TI Designs: TIDA-010021

Wide-Range (120° FoV at 1.6 Meters) Proximity Sensing Reference Design With Immunity to Sunlight

TEXAS INSTRUMENTS

Description

Proximity sensing with wide field-of-view (FoV) is getting more and more popular and important for people detection in many applications. This reference design uses optical time-of-flight (ToF) techniques to build small and cost-effective proximity sensor systems. A single proximity and distance sensor AFE (OPT3101) with three external NIR LEDs, and one photodiode covers a total 120° wide FoV and outputs accurate distance of people activity.

Resources

|	
TIDA-010021	Design Folder
OPT3101	Product Folder
MSP430FR2433	Product Folder
TLC59283	Product Folder
TLV702	Product Folder
TPD2E001	Product Folder

ASK Our E2E™ Experts

Features

- Three NIR emitters support up to 3 zones of detection with a single OPT3101 device
- Total system Field-of-View (FoV) of 120° is covered by three LED emitters and one photodiode
- Detection range up to 1.6 meters without lens
- Adaptive high dynamic range (HDR) feature enables the detection range of system very wide
- ToF based sensing AFE (opt3101) makes measurement insensitive to object color and reflectivity and supports operation under high ambient condition (outdoor and Indoor Conditions)
- Proximity sensing and direct distance measurement output with accuracy of ±10%
- Low power mode running at 1 sample per second with a power drain of 30 mW
- Exempt group lamp classification LED as emitter

Applications

- Air Conditioners
- Refrigerators & Freezers
- Cooker Hoods
- Washers & Dryers
- Other Appliances
- Personal Electronics
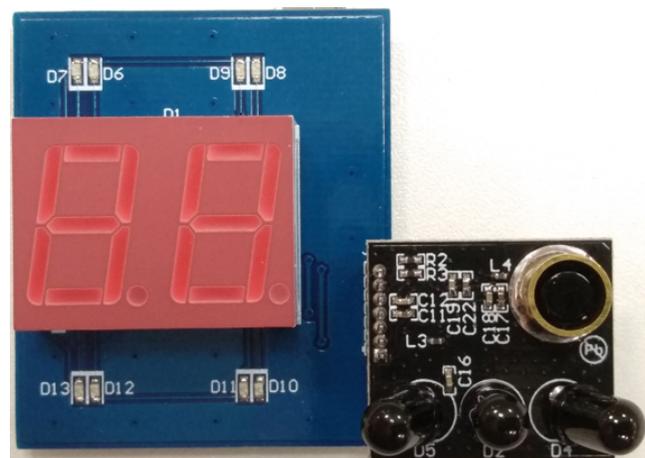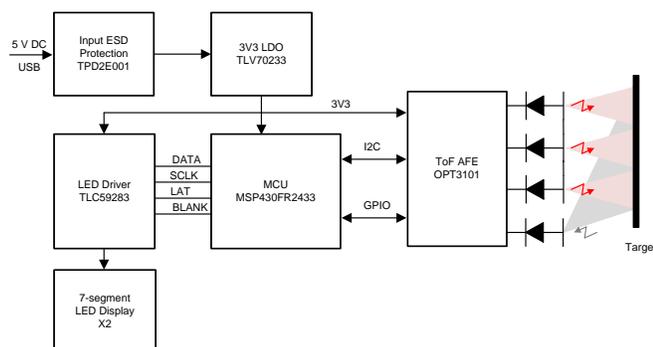
⚖ An IMPORTANT NOTICE at the end of this TI reference design addresses authorized use, intellectual property matters and other important disclaimers and information.

1 System Description

With the rapid development of smart home appliances, non-contact based proximity sensing and distance measuring are becoming one of the important features and capability in appliances like air conditioner, refrigerator, cooker hood and so on. Smart appliances often require end equipment to perceive the external environment and make responses. For instance, in high end air conditioner, it is often required that the end equipment should have the capability to sense where the people are and how far they are. With that data the end equipment can determine the air flow strength and direction. Another application example is for the appliances with big human machine interface (HMI) display screen. The power consumption for such kind of display is high and with proximity sensing they can only be activated when someone is present in front of it. Then significant amounts of energy can be saved and being environmental-friendly. The proximity sensing is also very useful for end equipment to operate in darkness when user cannot see HMI. Proximity sensing will be one smart feature for future appliances.

The purpose of TIDA-010021 is to expedite evaluation and system development of ToF for major appliance application scenarios, like proximity sensing and simple gesture recognition. This reference design includes two boards: sensor board and display board. The sensor board is a optical ToF proximity and distance sensing module, consisting of OPT3101 AFE and its peripheral device. Three LEDs and one photodiode are connected to the OPT3101 as illuminators and receiver. All the computation and corrections for crosstalk, phase offset, temperature-dependent phase drift, and ambient-dependent phase drift are done on the OPT3101. The display module uses an external MCU (MSP430FR2433IRGER) to control OPT3101 AFE and display the distance information of target to user through seven-segment led display (LTD-6910HR) after reading the data from sensor module. The MCU directly read out depth data thru an I^2C interface from sensing module.

Comparing to the other detection and ranging approaches such as ultrasonic and radar technologies, with weaknesses, such as accuracy and ambient immunity, TI's OPT3101, a long-range proximity and distance sensor Analog-Front-End (AFE), uses Time-of-Flight (ToF) principle to acquire distance measurement data with well performance of distance, accuracy and ambient.

The typical advantages of TI's OPT3101 AFE are as follows:

- **Flexibility:** OPT3101 offers flexibility to customize design for specific applications. It has a built in illumination driver, supporting up to three separate illumination channels activated in turn, with separate current control programmability. What's more, with different types of external illuminator (LED, VCSEL, or LASER) and corresponding photodiode, users have choice of wide wavelength of interest (visible or infrared) and field of view (FoV) based on added optics. This helps optimize the design both in terms of build of materials (BOM) and size to get the best end result.

- **High-speed and high-resolution:** OPT3101 has the sample rate up to 4 kHz, with ToF technology, operating much faster compared to other range sensing methods like ultrasonic sensing. OPT3101 has 16-Bit distance output at 15-m unambiguous range. In addition, TI's advanced ToF technology deploys multi-freq. techniques for de-aliasing to extend the distance range.

- **Object reflectivity independency:** ToF technology independently determines phase and amplitude, allowing for independency of object (color) reflectivity. It overcomes the drawback of amplitude based system, which estimates distance only based on reflected signal strength.

- **High ambient rejection ratio:** The OPT3101 device has excellent ambient and sunlight rejection performance. There exists an internal ambient cancellation block in OPT3101 that allows for great performance both indoors and outdoors, including full sunlight of 130 klx. The OPT3101 device also has other various calibrations and compensations approaches, ranging from crosstalk, phase offset, phase correction with temperature and ambient, and so forth, that ensures higher accuracy.

- **Adaptive HDR:** The timing sequencer is highly configurable to provide for application-specific trade-offs of power versus performance, ranging from μW to mW of power based on data and accuracy.

Adaptive HDR allows the sequencer switching between high and low illumination driver currents to extend the dynamic range, depending on the signal saturation and lower amplitude threshold, as well as save power.

1.1 Key System Specifications

Table 1. Key System Specifications

PARAMETER	MIN	NOM	MAX	UNIT	Comments
DC Input Power Supply	3.6	5	5.5	VDC	DC Input by J1
Sensor Power Supply	3	3.3	3.6	VDC	Sensor board J4
Detection Range	0.1	—	1.6	m	Without lens for all color target
Field of View (FOV)	-60	—	60	degree	Total FoV 120°
Gesture Recognition	0.1	—	0.5	Left - Right	With hands open at 0.5 m distance
Continuous Full Power	—	—	300	mW	Sensor board only, continuous measuring distance at 128 sub frames per sample and 31.25 samples per second
Accuracy	—	—	10	%	
Low Power Mode	—	—	30	mW	Wake up every 1 second for one sample (128 sub frames)
Operating Temperature	-20	—	85	°C	

2 System Overview

2.1 *Block Diagram*

Figure 1. TIDA-010021 Block Diagram
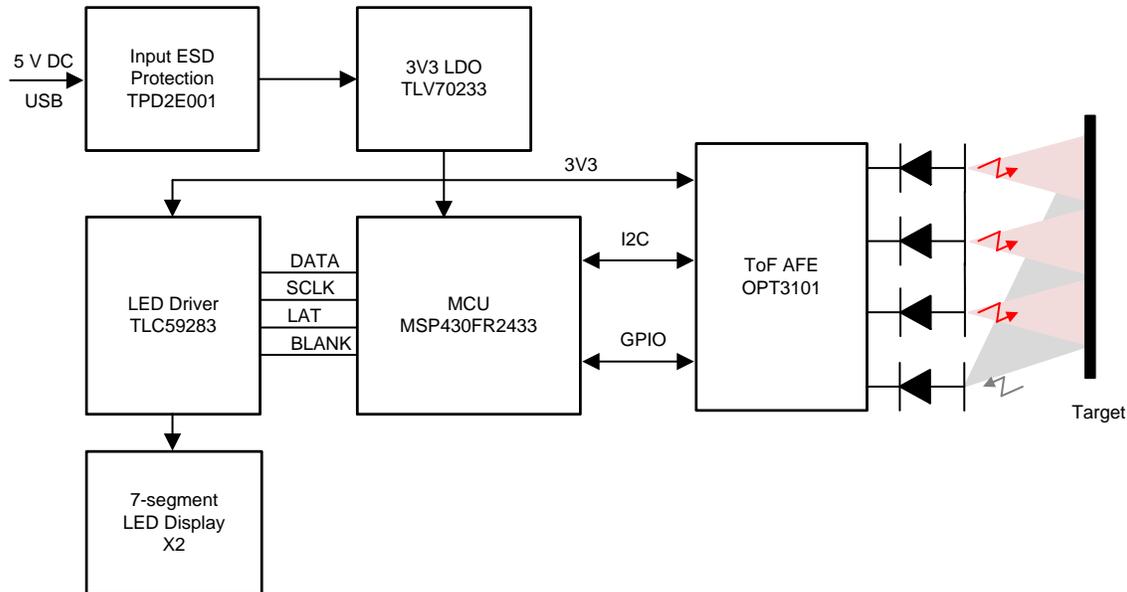
2.2 *Highlighted Products*

The following subsections detail the highlighted products used in this reference design, including the key features for their selection. See their respective product data sheets for complete details on any highlighted device.

2.2.1 OPT3101

The OPT3101 device is a high-speed, high-resolution and fully integrated analog front end (AFE) for continuous-wave, time-of-flight (TOF) based proximity sensing and range finding using active illumination. The OPT3101 AFE connects to an external illuminator (LED, VCSEL, or LASER) to transmit modulated optical signals, and reflected signals are received by an external photodiode which connects to the input of the AFE. The received signal is converted to amplitude and phase information by the AFE and depth engine. This output is stored in registers, which can be read out through the device I^{2}C interface.

The device integrates the complete depth processing pipeline that includes the ADC, timing sequencer, and the digital processing engine. The device also has a built-in illumination driver that covers most of the target applications. Given the high ambient rejection ratio, the device can support very high ambient conditions, including full sunlight of 130 klx. The timing sequencer is highly configurable to provide for application-specific trade-offs of power versus performance. The device provides depth data that consists of phase, amplitude, and ambient measurements. The calibration subsystem supports phase-data calibration for inaccuracies resulting from temperature and crosstalk.

Figure 2. OPT3101 Block Diagram
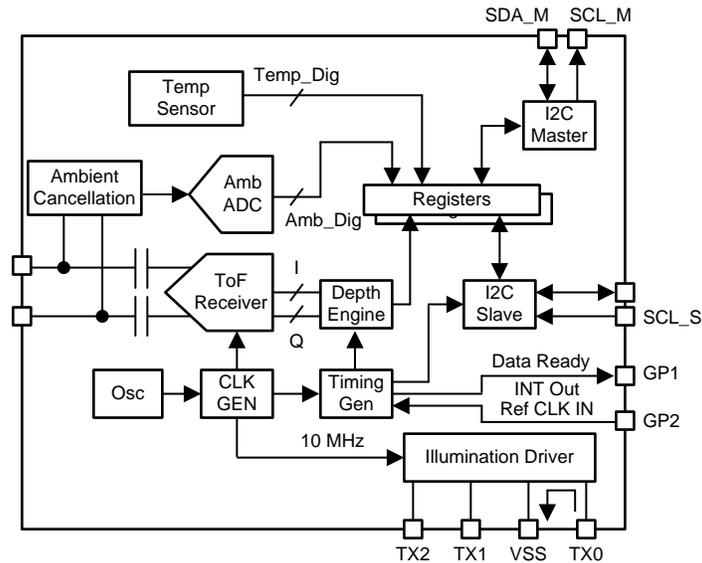
2.2.2 MSP430FR2433

The MSP430FR2433 microcontroller (MCU) is part of the MSP430™ value line sensing portfolio, TI's lowest-cost family of MCUs for sensing and measurement applications. The architecture, FRAM, and integrated peripherals, combined with extensive low-power modes, are optimized to achieve extended battery life in portable and battery-powered sensing applications in a small VQFN package (4 mm × 4 mm).

TI's MSP430 ultra-low-power FRAM microcontroller platform combines uniquely embedded FRAM and a holistic ultra-low-power system architecture, allowing system designers to increase performance while lowering energy consumption. FRAM technology combines the low-energy fast writes, flexibility, and endurance of RAM with the non-volatility of flash.

Figure 3 shows the functional block diagram.

Figure 3. MSP430FR2433 Block Diagram
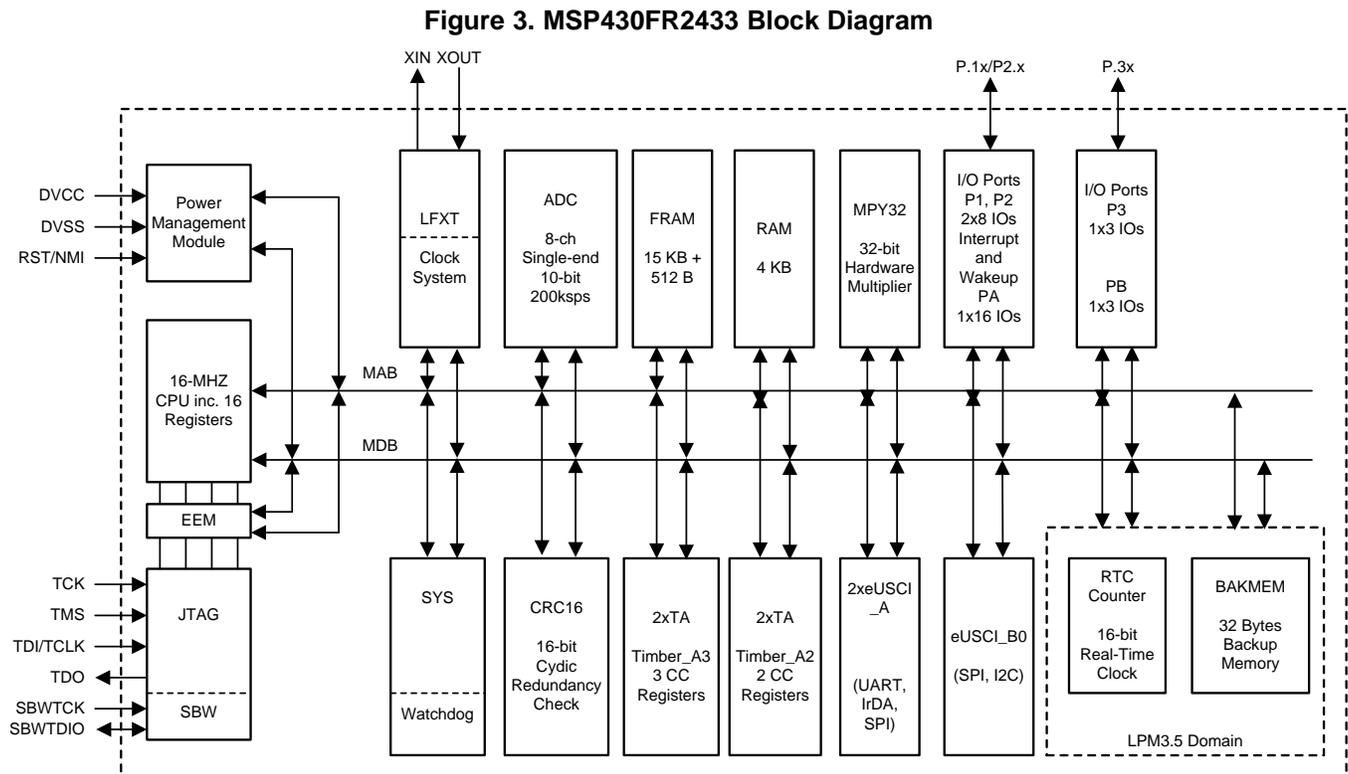
2.2.3 TLC59283

The TLC59283 is a 16-channel, constant-current sink light-emitting diode (LED) driver. Each channel can be individually controlled with a simple serial communications protocol that is compatible with 3.3-V or 5-V CMOS logic levels, depending on the operating VCC. When the serial data buffer is loaded, a LAT rising edge transfers the data to the OUTn outputs. The BLANK pin can be used to turn off all OUTn outputs during power-on and output data latching to prevent unwanted image displays during these times. The constant-current value of all 16 channels is set by a single external resistor. Each constant-current output has a pre-charge field-effect transistor (FET) that can reduce ghosting on the multiplexing (dynamic) drive LED display. Multiple TLC59283s can be cascaded together to control additional LEDs from the same processor.

Figure 4 shows the functional block diagram.

Figure 4. TLC59283 Block Diagram
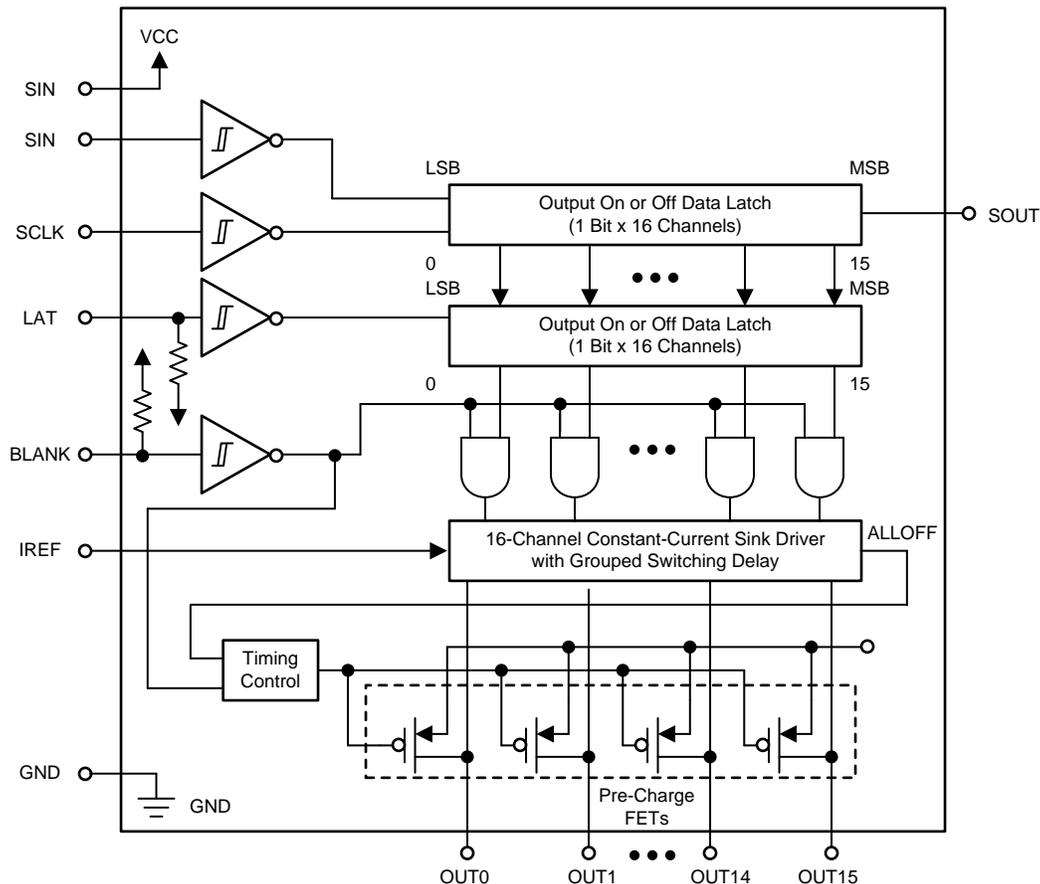
2.2.4 TLV70233

The TLV702 series of low-dropout (LDO) linear regulators are low quiescent current devices with excellent line and load transient performance. These LDOs are designed for power-sensitive applications. A precision band-gap and error amplifier provides overall 2% accuracy. Low output noise, very high power-supply rejection ratio (PSRR), and low dropout voltage make this series of devices ideal for most battery-operated handheld equipment. All device versions have integrated thermal shutdown, current limit, and undervoltage lockout (UVLO).

2.2.5 TPD2E001

The TPD2E001 device is a two-channel transient voltage suppressor (TVS) based ESD protection diode array. The TPD2E001 device is rated to dissipate ESD strikes at the maximum level specified in the IEC 61000-4-2 Level 4 international standard.

2.3 System Design Theory

The block diagram in Figure 1 shows that the complete system is composed by two main sections: miniature optical proximity sensing module with direct distance data output and display module which is used to control the sensor module and show the distance information measured by proximity sensing module to user.

2.3.1 Proximity Sensing Module Design

Proximity sensing is usually used to detect the person presence or motion within the FoV. It is one of the key features in smart appliances. Figure 5 shows an example of a typical system definition.

Figure 5. Proximity Sensing System in Appliances
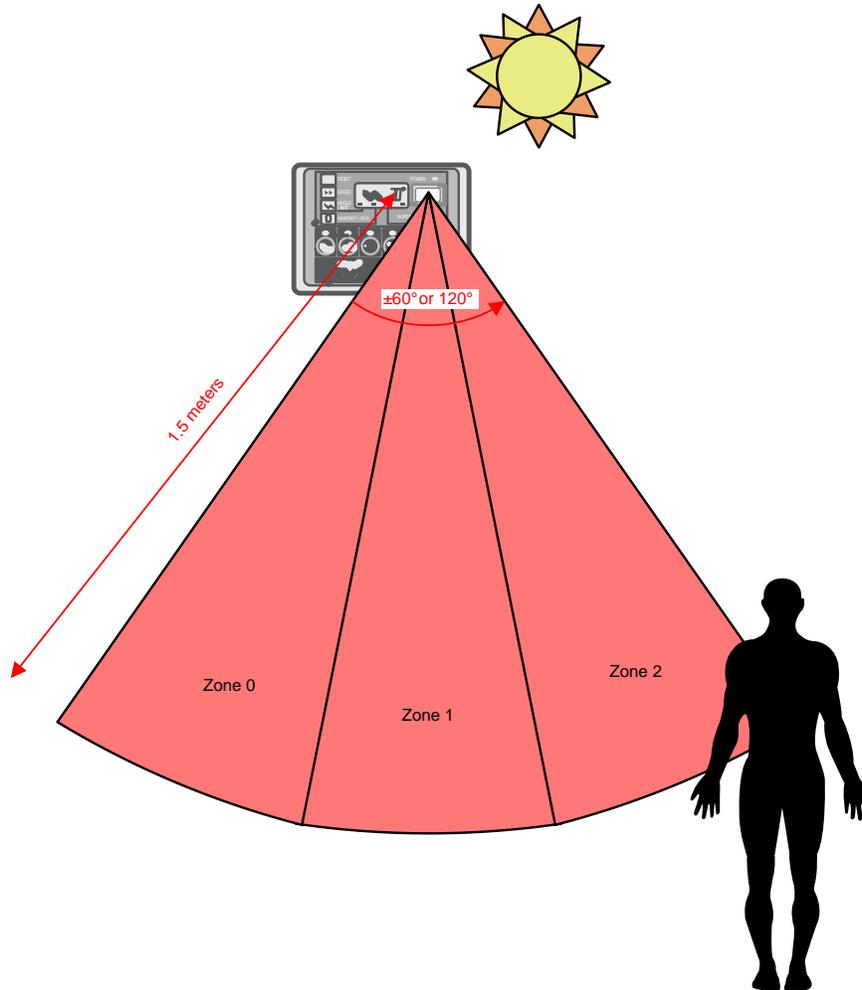
2.3.1.1 *System Design Goal Parameters*

Table 2 elucidates the design goal parameters for this TI Design. These parameters are used in further calculations to select components.

Table 2. Application Requirement Specifications

SPECIFICATION	VALUE	UNITS	COMMENTS
Maximum distance	1.6	m	For an object with 80% reflectivity
Minimum distance	0.1	m	
Distance accuracy	10	%	For an object with 20% reflectivity at 2 meters.
Field of View	±60	degrees	120° for full angle
Ambient light	130	klx	Sunlight condition
Samples rate	10	sps	For each channel

2.3.1.2 Target Type

Based on the reflectance of objects, the target can be classified as diffused reflector, shiny reflector and retroreflector. The details description of these three target type, see the Introduction to Time-of-Flight Optical Proximity Sensor System Design (Rev. A) for more information.

In this reference design, the sensor detects the proximity of human activity. Often times people wearing Clothes with different color is a diffused reflector. The reflectivity of the target expressed in ratio % is characterized by the ratio of the total amount of light reflected off the surface to the ratio of the light incident on the surface. White paper has a reflectivity of over 90% and black denim cloth has a reflectivity of approximately 10%. These are much easier to deal with since the light cast on the target is evenly distributed in all directions making the system immune to the angle and position in which the target lies.

2.3.1.3 Number of Zones

OPT3101 supports up to 3 transmitter channels for multi-zone operation. In other words, three zones can be measured simultaneously with one single OPT3101.

The system design goal FOV of sensor, as described in Table 2, is ±60° (120° full angle). Three options to choose:

- One emitter with one receiver for one zone solution
- Two emitters with one receiver for two zones solution
- Three emitters with one receiver for three zones solution

In the case of single-emitter systems, OPT3101 AFE measures distance of the target illuminated by the emitter. With a large emitter FoV the entire scene turns into a target, making the object of interest less prominent. For example: Imaging a presence-detection system in major appliances where the sensor is placed 1 meter from the ground. Assume the emitter FoV is ±45°. Even with no human presence in front of appliances, the cone of the emitter would engulf the floor starting from 1 meter turning it to a target. The same is applicable to anything in the FoV, including other inanimate objects like chairs, tables, side walls and so forth. The system measures a weighted average distance of all objects in the FoV. A person walking towards the FoV from 2+ meters occupies an insignificant portion of the FoV causing a very small change to the distance (could be undetectable since objects closer, occupying larger portion of the FoV are weighted more), unless the person walks very close to the sensor. This severely limits the range of systems with large-emitter FoVs. The recommendation in such scenarios is to consider multiple emitters each with lower FoV directing light to different portions of the overall detection FoV, which gives more data points per measurement for meaningful behavior detection.

To get accurate human proximity distance information, three zones solution is chosen for this reference design. Figure 6 shows how to realize three zones detection.

Figure 6. Three-Zone Detection With Single OPT3101
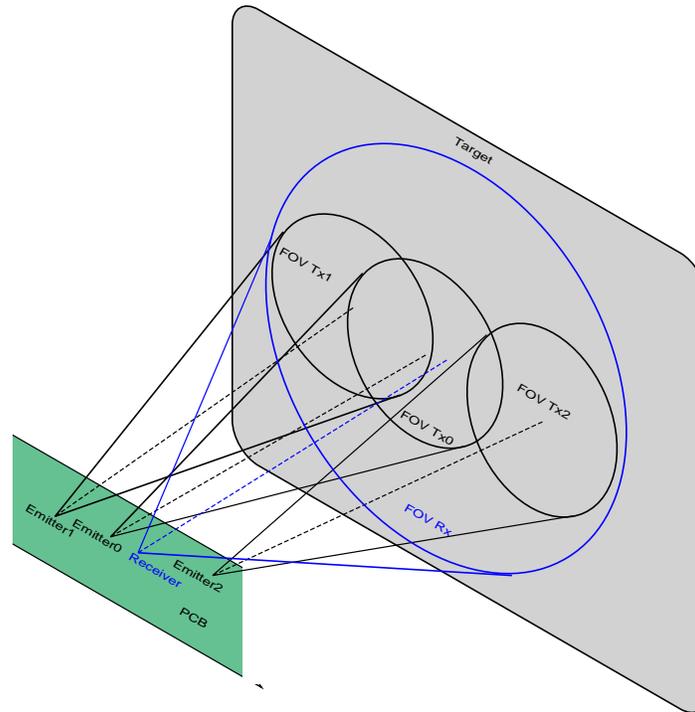
2.3.1.4   Field-of-View (FoV)

Figure 7 shows the definition of FoV. The performance of the system is a strong function of the FoV since many parameters are dependent on it. Generally, the narrower the FoV, the longer the range of the system. There are 2 fields-of-view to be considered, the FoV of the emitter and the FoV of the receiver.

Figure 7. Emitter and Receiver Fields-of-View
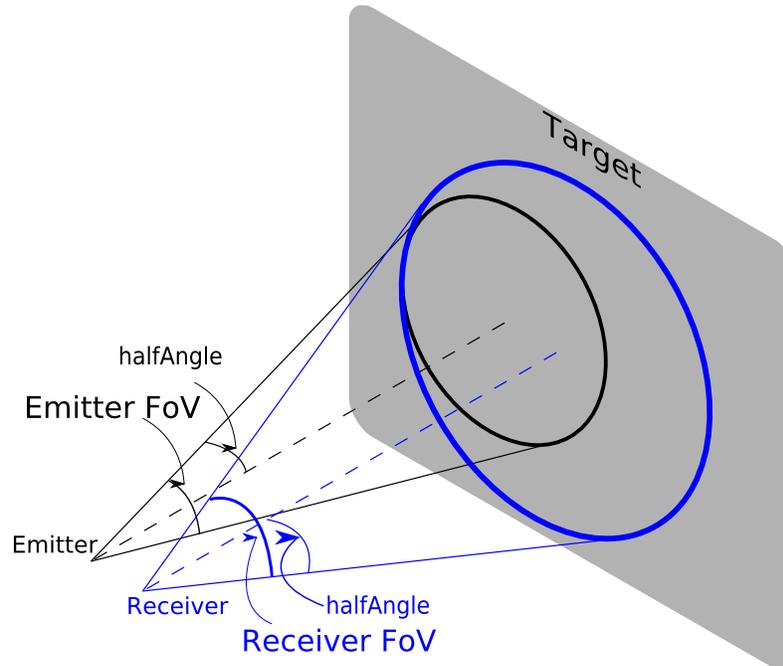
2.3.1.4.1   Emitter FoV

Often times the FOV of emitter is measured in degrees and expressed in half-angle or full-angle subtended by the cone of light emission. Selection of emitter FoV is application specific. Ranging applications demand extremely low emitter FoV whereas object or presence detection demands a large emitter FoV. Minimizing the FoV as small as possible (to a bare minimum, based on application requirement) helps improve the performance and range of the system.

As discussed in 4.3.1.3, the total FOV of system which is defined as 120° will be covered by three zones. The FOV of each zone is therefore 40°. So the emitter FOV should be no less than 40°. So the emitter FoV rang from 40° to 50° is the best choice.

2.3.1.4.2   FoV of Receiver

Similarly, FoV of receiver which is usually photodiode can be expressed in half-angle or full angle, subtended by the cone of light collection and measured in degrees. OPT3101 can only accept one receiver to receive the reflection of light. Therefore the FoV of receiver needs to be equal to or larger than the system FoV which is defined as 120°. But it is not the case that the larger, the better. Performance is a strong function of FoV and it has a great impact on both ambient light collection and signal light collection. First-order approximation for the respective gains are found using the following formula. This shows that reducing the FoV increases both signal gain and reduces ambient gain improving performance by a great deal.

$$signalGain \propto \frac{1}{\left(\tan\left(\frac{fov}{2}\right)\right)^2}$$

$$ambientGain \propto \left(\tan\left(\frac{fov}{2}\right)\right)^2$$

(1)

Therefore, FoV of receiver range from 120° to 130° is the best choice.

2.3.1.5 Wavelength (λ)

2.3.1.5.1 Medium of Transmission

In the application of proximity sensing for major appliances, the transmission medium is air, where the properties of transmission are the same in the wavelengths of consideration. Sometimes the sensor need to fixed behind some kind of glass or plastic panel which shield the visibility of sensor module from external. In this case, it is necessary to ensure that the material of the panel has good penetration to the light of the selected wavelength.

2.3.1.5.2 Eye and Skin Safety

Eye and skin safety standards are very dependent on the wavelength of operation. Based on the chosen wavelength, different aspects of safety measurements and safety analysis must be made to certify and classify the system. There are different lists of compliance checks and measurements based on wavelength chosen both for laser or VCSEL sources and LEDs. Hence while choosing center wavelength these parameters must be considered as well.

2.3.1.5.3 Visibility to Naked Eye

Visibility to naked eye of light source which is used as emitter depends on application requirement. The OPT3101 device being just an AFE, supports a wide variety of wavelengths subjected only to the availability of photodiode and emitter components. Emitter and photodiode should have matching peak sensitivities.

Emitters usually have two categories based on visibility to naked eye: visible spectrum and invisible spectrum. The visible light wavelength ranges from 390 nm to 700 nm and response of human eye peaks around 500 nm to 550 nm. In TOF-based systems, near-infrared (NIR) wavelength ranging from 750 nm to 1400 nm is in invisible spectrum and widely adopted. Since NIR wavelengths are very close to the visible range, NIR emitters are still visible to the naked eye under dark enough circumstances. This is predominant with emitters around 850 nm. This may be unacceptable in certain applications where users are distracted. In such cases going deeper into the NIR spectrum helps, like moving to 940 nm.

The proximity sensing in major appliances often require no visible detection wavelength. The spectrum of the emitter should be in near infrared field and the wavelength (λ in nm) of light illuminating by emitter should be no less than 850 nm.

2.3.1.6 Target Distance

Performance of the system is a strong function of the target distance. OPT3101-based systems are capable of operating over a wide range of target distances (from a few mm to 10s of meters) based on component selection and optics design. The target distance in this application ranges from 0.1 to 1.5 meters with 10% accuracy of distance output for proximity sensing.

2.3.1.7 Dynamic Range

In ToF based application, the strength of reflected light determine the dynamic range. The photodiode may enter saturation status when reflected light is too strong such as short distance measurement. But for long distance measurement, the strength of reflected light may be too weak for OPT3101 to operate reliably. So dynamic range is represented by the range of operating conditions for which the OPT3101-based system is expected to operate without losing performance target and saturation. Adaptive HDR of OPT3101 can be set to increase the dynamic range.

- **Distance range:**

  System is expected to work from 100 mm to 1500 mm, then the dynamic range required is 225 times or 47 dB (follows square law for distance).

- **Reflectivity range:**

  System is expected to work for both 10% reflectivity target and 90% reflectivity target, then the dynamic range required is 9 times or 19 dB

The dynamic range requirement for the system is 225 × 9 = 2025 (expressed in ratio of maximum to minimum) or when expressed in decibels – it is 66 dB.

2.3.1.8 Performance Target

Figure 8 shows the various performance parameters.

Figure 8. Performance Target Definitions
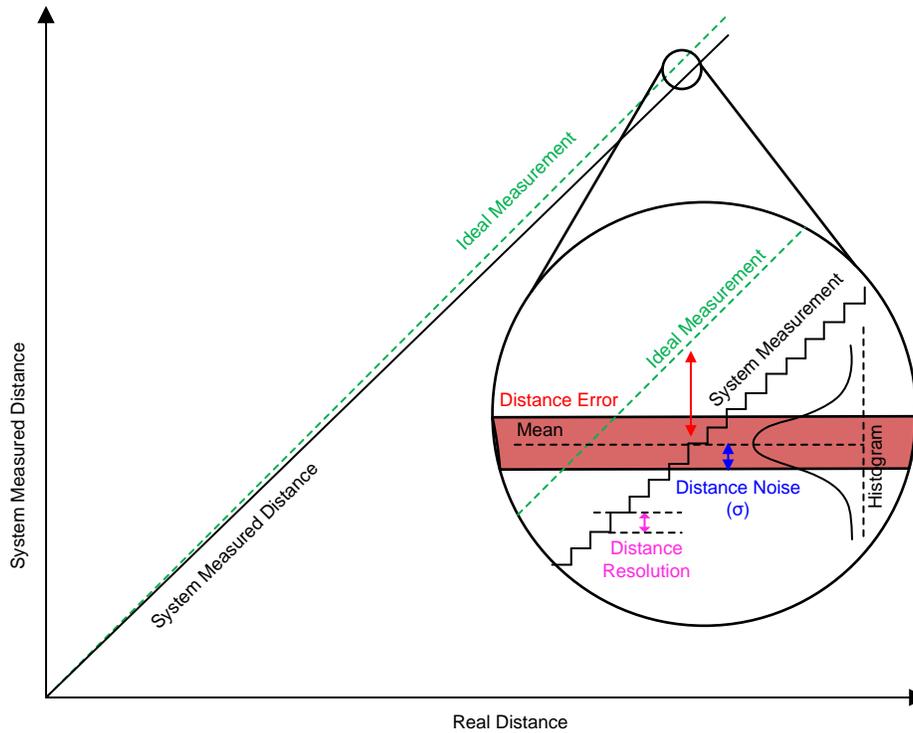
- Distance Resolution

  This is defined as the minimum possible distance that can be resolved by the OPT3101-based system. Distance resolution is usually not a key concern in proximity sensing applications. 1cm resolution is defined in this design.

- Distance Accuracy

  This is defined as the difference between actual target distance and the measured distance presented by the OPT3101-based system. This does not include distance noise and truly represents the offsets and drifts. In this design, distance accuracy is pre-defined in Table 3.

- Distance Noise (σ)

  This is defined as the standard deviation (σ) of the measurements over a set of samples taken over time. The larger the sample size, the better estimation of σ.

Table 3. Distance Accuracy in Various Operating Conditions

DISTANCE (m)	REFLECTIVITY (%)	ACCURACY (M)
0.1	20	0.01
	80	0.005
0.5	20	0.05
	80	0.025
1.0	20	0.1
	80	0.05
1.5	20	0.15
	80	0.1

Copyright © 2018, Texas Instruments Incorporated

2.3.1.9 Data Rate

Data rate is typically specified as a system vector input for the design based on application need. In this design, the data rate for proximity sensing is defined to run at 10 samples per second (sps). Since system FoV of 120° in this design is covered by three emitters, the total samples per second for OPT3101 is 30.

2.3.1.10 Selection of Emitter

2.3.1.10.1 Type of Illuminator

The OPT3101 device is a fully integrated analog front end (AFE) based on the time-of-flight (ToF) principle using active illumination. The OPT3101 AFE connects to an external illuminator (LED, VCSEL, or LASER) to transmit modulated optical signals, and reflected signals are received by an external photodiode which connects to the input of the AFE. The received signal is converted to amplitude and phase information by the AFE and depth engine.

LEDs are the most common and least expensive type of illuminator. LEDs are available in a wide range of wavelengths, power levels, and FoVs. LEDs tend to have lower efficiency due to light extraction loss and poor heat dissipation as compared to other illuminators. Since the light coming from the LED is not coherent and from a large surface area, these are extremely hard to collimate to a narrow beam. However, for application requirements larger than around a ±3° of FoV, LEDs are suitable. LEDs have robust construction, hence, have a better ESD performance and failure rate, and are therefore preferred for automotive applications compared to the other types of emitters. Depending on the power of the emitter, FoV LED certification and lamp source classification may be required

Edge-Lasers are available for specific wavelengths and power levels from selected distributors. These are more expensive compared to LEDs, but have higher efficiencies. Light generated is coherent, from a small apparent source; therefore, can be collimated to a very high degree. For example, a laser source with a collimating lens can be focused to a beam as narrow as a few mm in diameter, maintaining its beam diameter to a distance up to several meters. However, high-power lasers could be harmful and have export control regulations and require additional certification. These emitters are very sensitive to ESD and overvoltage damage. Adding protection circuitry in the illumination circuitry extends system longevity.

VCSELs are similar to lasers, except their construction allows them to be highly-efficient emitters available at various different power levels. Sometimes VCSELs are custom made as per required specifications. Due to their physical construction, VCSELs have the highest-efficiency emitters available in the smallest form-factor packages. VCSEL light is coherent and may be collimated to a great degree, similar to edge emitting lasers. VCSEL packages can also be designed to have specific diffusers as part of the package to achieve required intensity profiles. However, high-power VCSELs could be harmful to the naked eye; therefore, they have export control regulations and need additional certification. These emitters are very sensitive to ESD and overvoltage damage. Adding protection circuitry in the illumination circuitry helps system longevity.

For proximity sensing with wide FoV, high power Infrared LED is the best choice. The evaluation of eye safety occurs according to the standard IEC 62471:2006 (photo biological safety of lamps and lamp systems). Within the risk grouping system of this IEC standard, the LED falling into the class exempt group can be selected in this application.

2.3.1.10.2 Emitter Specification Parameters

Table 4 shows the parameters requirement for high power infrared LED selection based on previous discussion.

Table 4. Emitter Specification Parameters

| PARAMETERS	VALUE	UNIT	COMMENTS
FoV (Full-Angle)	40 – 50	degree	±20° – ±25° (Half-Angle)
Wavelength	≥ 850	nm	
Eye Safety	exempt group	–	standard IEC 62471:2006 (photo biological safety of lamps and lamp systems)

2.3.1.10.3 Selection Result

The OSRAM SFH4556 LED meets the required FoV specification and has peak spectral emission at 860 nm. Table 5 shows the radiation characteristics of the LED.

See the *Radiation Characteristics* graph in the SFH4556 data sheet from Osram Opto Semiconductors.

Figure 9. SFH4556 Relative Spectral Emission
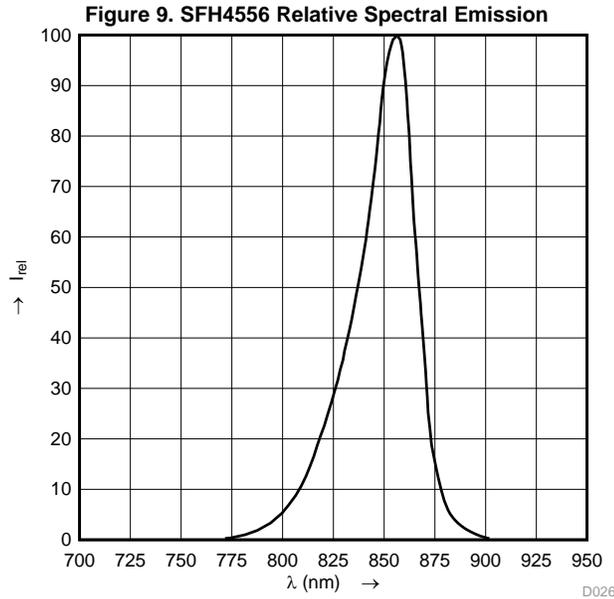
Table 5. Emitter Specification Parameters

SPECIFICATION	VALUE	UNITS
Peak wavelength	860	nm
Centroid wavelength	850	nm
Spectral bandwidth at 50% $I_{rel,max}$	30	nm
Half angle	20	degree
Rise time (10%, 90%) I_F = 100 mA; R_L = 50 Ω	12	ns
Fall time (10%, 90%) I_F = 100 mA; R_L = 50 Ω	12	ns

2.3.1.11 Photodiode Selection

2.3.1.11.1 Type of Photodiode

PIN photodiodes are recommended due to their responsivity and fast switching times. Photodiodes fundamentally respond to a large bandwidth of wavelengths (spectral bandwidth); however they have peak sensitivity only at particular wavelength. The photodiode should also have peak sensitivity matching the peak spectral emission of the LED.

2.3.1.11.2 Wavelength (λ in nm)

Photodiodes fundamentally respond to a large bandwidth of wavelengths (spectral bandwidth); however they have peak sensitivity only at particular wavelength. Photodiodes are best operated at that wavelength to reap the best performance, although not a strict requirement. The wider the spectral bandwidth of the photodiode, the more current it generates from sunlight or other ambient light posing a limitation to the system, hence, a photodiode with a built-in filter around the wavelength of interest helps improve ambient performance. In session 4.3.1.10, centroid wavelength of emitter is 850nm. So the wavelength of peak sensitivity for photodiode should be around 850nm.

2.3.1.11.3 *Junction Capacitance (C_j in pF)*

In an OPT3101 system the photodiode is reverse biased at a constant 1 V. Hence, the junction capacitance of the photodiode when reversed biased at 1 V determines the performance of the system. OPT3101 supports a maximum capacitance of 6 pF. So the junction capacitance of photodiode at 1 V bias should be less than 6 pF.

2.3.1.11.4 *Rise and Fall Times*

The OPT3101 device operates at 10 MHz, hence photodiodes with rise and fall times ≤ 10 ns are recommended. Choosing photodiodes with larger rise and fall times could mean loss in performance.

2.3.1.11.5 *Package and Case Type Selection*

Photodiodes come is various different packages and cases with different soldering options. SMD components tend to have profile height; therefore, better parasitic and crosstalk resilience. In this design, application requirements 120° FoV and covers by three emitters, so through-hole photodiodes are chosen so that they can be bent to the right direction.

2.3.1.11.6 *Photodiode Selection Parameters*

Table 6 shows the parameters requirement for photodiode selection based on previous discussion.

Table 6. Photodiode Selection Parameters

FoV	TYPE	WAVELENGTH	JUNCTION CAPACITANCE	RISE AND FALL TIMES	PACKAGE
≥ 120°	PIN	near 850 nm	< 6 pF at 1 V	≤ 10 ns	TH

2.3.1.11.7 Photodiode Selection Result

The OSRAM SFH203PFA photodiode meets the required parameters. Figure 10 and Figure 11 show the photodiode characteristics. Table 7 lists the photodiode specifications.

Figure 10. SFH203PFA Relative Spectral Sensitivity

Figure 11. SFH203PFA Photodiode Reverse Bias Capacitance
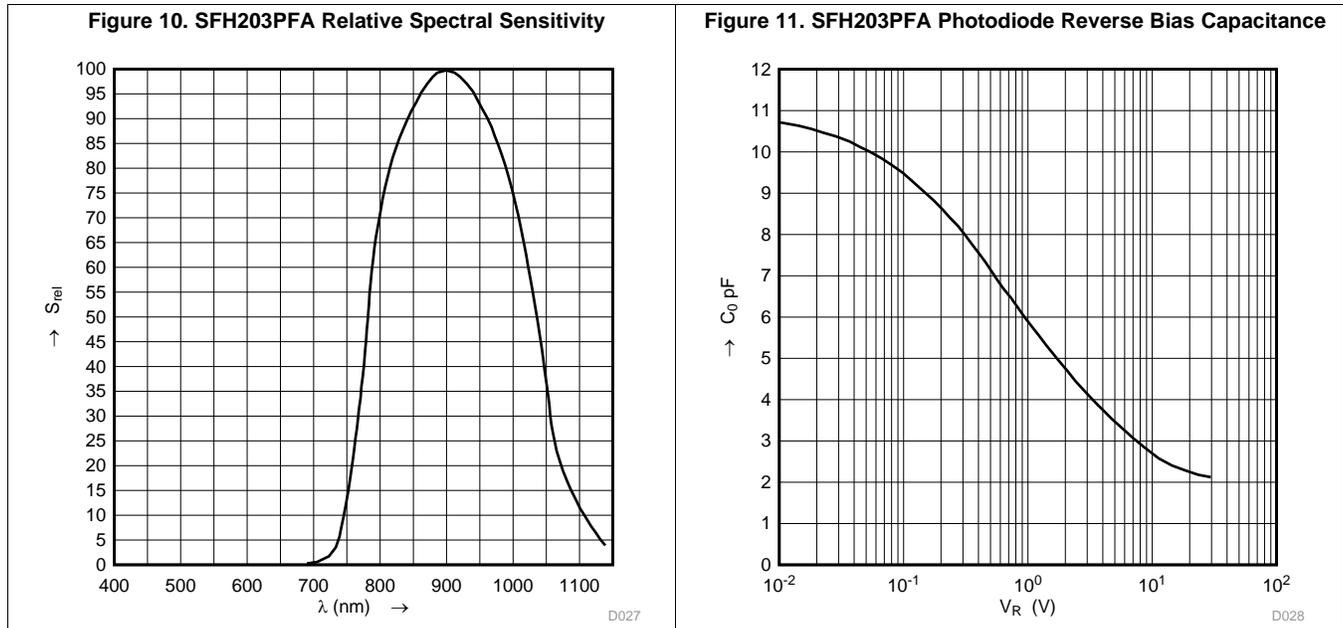
See the *Directional Characteristics* graph in the SFH 203 PFA data sheet from Osram Opto Semiconductors.

Table 7. Emitter Specification Parameters

SPECIFICATION	VALUE	UNITS	COMMENTS
Photodiode current with 1 mW/cm2	6.2	µA	Photodiode specification
Half-angle	± 75	degree	Photodiode specification
Ambient current	105	µA	See OPT3101 System Estimator
Reverse bias capacitance at VR = 1 V	5.8	pF	AFE supports a maximum capacitance of 6 pF

Use the OPT3101 System Estimator for system performance estimation.

2.3.1.11.8 Responsivity (Ƴ in A/W)

The responsivity of the photodiode is measured in A/W which determines the amount of current produced in Amperes for a given watt of monochromatic light (at a specified wavelength) thrown on to the photodiode. Variation in wavelength causes the responsivity to vary as per Figure 12. When a multichromatic light is thrown on the photodiode, the current generated is the integral of the multiplication of the spectral curves of the source and photodiode. This calculation is critical for ambient current calculation especially sunlight. See Table 7 for the calculation result.

Figure 12. SFH203PFA Photodiode Spectral Response and Sunlight Power Within Photodiode Spectral Bandwidth
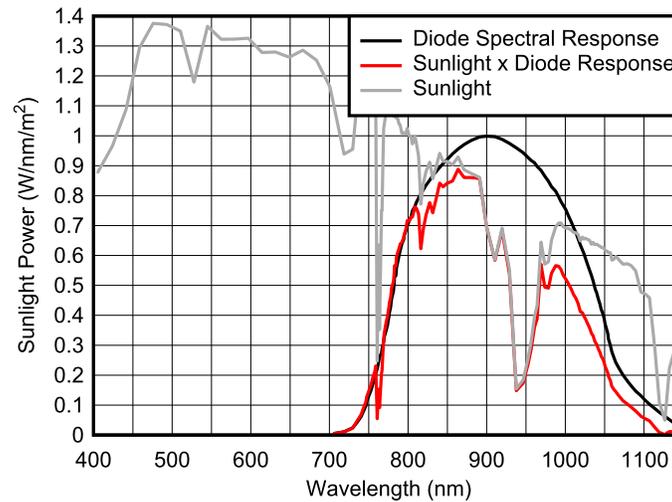
2.3.1.12   Power Supply Recommendations

The OPT3101 device requires 1.8-V and 3.3-V supplies. There are two 1.8-V supplies (AVDD and DVDD) and two 3.3-V supplies (AVDD3 and IOVDD). AVDD and AVDD3 are analog supplies, DVDD and IOVDD are digital and I/O supplies. VDD_LED is not a device pin, but the supply connecting to the anode of the LED (Illumination source). The transmitter and receiver of the OPT3101 device operate at the same modulation frequency (10 MHz). Any coupling from the transmitter switching to the AFE results in a crosstalk signal which affects the performance of the distance measurement. Achieving the lowest possible crosstalk is critical for an accurate distance measurement system. Care should be taken to isolate all analog and switching supplies. Use ferrite beads with the highest impedance at 10 MHz (> 500 Ω) in the series path of the supplies and decoupling capacitors with low impedance at f_{MOD} on the supplies very close to the device.

2.3.1.13   Sensor Module Schematic

Figure 13 shows the schematic of proximity sensor module based on OPT3101.

Figure 13. Sensor Module Schematic
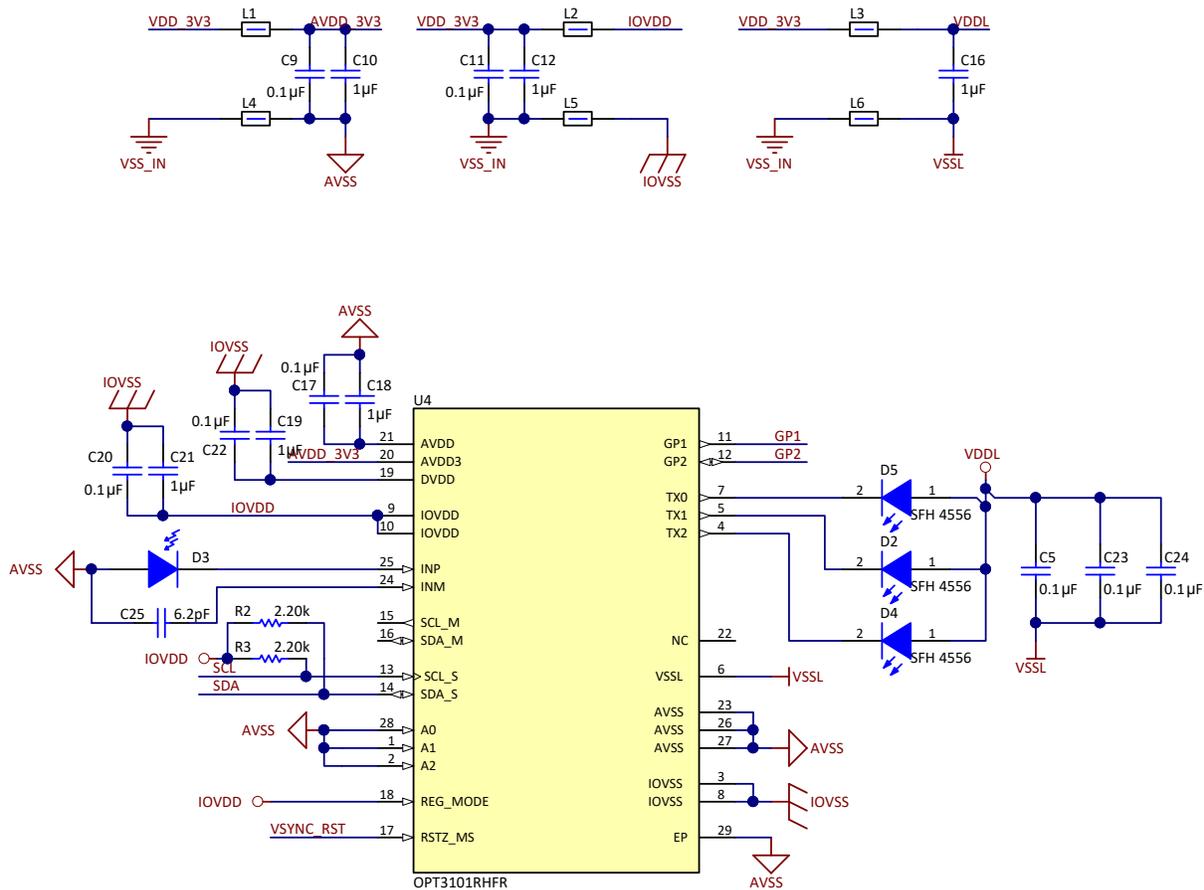
2.3.1.14 Isolation

2.3.1.14.1 Crosstalk

Crosstalk is defined as the signal detected by the AFE system when there is no target before the system. It could also be the signals detected by the AFE when the target is too far away to detect by the system. Crosstalk plays a critical role in determining the system's absolute error and dynamic range. Two types of crosstalk should be considered: electrical crosstalk and optical crosstalk.

Electrical crosstalk occurs due to electromagnetic coupling from transmitter or digital switching nets on the PCB to the analog side. Optical crosstalk occurs due to poor optical isolation or cover glass design.

The OPT3101 device has various built in crosstalk correction capabilities outlined in the data sheet and calibration guides of the device. However it is important to minimize the crosstalk as much as possible to extract best performance from the system.

2.3.1.14.2 Aggressor and Victim Nets

OPT3101 AFE input nets INP and INM are high impedance nets suitable to electromagnetic coupling. There are 2 mechanisms of coupling that induces crosstalk, the voltage coupling and the current coupling. OPT3101 AFE is immune to coupling from other frequencies apart from the modulation frequency. Hence a ripple frequency from a DC/DC convertor or other clock frequencies on the board would not have significant impact to crosstalk, however even a small amount of coupling from the TX0, TX1, TX2 nets would increase the crosstalk several fold.

Victims are always INP, INM, AVSS, AVDD and AVDD3 nets. Aggressors are TX0, TX1, TX2, VSSL, Anode of emitters, IOVSS, DVDD.

2.3.1.14.3 *Electrical Isolation*

A well designed PCB layout, which is discussed in 6.3, is crucial to minimize the electrical crosstalk and achieve best performance. Even if utmost care if taken to improve the PCB layout, the lead length and the spacing of the through hole LEDs and photodiode which is chosen in this design, make the loop area large and make the electrical crosstalk quite high reducing system dynamic range. In such cases an electrical isolation structure which is connected to AVSS is recommended around the photodiode to isolate the photodiode from coupling. It is recommended that the material has good electrically conductivity, magnetically inactive and soldered AVSS exposed pads on the PCB.

2.3.1.14.4 *Optical Isolation*

Optical isolation between the emitter and receiver is crucial to achieve good system performance. Having any amount of light leakage from the emitter directly to the receiver could make the system unusable. In this design, a specific ring is design to act electrical isolation and optical isolation.

Refer to Introduction to Time-of-Flight Optical Proximity Sensor System Design (Rev. A)chapter 7.2 for more information.

2.3.1.15 *System Estimator Tool*

The OPT3101 System Estimator is a tool for simulating the performance of the OPT3101 AFE under various conditions. Download *OPT3101 System Estimator Software* and read the *OPT3101 System Estimator* user guide. Evaluate the system performance with the selected parts. Figure 14 shows the performance estimation for this reference design. SFH2400FA is a similar part as SFH203PFA in characteristics which is selected in this reference design.

Figure 14. System Estimation

*Wide-Range (120° FoV at 1.6 Meters) Proximity Sensing Reference Design
With Immunity to Sunlight*
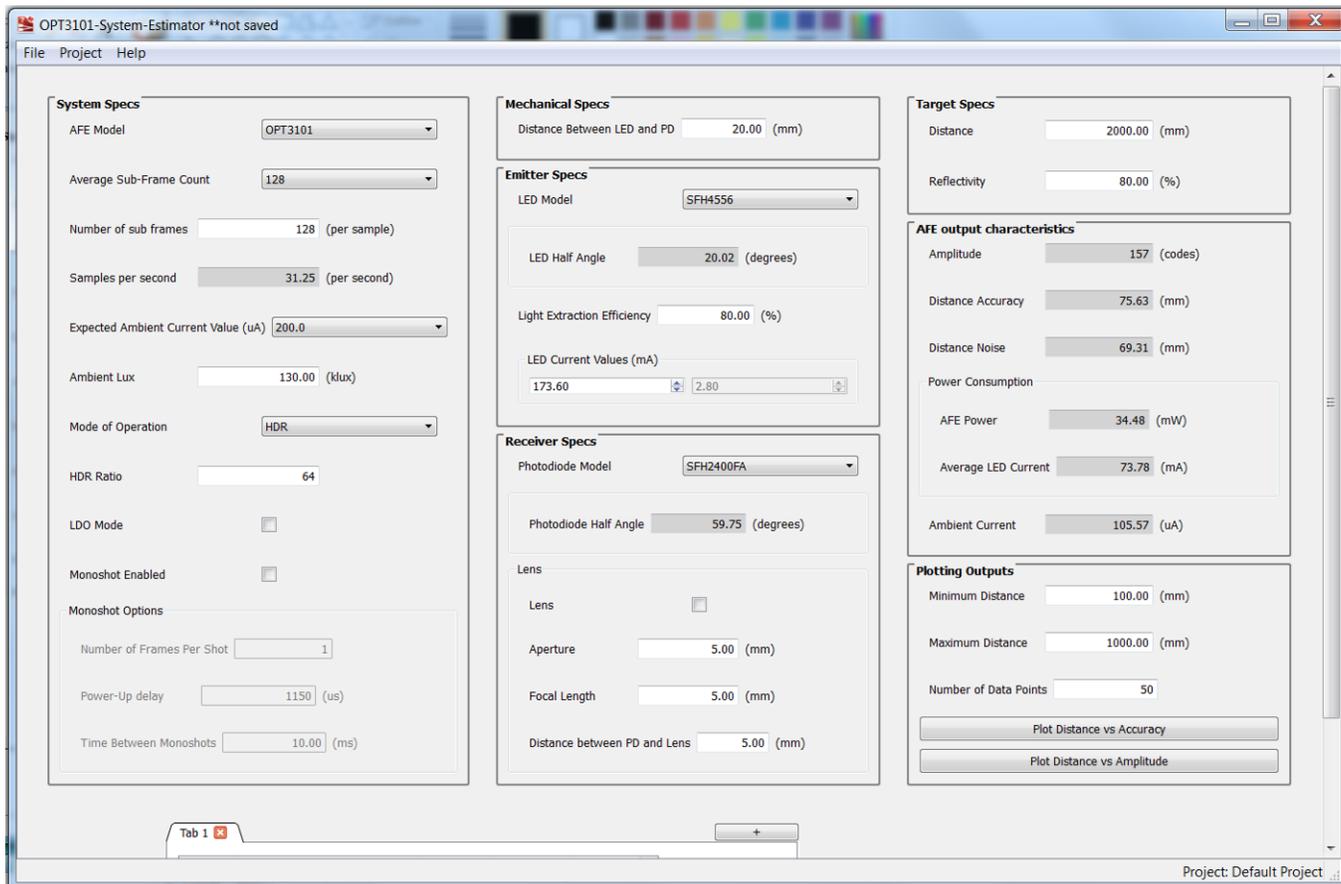
2.3.2   Display Module Design

A display module with the MSP430FR2433 microcontroller is designed to control OPT3101 and get depth data from it. Then the distance information for proximity sensing is shown in dual digital display. This reference design uses the 16-channel LED driver TLC59283 to drive display so that IOs of MCU can be saved.

Figure 15. Display Board Schematic

3 Hardware, Software, Testing Requirements, and Test Results

3.1 Required Hardware and Software

3.1.1 Hardware

3.1.1.1 Hardware Overview

The whole design consists of two parts: sensor board and display board. These two boards can be connected by J4. Figure 16 shows the overview of the PCB for sensor board and Figure 17 shows the display board. The user can also connect sensor board to their own controller system. A micro USB connector (J1) in display module is used only for 5-V power supply input without data communication.

Figure 16. Sensor Board - Top View and Bottom View

Figure 17. Display Board - Top View and Bottom View

3.1.1.2   Programming Interface for the MSP430™ MCU

J2 is reserved as the programming interface for the MCU. The designer can program the MSP430 MCU using the JTAG port, Spy-Bi-Wire (SBW), and the bootloader BSL. In this reference design, SBW has been adopted for programming and is a two-wire Spy-Bi-Wire interface. Spy-Bi-Wire can be used to interface with MSP430 development tools and device programmers. Table 8 lists the Spy-Bi-Wire interface pin requirements. For further details on interfacing to development tools and device programmers, see MSP430 Hardware Tools User's Guide.

Table 8. Spy-Bi-Wire Pin Requirements and Functions

J2 PIN NUMBER	DEVICE SIGNAL	DIRECTION	SBW FUNCTION
1	VSS	—	Ground supply
2	TEST/SBWTCK	IN	Spy-Bi-Wire clock input
3	RST/NMI/SBWTDIO	IN, OUT	Spy-Bi-Wire data input and output
4	VCC	—	Power supply

3.1.2   Firmware

3.1.2.1   Application Firmware Description

The firmware of this reference design runs on MSP430FR2433 device, in which an optical TOF based proximity sensing and system calibration is implemented. The firmware includes two parts: system calibration and proximity sensing. The system calibration firmware implements the OPT3101 calibration procedure to get calibration parameters and save to FRAM of MSP430FR2433. The proximity sensing firmware loads calibration parameters from FRAM to configure the OPT3101 device over I²C and reads the measured distance data. And then the firmware configures the TLC59283 device to drive LED segments to display distance. This system calibration routine must be done one time per board to get accurate distance measurements.

Table 9 lists the system components for the firmware of this reference design.

Table 9. TIDA-010021 Firmware System Components

ITEMS	DESCRIPTION
Integrated development environment (IDE)	Code Composer Studio™ v7.2
Target MCU	MSP430FR2433
LaunchPad™ Development Kit	MSP430™ LaunchPad™
MCU to OPT3101 connector	P1.2 - SDA; P1.3 - SCL; P1.7 – GP1, P2.2 – GP2
MCU to TLC59283 connector	P2.3 – SIN; P2.4 – SCLK; P2.5 – LAT; P2.6 – BLANK
MCU to LaunchPad connector	TEST – DEBUG; RESET- DEBUG; TXD – Reserved for User Interface; RXD – Reserved for User Interface

3.1.2.2 *Prerequisites for Developing and Running*

This reference design board can work as a stand-alone board after flashing the MCU firmware and downloading it to the MSP430™ MCU. To develop and debug the firmware using TI's CCS Integrated Development Environment (IDE), a TI LaunchPad kit or MSP-FET430UIF is required for programming and debugging the reference board. Figure 18 shows the hardware interconnections required between the design board and the LaunchPad for flashing the code in this reference design. Make sure that the jumper has been removed before connecting the LaunchPad and TIDA-010021 board.

Figure 18. LaunchPad™ and TIDA-010021 Board Connections Diagram
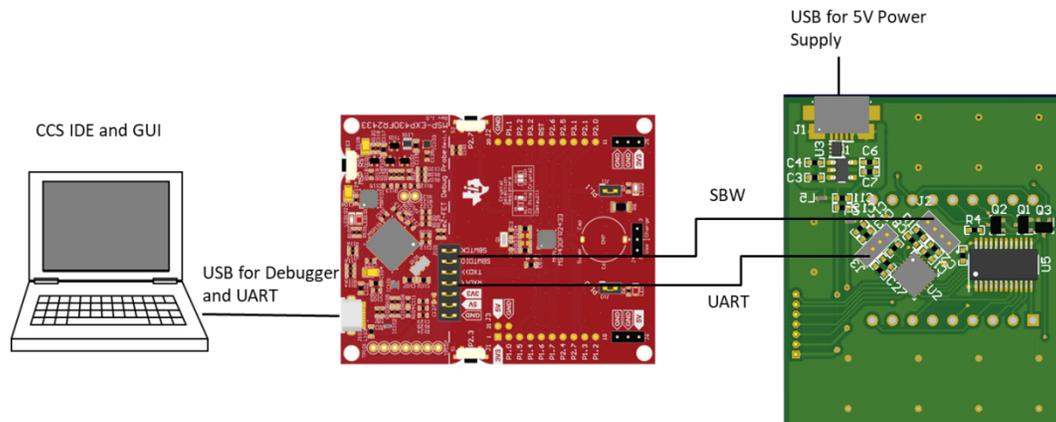
Make sure to download and install the following prerequisites to the computer:

* Code Composer Studio™ (CCS) v7.2
* TIDA_010021_RevA Firmware

Copyright © 2018, Texas Instruments Incorporated

3.1.2.3   *Programming the MSP430™*

The user can edit and program the firmware of the MSP430™ MCU. The instructions for programming the TIDA-010021 board are as follows:

1. Import the TIDA_010021_RevA project using TI's CCS software.

2. Connect the LaunchPad programmer to the TIDA-010021 board, as Figure 18 shows.

3. Build the project by clicking the *Build* button (hammer icon), which if run successfully, appears as follows in Figure 19.

4. Click the *Debug* button (bug icon) as Figure 19 shows.

Figure 19. Build and Debug Using Code Composer Studio™ From TI
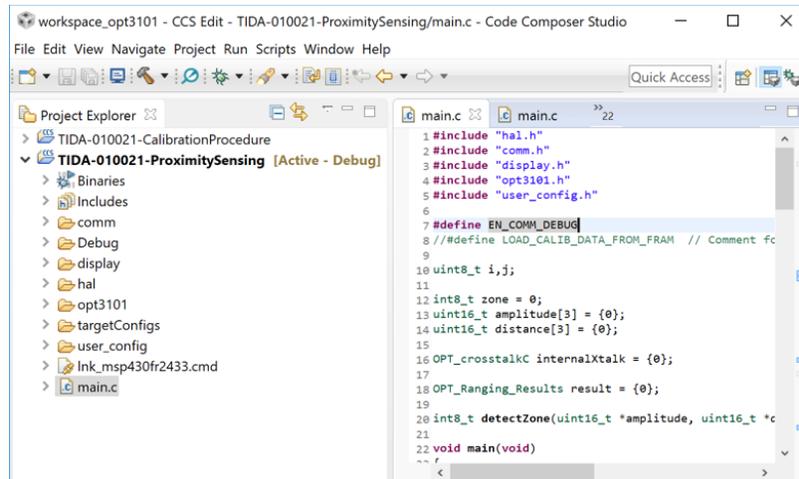
3.1.2.4   *Firmware Structure*

Figure 20 shows the TIDA-010021 firmware structure. The TIDA-010021 reference design firmware includes hardware peripheral drivers, onboard chip drivers and application code three parts. The user can port the TIDA-010021 firmware to other MSP430™ device by modifying the "Hal Layer" drivers easily.

Figure 20. TIDA-010021 Firmware Structure
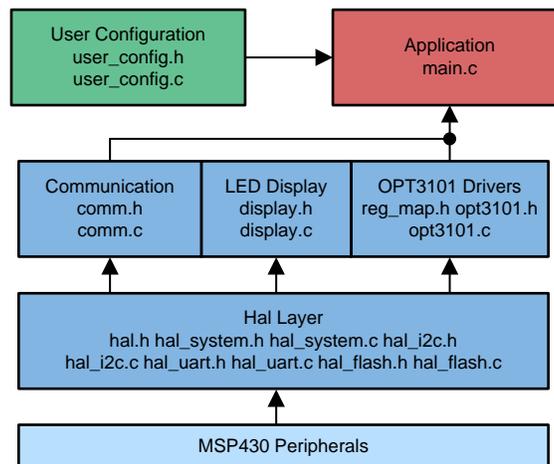
3.1.2.5   *User Application Flow Charts*

3.1.2.5.1   *Capture Flow Chart*

Figure 21 shows the flow chart of proximity application firmware in MCU. TI offers this firmware example in which system hardware initialization, OPT3101 calibration parameters loading and repeatedly proximity sensing has been implemented. If calibration parameters are not available in FRAM or <user_config.c>, the user need run the system calibration routine firstly. Besides, this firmware reserves the UART communication interface for directly reading and writing OPT3101 registers. User can use this interface to debug or develop a GUI on PC.

Figure 21. Proximity Application Flow Chart

Wide-Range (120° FoV at 1.6 Meters) Proximity Sensing Reference Design With Immunity to Sunlight

Copyright © 2018, Texas Instruments Incorporated
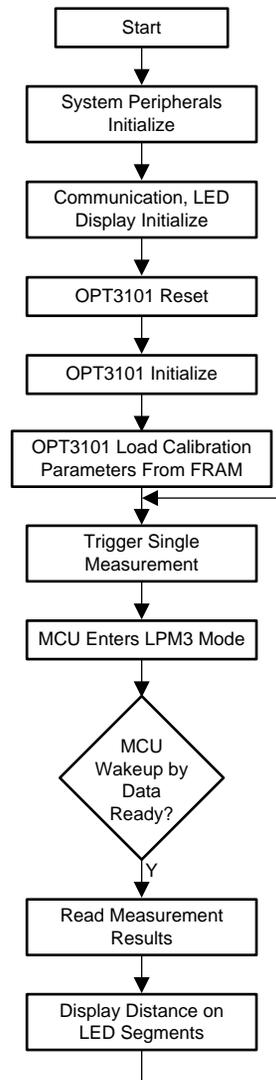
3.1.2.5.2   *System Calibration Flow Chart*

Figure 22 shows the flow chart of system calibration. This calibration routine must be done one time per TIDA-010021 board and save the calibration parameters to MSP430FR2433 on-chip FRAM memory space. Once running proximity application, MCU loads the calibration parameters from FRAM to OPT3101.

Figure 22. System Calibration Flow Chart

```
                 ┌──────────────────┐
                 │      Start       │
                 └──────────────────┘
                          │
                 ┌──────────────────┐
                 │ System Peripherals│
                 │     Initialize    │
                 └──────────────────┘
                          │
                 ┌──────────────────┐
                 │  OPT3101 Reset   │
                 └──────────────────┘
                          │
                 ┌──────────────────┐
                 │ OPT3101 Initialize│
                 └──────────────────┘
                          │
                 ┌──────────────────┐
                 │ Frequency Calibration│
                 │     (Optional)    │
                 └──────────────────┘
                          │
                 ┌──────────────────┐
                 │ Cover Photodiode and│
                 │ Illumination Crosstalk│
                 │    Calibration    │
                 └──────────────────┘
                          │
                 ┌──────────────────┐
                 │ Remove Cover, Set│
                 │  Target Object at │
                 │ Reference Distance│
                 └──────────────────┘
                          │
                 ┌──────────────────┐
                 │Phase Offset Calibration│
                 └──────────────────┘
                          │
                 ┌──────────────────┐
                 │ Save Calibration │
                 │  Data to FRAM    │
                 └──────────────────┘
                          │
                 ┌──────────────────┐
                 │       End        │
                 └──────────────────┘
```
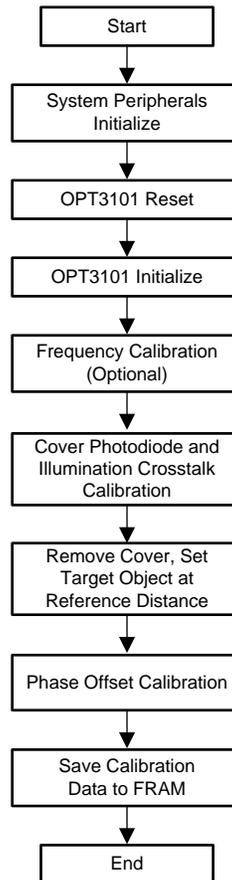
The user can run the <TIDA-010021-CalibrationProcedure> project to calibrate the crosstalk and phase offset for all three channels and illumination current. These calibration data will be stored to MSP430 FRAM and loaded when running <TIDA-010021-ProximitySensing> project. The reference distance setting should ensure the received signal amplitude is high (AMP_OUT > 10000). For more details about the calibration process, see the *OPT3101 Distance Sensor System Calibration* User's Guide.

The brief instructions for using the TIDA-010021 firmware calibration part are as follows:

1. Set the LED illumination driving current and target reference distance (for example 150 mm) in <user_config.c> source file for all three channels and two illumination current used in HDR mode, shown in Figure 23.

Figure 23. Calibration Settings in user_config.c Source File
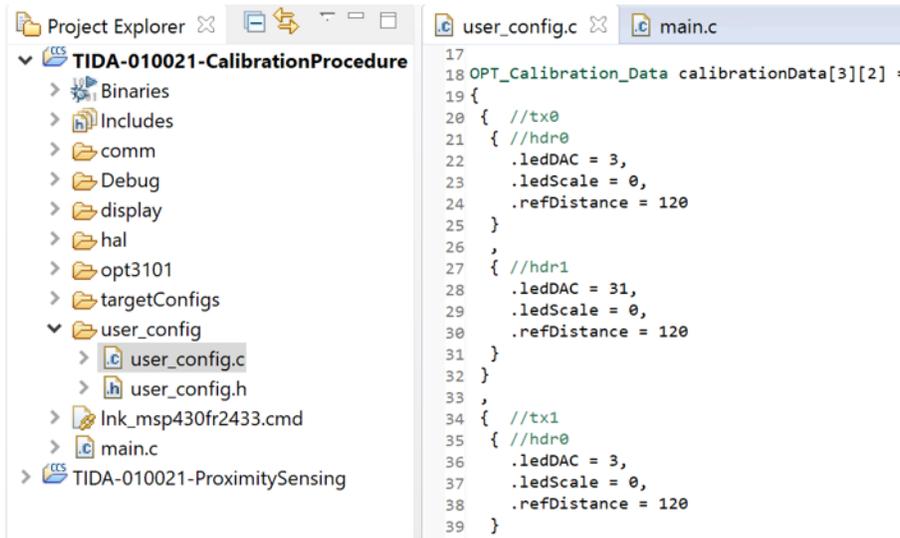
2. Build and program the TIDA-010021-CalibrationProcedure project into MSP430FR2433. Run the project in debug mode and set breakpoints shown in Figure 24.

Figure 24. Calibration Using TIDA-010021-Calibration Procedure Project
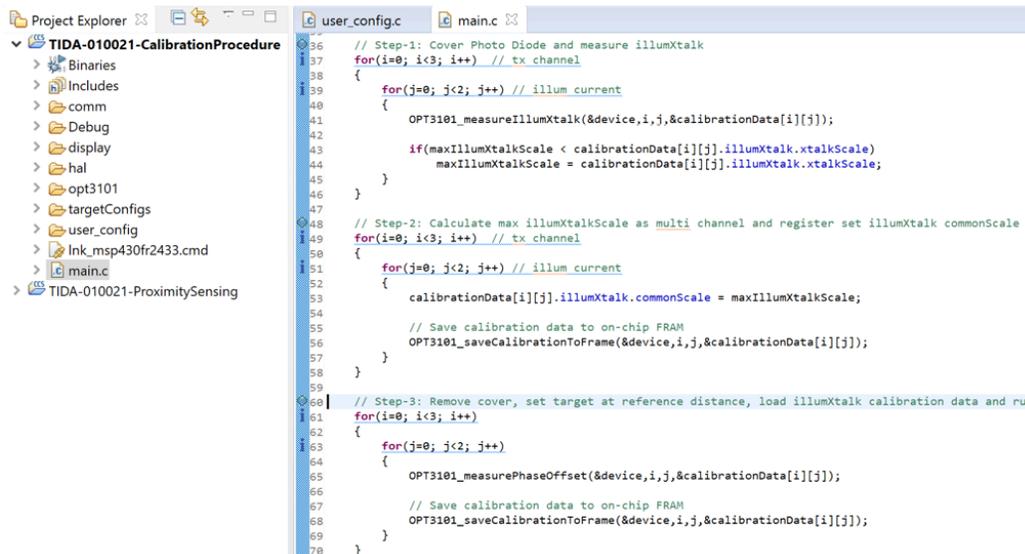
3. Run to first breakpoint and make sure the photodiode is covered. Then perform "Step-1" of code to measure illumination crosstalk.

4. Run "Step-1" of code to save crosstalk calibration data to MSP430 FRAM.

5. Remove the photodiode cover, set the target object at the reference distance (150 mm) and run "Step-3" of code.

6. After these calibration steps, you can run the TIDA-010021-ProximitySensing project to see the distance measurement results with calibrated crosstalk and phase offset.

7. Phase temperature calibration and phase calibration with ambient should be performed separately after previous step.

3.2 Testing and Results

The test results for this optical proximity sensing are divided into multiple sections that cover how to set up the test, the system performance under different ambient condition and different color of target object.

3.2.1 Test Setup

This section describes in detail the materials which are used for testing in the lab and how to set up the test platform step by step. Objects in different colors and other interference testing has also been performed to verify how the reference design acts in different environments.

3.2.1.1 Get Prepared

Testing the performance of the reference design and proximity sensor board requires some materials and equipment for preparation. Table 10 lists the materials required for the test setup and their basic usage.

Table 10. Materials for Test Setup

MATERIALS	USAGE	COMMENTS
Computer	Program, debug and continuously capture measurement data	Code Composer Studio™ v7.2 downloaded and installed
TIDA-010021 display board	Control the sensor board and read out the data	
TIDA-010021 sensor board	Measure the distance of target object	
Band tape	Measure the actual distance of target object	Minimum 2 meters
Photo meter	Measure the ambient light	Maximum range supports up to 130klx
Power meter	Test the power consumption of sensor module	

3.2.1.2 Test Setup Procedure

The following steps show how to set up the test platform in the lab during the detailed testing and debugging.

- Make sure that the firmware has been programmed into the MCU (see Section 3.1.2).
- Connect the sensor board and display board through J4.
- Connect the computer and sensor board through USB. The USB is only used for power input of display board without data communication
- Mount the sensor into a specified fixture and stand in front of it. The sensor display board should show the distance of target human.

3.2.2 Test Results

In this test, a human model wearing different color Clothes acts as proximity sensing target to simulate real application. Three application scenes, including darkness operation and sunlight operation, are tested. The total FOV 120° are covered by three zones: zone 0, zone 1 and zone 2. So the target in these three zones are tested separately.

3.2.2.1 Models for Testing

Figure 25 shows the three models wearing different color Clothes. They are marked with model A, B, and C. The tested data are given based on these three models. Different model has different NIR reflection. In general, the darker the color, the lower the reflectivity.

Figure 25. Human Model in Different Color Clothes as Test Target

(A)   (B)   (C)

3.2.2.2   *Scene 1 - Operation in Daytime With Light on (210 lux Ambient Light)*

Scene 1 aims to test the sensor performance in daytime with room light on (210 lux ambient light environment).

3.2.2.2.1   *Model A (White Clothes) as Target*

Model A wearing white color Clothes acts as target. Figure 26 shows the test setup.

Figure 26. Human Model in White Color Clothes as Test Target

Figure 27 shows the distance measured by sensor when model A is located in zone 1 and Figure 28 shows the error (in percent) with regards to distance.

Figure 27. Measurement Distance vs Actual Distance - Zone 1 Model A

Figure 28. Error % vs Distance - Zone 1 Model A
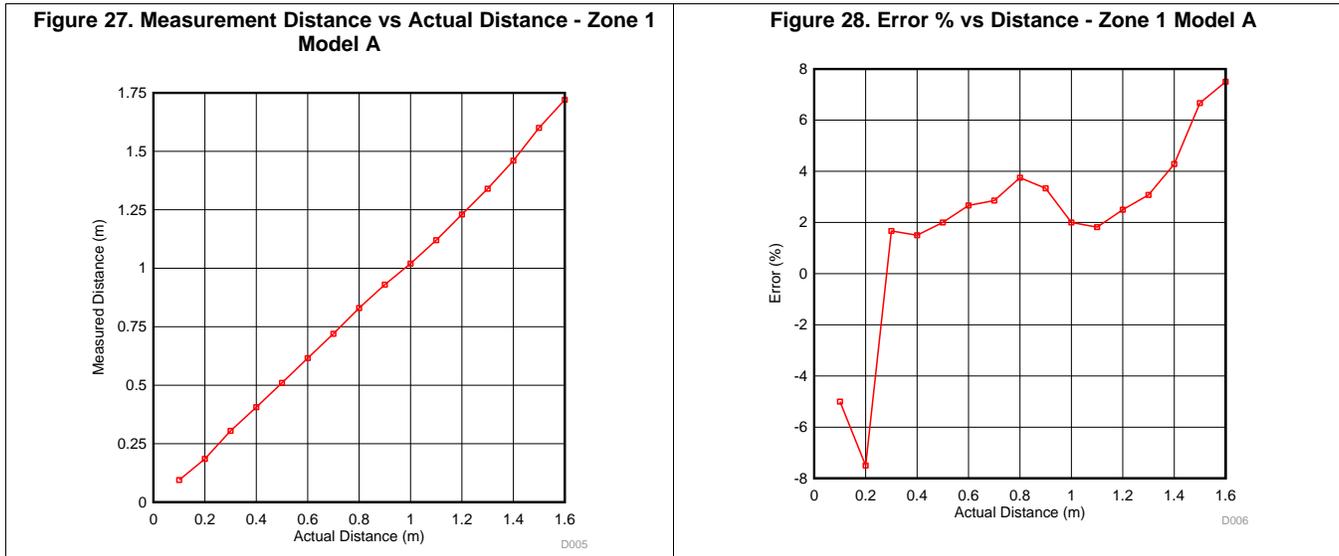
Figure 29 shows the distance measured by sensor when model A is located in zone 2 and Figure 30 shows the error (in percent) with regards to distance.

Figure 29. Measurement Distance vs Actual Distance - Zone 2 Model A

Figure 30. Error % vs Distance - Zone 2 Model A
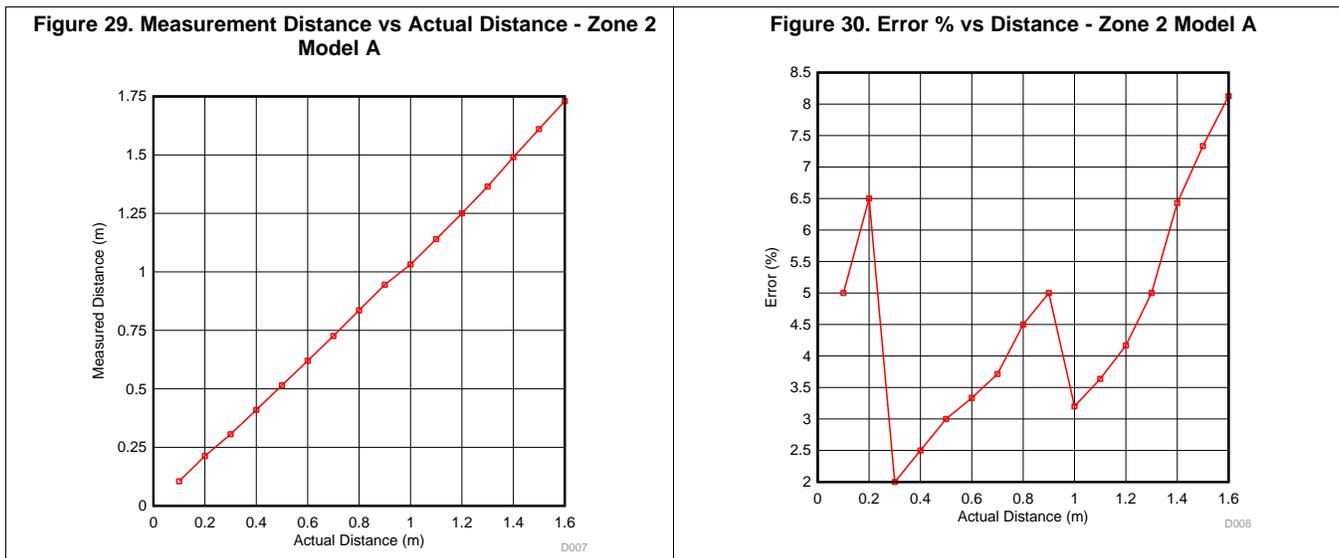
Figure 31 shows the distance measured by sensor when model A is located in zone 3 and Figure 32 shows the error (in percent) with regards to distance.

Figure 31. Measurement Distance vs Actual Distance - Zone 3 Model A

Figure 32. Error % vs Distance - Zone 3 Model A
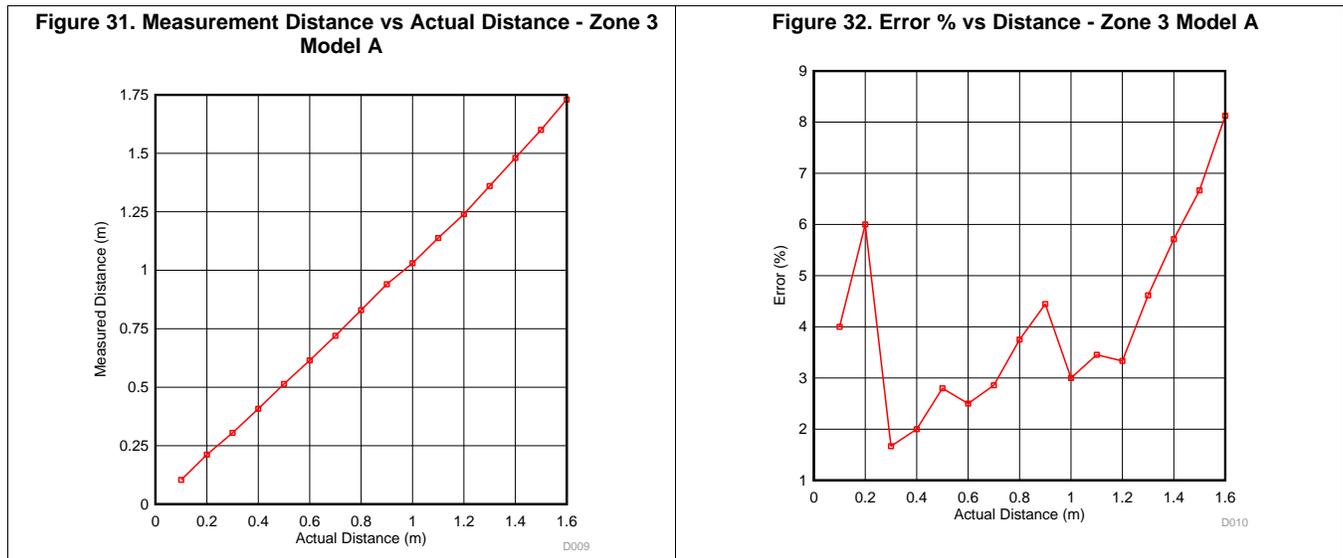
3.2.2.2.2   Model B (Pink Clothes) as Target

Model B wearing pink color Clothes acts as target. Figure 33 shows the test setup.

Figure 33. Human Model in Pink Color Clothes as Test Target

Copyright © 2018, Texas Instruments Incorporated

Figure 34 shows the distance measured by sensor when model B is located in zone 1 and Figure 35 shows the error (in percent) with regards to distance.


Figure 34. Measurement Distance vs Actual Distance - Zone 1 Model B

Figure 35. Error % vs Distance - Zone 1 Model B
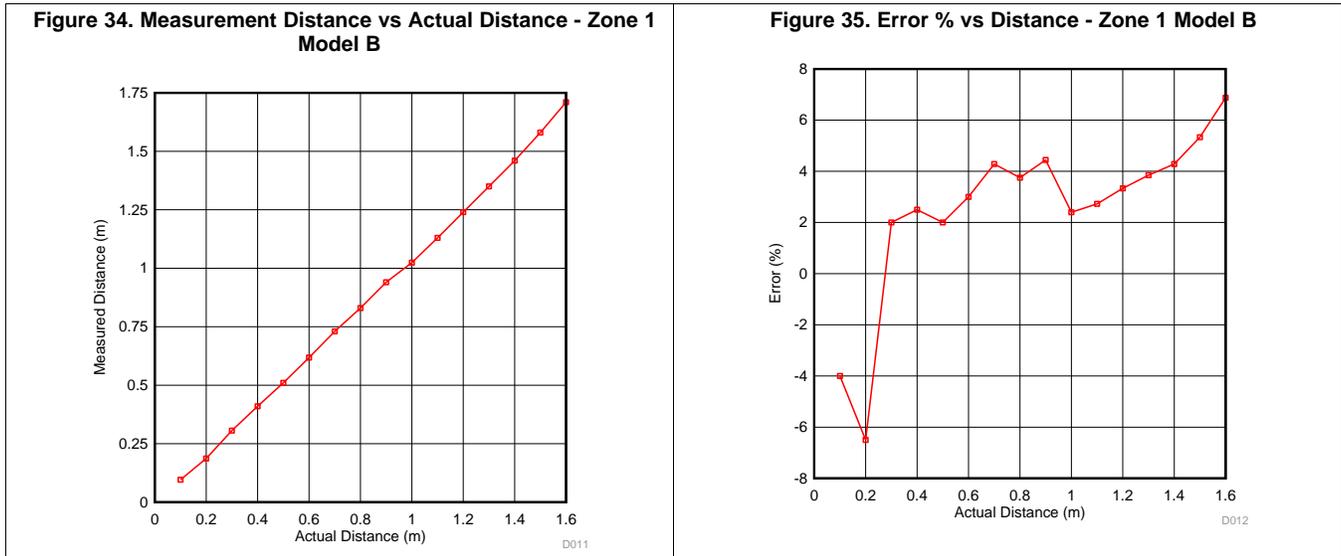
Figure 36 shows the distance measured by sensor when model B is located in zone 2 and Figure 37 shows the error (in percent) with regards to distance.


Figure 36. Measurement Distance vs Actual Distance - Zone 2 Model B

**Figure 37. Error % vs Distance - Zone 2 Model B**
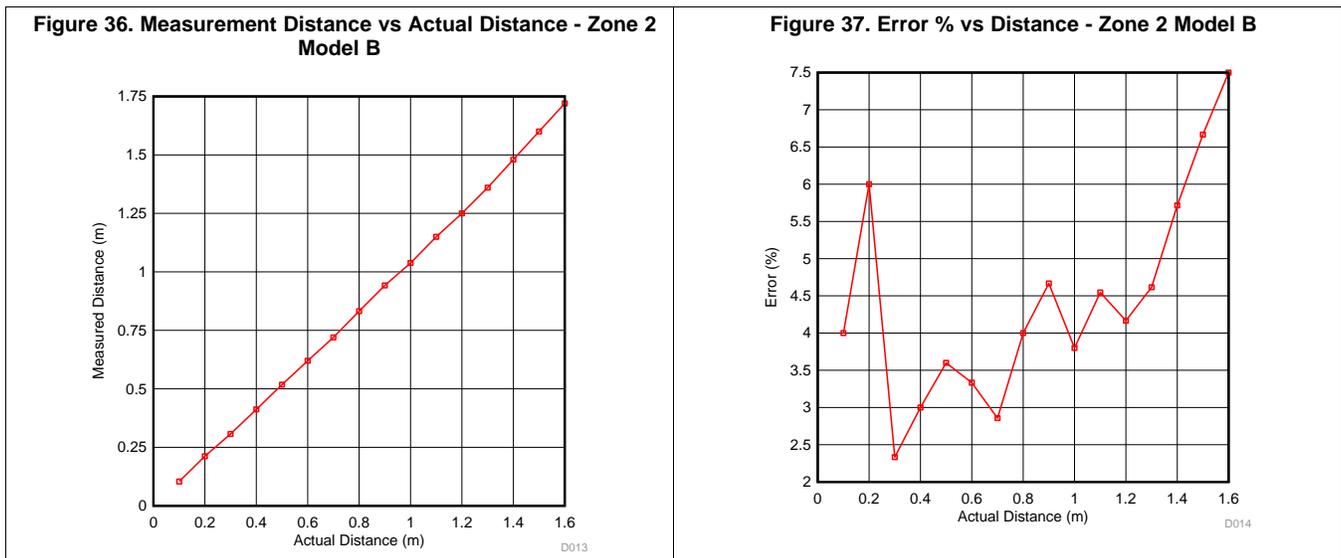
Figure 38 shows the distance measured by the sensor when model B is located in zone 3 and Figure 39 shows the error (in percent) with regards to distance.

Figure 38. Measurement Distance vs Actual Distance - Zone 3 Model B

Figure 39. Error % vs Distance - Zone 3 Model B
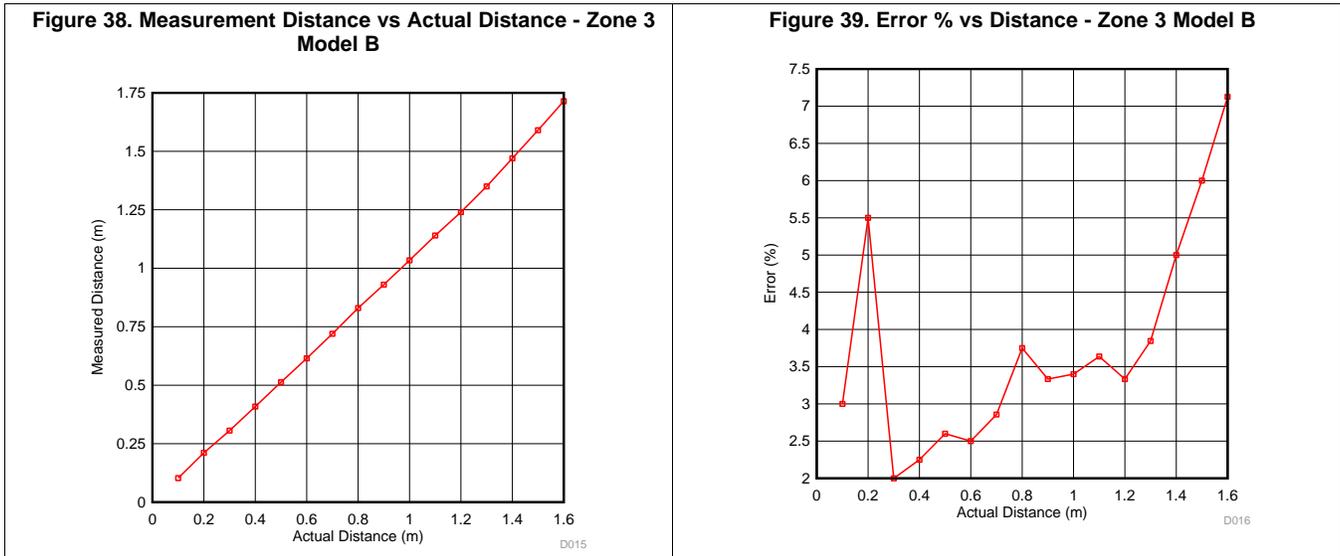
3.2.2.2.3 *Model C (Black Clothes) as Target*

Model C wearing black color Clothes acts as target. Figure 40 shows the test setup.

Figure 40. Human Model in Black Color Clothes as Test Target

Figure 41 shows the distance measured by sensor when model C is located in zone 1 and Figure 42 shows the error (in percent) with regards to distance.

Figure 41. Measurement Distance vs Actual Distance - Zone 1 Model C

Figure 42. Error % vs Distance - Zone 1 Model C
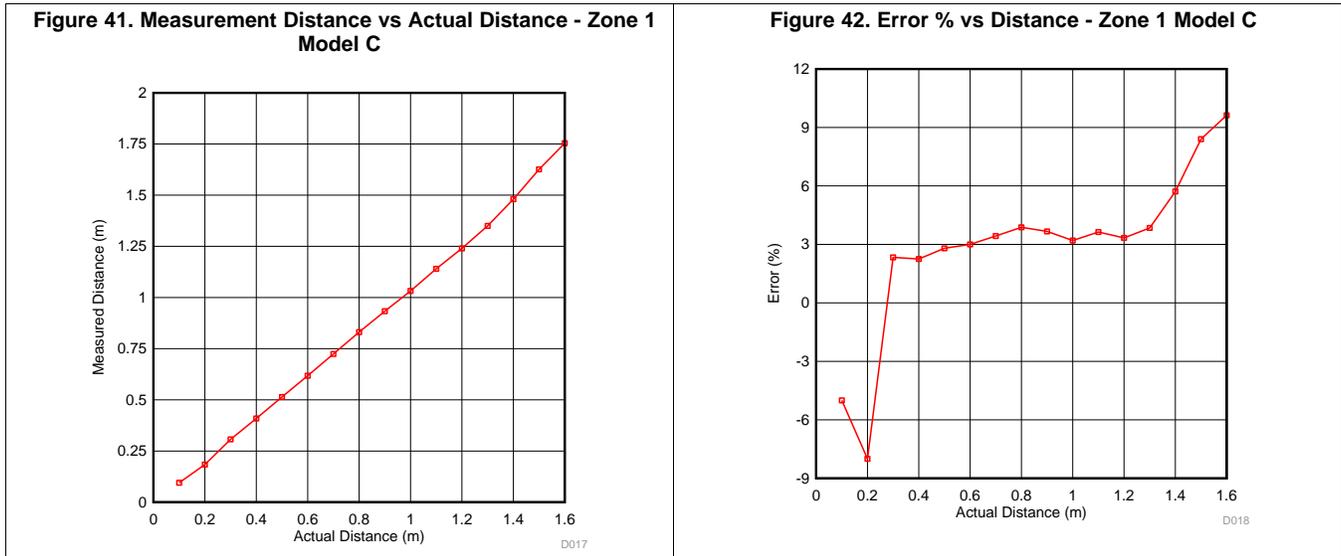
Figure 43 shows the distance measured by sensor when model C is located in zone 2 and Figure 44 shows the error (in percent) with regards to distance.

Figure 43. Measurement Distance vs Actual Distance - Zone 2 Model C

Figure 44. Error % vs Distance - Zone 2 Model C
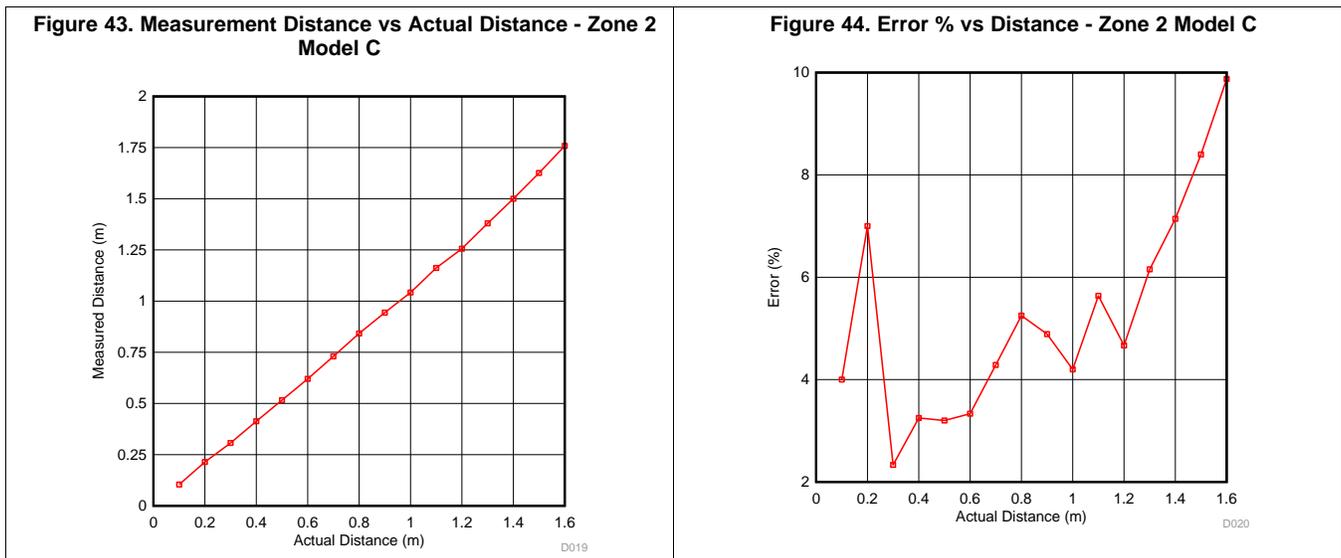
Figure 45 shows the distance measured by the sensor when model C is located in zone 3 and Figure 46 shows the error (in percent) with regards to distance.

Figure 45. Measurement Distance vs Actual Distance - Zone 3 Model C

Figure 46. Error % vs Distance - Zone 3 Model C
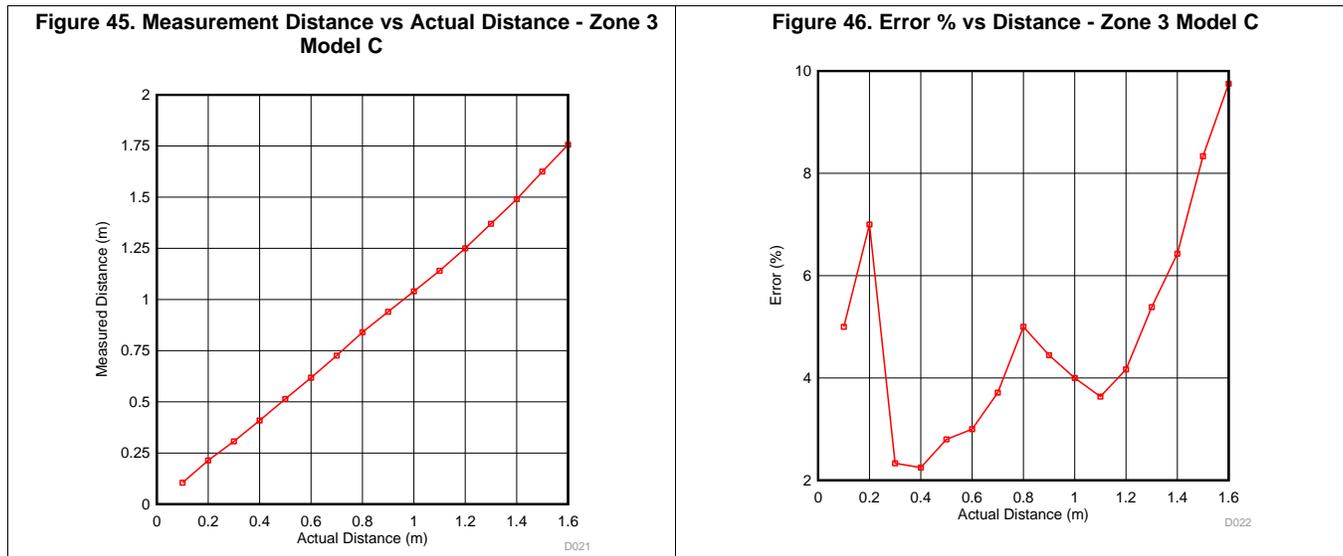
The test results in the previous images show that the target with different color Clothes may affect the NIR reflection but sensor is not sensitive to object color. The measured distance error is within the scope of pre-defined parameters for different color objects.

3.2.2.3   *Scene 2 - Darkness Operation*

Scene 2 aims to test the sensor performance under darkness operation, for example, evening or night when there is no ambient light or low ambient light. Figure 47 shows the test setup under dark environment.

Figure 47. Darkness Operation

For the darkness operation, only model B is chosen and placed in Zone 2 for the test. Comparing with the same position of Scene 1, sensor performance under darkness operation can be observed and effects of low ambient light can be concluded. In Figure 48, the red line shows the test results comparing with gray line which is sensor performance in Scene 1.

Figure 48 shows that sensor performance under darkness operation is good or even better comparing scene 1.

Figure 48. Operation in Darkness Comparing with Scene 1
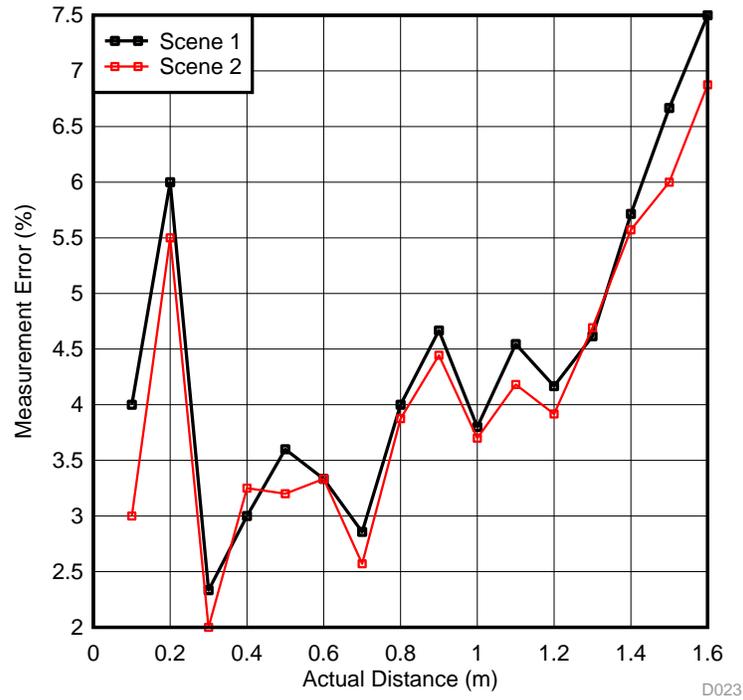
3.2.2.4   Scene 3 - Operation Under Sunlight (86 klx Ambient Light)

Scene 4 aims to test the sensor performance under sunlight environment, for example, when the sunshine comes into the room at noon. Figure 49 shows the test setup at 86-klx sunlight environment.

Figure 49. 86 klx Ambient Light Operation

For the high ambient light operation, only model B is chosen for the test. Comparing with the same position of Scene 1, sensor performance under sunlight operation can be observed and effects of high ambient light can be concluded. In Figure 50, the red line shows the test results comparing with gray line which is sensor performance in Scene 1.

Figure 50. Operation Under Sunlight Comparing With Scene 1
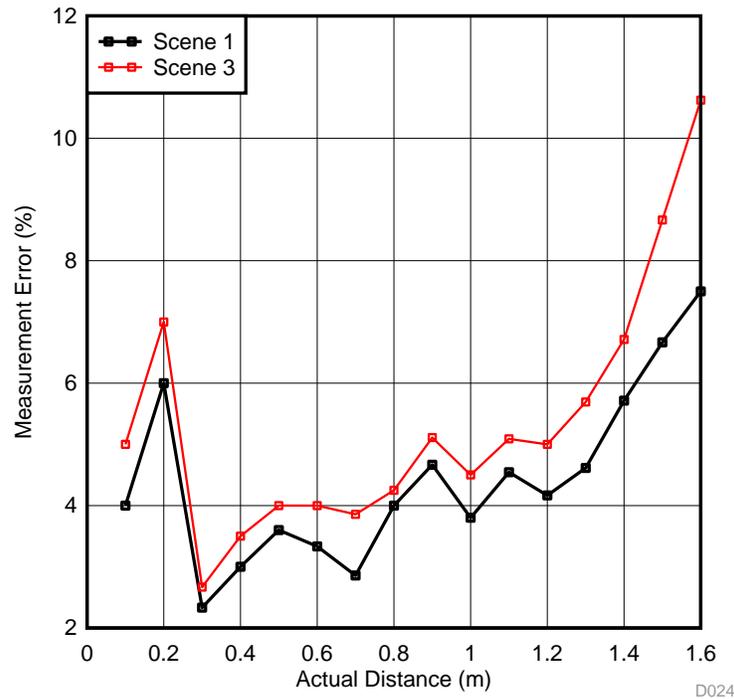
Figure 50 shows that sensor support high ambient light operation and performance is much better than other optical technics for proximity sensing.

3.2.2.5   Power Consumption

The sensor can run in normal operating mode (10 SPS) and low power mode. In low power mode, sensor wake up every 1 s and output 1 sample. When a movement is detected, the sensor run into normal operating mode.

Table 11. Consumption at Ambient Temperature

PARAMETER	MIN	MAX	UNIT	COMMENTS
HW standby		80	uA	Deep sleep mode
Operating current	25	90	mA	Continuous measuring distance at 128 sub frames per sample and 31.25 samples per second
Operating power consumption	82.5	297	mW	3.3-V power supply
Current in low power mode	3	9	mA	Wake up every 1 s
Power consumption at low power mode	10	30	mW	Wake up every 1 second for one sample (128 sub frames)

4 Design Files

4.1 Schematics

To download the schematics, see the design files at TIDA-010021.

4.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-010021.

4.3 PCB Layout Recommendations

Reducing coupling between transmitter and receiver is very critical to achieve good system performance. Area of transmitter current carrying loop through LED supply decoupling capacitor, LED and the AFE pins TX*, VSSL should be minimized. Similarly receiver loop involving the photodiode, matching capacitor and the AFE pins INP, INM should be minimized. It is recommended to use the layout as it is to get the best performance. If any changes to are intended, the guidelines below need to be strictly followed to keep the crosstalk between transmitter and receiver low.

- A 4-layer board is proposed, so that all the analog and digital supplies can be well isolated from each other.
- Place photodiode and LED oriented orthogonal to each other.
- Minimize the area of the transmitter current carrying loop involving LED, VDD_LED to VSSL decoupling capacitor, and AFE.
- Minimize the area of the receiver loop involving photodiode, matching capacitor and AFE.
- Shield the receiver loop using AVSS ground in TOP and bottom PCB layers. Also place a shielding ring around the photodiode and connect the shielding ring to AVSS. This shielding ring will help in reducing the electrical and optical crosstalk.
- Shield the transmitter loop using IOVSS ground in all the PCB layers. Also place a shielding ring around the LED and connect the shielding ring to IOVSS.
- LED terminals should not see the photodiode terminals directly. Any small amount of capacitive coupling between photodiode and LED terminals result in huge crosstalk. Grounded metal rings around photodiode and LED will help in shielding.
- Use vias around the transmitter and receiver loops in respective ground planes to improve the shielding.
- Connect the device thermal pad to AVSS.
- Do not overlap different ground planes, keep them well isolated.

See the Introduction to Time-of-Flight Optical Proximity Sensor System Design for more information.

4.3.1 Layout Prints

To download the layer plots, see the design files at TIDA-010021.

4.4 Altium Project

To download the Altium Designer® project files, see the design files at TIDA-010021.

4.5 Gerber Files

To download the Gerber files, see the design files at TIDA-010021.

4.6 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-010021.

5 Software Files

To download the software files, see the design files at TIDA-010021.

6 Related Documentation

1. Texas Instruments, *OPT3101 ToF-Based Long-Range Proximity and Distance Sensor AFE Data Sheet*
2. Texas Instruments, *Introduction to Time-of-Flight Optical Proximity Sensor System Design User's Guide*
3. Texas Instruments, *OPT3101 Distance Sensor System Calibration User's Guide*
4. Texas Instruments, *OPT3101 System Estimator User's Guide*

6.1 Trademarks

E2E, LaunchPad, MSP430, Code Composer Studio are trademarks of Texas Instruments.
Altium Designer is a registered trademark of Altium LLC or its affiliated companies.
All other trademarks are the property of their respective owners.

6.2 Third-Party Products Disclaimer

TI'S PUBLICATION OF INFORMATION REGARDING THIRD-PARTY PRODUCTS OR SERVICES DOES NOT CONSTITUTE AN ENDORSEMENT REGARDING THE SUITABILITY OF SUCH PRODUCTS OR SERVICES OR A WARRANTY, REPRESENTATION OR ENDORSEMENT OF SUCH PRODUCTS OR SERVICES, EITHER ALONE OR IN COMBINATION WITH ANY TI PRODUCT OR SERVICE.

7 Terminology (Optional)

FoV — Field of View

AFE — Analog Front End

NIR — Near Infrared

ToF — Time of Flight

HDR — High-Dynamic Range

MCU — Microcontroller unit

ESD — Electrostatic discharge

8 About the Author

YICHANG (RICHARD) WANG is a Systems Architect at Texas Instruments, where he is responsible for developing reference design solutions for the industrial segment. Richard brings to this role his extensive experience in home appliances, including power electronics, high frequency DC/DC, AC/DC converter, analog circuit design and so on. Richard got his master's degree in Electrical Engineering and Automation from Nanjing University of Aeronautics and Astronautics, China.

DONGZHI (WINTER) YU is an application engineer at Texas Instruments, where he is responsible for supporting MSP430™ microcontroller products. Winter brings to this role his extensive experience in microcontroller, embedded system software and MSP430™ FRAM based ultra-low power sensing and measurement solutions.