Design Guide: TIDA-010077

Obstacle, Cliff Detection and Stuck Prevention All-In-One Reference Design for Robotic Applications

Description

Obstacle avoidance, cliff detection, stuck prevention, and wall follow are key features for robotic systems. This reference design uses optical time-of-flight (ToF) techniques to build small and cost-effective proximity sensor systems to achieve these features. with a single proximity and distance sensor analog front end (AFE) (OPT3101) with three external near-infrared (NIR) LEDs, and one photodiode.

Resources

TIDA-010077	Design Folder
OPT3101	Product Folder
LM2664	Product Folder
MSP430FR2476	Product Folder
TLC59283	Product Folder
TLV702	Product Folder
TPD2E001	Product Folder

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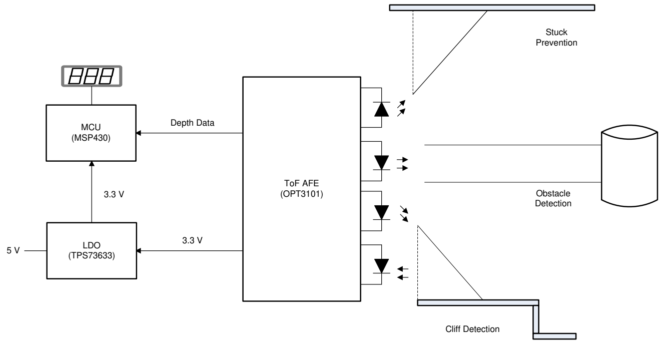
Features

- Three NIR emitters can be configured for different functions: Cliff detection, obstacle avoidance, stuck prevention, and wall follow
- Detection range up to 1.5 meters without a lens for obstacle avoidance
- Adaptive high dynamic range (HDR) enables the detection range to be short enough for cliff detection and stuck prevention
- ToF-based sensing AFE (OPT3101) makes measurement insensitive to object color and reflectivity and supports operation under high ambient condition (outdoor conditions)
- Direct distance measurement output with an accuracy of ±5%
- Low-power mode running at 1 sample per second with a power drain of 30 mW

Applications

- Vacuum robot
- Robotic lawn mower
- Other robot



1 System Description

With the rapid development of household and industrial robots, highly-reliable proximity sensing is becoming an important feature and capability. A robot is often required to sense any objects in front of it to make responses. For instance, a robotic should have the capability to sense obstacles and to avoid a collision. It also needs to sense any cliff ahead to avoid dropping or any object above it to avoid being trapped. One of the most common challenges for obstacle sensing is that the traditional sensor can easily get affected by temperature, object color, and ambient light, causing large detection error or even false triggering. Another common design challenge is that traditional sensor can only sense the object in horizontal plane, which may cause the robot to become in certain conditions, for example under the bed. ToF technology is the suitable solution to solve these issues.

The purpose of the TIDA-010077 reference design is to demonstrate the 1D ToF capabilities of TI's OPT3101 device to solve the previously-mentioned design challenges in different application scenarios for robotics. This reference design includes two boards: the sensor board and the display board. The sensor board is an optical ToF proximity and distance sensing module, consisting of the 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 device. The display module uses an external MCU (MSP430FR2476RGER) to control the OPT3101 AFE and an external EEPROM to store calibration data, and then display the distance information of the target to the user through a seven-segment LED display (LTD-6910HR) after reading the data from the sensor module. The MCU directly reads out the depth data through an I^2C interface from the sensing module. The MCU can also be used for factory calibration purposes.

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 device, a long-range proximity and distance sensor Analog-Front-End (AFE), uses the Time-of-Flight (ToF) principle to acquire distance measurement data with well performance of distance, and accuracy under different ambient conditions.

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

- **Flexibility:** The OPT3101 device offers the flexibility to customize a 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. Additionally, with different types of external illuminators (LED, VCSEL, or LASER) and corresponding photodiodes, users have the choice of a 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:** The OPT3101 device has the sample rate up to 4 kHz, with ToF technology, operating much faster compared to other range-sensing methods like ultrasonic sensing. The OPT3101 device has 16-bit distance output at 15-m unambiguous range. In addition, TI’s advanced ToF technology deploys multi-frequency techniques for de-aliasing to extend the distance range.
- **Object reflectivity independency:** The ToF technology independently determines phase and amplitude, allowing for independency of object (color) reflectivity. It overcomes the drawback of an amplitude based system, which estimates distance only based on the 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 the OPT3101 device that allows for great performance both indoors and outdoors, including full sunlight of 130 klx. The OPT3101 device also has other various calibrations and compensation 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

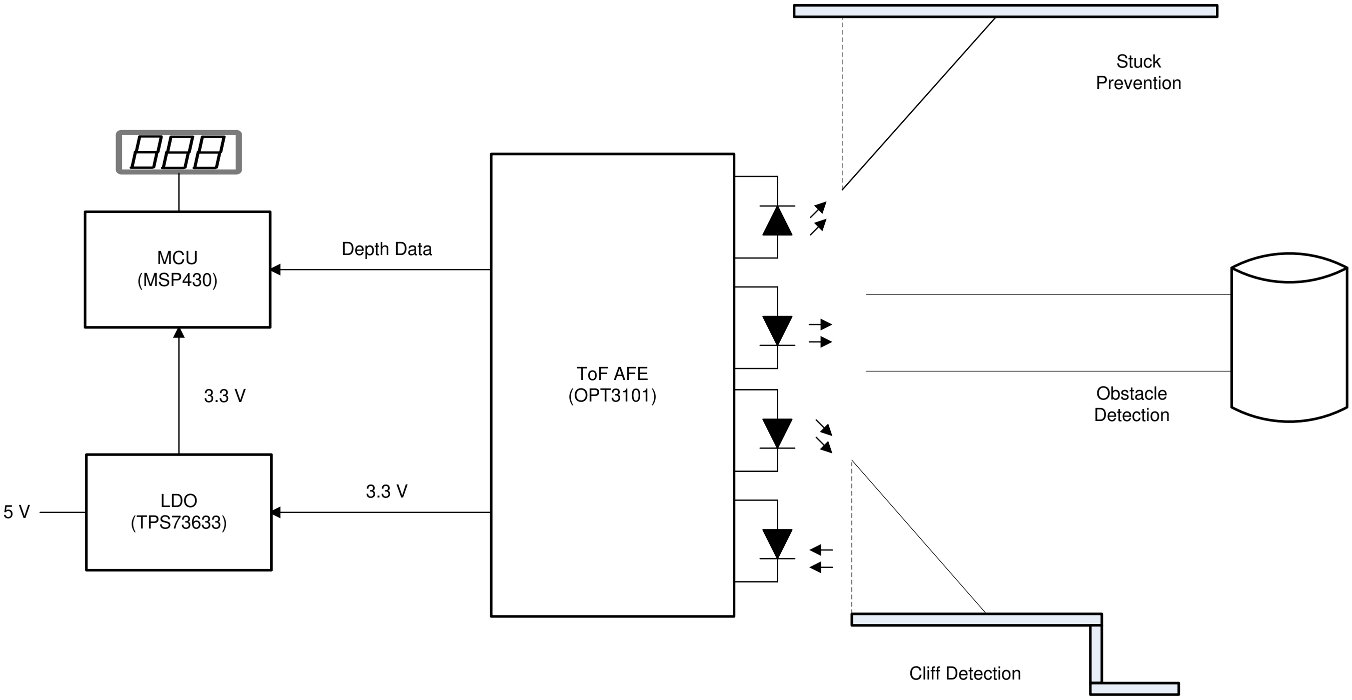
Table 1. Key System Specifications

PARAMETER	MIN	NOM	MAX	UNIT	Comments
DC input power supply	3.6	5	5.5	VDC	DC input by J4 (display board USB)
Sensor power supply	3	3.3	3.6	VDC	Sensor board J1
Detection range (Channel 1)	0.05	—	1.5	m	Obstacle detection without lens for all color target
Detection range (Channel 0, 2)	0.01	—	0.5	m	Cliff detection, stuck prevention, and wall follow
Field of View (FOV for Channel 0)	–5	—	5	degree	Cliff detection
Field of View (FOV for Channel 1)	–20	—	20	degree	Obstacle detection
Field of View (FOV for Channel 2)	–3	—	3	degree	Stuck prevention, wall follow
Continuous full power	—	—	300	mW	Sensor board only, continuous measuring distance at 128 sub frames per sample and 31.25 samples per second
Accuracy	—	—	5	%	
Low-power mode	—	—	30	mW	Wake up every 1 s for one sample (128 sub frames)
Operating temperature	–20	—	60	°C	

2 System Overview

2.1 Block Diagram

Figure 1. TIDA-010077 Block Diagram



2.2 Design Considerations

This reference design is based on the OPT3101 (TI 1D ToF AFE) to realize cliff detection, obstacle avoidance, and stuck prevention functions in one miniature module. It can also be used for wall follow.

The OPT3101 device supports up to three transmitter channels for multi-zone operation. Based on this feature, one OPT3101 device can be used for multi-functions. Different functions have different requirements and the OPT3101 AFE is flexible enough to customize a design with a wide variety of photodiodes and emitters. For example, obstacle detection requires a wide field-of-view and longer detection range so an emitter with a wide FoV is needed when cliff detection needs a narrow FoV and short distance detection capability. See Section 2.4 for details.

2.3 Highlighted Products

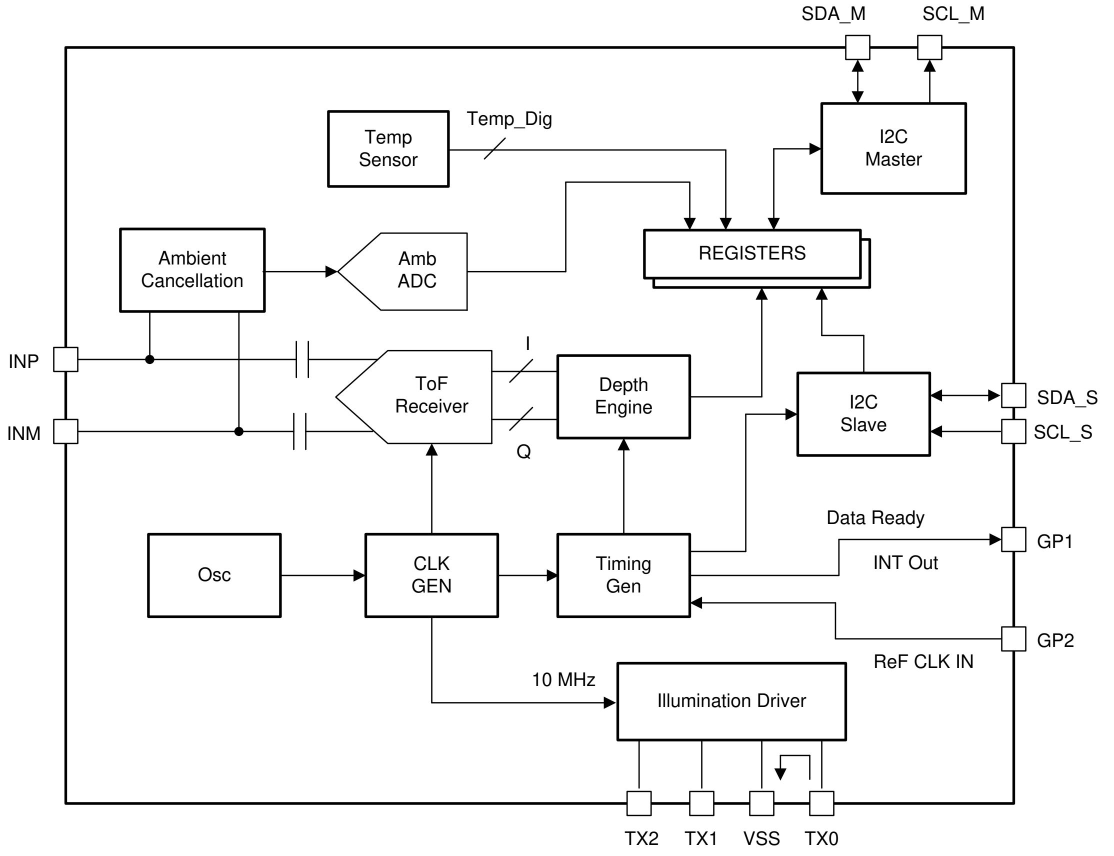
The following subsections detail the highlighted products used in this reference design, including the key features for their selection. See their respective product data sheets for the complete details on any highlighted device.

2.3.1 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



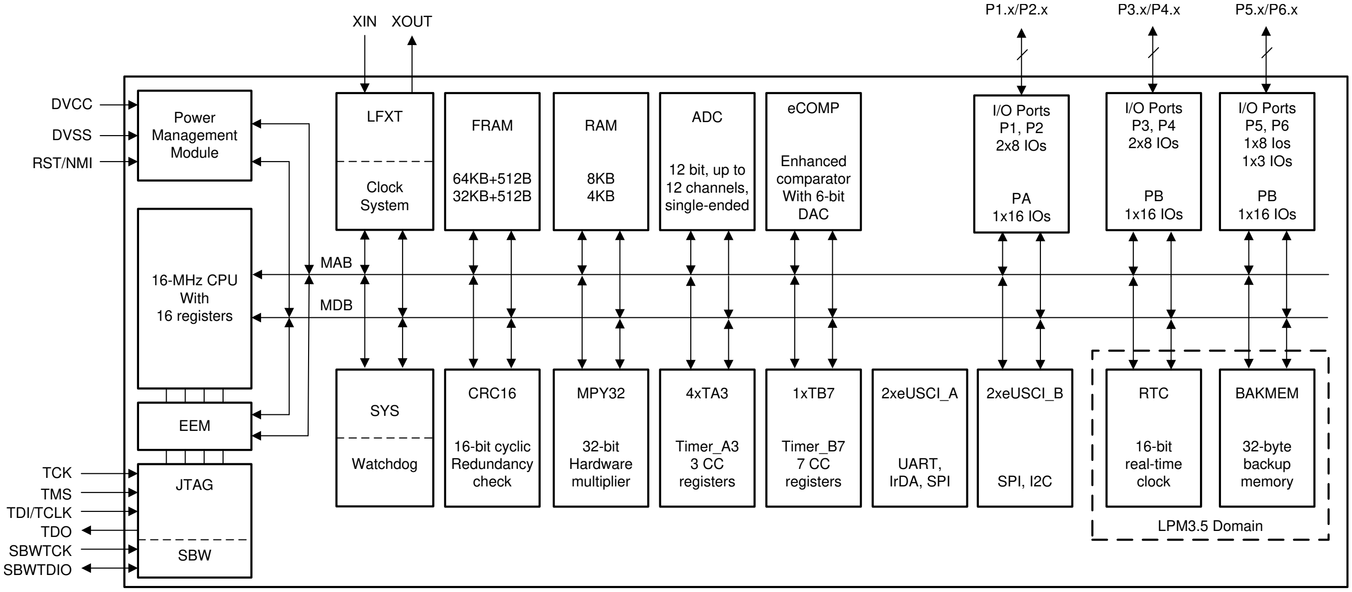
2.3.2 MSP430FR2476

The MSP430FR2476 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, ferroelectric RAM (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. MSP430FR2476 Block Diagram

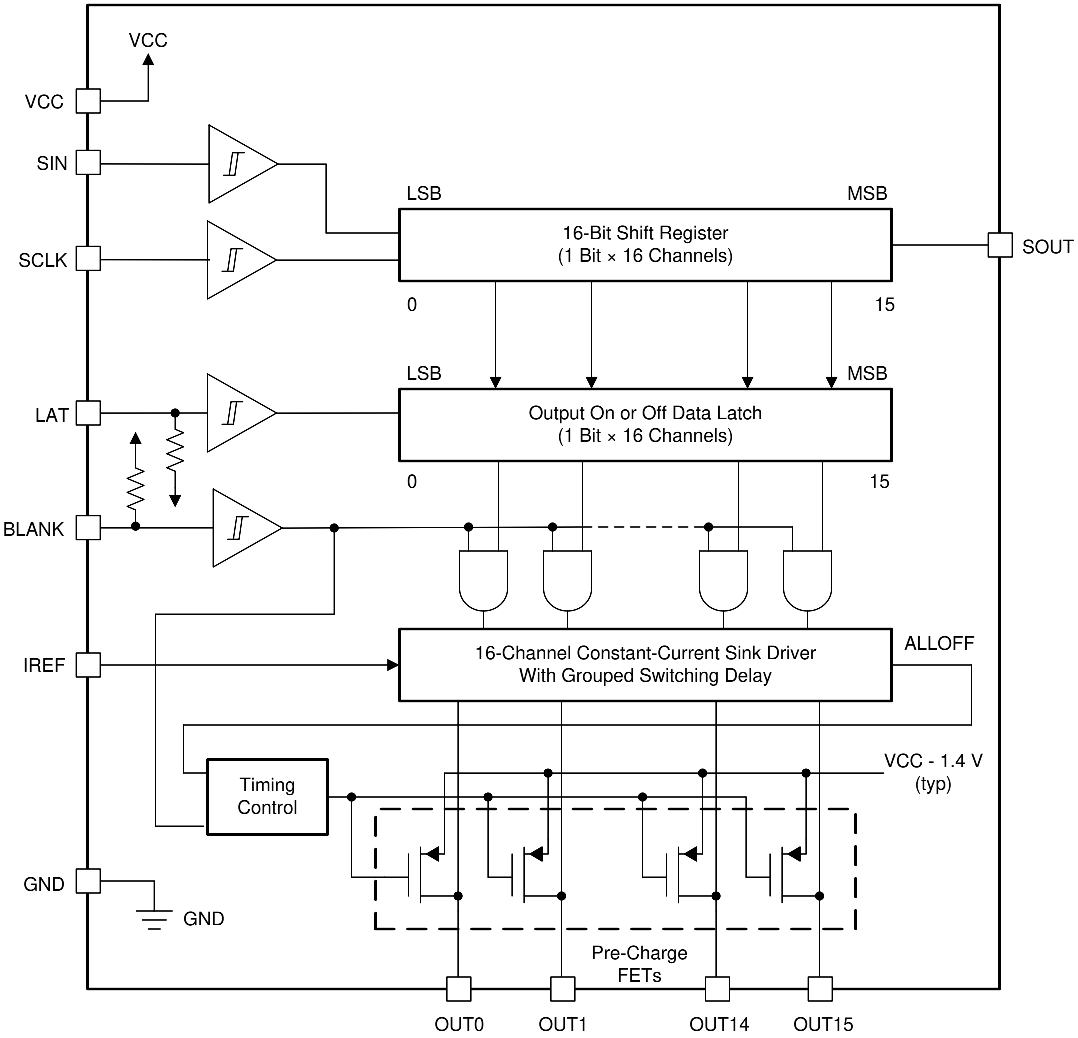


2.3.3 TLC59283

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



2.3.4 LM2664

The LM2664 CMOS charge-pump voltage converter inverts a positive voltage in the range of 1.8 V to 5.5 V to the corresponding negative voltage of −1.8 V to −5.5 V. The device uses two low-cost capacitors to provide up to 40 mA of output current.

The LM2664 operates at 160-kHz oscillator frequency to reduce output resistance and voltage ripple. With an operating current of only 220 µA (operating efficiency greater than 91% with most loads) and 1-µA typical shutdown current, the LM2664 provides ideal performance for battery-powered systems.

2.3.5 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).

2.3.6 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.

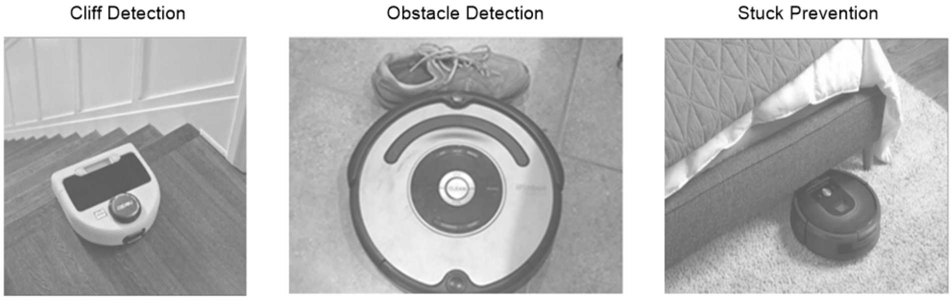
2.4 System Design Theory

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

2.4.1 Sensor Module Design

The sensor module design aims to achieve the obstacle avoidance, cliff detection, stuck prevention, and wall follow functions. Figure 5 shows an example of a typical system definition.

Figure 5. Sensor Key Functions in Robot



Cliff Detection

Obstacle Detection

Stuck Prevention

2.4.1.1 System Design Goal Parameters

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

Table 2. Application Requirement Specifications

SPECIFICATION		VALUE	UNITS	COMMENTS
Channel 0	Maximum distance	0.5	m	For an object with 20% to approximately 80% reflectivity
	Minimum distance	0.01	m	For an object with 20% to approximately 80% reflectivity
	Distance accuracy	10	%	For an object with 20% reflectivity at 0.5 meters worst.
	Field of View	≤ ±5	degrees	≤ 10° for full angle
Channel 1	Maximum distance	1.5	m	For an object with 2080% reflectivity
	Minimum distance	0.05	m	For an object with 20% to approximately 80% reflectivity
	Distance accuracy	10	%	For an object with 20% reflectivity at 1.5 meters worst.
	Field of View	±20	degrees	40° for full angle
Channel 2	Maximum distance	0.5	m	For an object with 20% to approximately 80% reflectivity
	Minimum distance	0.01	m	For an object with 20% to approximately 80% reflectivity
	Distance accuracy	10	%	For an object with 20% reflectivity at 0.5 meters worst.
	Field of View	≤ ±5	degrees	≤ 10° for full angle
All	Ambient light	130	klx	Sunlight condition
	Samples rate	10	SPS	For each channel

2.4.1.2 Target Type

Based on the reflectance of objects, the target can be classified as diffused reflector, shiny reflector, and retroreflector. For a detailed description of these three target type, see the *Introduction to Time-of-Flight Long Range Proximity and Distance Sensor System Design User's Guide* for more information.

In this reference design, the sensor detects the objects in the sensing area. Target objects are often diffused reflectors. 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.

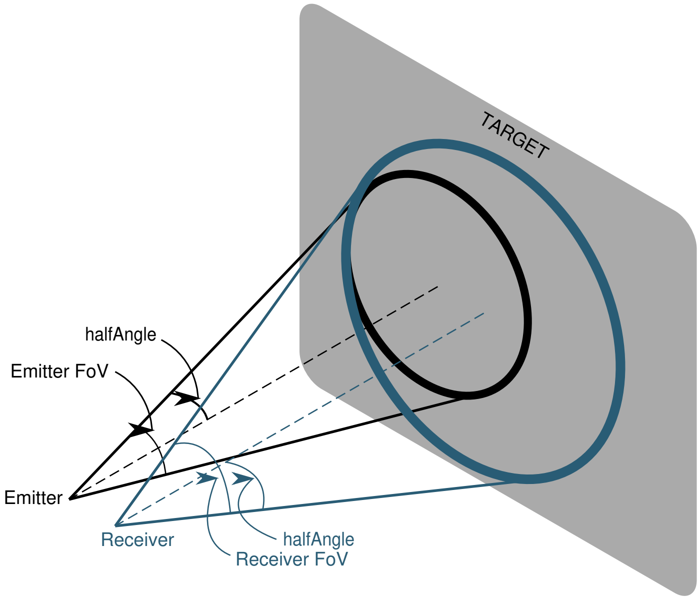
2.4.1.3 Number of Channels

The OPT3101 device supports up to 3 transmitter channels. In other words, three channels can be measured simultaneously with one single OPT3101 device to realize different functions, such as cliff detection, obstacle detection, stuck prevention, and wall follow. All these functions can be realized with one miniature sensor module.

2.4.1.4 Field-of-View (FoV)

Figure 6 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 6. Emitter and Receiver Fields-of-View



2.4.1.4.1 Emitter FoV

The FOV of emitter is often measured in degrees and expressed in half-angle or full-angle subtended by the cone of light emission. The selection of the 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.

In this design, the emitter FOV for obstacle detection should be no less than 40°. The emitter FoV for cliff detection, stuck prevention, and wall follow can be less than 10°, for example ±5°, ±3°.

2.4.1.4.2 FoV of Receiver

Similarly, the FoV of the receiver which is usually a photodiode can be expressed in half-angle or full angle, subtended by the cone of light collection and measured in degrees. The OPT3101 device can only accept one receiver to receive the reflection of light. Therefore, the FoV of the 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 Equation 1. This shows that reducing the FoV increases both signal gain and reduces ambient gain improving performance by a great deal.

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

$$\text{ambientGain} \propto \left(\tan\left(\frac{\text{fov}}{2}\right)\right)^2 \qquad (1)$$

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

2.4.1.5 Wavelength (λ)

2.4.1.5.1 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 needs to fixed behind some kind of glass or plastic panel which shields the visibility of the sensor module from external influences. In this case, it is necessary to ensure that the material of the panel has good penetration to the light of the selected wavelength.

2.4.1.5.2 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 the wavelength chosen both for laser or VCSEL sources and LEDs. Hence, while choosing center wavelength these parameters must be considered as well.

2.4.1.5.3 Visibility to Naked Eye

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

Emitters usually have two categories based on visibility to the naked eye: visible spectrum and invisible spectrum. The visible light wavelength ranges from 390 nm to 700 nm and the response of the human eye peaks around 500 nm to 550 nm. In ToF-based systems, a near-infrared wavelength ranging from 750 nm to 1400 nm is in the 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 the NIR field and the wavelength (λ in nm) of light illuminating by emitter should be no less than 850 nm.

2.4.1.6 Target Distance

The 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 tens of meters) based on component selection and optics design. In this design of application, the target distance in this application is different for three channels. Obstacle detection channel 1 ranges from 0.05 to 1.5 meters with 10% accuracy of distance output, while channel 0 and 2 for cliff detection, stuck prevention, or wall follow ranges from 0.01 to 0.5 meters.

2.4.1.7 Dynamic Range

In ToF-based applications, the strength of reflected light determines 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 the OPT3101 device 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. The adaptive HDR of the OPT3101 device can be set to increase the dynamic range.

- **Distance range:**

  System is expected to work from 50 mm to 1500 mm for channel 1, then the dynamic range required is 900 times or 59 dB (follows the square law for distance)

  System is expected to work from 10 mm to 500 mm for channel 0 and 2, then the dynamic range required is 2500 times or 68 dB (follows the 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 channel 1 is 900 × 9 = 8100 (expressed in ratio of maximum to minimum) or when expressed in decibels – it is 78 dB.

The other two channels is 2500 × 9 = 22500 (expressed in ratio of maximum to minimum) or when expressed in decibels – it is 87 dB.

2.4.1.8 Data Rate

The 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 the system FoV of 120° in this design is covered by three emitters, the total samples per second for the OPT3101 device is 30.

2.4.1.9 Selection of Emitter

2.4.1.9.1 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. The 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 applications like cliff detection, obstacle detection, stuck prevention, and wall follow, 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.

2.4.1.9.2 Emitter Specification Parameters

Table 3 shows the parameters requirement for high-power infrared LED selection based on previous discussion.

Table 3. Emitter Specification Parameters

PARAMETERS	VALUE	UNIT	COMMENTS
FoV (Full-Angle)	40–50	degree	±20° – ±25° (Half-Angle) for obstacle detection
FoV (Full-Angle)	< 10	degree	Cliff detection, stuck prevention, and wall follow
Wavelength	≥ 850	nm	
Eye safety	exempt group	–	Standard IEC 62471:2006 (photo-biological safety of lamps and lamp systems)

2.4.1.9.3 Selection Result

Three different types of infrared LED are chosen in this design for specific functions. Table 4 shows the brief parameters for these LEDs. Download the data sheet for these LEDs by clicking the part number in the following table.

Table 4. Emitter Specification Parameters

SPECIFICATION	SFH 4550	SFH 4555	SFH 4556
Peak wavelength (nm)	860	860	860
Centroid wavelength (nm)	850	850	850
Spectral bandwidth at 50% $I_{rel,max}$ (nm)	30	30	30
Half angle (degree)	3	5	20
Rise time (10%, 90%) I_F = 100 mA; R_L = 50 Ω (ns)	12	12	12
Fall time (10%, 90%) I_F = 100 mA; R_L = 50 Ω (ns)	12	12	12

2.4.1.10 Photodiode Selection

2.4.1.10.1 Type of Photodiode

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

2.4.1.10.2 Wavelength (λ in nm)

Photodiodes fundamentally respond to a large bandwidth of wavelengths (spectral bandwidth); however, they have peak sensitivity only at a particular wavelength. Photodiodes are best operated at that wavelength to reap the best performance, although this is 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 Section 2.4.1.9.3, the centroid wavelength of emitter is 850 nm. So the wavelength of peak sensitivity for the photodiode should be around 850 nm.

2.4.1.10.3 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. The OPT3101 device supports a maximum capacitance of 6 pF. So the junction capacitance of the photodiode at 1-V bias should be less than 6 pF. Negative voltage to photodiode help to reduce the crosstalk. As is described in Section 2.4.1.11, -3.3-V is connected to photodiode In this design.

2.4.1.10.4 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 a loss in performance.

2.4.1.10.5 Package and Case Type Selection

Photodiodes come in 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, the application requires a 120° FoV that is covered by three emitters; therefore, through-hole photodiodes are chosen so that they can be bent to the right direction.

2.4.1.10.6 Photodiode Selection Parameters

Table 5 shows the parameter requirements for photodiode selection, based on the previous discussion.

Table 5. 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

2.4.1.10.7 Photodiode Selection Result

The OSRAM SFH203PFA photodiode meets the required parameters. Figure 7 and Figure 8 show the photodiode characteristics. Table 6 lists the photodiode specifications.

Figure 7. SFH203PFA Relative Spectral Sensitivity

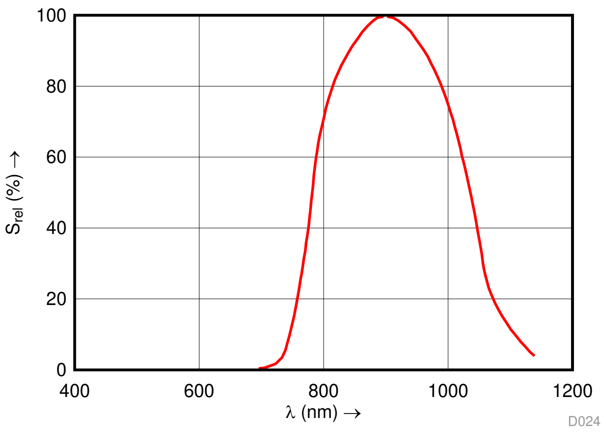
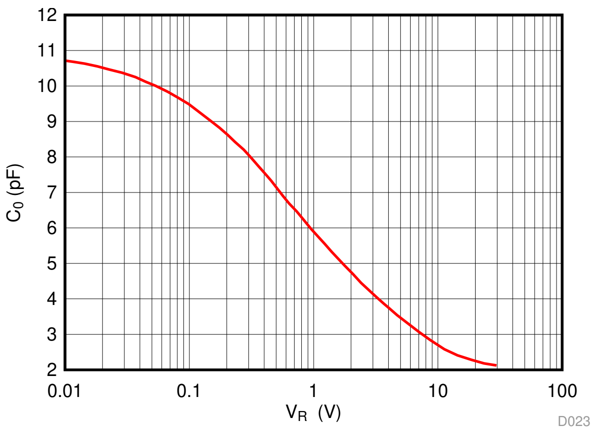


Figure 8. SFH203PFA Photodiode Reverse Bias Capacitance



See the *Directional Characteristics* graph in the *SFH 203 PFA Data Sheet* from Osram Opto Semiconductors.

Table 6. Emitter Specification Parameters

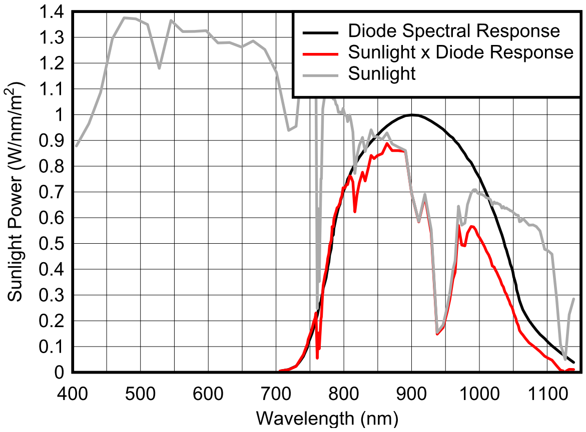
SPECIFICATION	VALUE	UNITS	COMMENTS
Photodiode current with 1 mW/cm^2	6.2	µA	Photodiode specification
Half-angle	±75	degree	Photodiode specification
Ambient current	105	µA	See the OPT3101 system estimator tool
Reverse bias capacitance at VR = 1 V	5.8	pF	AFE supports a maximum capacitance of 6 pF
Reverse bias capacitance at VR = 4.3 V	3.6	pF	-3.3V connected to photodiode

Use the OPT3101 System Estimator Software for system performance estimation.

2.4.1.10.8 Responsitivity (ϒ in A/W)

The responsitivity 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 the wavelength causes the responsitivity to vary as per Figure 9. When a multichromatic light is exposed 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.

Figure 9. SFH203PFA Photodiode Spectral Response and Sunlight Power Within Photodiode Spectral Bandwidth



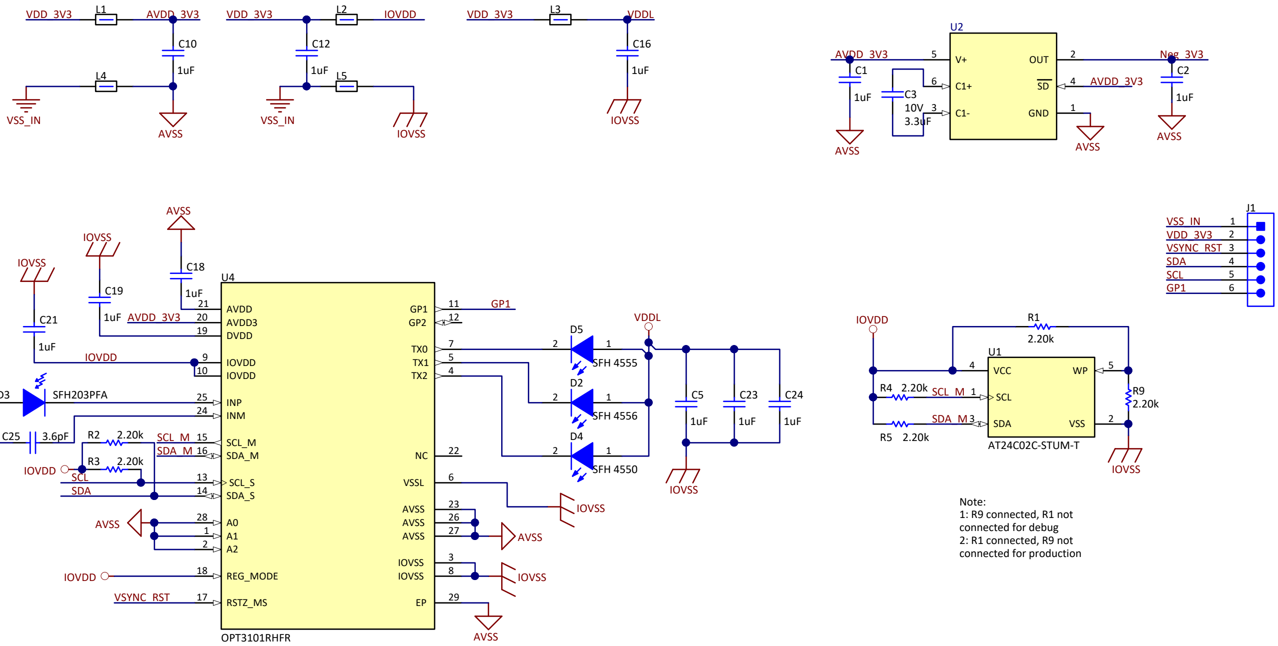
2.4.1.11 Power Supply Recommendations

The OPT3101 device requires 1.8- 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. Negative voltage on the photodiode help to reduce the crosstalk. Voltages of –3.3 V or –5 V is recommended to connect to the anode of the photodiode.

2.4.1.12 Sensor Module Schematic

Figure 10 shows the schematic of sensor module based on the OPT3101 device.

Figure 10. Sensor Module Schematic



Note:
1: R9 connected, R1 not connected for debug
2: R1 connected, R9 not connected for production

2.4.1.13 Isolation

2.4.1.13.1 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 for the system to detect. Crosstalk plays a critical role in determining the absolute error and dynamic range of the system. Two types of crosstalk should be considered: electrical crosstalk and optical crosstalk.

Electrical crosstalk occurs due to electromagnetic coupling from the 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 the best performance from the system.

2.4.1.13.2 Aggressor and Victim Nets

The 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. The 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, and 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.

2.4.1.13.3 Electrical Isolation

A well-designed PCB layout, which is discussed in Section 4.3, is crucial to minimize the electrical crosstalk and achieve the best performance. Even if utmost care is 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 electrical conductivity, is magnetically inactive, and soldered AVSS exposed pads on the PCB.

2.4.1.13.4 Optical Isolation

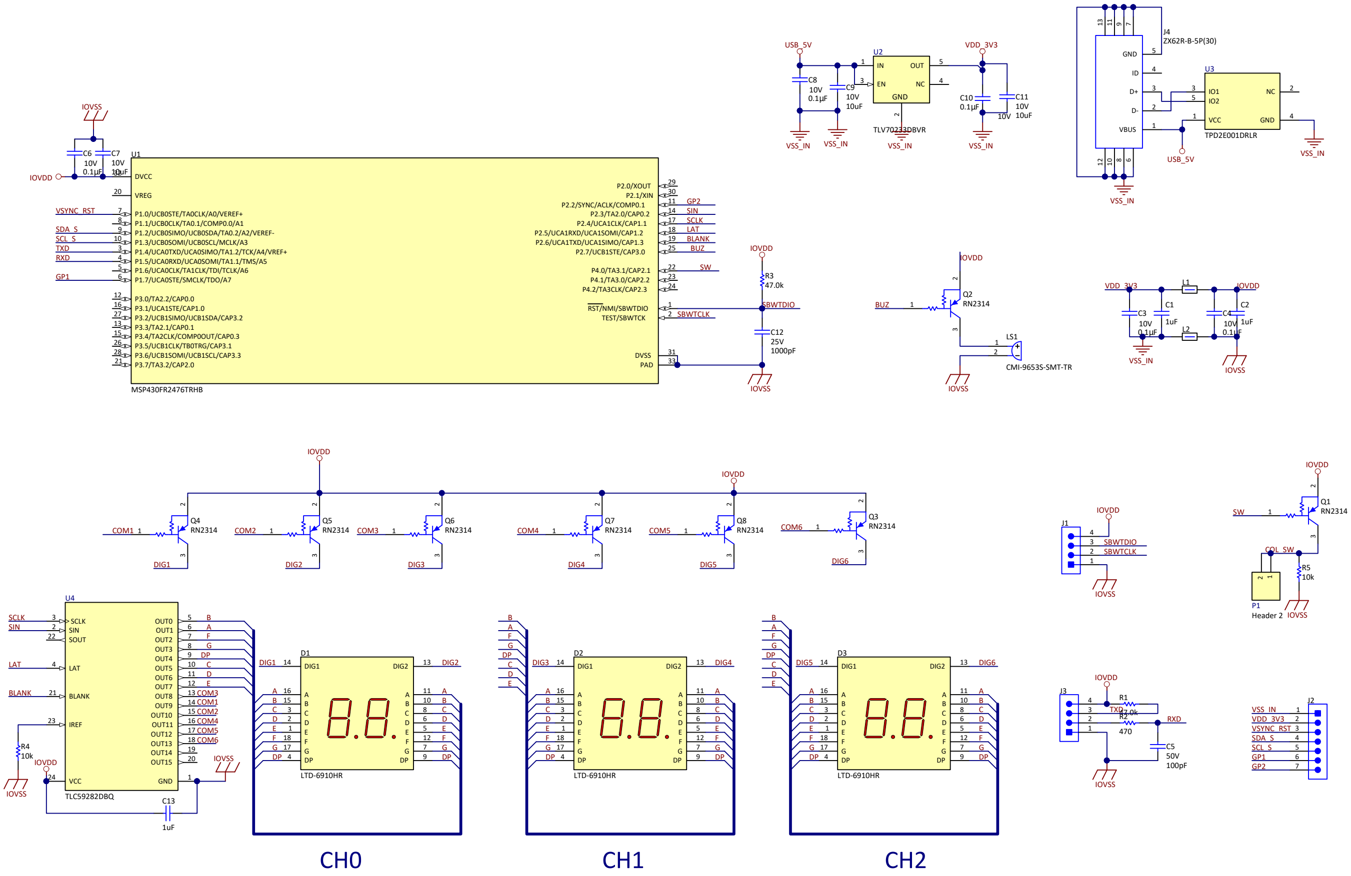
Optical isolation between the emitter and receiver is crucial to achieve good system performance. Having any amount of light leakage from the emitter directly to the receiver could make the system unusable. In this reference design, a specific ring is designed to act electrical isolation and optical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

See the *Mechanical Specifications* section in the *Introduction to Time-of-Flight Long Range Proximity and Distance Sensor System Design User's Guide* for more information.

2.4.1.13.5 Display Module Design

A display module with the MSP430FR2476 microcontroller is designed to control the OPT3101 device and get depth data from it. Then the distance information for proximity sensing is shown in the dual digital display. This reference design uses the 16-channel LED driver TLC59283 to drive the display so that IOs of the MCU can be saved.

Figure 11. Display Board Schematic



1. Delete extra LEDs
2. Add buzzer
3. Add On/Off control to minic Mechanical Switch
4. One TLC59283 for LED matrix
4. Change one MCU

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: a sensor board and display board. These two boards can be connected by J2 (display board) and J1 (sensor board). Figure 12 shows the overview of the PCB for the sensor board and Figure 13 shows the display board. The user can also connect the sensor board to their own controller system. A micro USB connector (J1) in the display module is used only for the 5-V power supply input without data communication.

Figure 12. Sensor Board - Top View and Bottom View

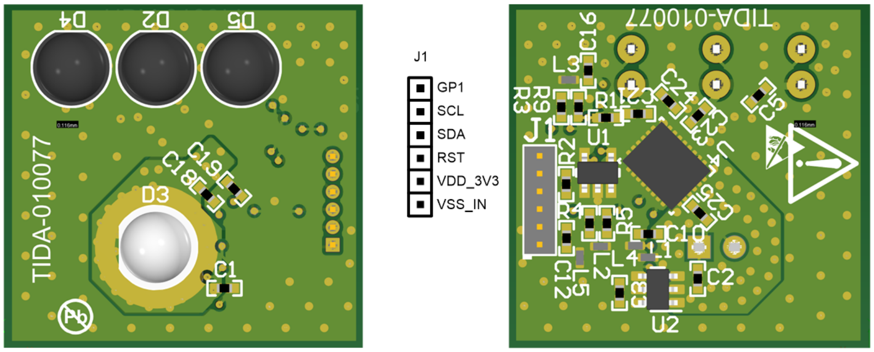
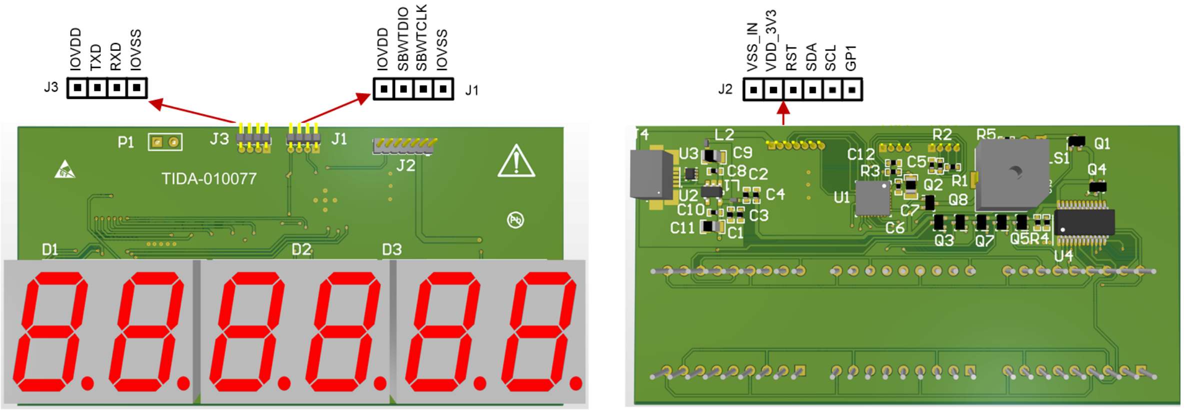


Figure 13. Display Board - Top View and Bottom View



3.1.1.2 Programming Interface for the MSP430™ MCU

The J1 (display board) 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 the MSP430 development tools and device programmers. Table 7 lists the Spy-Bi-Wire interface pin requirements. For further details on interfacing to development tools and device programmers, see the *MSP430 Hardware Tools User's Guide*.

Table 7. Spy-Bi-Wire Pin Requirements and Functions

J2 PIN NUMBER	DEVICE SIGNAL	DIRECTION	SBW FUNCTION
1	VSS	—	Ground supply

Table 7. Spy-Bi-Wire Pin Requirements and Functions (continued)

J2 PIN NUMBER	DEVICE SIGNAL	DIRECTION	SBW FUNCTION
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 the MSP430FR2476 device, in which an optical ToF-based proximity sensing and system calibration is implemented. The firmware includes two parts: system calibration and sensor output capture . The system calibration firmware implements the OPT3101 calibration procedure to get calibration parameters and save to an external EEPROM. The OPT3101 device loads calibration parameters from the external EEPROM automatically after power on to configure the registers inside the device over I²C and reads the measured distance data. Next, the firmware configures the TLC59283 device to drive LED segments to display the distance. This system calibration routine must be done one time per board to get accurate distance measurements.

Table 8 lists the system components for the firmware of this reference design.

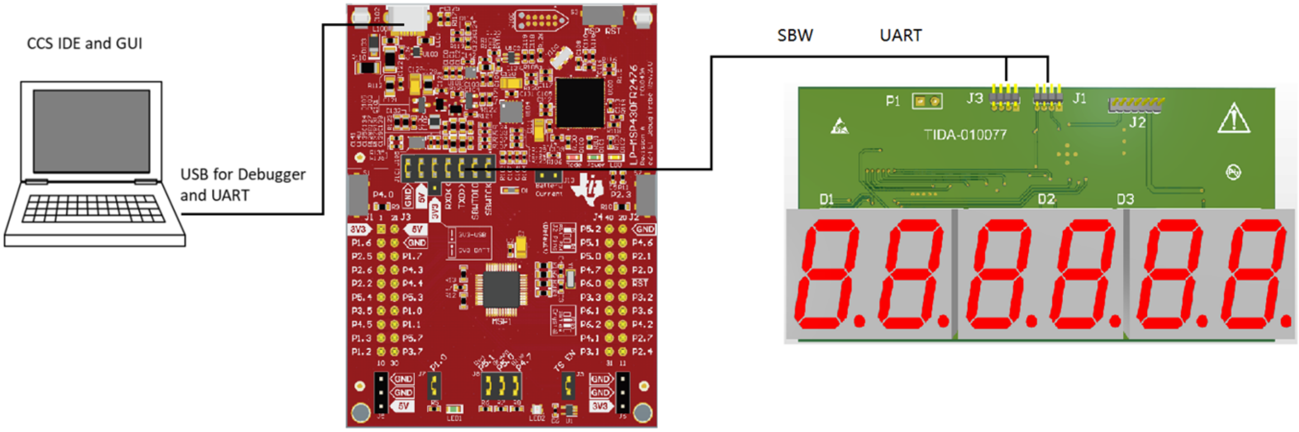
Table 8. TIDA-010021 Firmware System Components

ITEMS	DESCRIPTION
Integrated development environment (IDE)	Code Composer Studio™ v9.0
Target MCU	MSP430FR2476
OPT3101 SDK	OPT3101 software development kit (SDK)
LaunchPad™ Development Kit	MSP430™ LaunchPad™
MCU to OPT3101 connector	P1.2 - SDA; P1.3 - SCL; P1.7 – GP1
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 works 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 Code Composer Studio Integrated Development Environment (IDE), a MSP430FR2476 LaunchPad™ Development Kit or MSP-FET430UIF is required for programming and debugging the reference board. Figure 14 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 14. LaunchPad™ and TIDA-010077 Board Connections Diagram



Make sure to download and install the following prerequisites to the computer:

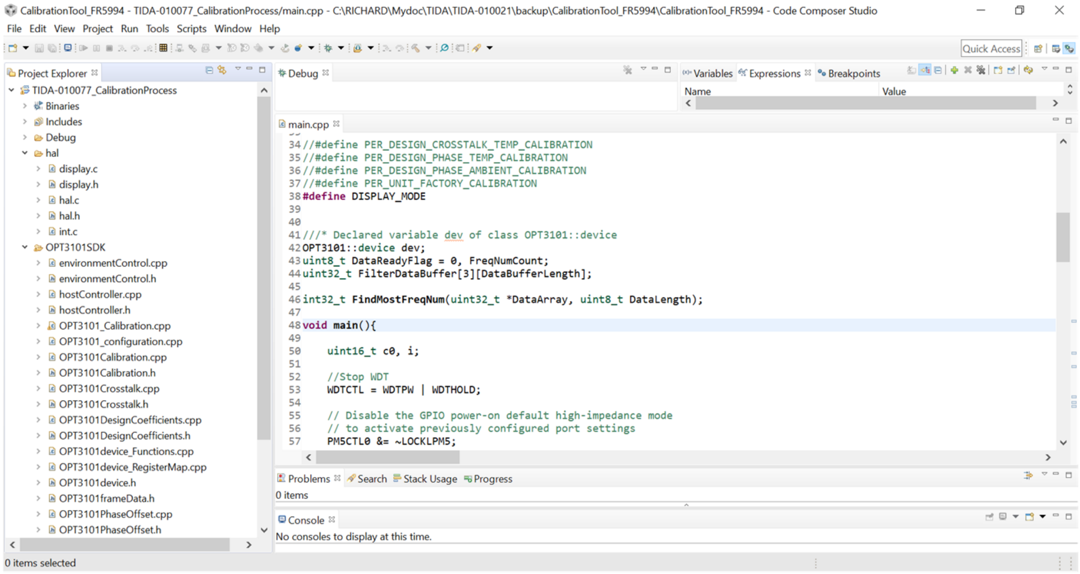
- Code Composer Studio™ v9.0
- TIDA-010077_RevA Firmware

3.1.2.3 Programming the MSP430™

The user can edit and program the firmware of the MSP430™ MCU. The TIDA-010077 board programming instructions follow:

1. Import the TIDA_010077_RevA project using TI's Code Composer Studio software.
2. Connect the LaunchPad programmer to the TIDA-010077 board, as Figure 14 shows.
3. Build the project by clicking the *Build* button (hammer icon), which if run successfully, appears as Figure 15 shows.
4. Click the *Debug* button (bug icon) as Figure 15 shows.

Figure 15. Build and Debug Using Code Composer Studio™ From TI



```
//#define PER_DESIGN_CROSSTALK_TEMP_CALIBRATION
//#define PER_DESIGN_PHASE_TEMP_CALIBRATION
//#define PER_DESIGN_PHASE_AMBIENT_CALIBRATION
//#define PER_UNIT_FACTORY_CALIBRATION
#define DISPLAY_MODE


///* Declared variable dev of class OPT3101::device
OPT3101::device dev;
uint8_t DataReadyFlag = 0, FreqNumCount;
uint32_t FilterDataBuffer[3][DataBufferLength];

int32_t FindMostFreqNum(uint32_t *DataArray, uint8_t DataLength);

void main(){

    uint16_t c0, i;

    //Stop WDT
    WDTCTL = WDTPW | WDTHOLD;

    // Disable the GPIO power-on default high-impedance mode
    // to activate previously configured port settings
    PM5CTL0 &= ~LOCKLPM5;
```

0 items

No consoles to display at this time.

3.1.2.4 OPT3101 SDK

The OPT3101 software development kit (SDK) provides a C++ library of functions to control and calibrate systems using the OPT3101 device, which is a ToF-based, long-range proximity and distance sensor analog front end (AFE).

The OPT3101 SDK features follow:

1. Enables access to registers by name instead of physical address
2. Enables control and access to groups of registers to achieve specific functionality
3. Contains data types (classes) to hold, analyze, and report calibration data
4. Allows templatizing of classes for environment and host controls

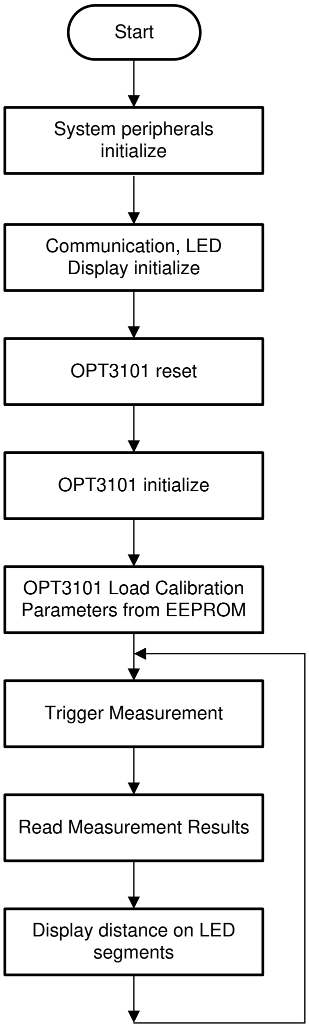
For more SDK details, see the *OPT3101 software development kit (SDK)*.

3.1.2.5 User Application Flow Charts

3.1.2.5.1 Distance Capture Flow Chart

Figure 16 shows the flow chart of distance data capture from the OPT3101 firmware in the MCU. TI offers this firmware example in which system hardware initialization, OPT3101 calibration parameters loading, and repeatedly distance data capture has been implemented. Calibration parameters are in external EEPROM and load automatically to the OPT3101 device, the user must run the system calibration routine first for new projects. Additionally, this firmware reserves the UART communication interface for directly reading and writing OPT3101 registers. The user can use this interface to debug or develop a GUI on the PC.

Figure 16. Proximity Application Flow Chart

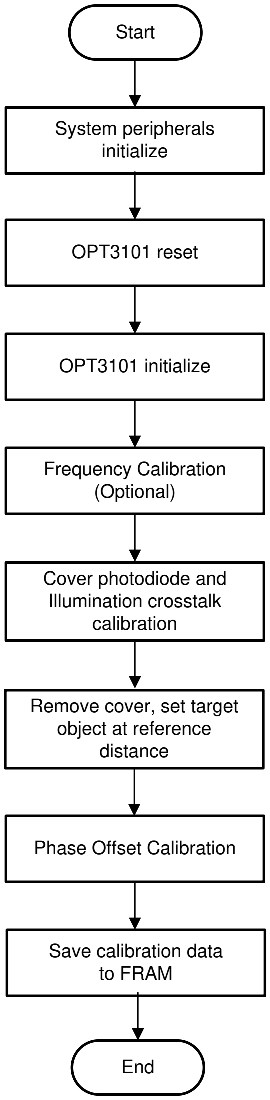


3.1.2.5.2 *System Calibration Flow Chart*

System calibration is critical for this design. See the *OPT3101 Distance Sensor System Calibration User's Guide* and the *How to Set Up and Calibrate OPT3101 Based Systems for Proximity Sensing User's Guide* for more details.

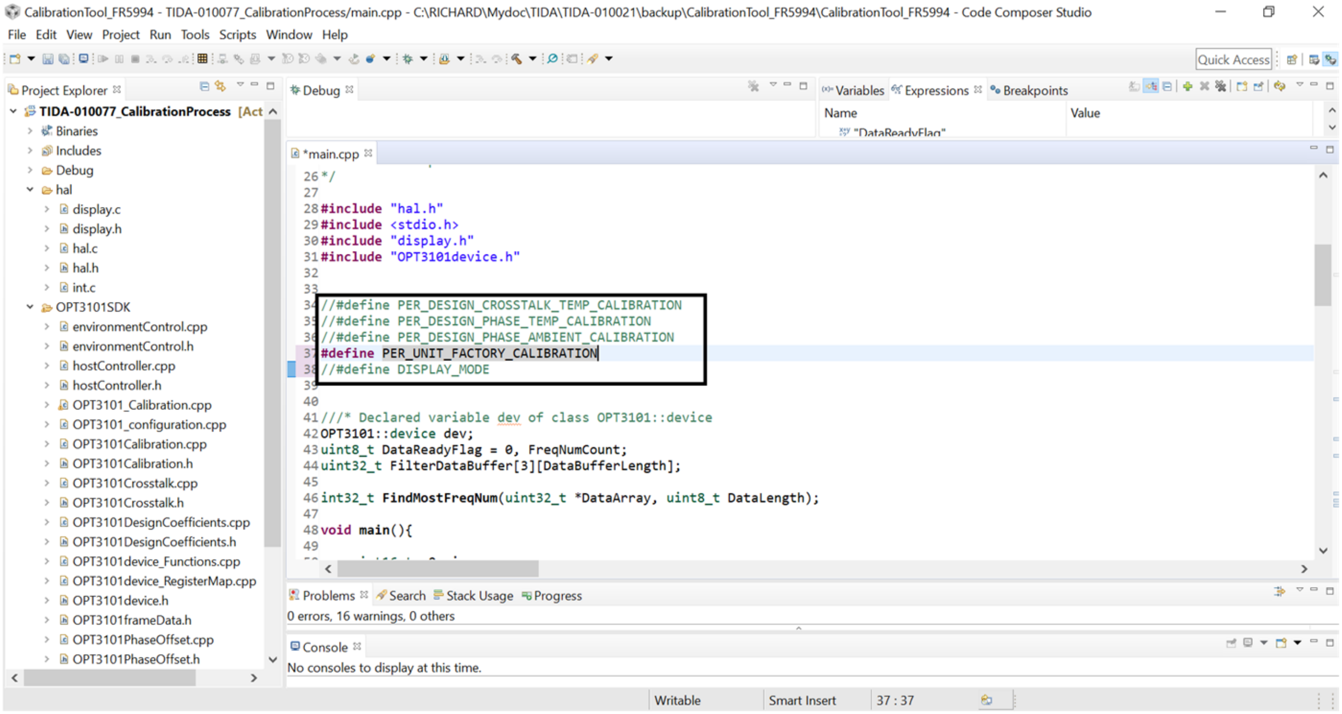
Figure 17 shows the system calibration flow chart. This calibration routine must be done one time per TIDA-010077 board and save the calibration parameters to external EEPROM memory. Once the data capture application runs, the OPT3101 device loads the calibration parameters from the external EEPROM automatically after power on.

Figure 17. System Calibration Flow Chart



Choose the specific calibration step and comment out the others as Figure 18 shows. The reference distance setting should ensure the received signal amplitude is high (AMP_OUT > 10000).

Figure 18. Code Example for Calibration



```
*/

#include "hal.h"
#include <stdio.h>
#include "display.h"
#include "OPT3101device.h"


//#define PER_DESIGN_CROSSTALK_TEMP_CALIBRATION
//#define PER_DESIGN_PHASE_TEMP_CALIBRATION
//#define PER_DESIGN_PHASE_AMBIENT_CALIBRATION
#define PER_UNIT_FACTORY_CALIBRATION
//#define DISPLAY_MODE


///* Declared variable dev of class OPT3101::device
OPT3101::device dev;
uint8_t DataReadyFlag = 0, FreqNumCount;
uint32_t FilterDataBuffer[3][DataBufferLength];

int32_t FindMostFreqNum(uint32_t *DataArray, uint8_t DataLength);

void main(){

```

```
0 errors, 16 warnings, 0 others
```

```
No consoles to display at this time.
```

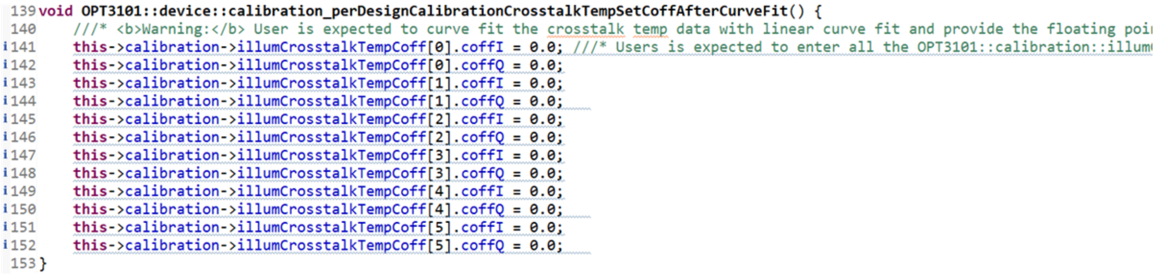
Table 9 shows the description of each function.

Table 9. Subfunction Description

ITEMS	DESCRIPTION
PER_DESIGN_CROSSTALK_TEMP_CALIBRATION	Crosstalk temperature calibration test for each design
PER_DESIGN_PHASE_TEMP_CALIBRATION	Phase temperature calibration test for each design
PER_DESIGN_PHASE_AMBIENT_CALIBRATION	Phase ambient calibration for each design
PER_UNIT_FACTORY_CALIBRATION	Factory calibration for each unit
DISPLAY_MODE	Distance data capture and display

Update the parameters in Figure 19 when the crosstalk temperature test is finished.

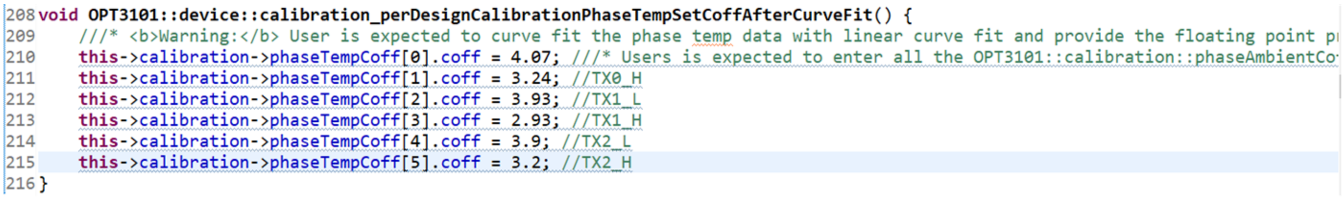
Figure 19. Crosstalk Temperature Parameters



```
void OPT3101::device::calibration_perDesignCalibrationCrosstalkTempSetCoffAfterCurveFit() {
    ///* <b>Warning:</b> User is expected to curve fit the crosstalk temp data with linear curve fit and provide the floating poi
    this->calibration->illumCrosstalkTempCoff[0].coffI = 0.0; ///* Users is expected to enter all the OPT3101::calibration::illum
    this->calibration->illumCrosstalkTempCoff[0].coffQ = 0.0;
    this->calibration->illumCrosstalkTempCoff[1].coffI = 0.0;
    this->calibration->illumCrosstalkTempCoff[1].coffQ = 0.0;
    this->calibration->illumCrosstalkTempCoff[2].coffI = 0.0;
    this->calibration->illumCrosstalkTempCoff[2].coffQ = 0.0;
    this->calibration->illumCrosstalkTempCoff[3].coffI = 0.0;
    this->calibration->illumCrosstalkTempCoff[3].coffQ = 0.0;
    this->calibration->illumCrosstalkTempCoff[4].coffI = 0.0;
    this->calibration->illumCrosstalkTempCoff[4].coffQ = 0.0;
    this->calibration->illumCrosstalkTempCoff[5].coffI = 0.0;
    this->calibration->illumCrosstalkTempCoff[5].coffQ = 0.0;
}
```

Update the parameters in Figure 20 when the phase temperature test is finished.

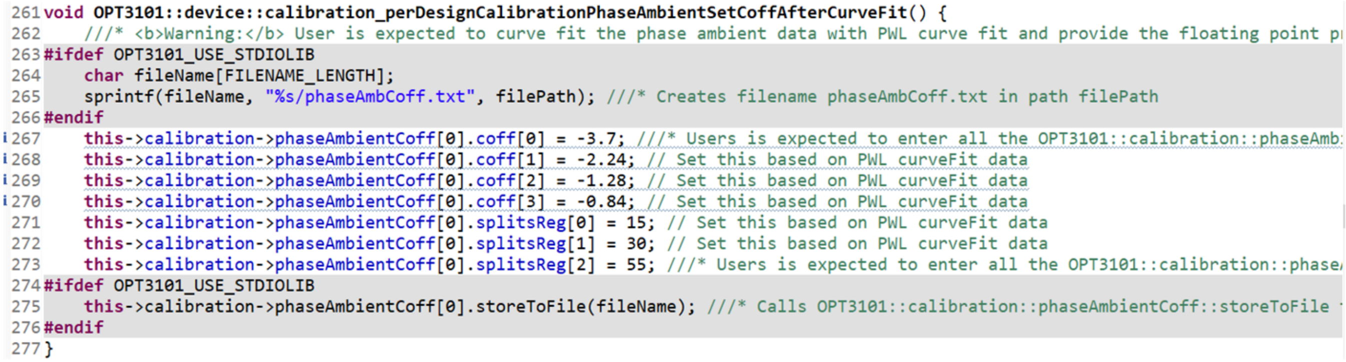
Figure 20. Phase Temperature Parameters



```
void OPT3101::device::calibration_perDesignCalibrationPhaseTempSetCoffAfterCurveFit() {
    ///* <b>Warning:</b> User is expected to curve fit the phase temp data with linear curve fit and provide the floating point
    this->calibration->phaseTempCoff[0].coff = 4.07; ///* Users is expected to enter all the OPT3101::calibration::phaseAmbientCo
    this->calibration->phaseTempCoff[1].coff = 3.24; //TX0_H
    this->calibration->phaseTempCoff[2].coff = 3.93; //TX1_L
    this->calibration->phaseTempCoff[3].coff = 2.93; //TX1_H
    this->calibration->phaseTempCoff[4].coff = 3.9; //TX2_L
    this->calibration->phaseTempCoff[5].coff = 3.2; //TX2_H
}
```

Update the parameters in Figure 21 when the phase ambient test is finished.

Figure 21. Phase Ambient Parameters



```
void OPT3101::device::calibration_perDesignCalibrationPhaseAmbientSetCoffAfterCurveFit() {
    ///* <b>Warning:</b> User is expected to curve fit the phase ambient data with PWL curve fit and provide the floating point
#ifdef OPT3101_USE_STDIOLIB
    char fileName[FILENAME_LENGTH];
    sprintf(fileName, "%s/phaseAmbCoff.txt", filePath); ///* Creates filename phaseAmbCoff.txt in path filePath
#endif
    this->calibration->phaseAmbientCoff[0].coff[0] = -3.7; ///* Users is expected to enter all the OPT3101::calibration::phaseAmb
    this->calibration->phaseAmbientCoff[0].coff[1] = -2.24; // Set this based on PWL curveFit data
    this->calibration->phaseAmbientCoff[0].coff[2] = -1.28; // Set this based on PWL curveFit data
    this->calibration->phaseAmbientCoff[0].coff[3] = -0.84; // Set this based on PWL curveFit data
    this->calibration->phaseAmbientCoff[0].splitsReg[0] = 15; // Set this based on PWL curveFit data
    this->calibration->phaseAmbientCoff[0].splitsReg[1] = 30; // Set this based on PWL curveFit data
    this->calibration->phaseAmbientCoff[0].splitsReg[2] = 55; ///* Users is expected to enter all the OPT3101::calibration::phase
#ifdef OPT3101_USE_STDIOLIB
    this->calibration->phaseAmbientCoff[0].storeToFile(fileName); ///* Calls OPT3101::calibration::phaseAmbientCoff::storeToFile
#endif
}
```

3.2 Testing and Results

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

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 was also performed to verify how the reference design acts in different environments.

3.2.1.1 Test Setup Preparation

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™ v9.0 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 130 klx
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.
- Connect the sensor board and display board.
- Connect the computer and sensor board through USB. The USB is only used for the power input of the display board without data communication.
- Mount the sensor into a specified fixture.

3.2.2 Test Results

In this test, a wall with different color acts as a sensing target to simulate a real application. Three application scenes, including darkness operation and sunlight operation, are tested. The target for 3 channels (TX0, TX1, TX2) are tested separately.

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

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

3.2.2.1.1 White Wall as Target

A white wall acts as the target. Figure 22 shows the test setup.

Figure 22. White Wall as Test Target

Figure 23 shows the distance measured by the sensor when a white wall acts as the target for TX0 and Figure 24 shows the error (in percent) with regards to distance.

Figure 23. Measurement Distance vs Actual Distance - TX0 White Wall

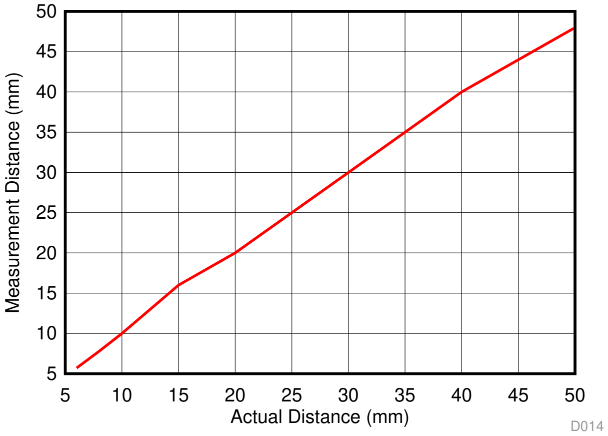


Figure 24. Error % vs Distance - TX0 White Wall

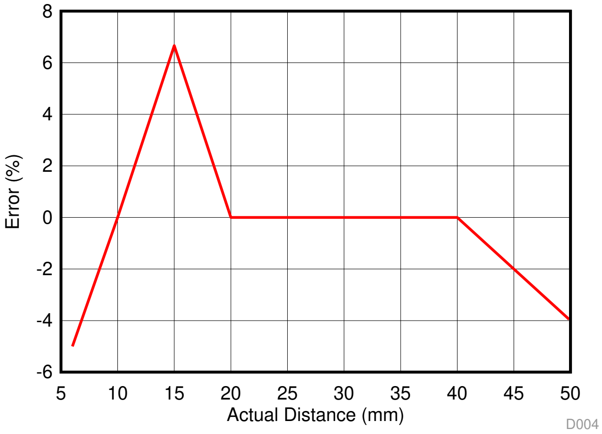


Figure 25 shows the distance measured by the sensor when a white wall acts as the target for TX1 and Figure 26 shows the error (in percent) with regards to distance.

Figure 25. Measurement Distance vs Actual Distance - TX1 White Wall

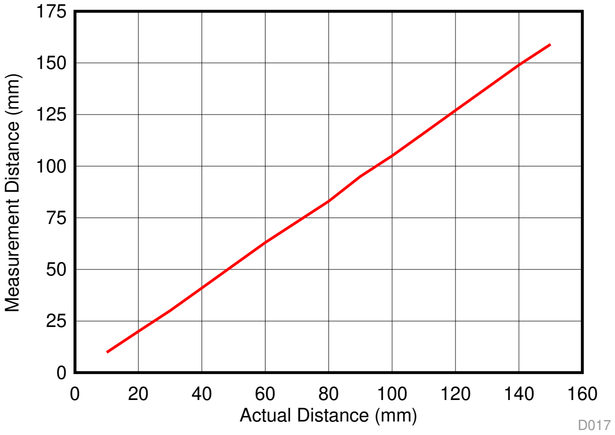


Figure 26. Error % vs Distance - TX1 White Wall

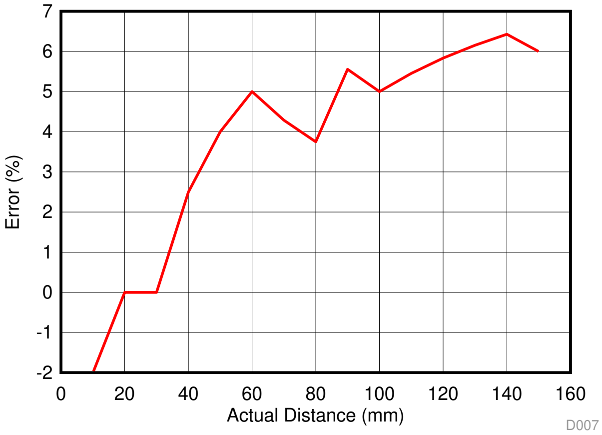


Figure 27 shows the distance measured by the sensor when a white wall acts as the target for TX2 and Figure 28 shows the error (in percent) with regards to distance.

Figure 27. Measurement Distance vs Actual Distance - TX2 White Wall

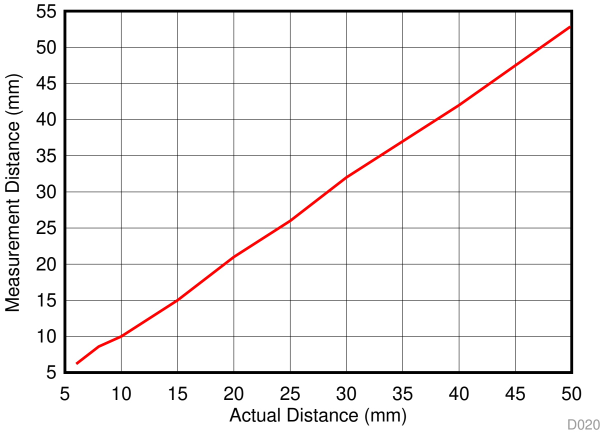
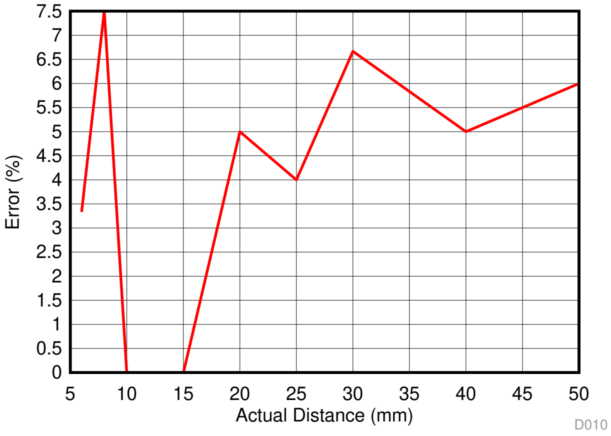


Figure 28. Error % vs Distance - TX2 White Wall



3.2.2.1.2 Green Wall as Target

A green wall acts as the target. Figure 29 shows the test setup.

Figure 29. Green Wall as Test Target

Figure 30 shows the distance measured by the sensor when a green wall acts as the target for TX0 and Figure 31 shows the error (in percent) with regards to distance.

Figure 30. Measurement Distance vs Actual Distance - TX0 Green Wall

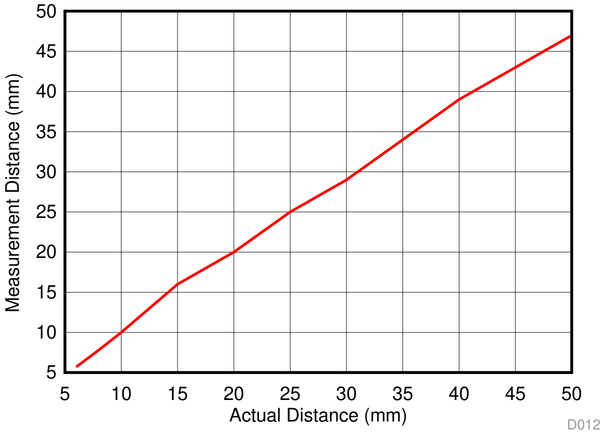


Figure 31. Error % vs Distance - TX0 Green Wall

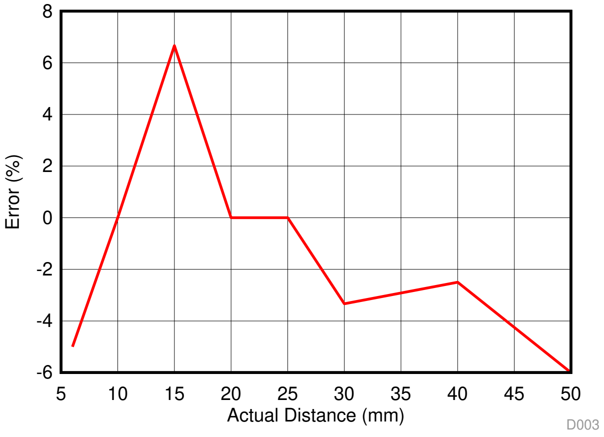


Figure 32 shows the distance measured by the sensor when a green wall acts as the target for TX1 and Figure 33 shows the error (in percent) with regards to distance.

Figure 32. Measurement Distance vs Actual Distance - TX1 Green Wall

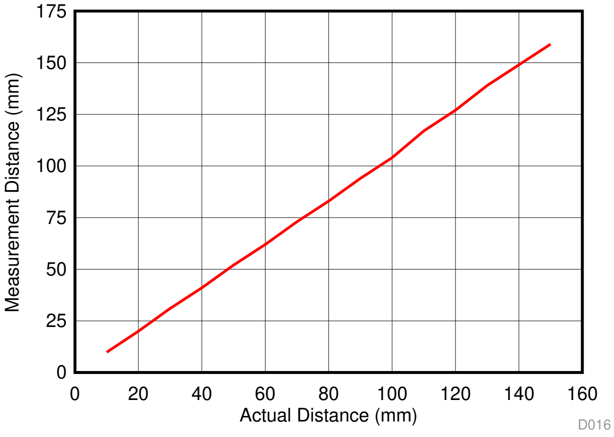


Figure 33. Error % vs Distance - TX1 Green Wall

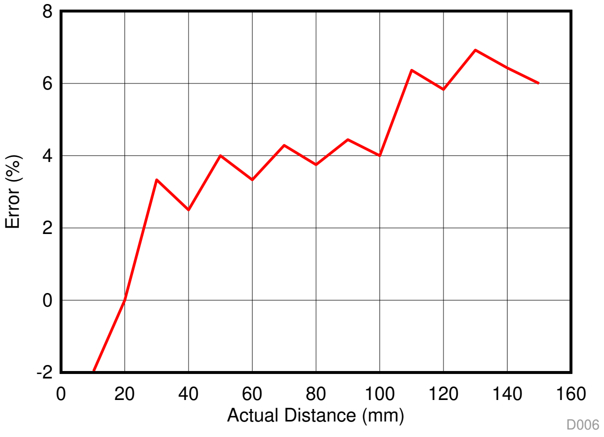


Figure 34 shows the distance measured by the sensor when a green wall acts as the target for TX2 and Figure 35 shows the error (in percent) with regards to distance.

Figure 34. Measurement Distance vs Actual Distance - TX2 Green Wall

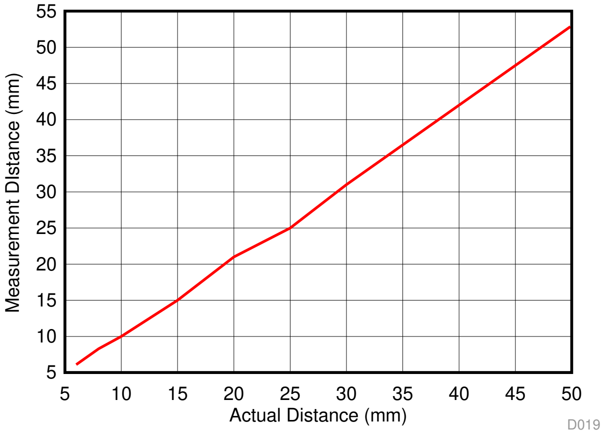
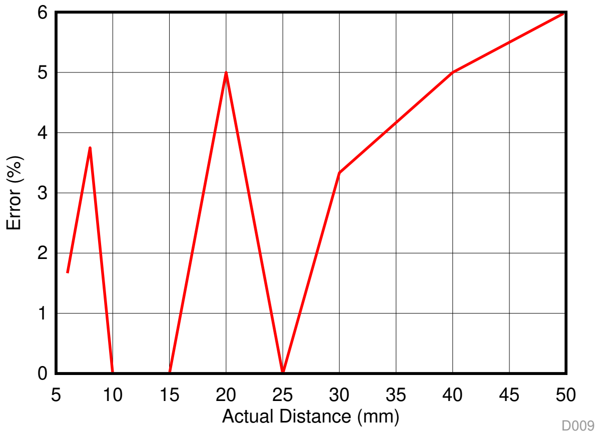


Figure 35. Error % vs Distance - TX2 Green Wall



3.2.2.1.3 Black Wall as Target

A black wall acts as the target. Figure 36 shows the test setup.

Figure 36. Black Wall as Test Target

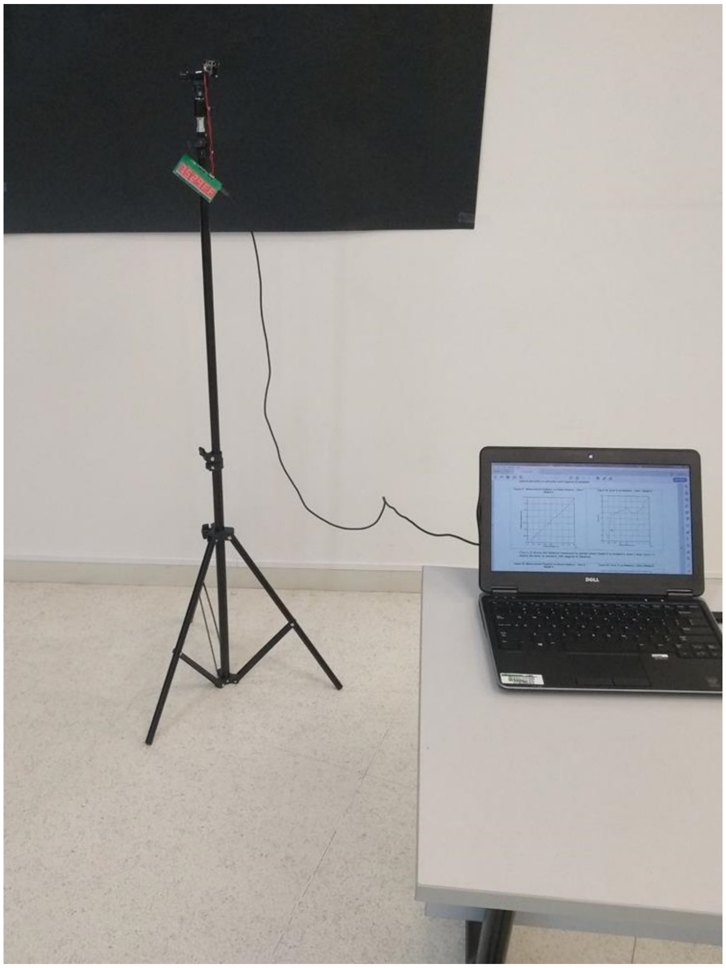


Figure 37 shows the distance measured by the sensor when a black wall acts as the target for TX0 and Figure 38 shows the error (in percent) with regards to distance.

Figure 37. Measurement Distance vs Actual Distance - TX0 Black Wall

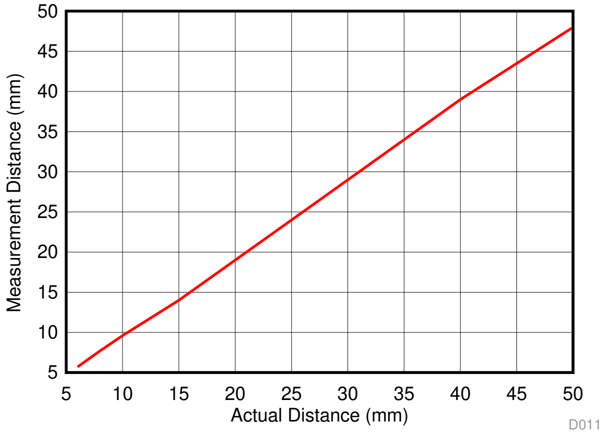


Figure 38. Error % vs Distance - TX0 Black Wall

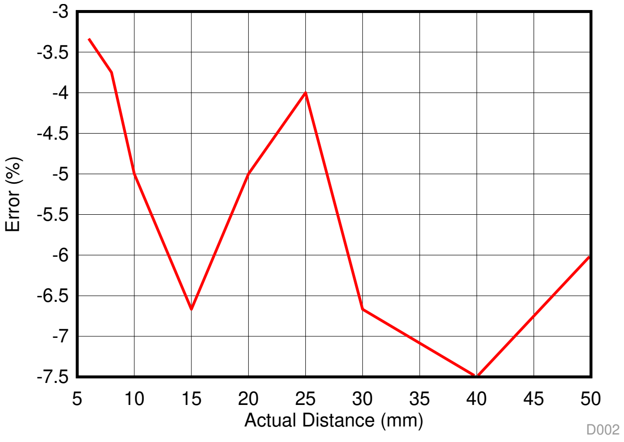


Figure 39 shows the distance measured by the sensor when a black wall acts as the target for TX1 and Figure 40 shows the error (in percent) with regards to distance.

Figure 39. Measurement Distance vs Actual Distance - TX1 Black Wall

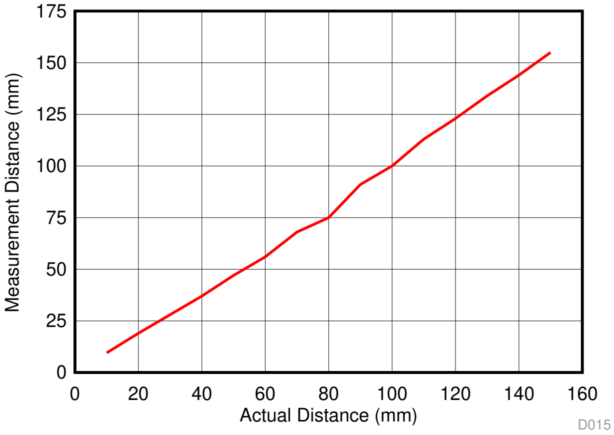


Figure 40. Error % vs Distance - TX1 Black Wall

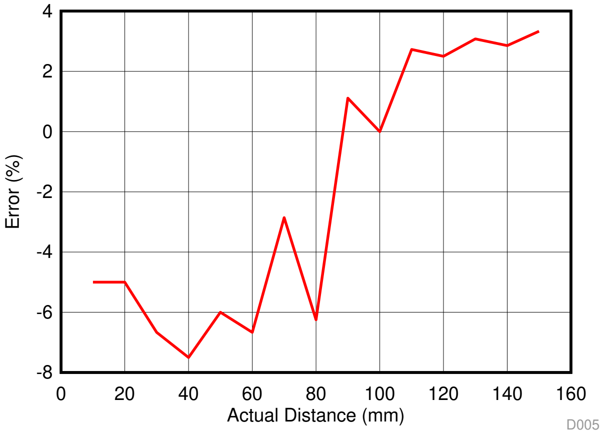


Figure 41 shows the distance measured by the sensor when a black wall acts as the target for TX2 and Figure 42 shows the error (in percent) with regards to distance.

Figure 41. Measurement Distance vs Actual Distance - TX2 Black Wall

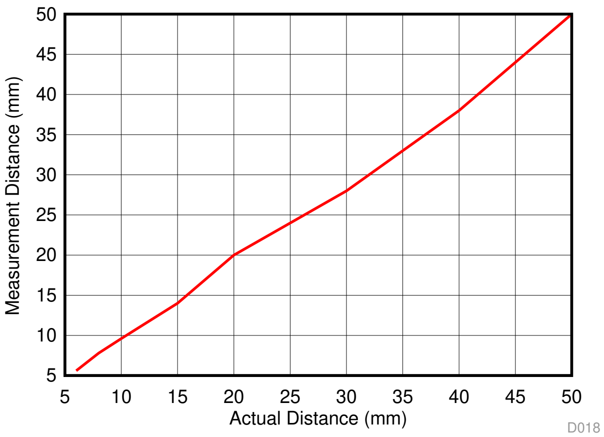
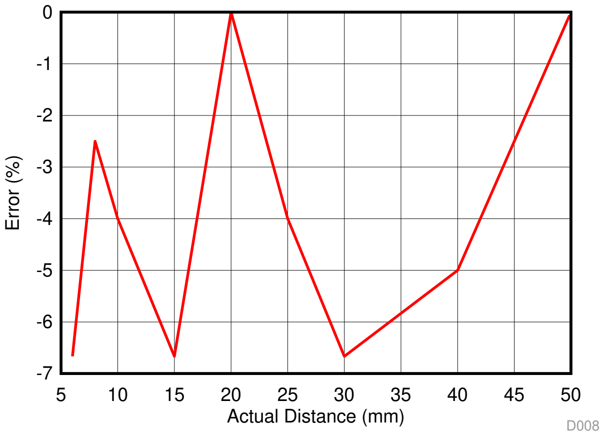


Figure 42. Error % vs Distance - TX2 Black Wall



The test results in the previous images show that the target with a different color may affect the NIR reflection but the sensor is not sensitive to object color. The measured distance error is within the scope of pre-defined parameters for different color walls.

3.2.2.2 Scene 2 - Darkness Operation

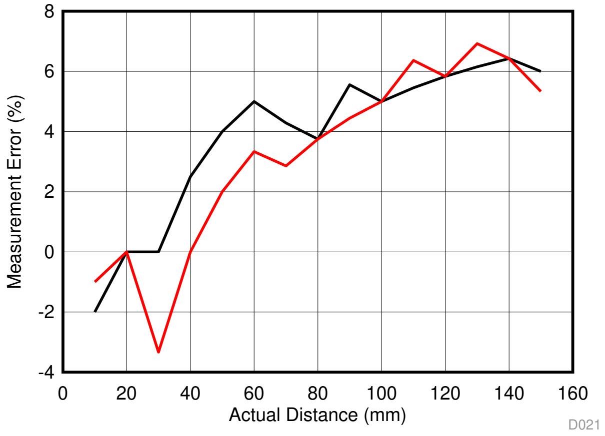
Scene 2 aims to test the sensor performance under darkness operation, for example, evening or night when there is no ambient light or low ambient light. Figure 43 shows the test setup under a dark environment.

Figure 43. Darkness Operation

For the darkness operation, only TX1 is chosen and a white wall acts as the target for the test. Comparing with the same position of *Scene 1*, sensor performance under darkness operation can be observed and the effects of low ambient light can be concluded. In Figure 44, the red line shows the test results comparing with the black line which is sensor performance in *Scene 1*.

Figure 44 shows that sensor performance under darkness operation is good or even better comparing *Scene 1*.

Figure 44. Operation in Darkness Comparing With Scene 1



3.2.2.3 Scene 3 - Operation Under Sunlight (86 klx Ambient Light)

Scene 3 aims to test the sensor performance under a sunlight environment, for example, when the sunshine comes into the room at noon. Figure 45 shows the test setup at 86-klx sunlight environment.

Figure 45. 86-klx Ambient Light Operation

For the high ambient light operation, only TX1 is chosen and a white wall acts as the target for the test. Comparing with the same position of *Scene 1*, the sensor performance under sunlight operation can be observed and the effects of high ambient light can be concluded. In Figure 46, the red line shows the test results comparing with the black line which is the sensor performance in *Scene 1*.

Figure 46. Operation Under Sunlight Comparing With Scene 1

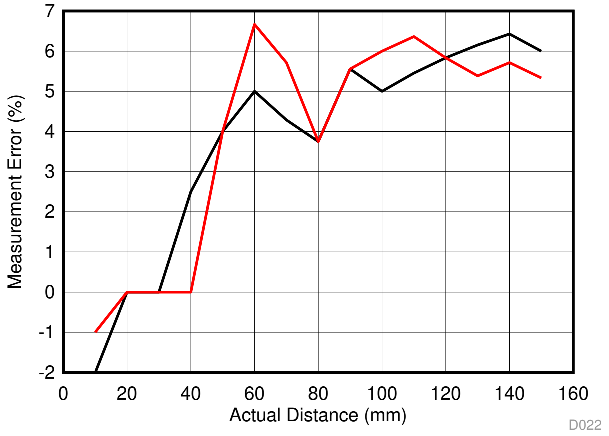


Figure 46 shows that sensor support high ambient light operation and performance is much better than other optical technics for proximity sensing.

3.2.2.4 Power Consumption

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

Table 11. Consumption at Ambient Temperature

PARAMETER	MIN	MAX	UNIT	COMMENTS
HW standby		80	µA	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 s for one sample (128 sub frames)

4 Design Files

4.1 Schematics

To download the schematics, see the design files at TIDA-010077.

4.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-010077.

4.3 PCB Layout Recommendations

Reducing the coupling between the transmitter and receiver is critical to achieve good system performance. Minimize the area of transmitter current carrying loop through the LED supply decoupling capacitor, LED and the AFE pins TX*, VSSL. Also minimize the receiver loop involving the photodiode, matching capacitor and the AFE pins INP, INM. It is recommended to use the layout as it is to get the best performance. If changes are needed, the following guidelines must 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 the 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 the top and bottom PCB layers. Also place a shielding ring around the photodiode and connect the shielding ring to AVSS. This shielding ring reduces 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.
- The LED terminals and the photodiode terminals must not be directly exposed to each other. Any small amount of capacitive coupling between photodiode and LED terminals result in huge crosstalk. Grounded metal rings around the photodiode and LED improves shielding.
- Use vias around the transmitter and receiver loops in the 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 Long Range Proximity and Distance Sensor System Design User's Guide* for more information.

4.3.1 Layout Prints

To download the layer plots, see the design files at TIDA-010077.

4.4 Altium Project

To download the Altium Designer® project files, see the design files at TIDA-010077.

4.5 Gerber Files

To download the Gerber files, see the design files at TIDA-010077.

4.6 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-010077.

5 Software Files

To download the software files, see the design files at TIDA-010077.

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 Long Range Proximity and Distance 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*

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7 Terminology

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

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