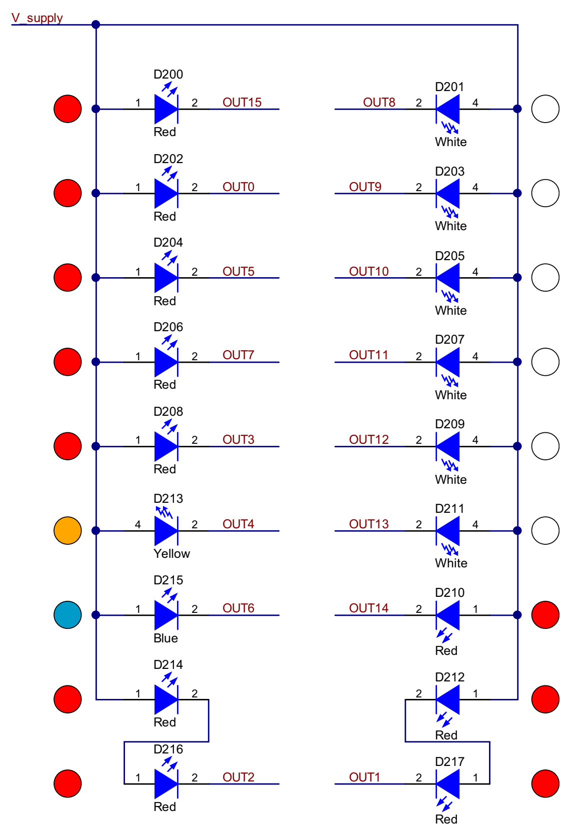

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Figure 10. 18 LEDs (1)

(1) The colored circles represent the color of each individual LED.

2.3.3 Ambient Light Sensor OPT3001-Q1

This reference design uses an ambient light sensor (OPT3001-Q1) that continuously measures the ambient light intensity and delivers the data through the I^2C bus to the MCU (LaunchPad), after which the MCU sets the duty cycle of each LED to adapt the light intensity of the LEDs to the environmental light intensity. Figure 11 shows the circuit diagram of the OPT3001 sensor. The pullup resistances for the I^2C are located at the LED driver (see Figure 9). The INT pin of the device represents an open-drain output and is required for the placement of a pullup resistor. The measurement result of the sensor can be used to alert a system and interrupt the MCU with the INT pin. The power supply is bypassed with a 100-nF ceramic capacitance placed close to the VDD-pin of the OPT3001. The ADDR pin allows the designer to set the I^2C address of the device, which is 1000 100 in this case.

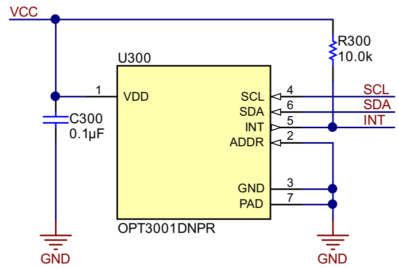

Figure 11. OPT3001-Q1 Ambient Light Sensor

3 Getting Started Hardware

Figure 12 shows the TIDA-01500 board mounted on the MSP-EXP430G2553 LaunchPad. The following LEDs are mounted on the TIDA-01500 board: six white LEDs, ten red LEDs, one amber LED, and one blue LED. The TIDA-01500 board is supplied with 12 V. The software in the MSP430G2553 device controls the ambient light sensor and LED driver autonomously through the I^2C bus. Cover the opening on the left corner of the HMI housing to see the dimming effect on the HMI surface (see Figure 13).

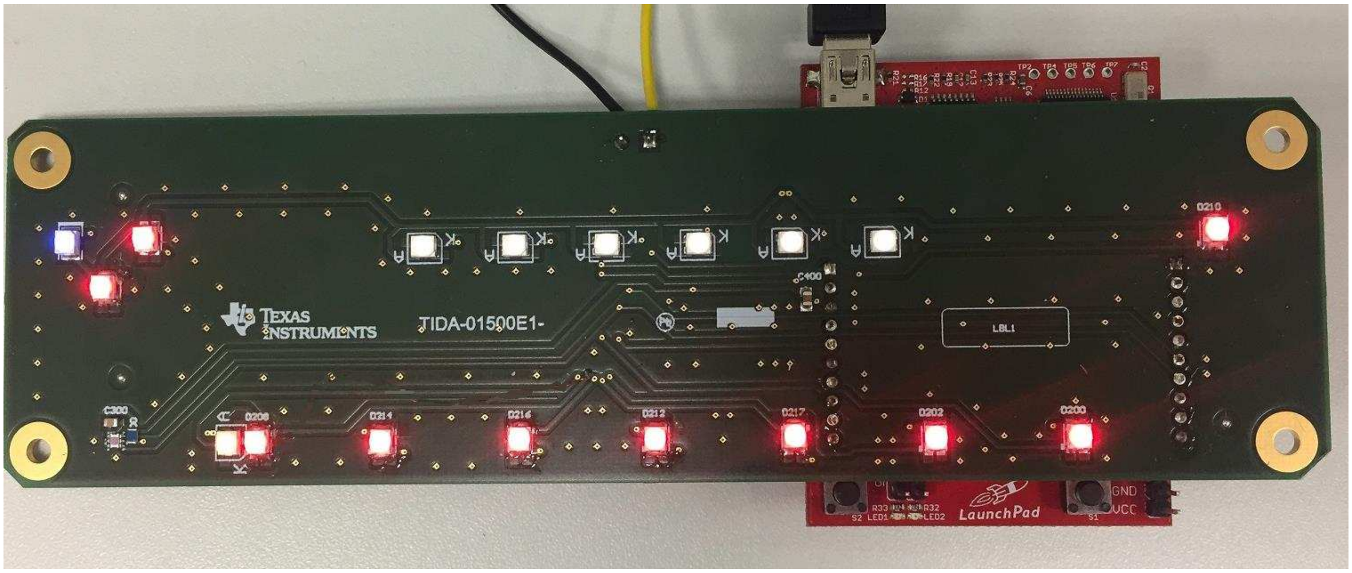

Figure 12. TIDA-01500 With MSP-EXP430G2553

Figure 13. TIDA-01500 into HMI Housing

3.1 LaunchPad™

LaunchPads are MCU development kits from TI. These kits are available in a variety of types to address various applications. The MSP-EXP430G2553 is an inexpensive and simple development kit for the MSP430G2553. This LaunchPad offers an easy way to begin developing on the TI MSP430™ MCU, with onboard emulation for programming and debugging as well as buttons and LEDs for the user interface (see Figure 14).

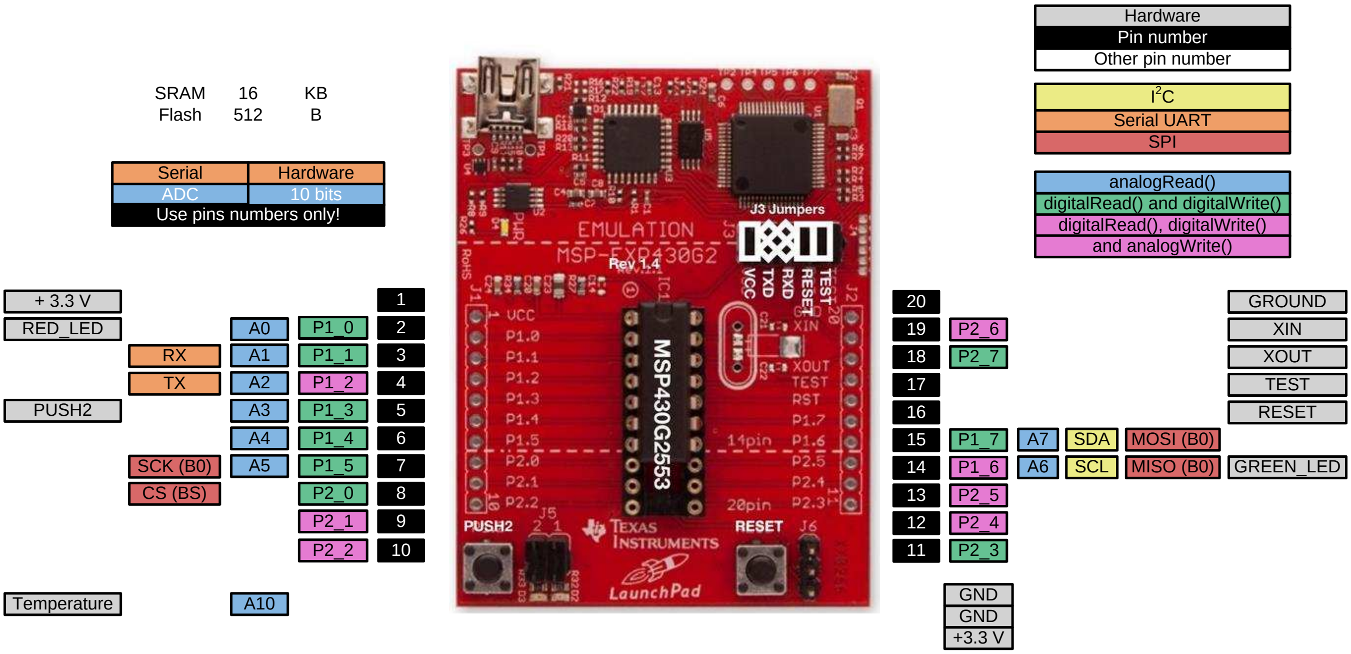

Figure 14. MSP-EXP430G2553

Figure 15 shows the pinout of the G2553 LaunchPad, which allows easy access to all the peripherals on the G2553 device.

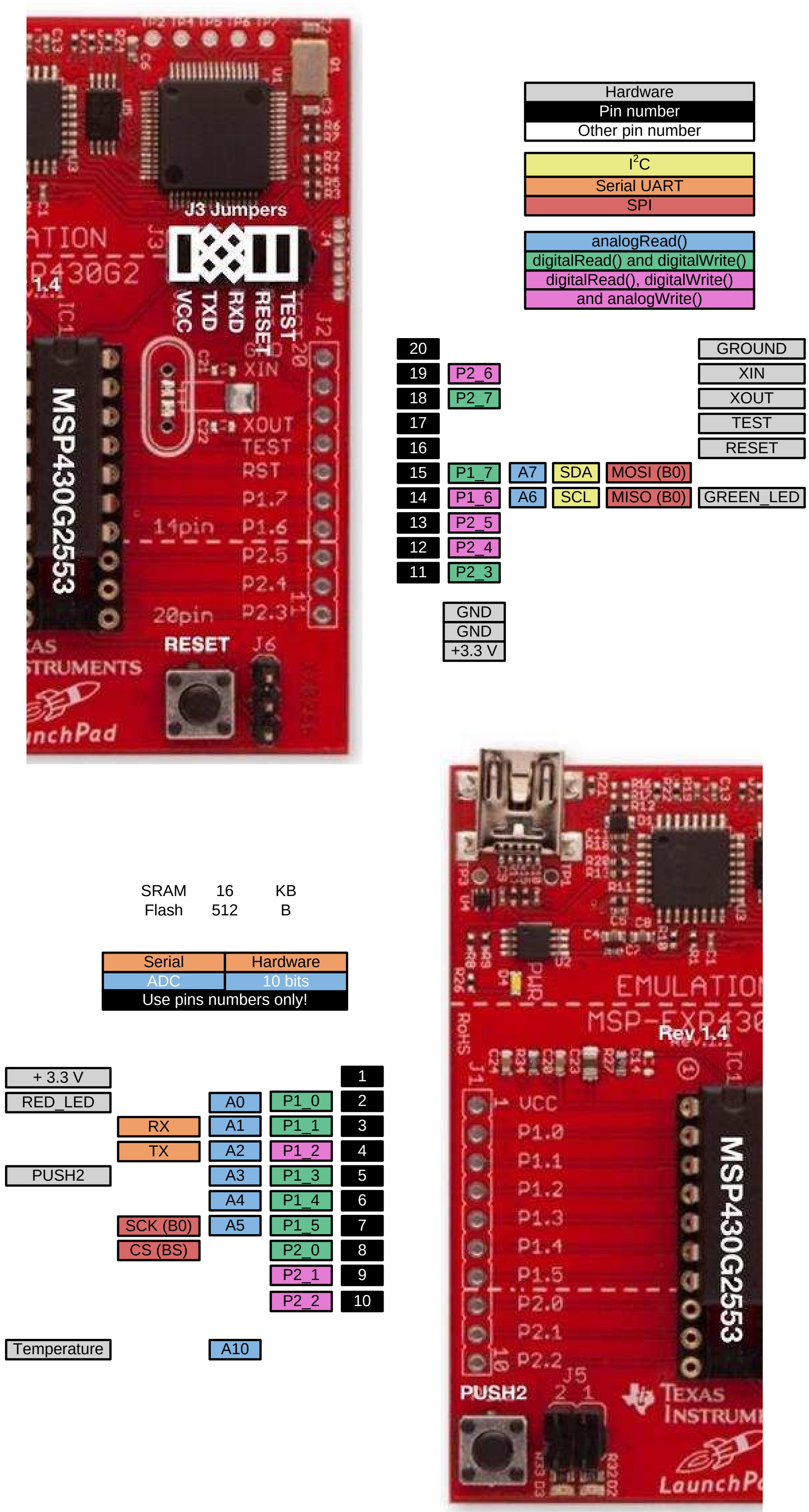

Figure 15. MSP-EXP430G2553 Pinout

The schematic in Figure 16 shows the connections on the J400 and J401 pins, both of which are ten-pin connectors. The pin assignments are in accordance with the BoosterPack™ Plug-in Module standard, which allows connection to various LaunchPad boards. All the logic signals from an MCU are referenced to the 3.3 V that the LaunchPad delivers. The active-low RESET pin goes to the TLC59116-Q1 device. The INT pin is from the OPT3001-Q1 driver and may be used as the external interrupt for the MCU. The SDA and SCL pins on J401 represent the I^2C bus. This design uses only one I^2C bus, where the MSP430 MCU functions as the master and the TLC59116 and OPT3001 devices function as the slaves.

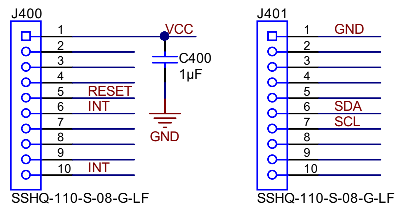

Figure 16. TIDA-01500 Board Connections to LaunchPad™

3.2 Software

Special testing software has been created for this design which controls the LED driver as well as the ambient light sensor through the I^2C bus. The software is structured in such a way that the MCU systematically requests the ambient light values from the OPT3001-Q1 driver, starts exponential smoothing of the raw data stream, and then takes the duty cycle value (%) from the predefined look-up table and sets the appropriate registers in the TLC59116 device so that all the LEDs on the output have an equivalent lighting intensity. The flow chart in Figure 17 shows the structure of the software.

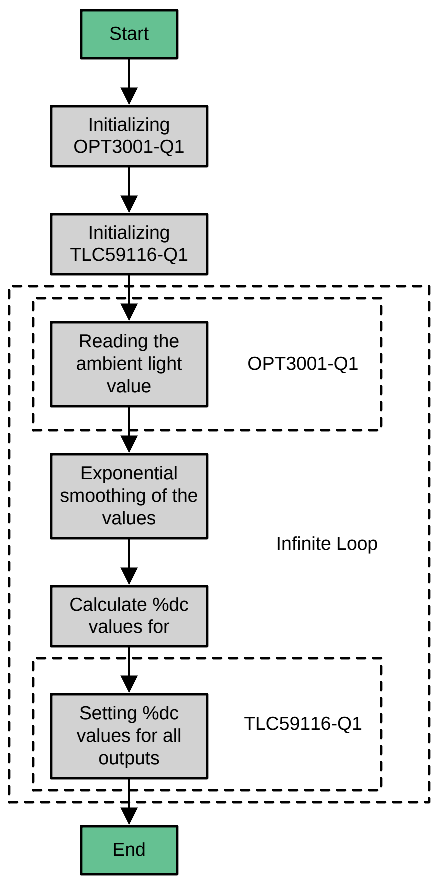

Figure 17. Software Flow Chart

4 Testing and Results

The goal of this reference design is to drive multiple LEDs and adapt the LED lighting intensity to the ambient light intensity level by dimming each LED individually or dimming all 18 LEDs simultaneously (group dimming). The best way to see the effect of LED dimming for the HVAC HMI application is to put the TIDA-01500 device into the HMI housing and monitor the LED lighting intensity based on the ambient light level. The following Figure 18 through Figure 21 show the difference in LED lighting intensity between a 4%, 20%, 45%, and 80% duty cycle.

Figure 18. LED Dimming With 4% Duty Cycle

Figure 19. LED Dimming With 20% Duty Cycle

Figure 20. LED Dimming With 45% Duty Cycle

Figure 21. LED Dimming With 80% Duty Cycle

5 Design Files

5.1 Schematics

To download the schematics, see the design files at TIDA-01500.

5.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-01500.

5.3 PCB Layout Recommendations

Figure 22 shows the bottom view of the TIDA-01500 board. As the top layer of the board shows, the battery (supply) voltage is delivered to the voltage regulator through a protection circuit, which consists of two ESD ceramic capacitances (L-shape placing), a reverse-polarity protection diode, and a TVS diode. All the components of the protection circuit are placed very close to each other. The voltage regulator uses two ceramic input capacitances in parallel and one output ceramic capacitance—all three caps are placed to the pins as close as possible. The TLC59116-Q1 device has one 100-nF ceramic cap on the VCC pin and a connected 665-Ω resistance next to the REXT-pin which defines the output current level. Both components are placed as close as possible to the TLC device.

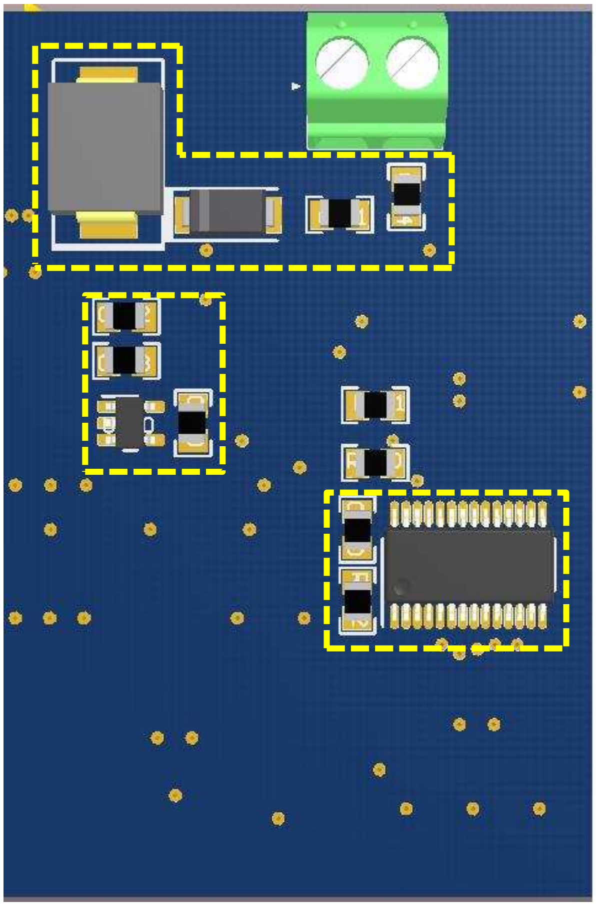

Figure 22. TIDA-01500 Bottom Layer

5.3.1 Layout Prints

To download the layer plots, see the design files at TIDA-01500.

5.4 Altium Project

To download the Altium project files, see the design files at TIDA-01500.

5.5 Gerber Files

To download the Gerber files, see the design files at TIDA-01500.

5.6 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-01500.

6 Software Files

To download the software files, see the design files at TIDA-01500.

7 Related Documentation

1. Texas Instruments, *16-Channel FM+I2C-Bus Constant-Current LED Sink Driver*, TLC59116-Q1 Data Sheet
2. Texas Instruments, *150-mA, 30-V, 1µA Iq Voltage Regulators with Enable*, TPS709-Q1 Data Sheet
3. Texas Instruments, *Ambient Light Sensor (ALS)*, OPT3001-Q1 Data Sheet

7.1 Trademarks

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8 About the Author

LEVAN BIDZISHVILI is a systems engineer at Texas Instruments where he is responsible for developing reference design solutions for the automotive body and HVAC segment. Levan brings his extensive experience of more than 7 years of automotive analog and digital applications to this role. Levan earned his master 's degree of engineering in sensor systems technology from the University of Applied Sciences in Karlsruhe, Germany.

Revision History

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

Changes from Original (November 2017) to A Revision	Page
• Changed OPT3004-Q1 to OPT3001-Q1	10