Application Report

SBAA296–July 2018

Application of OPT3101 in Precise Distance Measurement and Ranging Applications

ABSTRACT

There are many applications where non-contact based distance measurement is a need, with requirements varying from precise measurement, coarse-but-fast measurement, to just present-absent kind of scenarios. For instance, on a factory conveyor line, the distance is measured to either trigger a barcode reader, count objects, or help with robotic arm positioning. In building automation ,the distance could be used to sense an approaching user, trigger the auto-opening of doors, or even to enable displays. In appliances and toys such as drones, the distance measurement can be used to measure the distance to the ground when the drone lands. The requirements span across different vectors — from high precision, object color independence, indoor and outdoor operation to high speed measurements.

Figure 1. Applications of Distance Measurement Systems

This application report gives an overview of the Time-of-Flight (ToF) technology using the OPT3101 integrated Distance Sensor Analog-Front-End (AFE). Measurements results under different conditions and tools for “what-if” analysis are introduced. Texas Instruments' Time of Flight AFEs and chipsets offers a wide range of flexibility with the choice of design parameters such as sample rate, light wavelength, field of view, and so on.

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1 Introduction Of Time-of -Flight (ToF) Analog Front End (AFE)

There are various detection and ranging methods that can be used in these applications; with the most commonly used being Photo-electric, Ultrasonic and Radar technologies. Normally for ranging applications, the most important considerations are distance, accuracy, and environmental performance. Each of the methods of ranging stated above has unique strengths and weaknesses. Photoelectric sensors are cheap and fast but have range distance limitations. Ultrasonic gets a low-cost solution but with limited range distance, slower data rate, and performance dependent on surface and angle of attack. With radar, range distance can be much superior to others, but with potential refresh rate limitations and false echoes.

Under the photo-electric principle, TI's OPT3101, which is a Distance sensor Analog-Front-End (AFE) uses Time-of-Flight (ToF) principle to help accurate measurement of distance. With an external LED and photodiode, it can be used to implement a high speed, and high resolution distance sensor. OPT3101 offers the flexibility to adapt a design that best suits the application. With external transmit and receive, the user has the choice of any wavelength of interest (visible or IR), any illumination source (LED or VCSEL), and any field of view 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.

Time-of-Flight technology has certain distinct benefits. Firstly, since it senses at the speed of light, OPT3101 and other ToF technologies operate very fast compared to other range sensing methods like ultrasonic sensing. OPT3101 can provide data up to 4000 samples/second. Secondly it helps in measuring distance independent of object color. An amplitude based system estimates distance based on reflected signal strength. Signal received back from a white reflective object at further range can be similar to that of a black low reflective object at close distance, making it difficult to differentiate between the two. This often leads to erroneous distance reporting. ToF technologies independently determine phase and amplitude, allowing for the color independency. Lighter colors reflect back a strong signal with a high signal-to-noise ratio (SNR). When light is reflected off dark colors, the return waveform is weaker, with shorter amplitude, and more noise. Nonetheless, the mean of the waveform is still the same, thus giving the correct distance.

Unique to OPT3101, there is an internal ambient cancellation block that allows for great performance both indoors and outdoors, including full sunlight of 130 Klux. For more information on this refer to Section. 7.3.3. of the OPT3101 datasheet. OPT3101 also has other ways to make sure the accuracy is high. It has various calibrations and compensations listed in the *OPT3101 Distance Sensor System Calibration* user's guide, ranging from crosstalk, phase offset, phase correction with temperature and ambient etc. that helps achieve better performance.

2 Measurement Data Using OPT3101

In the following sections, data measured under a few different conditions, along with test setup, are described. The following are three test scenarios used in this application report:

1. Short distance: a lab characterization measurement using two reflective targets (80% and 5%) with range up to 2.5m
2. Long distance: an indoor and outdoor measurement which covers various ambient conditions with a range up to 10m
3. Very long distance: using a retroreflective object as target to reach a range of up to 40m

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2.1 Test Scenario 1: Short Distance

Figure 2 shows how measurement data is collected using the *OPT3101 Evaluation Module*. This module uses two components to transmit and to receive information. The components are:

- Illumination: Osram SFH4550, 850nm, ± 3 degrees, driven by an OPT3101 internal LED driver
- Photodiode: Osram SFH 213FA, pindiode with a 0.65A/W responsivity of 850nm

The data measurements in Figure 2 show two different reflectivity conditions with a range of up to 2.5m. 32 samples are used and averaged per output which overall results in 125 frames per second. When comparing the two plots, the measured versus actual distance plots are linear. As expected, the noise is lower with high reflectivity, and the noise is higher with low reflectivity.

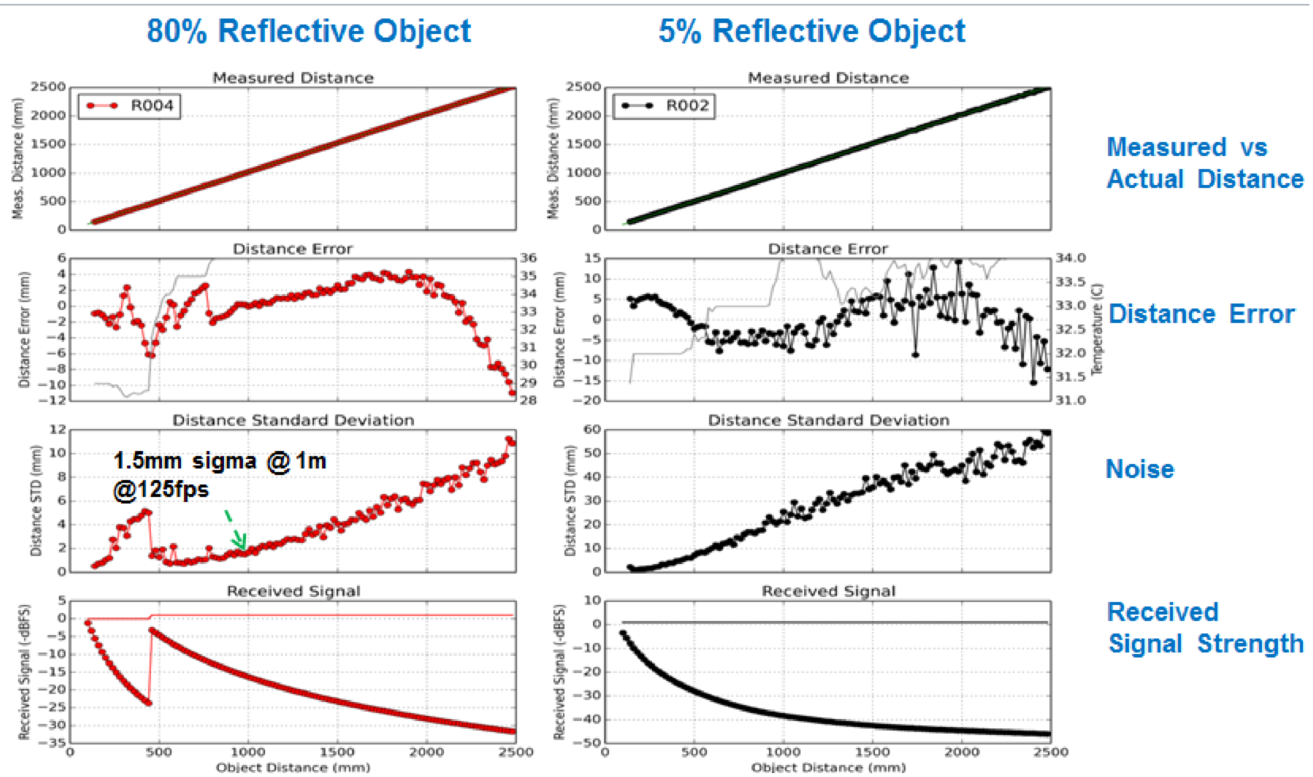

Figure 2. OPT3101 EVM Based Measurements

NOTE: The data is collected using indoor conditions with a well-calibrated lab set up. This allows for the precise stepping controls to collect accurate step data.

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2.2 Test Scenario 2: Long Distance

In this scenario, the long range capabilities of the device were tested using both the indoor and the outdoor conditions. When measuring longer distances care needs to be taken that target object is flat so one can get precise characterization data. The Field of View (FoV) of the Evaluation module is reasonably small (±3 degrees), but at a longer range, the spot size can increase significantly. To avoid the FoV from falling to the ground, the EVM is mounted on a tripod. The tripod is raised high from the ground and is aimed at a flat wall.

For the indoor target, a flat 10m x 10m white wall with approximately 90% reflectivity (as shown in Figure 3) was chosen. A wall of this size makes the whole target within the FoV range of the OPT3101 system nearly identical. The location was chosen accordingly, to make sure there are no objects within the field of view — up to nearly 10 meters.

Figure 3. Indoor Measurement Set Up

Figure 4. Outdoor Measurement Setup

Similarly for measuring the performance of OPT3101 in outdoor conditions, a flat 10m x 10m wall was used. One difference in the two setting, besides the ambient condition, is the wall color. The outdoor was measured on a brown color wall surface which was about 50% reflective (as shown in Figure 4), and should be taken into consideration while reading the results given below.

For both the indoor and outdoor measurement, a laser distance measurement device was mounted with the EVM to get the actual distance data. The test data is taken by interfacing the OPT3101 EVM using the laptop, and running the TI Latte software to record the amplitude, the distance, and the noise numbers.

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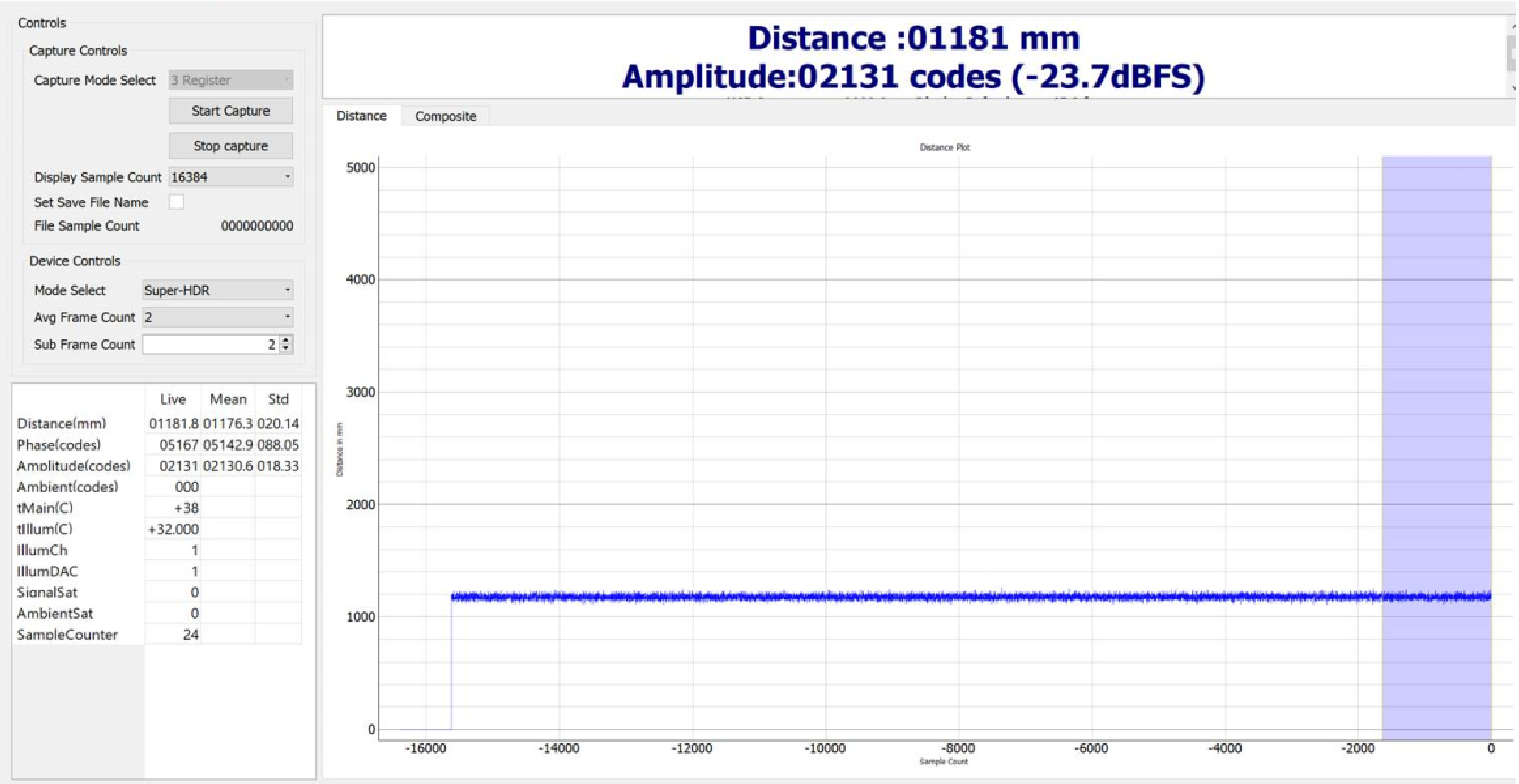

Figure 5. OPT3101 Evaluation Module GUI

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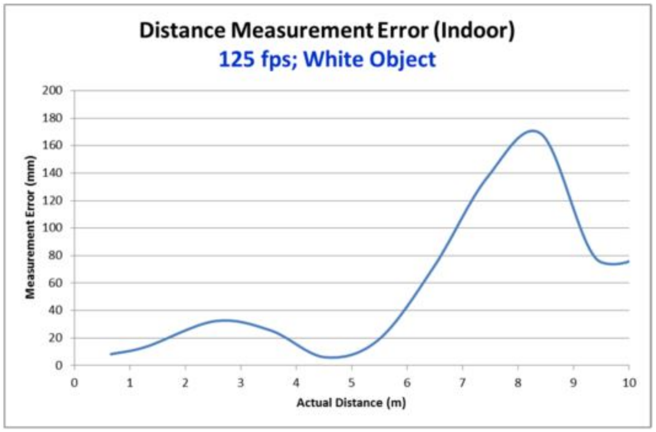

Figure 6. Error vs Distance (Indoor)

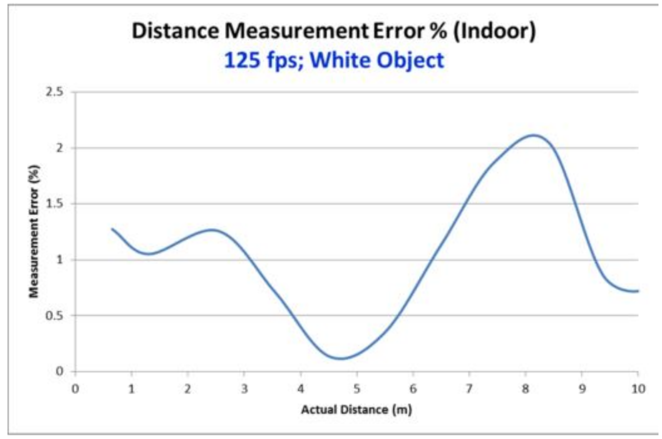

Figure 7. Error % vs Distance (Indoor)

Figure 6 and Figure 7 shows the performance of OPT3101 in indoor conditions which is measured using the setup described in this section. 32 samples are taken and then averaged, resulting in an effective 125fps output data rate. The average of the measurements is 125fps and this number is considered effective. Error in distance measurement is the difference between the distance measured by the OPT3101 and the actual distance using the laser measurement unit.

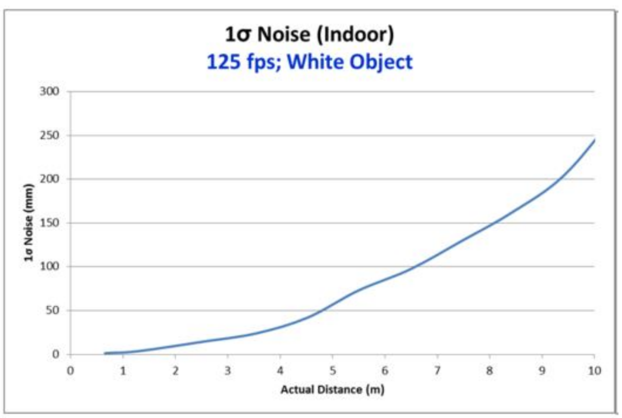

Figure 8. 1σ Noise vs Distance (Indoor)

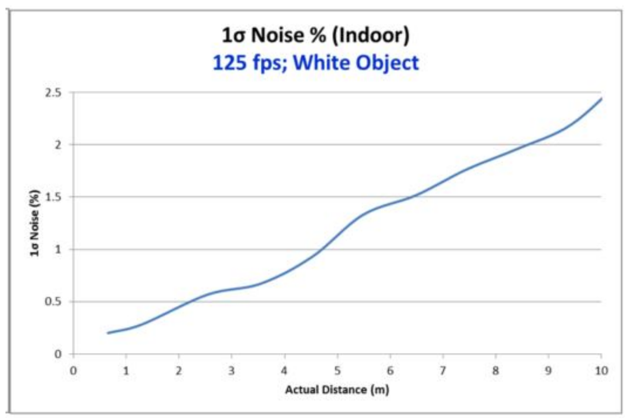

Figure 9. 1σ Noise % vs Distance (Indoor)

Figure 8 and Figure 9 shows how noise (σ) changes with distance.

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The data for outdoor measurement are shown below (Figure 10- Figure 13).

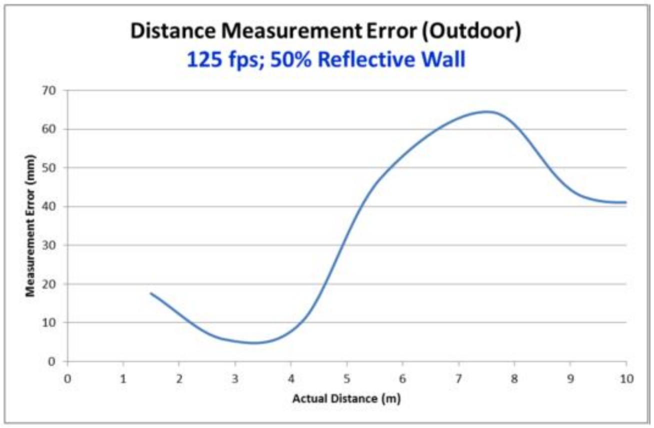

Figure 10. Error vs Distance (Outdoor)

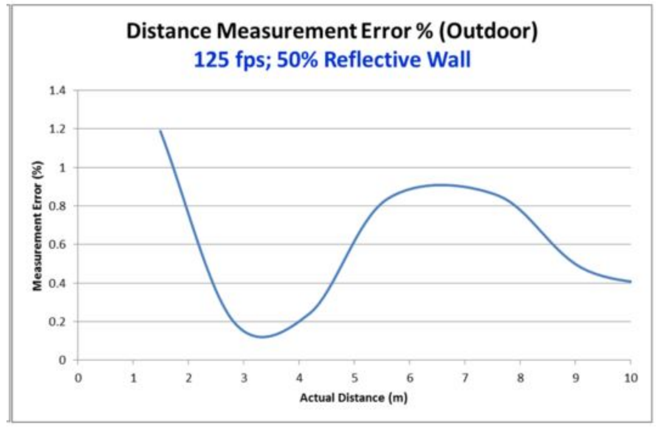

Figure 11. Error % vs Distance (Outdoor)

In Figure 11, the data shows that at about 10 meters and in high ambient outdoor conditions, the error in distance measurement is within 1.2% of the actual distance.

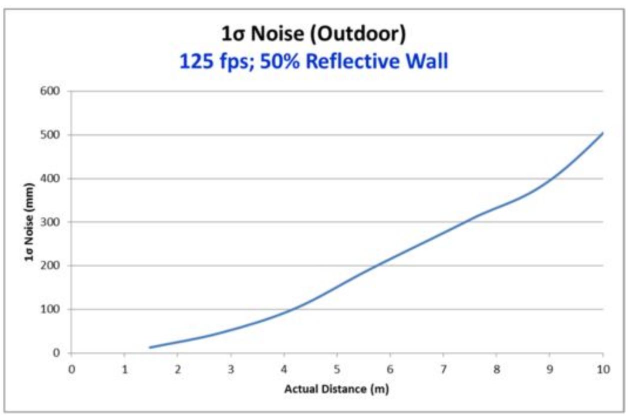

Figure 12. 1σ Noise vs Distance (Outdoor)

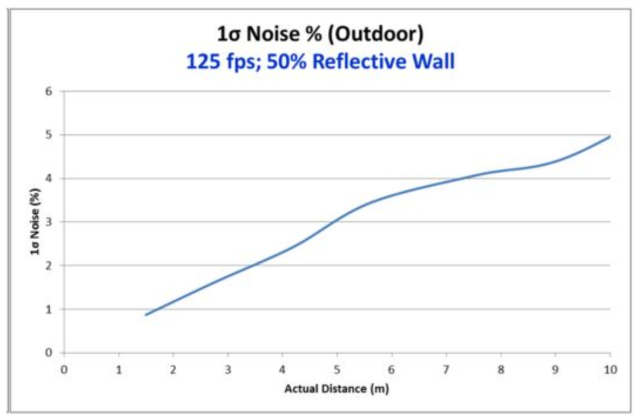

Figure 13. 1σ Noise % vs Distance (Outdoor)

The noise difference is about double between indoor and outdoor conditions and is attributed to the reflectivity difference. This confirms that the system is only limited to thermal noise and has excellent ambient performance.

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2.3 Test Scenario 3: Very Long Distance

In the following experiment, measurement over very long range is tested. At a longer distance, the reflected energy is almost zero unless very high energy is transmitted, which has other constraints like eye-safety, heat dissipation et cetera. In the following test setup, an A4 size, high intensity prismatic grade retroreflector is attached to the target. A long corridor in the building was used to measure the below. As explained in previous section, even with small Field of View (FoV) the spot size at 30-40m gets very big (a circle with radius of ~3.5m). Even though the corridor was not that wide, it does not impact the measurement because any signal hitting the side walls will not reflect much energy. Only the energy from the reflectors reaches the sensor back.

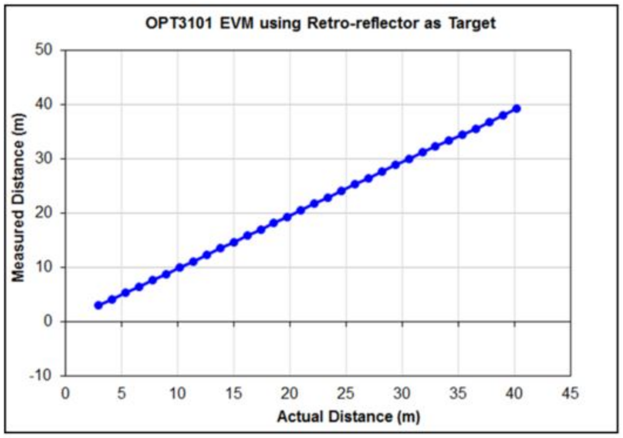

Figure 14. Measurement Distance vs Actual Distance

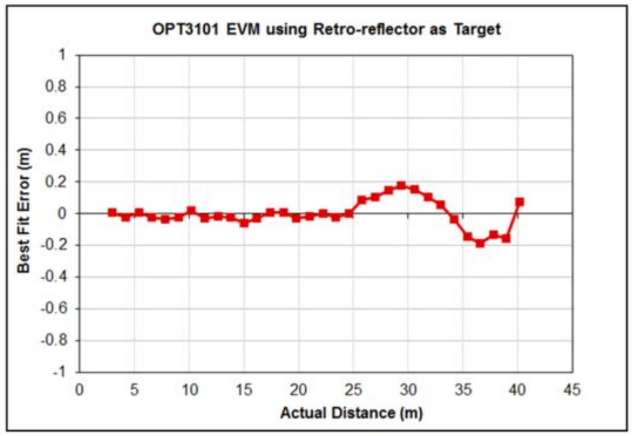

Figure 15. Best Fit Error vs Actual Distance

Figure 14 and Figure 15 shows that using a good retro-reflector and having a narrow field of view design one can achieve a very long range. This is applicable in factory automation, where there is a controlled environment, and you can use reflectors at a target distance. The OPT3101 gives the flexibility to design a system with various options of field of view and wavelength which allows for ease of customization based on the application and the use case.

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3 Overview of the Simulator Tool

The above measurement data were done with the OPT3101 EVM that was designed using a particular combination of LED and photodiode. To aid with doing more what-if analysis with different LED/PD components and different use case conditions, an OPT3101 System Estimator Tool is also available online.

The tool offers many options to help simulate different scenarios. You can change the averaging rate, introduce various sunlight conditions, and also have the option to choose emitter and receiver specifications. For ease of use, a few standard LED/PD components are already included, and the critical parameters for these (half angle, efficiency, and so on) are already pre-populated. You can also add new components to the library and use the new components for simulation. Mechanical parameters such as distance between the PD and the LED, along with any angle between these two, are also included as they impact the region of coverage.

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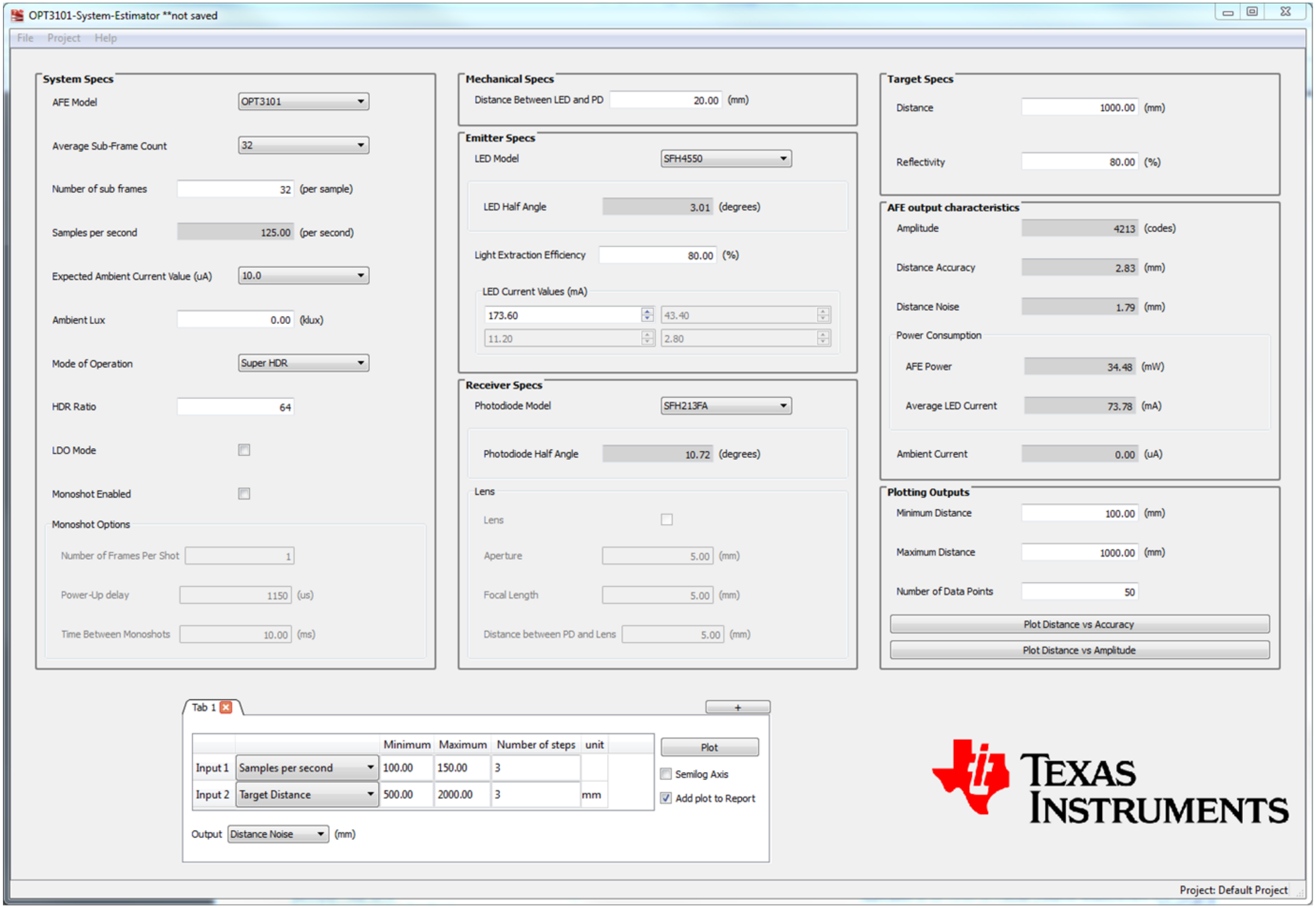

Figure 16. OPT3101 System Estimator Tool

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The tool uses the OPT3101 Analog Front End characteristics running in the background to estimate the overall system performance with the chosen LED and PD combination. The tool can plot graphs to show how the accuracy changes with the distance range. The tool can also show how the received signal changes with the object distance, the reflectivity, and the transmit power. A comprehensive report from different simulations can be created by clicking on the **Project** button , followed by clicking on the **Generate Report** option. As shown Figure 16, if you use the same components that are used in this EVM, the noise data for indoor & good reflective object shows to be close to 1.7mm which is comparable to the actual measurement of 1.5mm.

While this tool is a good representation of what the overall system behavior would be, it should not be treated as absolute guarantee of performance. It is intended to be used to do a first cut analysis of what is achievable and what is the trade-offs to consider in the system design.

4 Summary

This document gives a quick overview of the applications and use case of the OPT3101 AFE and how it can be used to result precise long range measurements. In this application report, various tools availability (EVM, Simulator Tool, Documentation) are shown along with measured results through a few different scenarios such as different reflective objects, different ranges, and varied ambient conditions. The application report also includes some key benefits of Time-of-flight technology, and the inherent advantages these systems have to offer.

5 References

- *OPT3101 ToF-Based long-Range Proximity and Distance Sensor AFE* data sheet
- *OPT3101 Evaluation Module* user's guide
- *OPT3101 Simulator* tool

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