Application Note

Standalone Evaluation Platform for TI Light Sensors

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ABSTRACT

Electronic devices that use light sensors are becoming more prevalent in applications such as smart watches, laptops, TVs, automotive displays, and video surveillance cameras. TI's light sensor portfolio includes devices to measure photopic, broad, and light color spectrums. A standalone evaluation test is needed to make sure that the light sensors are working as expected before being mounted on a board (flex or non-flex PCB) for production use. TI's standalone test platform evaluates light sensors without external computers or hardware. Optionally, custom evaluation platforms are another method to test. This application note describes how to build a standalone evaluation test, including material inspection, hardware design considerations, and the assembly of test platforms.

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1 Introduction to TI's Light Sensor Portfolio

A light sensor is a device that outputs a signal that is proportional to the amount of light incident upon the sensor area. In many industrial, automotive, and personal electronic display applications, the light sensor is placed behind a dark glass window or around a display to sense ambient light.

TI's light sensor portfolio has several light sensors that fit various applications. Some popular sensors are the OPT3004, OPT3007, and OPT4001. TI light sensors are available in three package options: USON-6, SOT-8, and PicoStar™. USON-6 and SOT-8 are top-facing packages with the sensor and pins on opposite sides of the package. The USON-6 and SOT-8 packages are available for the OPT3004 and OPT4001. The PicoStar package is bottom-facing, with the sensor and pins on the same side. Bottom-facing sensors require a hole cut through the flex PCB to allow light through. For more information on bottom-facing light sensors see also the System design for bottom facing light sensors video. The PicoStar is significantly smaller than the top-facing packages and is available for the OPT3007 and OPT4001. The package shown in Figure 1-1 is a top-facing SOT-8 package, and the package shown in Figure 1-2 illustrates the sensor position of the bottom-facing PicoStar package.

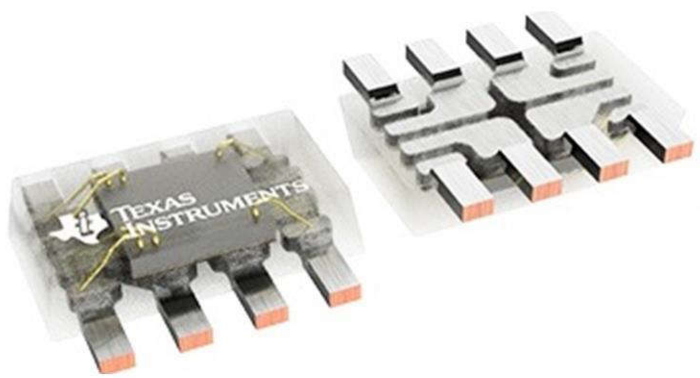

Figure 1-1. Sensor Position of the SOT-8 Package

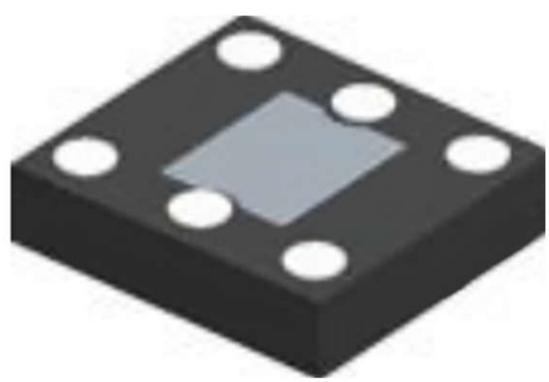

Figure 1-2. Sensor Position of the PicoStar™ Package

The USON-6 is an unleaded 6-pin package, while the SOT-8 is a leaded 8-pin device that operates like the USON-6 package by using only 6 pins. The two unused pins are no-connect. In contrast, the PicoStar is a 6-pin package that uses only 4 pins to operate. The address and interrupt pins are removed to accommodate a large sensor area hole on the package bottom.

2 Material Inspection

TI light sensors receive an appearance test when shipped out from TI factories. But as with any optical product, the designer must pay attention when handling the light sensor because light sensors are sensitive to dust and scratches. Use the OPT4001 data sheet as a guideline. Customers can also refer to the SMT process in the QFN and SON PCB Attachment application note.

3 Sensor Board Hardware Design

Figure 3-1 shows the OPT4001 light sensor design schematic. The light sensor is typically mounted on a dedicated sensor board and is separate from the main board. The light sensor board is able to connect to the main board. Refer to the following design tips:

- The SDA and SCL pins require pullup resistors. Customers can add resistors to the light sensor board or the main board. For the best signal quality, avoid using long wires or traces. Pullup resistors are not shown in Figure 3-1 since these resistors are added to the main board.
- The OPT4001 VDD pin must have a stable, low-noise power supply with a 100-nF bypass capacitor close to the device and solid grounding.
- The INT test pin is optional. If needed, include a pullup resistor, since the INT pin is an open drain.
- The PicoStar™ package does not have ADDR and INT pins.

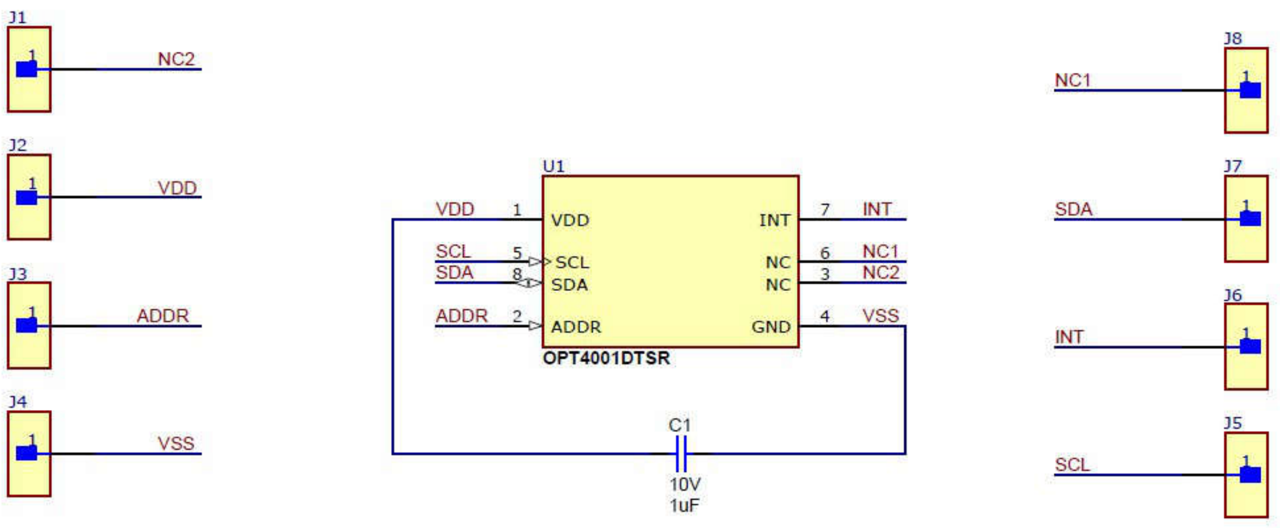

Figure 3-1. OPT4001 Schematic

For all TI light sensors, follow the PCB layout guidelines in the Layout section of the OPT4001 data sheet.

4 Build-up Standalone Light Sensor Test Platform

After assembling the light sensor onto a board to test with, the light sensor is ready to be evaluated for functionality. An evaluation system needs to be built and connected to the light sensor board to display the performance of the light sensor.

The functional tests are similar for automotive applications, but the designer must determine if the test platform socket needs to change to the automotive level.

4.1 Functional Test

There are two main tests that are required to make sure the light sensor functions correctly:

1. Test if the I^2C mode functions properly.
2. Test if the digital values the light sensor converts are changing together with a light source.

4.1.1 Communication Test

To verify that the I^2C mode is functioning correctly, read the *Device ID Register*, as shown in Table 4-1 and Table 4-2 for OPT4001. For example, when the *Device ID Register* for the OPT4001 reads 121h, I^2C is working correctly. Check the data sheet to verify the correct readout as the readout can differ for other light sensors. For example, the *Device ID Register* readout needs to be 3001h for all OPT300x devices, such as the OPT3004 or OPT3007.

Table 4-1. OPT4001 Device ID Register 11h

Register 11h (offset = 11h) [reset = 121h]							
This register is also intended to help uniquely identify the device							
15	14	13	21	11	10	9	8
0	0	DIDL		DIDH			
Read or Write-0h	Read or Write-0h	Read-0h		Read-1h			
7	6	5	4	3	2	1	0
DIDH							
Read-21h							

Table 4-2. OPT4001 Device ID Register Field Descriptions

Bit	Field	Type	Reset	Description
15-14	0	Read or Write	0h	Must read or write 0
13-12	DIDL	Read	0h	Device ID L
11-0	DIDH	Read	121h	Device ID H

Another method to test I^2C functionality is to write to and read back from the *Configuration Register* (offset = 11h). This test can be desired in addition to the read Device ID Register test to exercise both read and write functions.

4.1.2 Sensor Function Test

The user needs a way to observe if the converted digital value changes under different light sources to test the light sensor function.

The OPT4001 device measures light and updates output registers with proportional ADC codes. The device output is represented by two parts, 4 bits of EXPONENT and 20 bits of MANTISSA. The arrangement of binary logarithmic full-scale range with linear representation within a range helps to cover a wide dynamic range of measurements. MANTISSA represents the linear ADC codes proportional to the measured light within a given full-scale range. The EXPONENT represents the current-full scale range selected. The selected range can be automatically determined by the auto-range selection logic or is manually set.

The MANTISSA can be determined using the following equation:

$$\text{MANTISSA} = (\text{RESULT\_MSB} \ll 8) + \text{RESULT\_LSB} \quad (1)$$

where RESULT_MSB, RESULT_LSB, and EXPONENT are parts of the output register as shown in Table 4-3 and Table 4-5. Descriptions of the RESULT_MSB, RESULT_LSB, and EXPONENT values can be found in Table 4-4 and Table 4-6. The RESULT_MSB register carries the most significant 12 bits of the MANTISSA and the RESULT_LSB register carries the least significant 8 bits of the MANTISSA. The MANTISSA is then computed using the preceding equation to get the 20-bit number. EXPONENT is directly read from the register, which is 4 bits.

Once the EXPONENT and MANTISSA portions are calculated, the linearized ADC_CODES value is calculated using the following equation:

$$\text{ADC\_CODES} = (\text{MANTISSA} \ll \text{E}) \tag{2}$$

With the maximum value for register E equal to 8, ADC_CODES is effectively a 28-bit number. The semi-logarithmic numbers have been converted to a linear ADC_CODES representation, which is simple to convert to lux using the following formulas. To calculate lux for the PicoStar package from TI, use the following equation:

$$\text{lux}_{\text{PicoStar™}} = \text{ADC\_CODES} \times \left(312.5 \times 10^{-6}\right) \tag{3}$$

Use the following equations to calculate lux for the SOT-8 package.

$$\text{lux}_{\text{SOT-8}} = \text{ADC\_CODES} \times \left(437.5 \times 10^{-6}\right) \tag{4}$$

Table 4-3. OPT4001 Result Register 00h (Read Only)

Register 0h (offset = 0h) [reset = 0h]							
15	14	13	21	11	10	9	8
EXPONENT				RESULT_MSB			
Read-0h				Read-0h			
7	6	5	4	3	2	1	0
RESULT_MSB							
Read-0h							

Table 4-4. OPT4001 Result Register 00h Field Descriptions

Bit	Field	Type	Reset	Description
15-12	EXPONENT	Read	0h	EXPONENT output. Determines the full-scale range of the light measurement. Used as a scaling factor for lux calculation.
11-0	RESULT_MSB	Read	0h	Result register MSB (Most Significant Bits). Used to calculate the MANTISSA. Representing light level within a given EXPONENT or full-scale range.

Table 4-5. OPT4001 Result Register 01h (Read Only)

Register 1h (offset = 1h) [reset = 0h]							
15	14	13	21	11	10	9	8
RESULT_LSB							
Read-0h							
7	6	5	4	3	2	1	0
Counter				CRC			
Read-0h				Read-0h			

Table 4-6. OPT4001 Result Register 01h Field Descriptions

Bit	Field	Type	Reset	Description
15-8	RESULT_LSB	Read	0h	Result register LSB (Least Significant Bits). Used to calculate MANTISSA representing light level within a given EXPONENT or full-scale range.
7-4	Counter	Read	0h	Sample counter. Rolling counter which increments for every conversion.
3-0	CRC	Read	0h	CRC bits. R[19:0]=MANTISSA=((RESULT_MSB<<8)+ RESULT_LSB X[0]=XOR(E[3:0],R[19:0],C[3:0]) XOR of all bits X[1]=XOR(C[1],C[3],R[1],R[3],R[5],R[7],R[9],R[11],R[13],R[15],R[17],R[19],E[1],E[3]) X[2]=XOR(C[3],R[3],R[7],R[11],R[15],R[19],E[3]) X[3]=XOR(R[3],R[11],R[19])

Users can set up a standard test platform to compare the lux value, the light sensors detect, and the lux meter value. The values are not exactly the same but there is likely a positive correlation under different light sources.

4.2 Test Equipment

To create a test platform with a defined light source, users can refer to the OPT3001: Ambient Light Sensor Application Guide application note.

This application note uses the following equipment for calibration:

- Konica Minolta® Illuminance Meter T-10MA, lux meter
- CREE® XLamp® Cool White 5000k, large white LED array light source
- Yokogawa® GS610 Source Measure Unit (SMU), LED power supply

The OPT4001 device can be configured to operate with light conversion times from 600 µs to 800 ms in 12 steps, providing system flexibility based on application needs. Conversion time includes the integration time and ADC conversion time. The resolution of the measurement is determined by a combination of light intensity and the integration time, effectively bringing in the capability to measure down to 312.5 µlux of light intensity changes for the PicoStar™ variant and 437.5 µlux for the SOT-8 variant. The conversion time is the time taken to complete one light measurement and update the results in the output register. Resolution is configured in the conversion time register. For example, using a section of the OPT4001 resolution table shown in 4-7, the resolution is 0.02 lux when the conversion time register is set to 50 ms and the lux intensity is approximately 1310 lux. For the full resolution table, see the OPT4001 data sheet.

Table 4-7. Section of the OPT4001 Resolution Table

Conversion Time Register	Conversion Time (ms)	EXPONENT	0	1	2	4
		Full-scale lux	328	655	1310	2621
		Effective Resolution in lux				
6	25		0.01	0.02	0.04	0.08
7	50		5 m	0.01	0.02	0.04
8	100		2.5 m	50 m	0.01	0.02

4.3 Hardware Platform

The standalone test platform can evaluate the light sensor without external hardware such as a computer monitor. The display shows the device ID and lux values on the screen of the test platform, as shown in Figure 4-1. The interrupt and address operations are optional. If preferred, the test platform can connect externally to a PC using UART to print the device ID and lux.

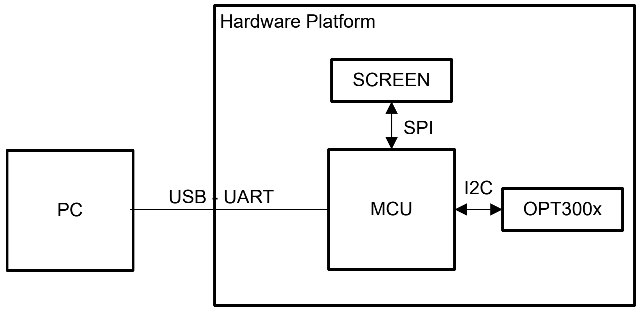

Figure 4-1. Light Sensor Hardware Test Platform

TI provides hardware that can simplify the light sensor testing process, such as the microcontroller MSP-EXP432E401Y and sensor plus display board BOOSTXL-EDUMKII shown in Figure 4-2 and Figure 4-3. To use this hardware, place the OPT4001 on the BOOSTXL-EDUMKII board. Plug the BOOSTXL-EDUMKII into MSP-EXP432E401Y and download the correct firmware introduced in Section 4.4. The measured lux is printed on the BOOSTXL-EDUMKII screen and changes with the environmental light conditions. Before testing, confirm that the J5 jumper on the BOOSTXL-EDUMKII connects to the LCD backlight.

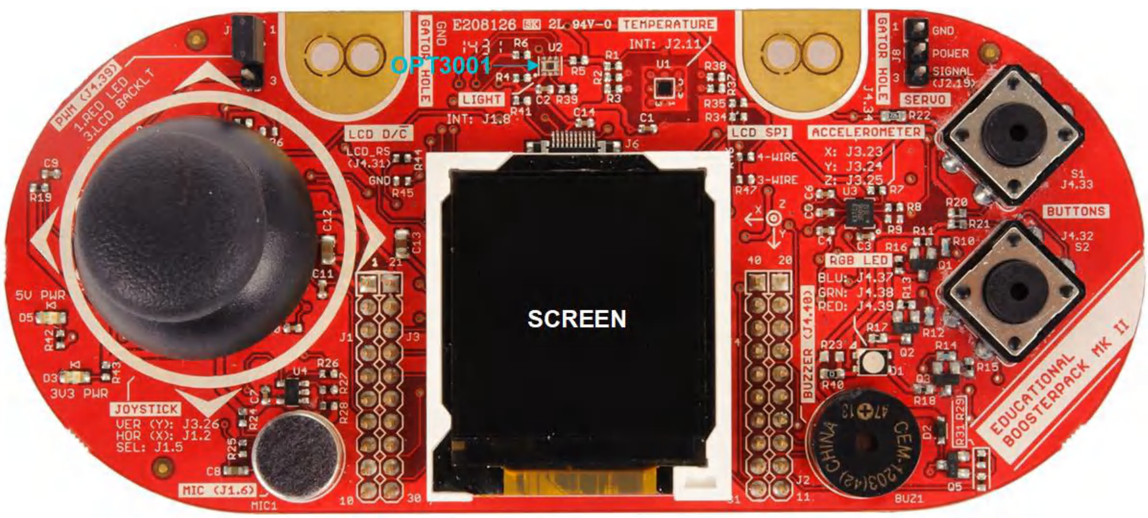

Figure 4-2. BOOSTXL-EDUMKII Board

If preferred, MSP-EXP432E401Y has a UART to USB interface that can connect to the PC to display the light sensor readings.

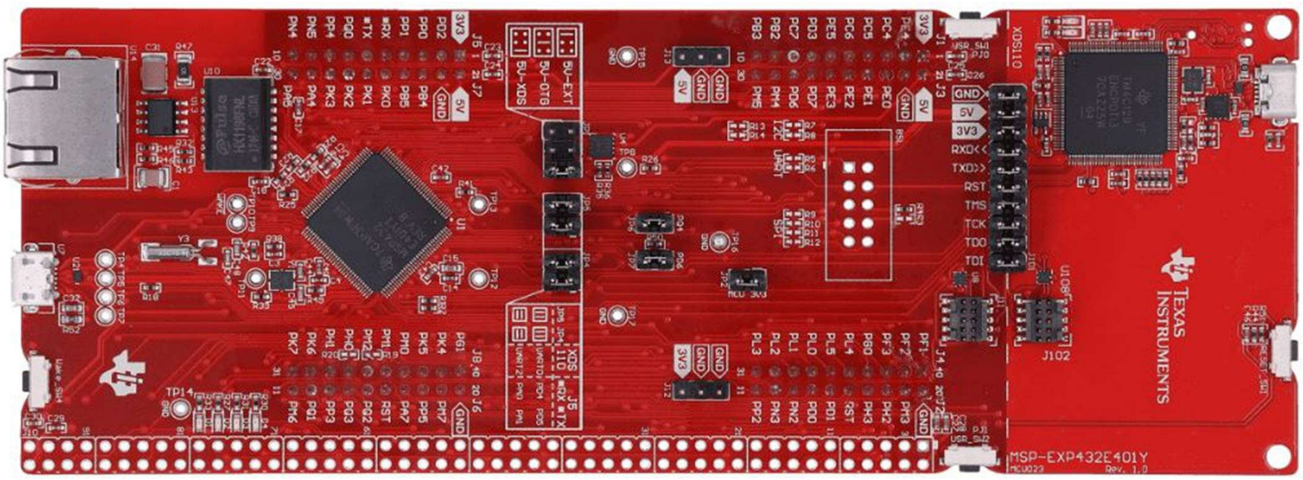

Figure 4-3. MSP-EXP432E401Y Board

The OPT3007 and OPT4001 PicoStar™ tests are similar, but the designer must build conversion boards because the PicoStar package has a bottom-facing sensor.

While any MCU can be used to build the standalone test platform, the BOOSTXL-EDUMKII Educational BoosterPack™ Plug-in Module Mark II user's guide and the SimpleLink™ Ethernet MSP432E401Y Microcontroller LaunchPad™ Development Kit (MSP-EXP432E401Y) user's guide provide all the necessary materials, including the schematic and build of materials.

4.4 Software Code Examples

TI provides light sensor drivers based on both microcontrollers and Android™ operating systems. The provided example code for the hardware platform, adjusts the backlight of the LCD and displays the measured lux value of the light sensor on the colored LCD. After installing Code Composer Studio™ (CCS), the example code is located at **/i2copt3001_cpp**, shown selected in Figure 4-4.

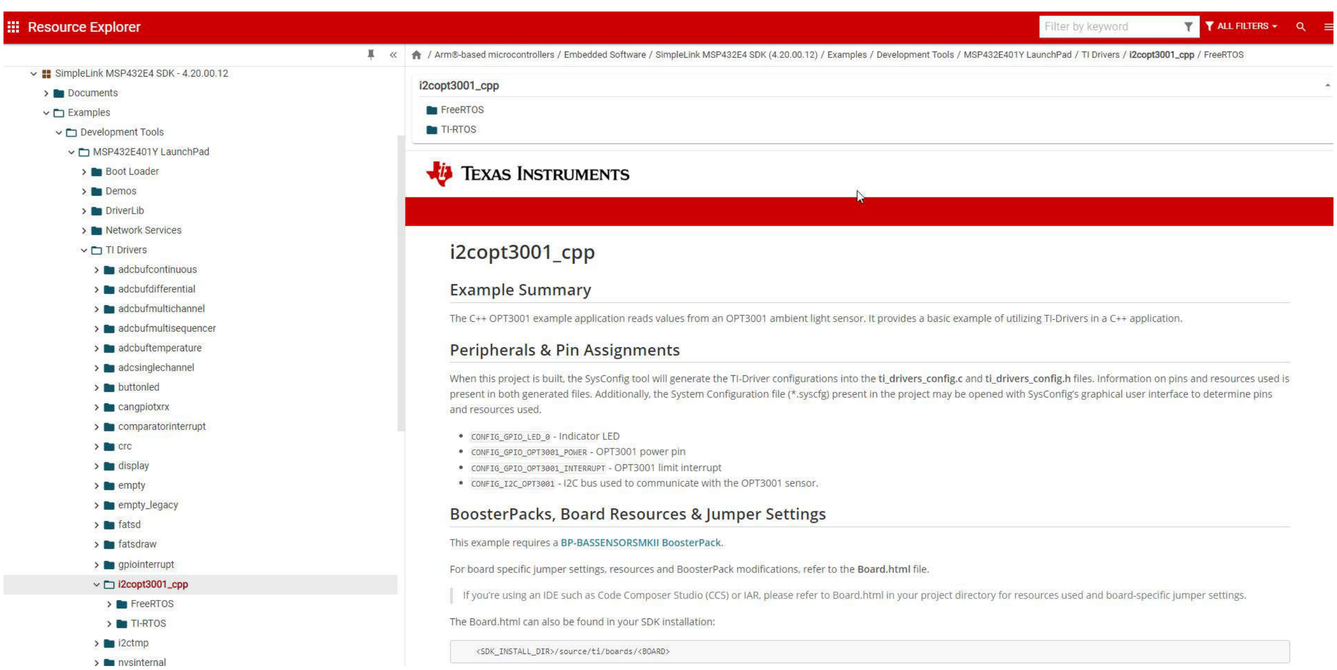

Figure 4-4. Light Sensor Test Code Example Location in CCS

Download MSP432-SDK using the code example located in **/i2copt3001_cpp**

The code examples are open source and can be modified as needed.

5 Summary

To properly evaluate a light sensor for an application, a test platform must be used to validate performance. Evaluation can be done by building a standalone evaluation test that includes the material inspection, hardware design, and assembly of the test platform. The material must not have any scratches or heavy dust as to not damage the sensor. When designing the hardware, it is important to mount the light sensor on a dedicated board which can then be connected to the main board. This setup is used for evaluation in which functional tests are run to make sure the light sensors are running correctly. Tests can be performed using calibration equipment or TI's hardware platform. For more information on device setup and use, see also the specific device data sheet.

6 References

- Texas Instruments, *OPT4001 High Speed, High Precision, Digital Ambient Light Sensor* data sheet
- Texas Instruments, *OPT3001: Ambient Light Sensor Application Guide* application note
- Texas Instruments, *QFN and SON PCB Attachment* application note
- Texas Instruments, *OPT3004 Ambient Light Sensor (ALS) With Excellent Angular IR Rejection* data sheet
- Texas Instruments, *OPT3007: Ultra-Thin Ambient Light Sensor* data sheet
- Texas Instruments, *BOOSTXL-EDUMKII Educational BoosterPack Plug-in Module Mark II* user's guide
- Texas Instruments, *SimpleLink™ Ethernet MSP432E401Y Microcontroller LaunchPad™ Development Kit (MSP-EXP432E401Y)* user's guide
- Texas Instruments, *MSP-EXP432E401Y* design resource

7 Revision History

Changes from Revision * (April 2020) to Revision A (May 2023)	Page
• [illegible] tables, figures, and cross-references throughout the document	[illegible]