Differential optical force sensing

Application Note

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Differential optical force sensing

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Valid for:
AS7100, AS7150, AS7160

Abstract

An optical force sensing system uses a light emitter and a light sensor that are located side-by-side below a flexible (and reflective) surface. The more forceful a press on that surface, the greater its deflection, the higher the value reported by the sensor. In other words, optical force sensors implement a (force aware) button. This application note reviews the design aspects of such a system, covering optical, electrical, mechanical and even driver and application software. It discusses various component selections from discrete solutions to fully integrated and suggest applications like keypads or even sliders.

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1 Introduction

Optical Force Sensing (OFS) is a new technology that uses a light emitter and sensors below a flexible or reflective surface to implement buttons. This technique provides distinct advantages from traditional button implementations, such as higher sensitivity, multi-level support, robustness, water or dust resistance, and many more. Please refer to the Optical Force Sensing design consideration application note for a deeper understanding of how to implement it in your solution. This document discusses differential optical force implementation and its benefits.

Referring documents:

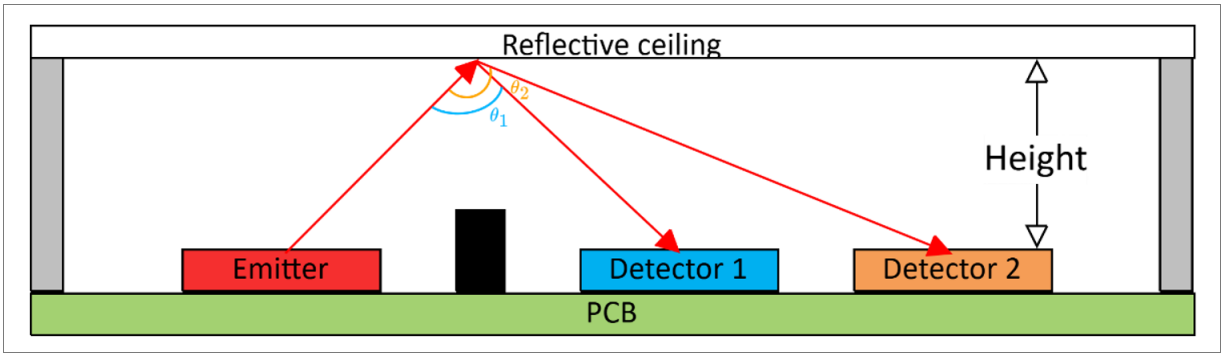
For a detailed description of Optical Force Sensing, please refer to the Optical Force Sensing design considerations application note:

- AN001061

2 Optical force sensing concept

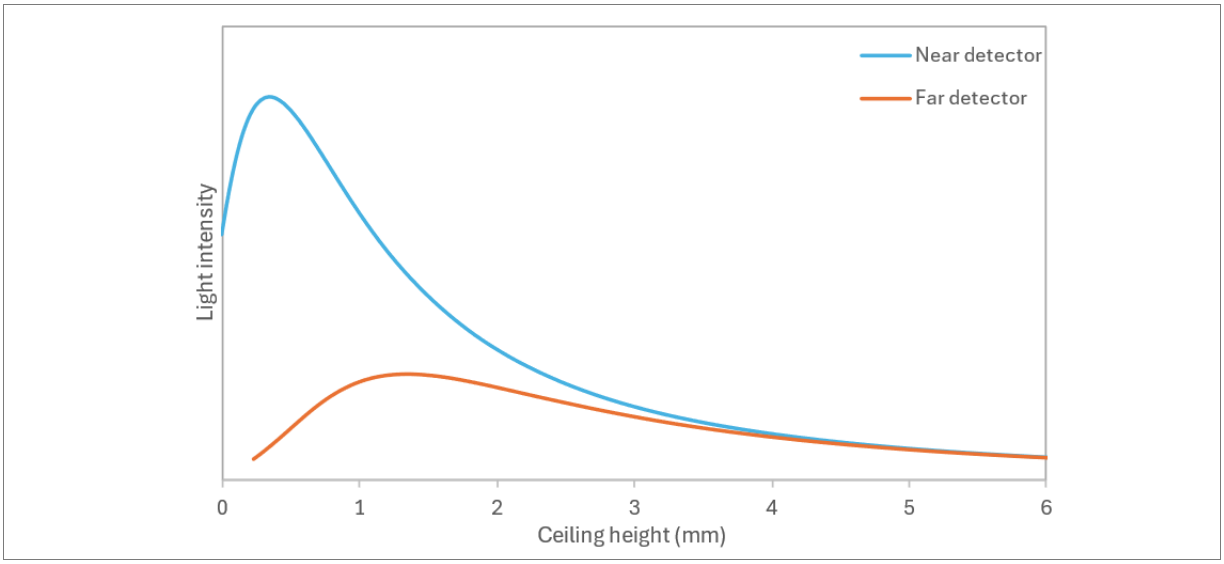
An Optical Force Sensing system consists of a light emitter and detector mounted below a reflective ceiling. The emitter radiates light towards the ceiling, and the detector senses the intensity of the reflected light. The intensity of this reflected light depends on two mechanical factors, i.e. the angle of the reflected light (θ) and the distance of the optical components from the reflective surface.

Figure 1: Optical force sensing system



Depending on these two factors, the peak point of the light intensity curve can be determined. This peak point can also be changed if the detector distance is altered from the emitter. For an emitter-detector combination where both components are placed close to each other, the peak of the curve will occur at a shorter distance compared to a combination where the emitter and detector are placed far from each other, as shown in Figure 2.

Figure 2: Reflected light intensity curves for two detectors



3 Types of optical force sensing

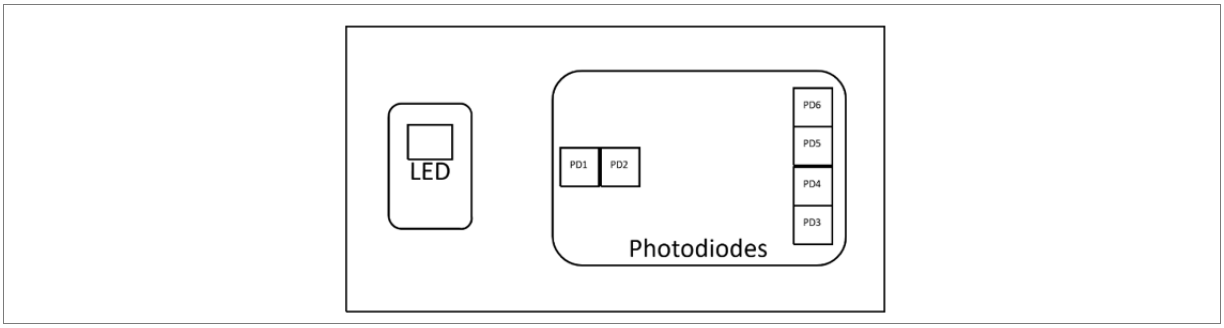
There are two types of OFS based on the method of implementation.

3.1 Single-channel optical force sensing

Single-channel optical force sensing (OFS-S) is the easiest type, which uses a single light emitter and detector combination to measure surface changes. A detailed description of this OFS-S concept can be found in the Optical Force Sensing Design Considerations application note (AN001061).

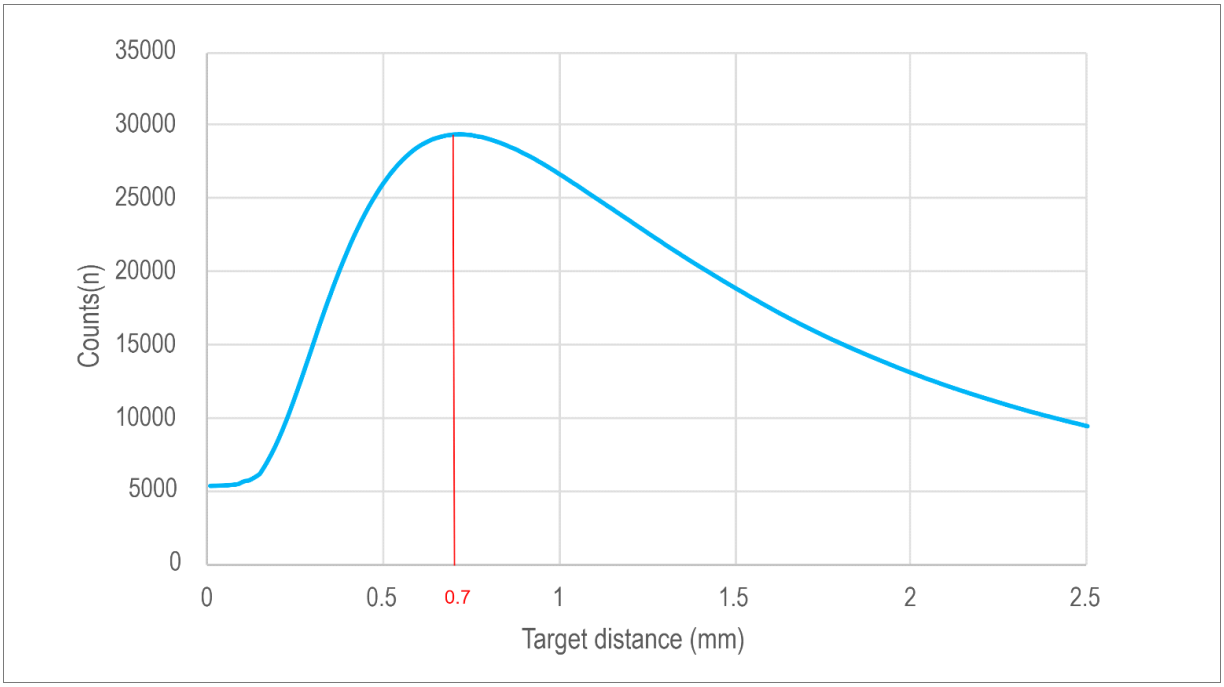
The AS7100 is a fully integrated OFS solution developed by ams OSRAM that contains six photodiodes (two near, four far) and one IR LED (Infrared light emitting diode), as shown in Figure 3. Any one of these photodiodes can be used to implement OFS-S.

Figure 3: AS7100 top view



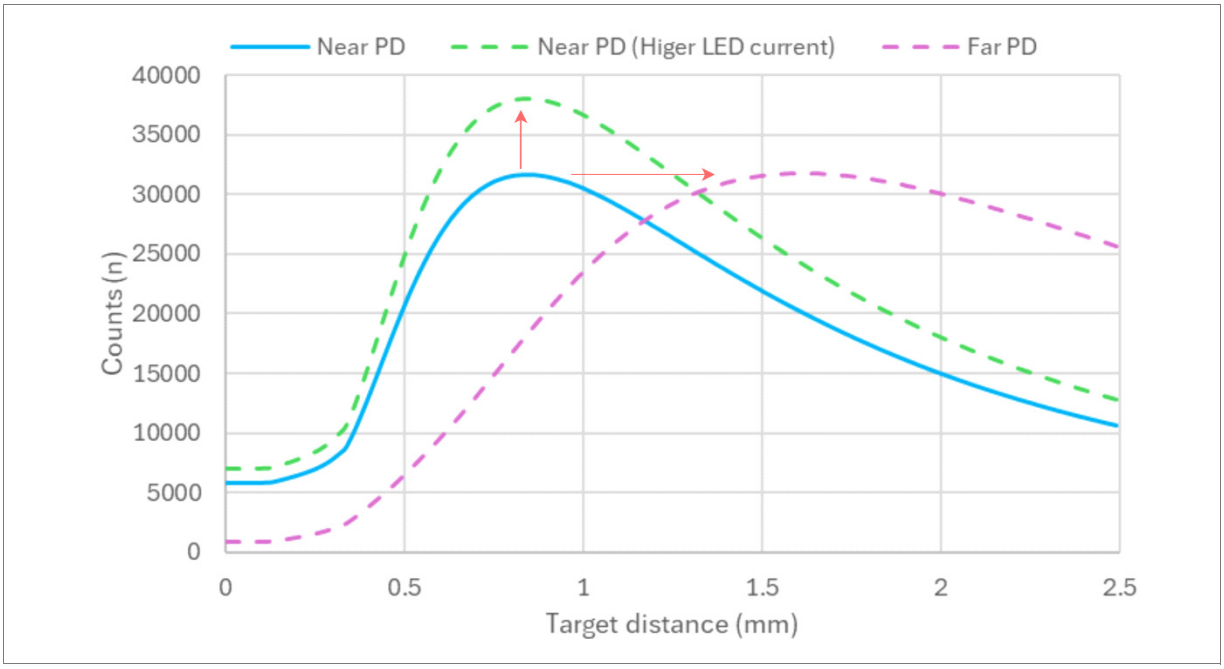
If a near photodiode (e.g. PD1) is used for OFS-S, the corresponding ADC (Analog-to-digital converter) count will reach the maximum counts at a target distance of 0.7 ± 0.1 mm, and then start to decrease, as shown in Figure 4. Thus, the minimum working distance using this configuration is 0.7 ± 0.1 mm.

Figure 4: AS7100 PD1 OFS-S signal



This signal curve can be shifted upwards if a higher LED current is used, thus achieving higher working distances, but at the expense of the whole peak signal not being used due to saturation (indicated by on-chip saturation flags). Therefore, choose the configuration parameters carefully for the system design and use case. The near photodiode will create a signal peak at a shorter distance, while the far photodiode will create a signal peak at a greater distance, as shown in Figure 5.

Figure 5: Shifting PD signal



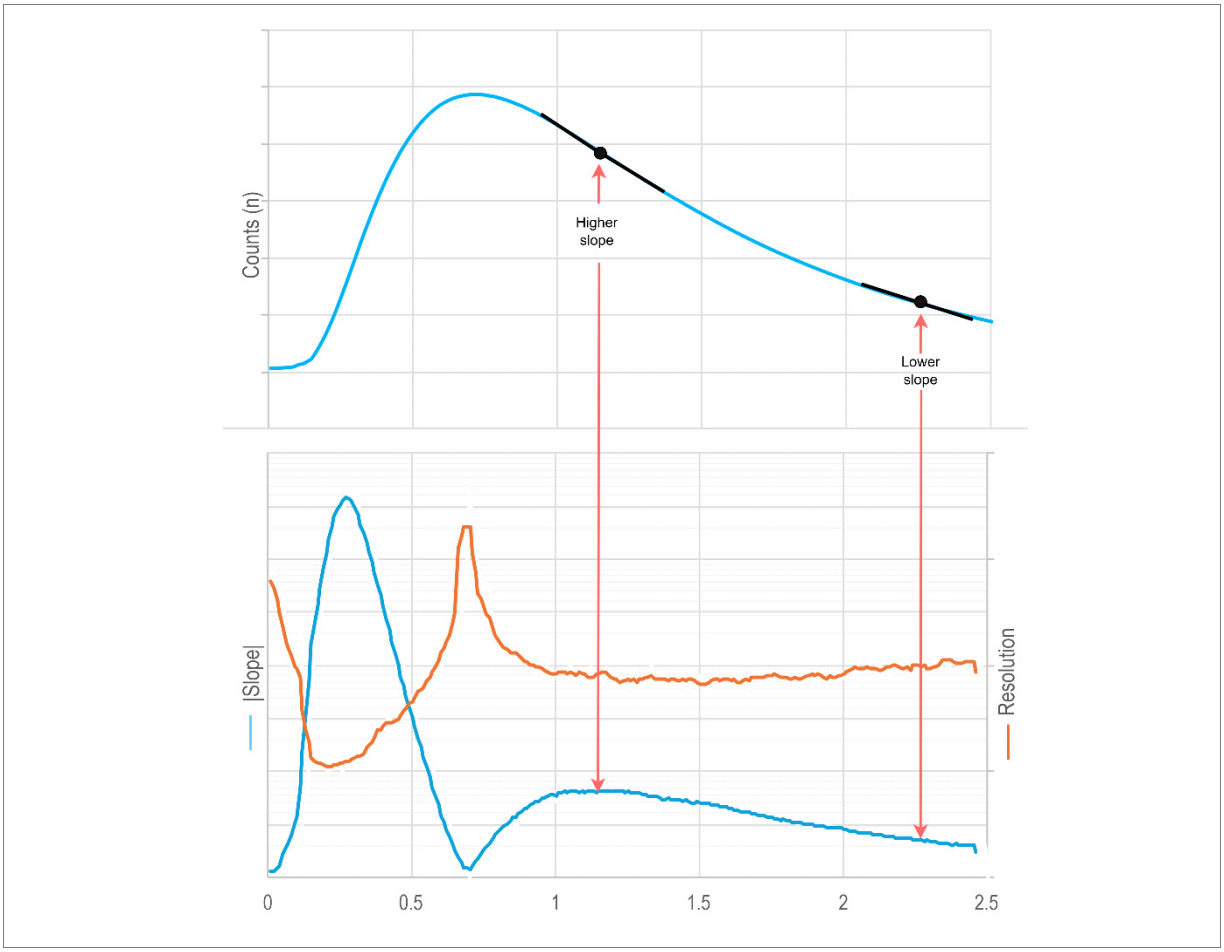
The OFS resolution is defined as the smallest displacement the system can detect and is an important parameter for evaluating the OFS system performance. It can be calculated with the following equation:

Equation 1:

$$resolution = \frac{6\sigma}{|slope|}$$

Where slope is the slope of the OFS signal curve. A higher slope results in a better resolution, as shown in Figure 6, with a theoretical signal with a standard deviation of one.

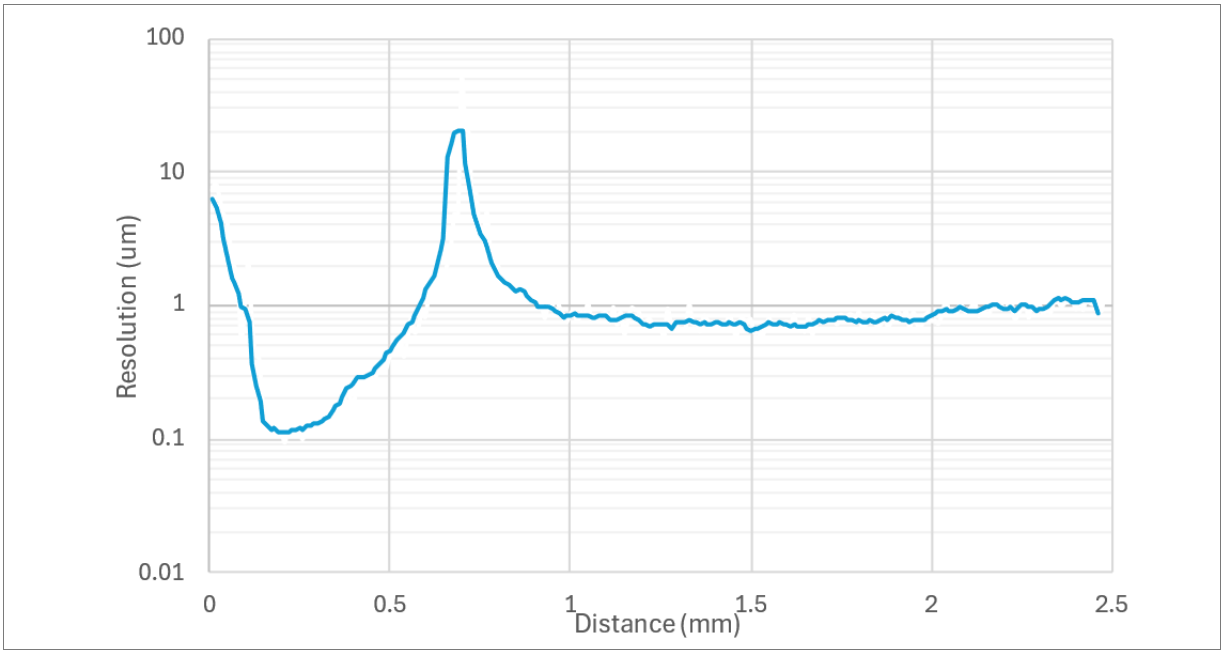
Figure 6: Relation between OFS signal, slope and resolution



In Figure 6, the blue curve in the upper graph shows the raw ADC counts for a PD. For slope estimation, a point is chosen on the curve, and with nearby points, a black line is drawn to estimate the slope. The chosen points can then be aligned to the slope curve, and together with the standard deviation (6sigma), an achievable resolution can be calculated (shown with the orange curve).

The calculated resolution of the AS7100 from Equation 1 is shown in Figure 7 for PD1. In this graph, the best resolution achieved is around 1 µm[1].

Figure 7: AS7100 PD1 resolution



3.2 Differential optical force sensing

Differential optical force sensing (OFS-D) is an enhanced implementation of optical sensing that uses two photodiodes to concurrently measure change in light intensity due to the bending surface. It is based on the concept that different emitter-detector distances create peaks in the light intensity curve at different distances. The data from these different curves is combined to provide more information than a single-channel OFS.

OFS-D is helpful in two scenarios:

- Increasing the OFS signal resolution
- OFS extension with proximity

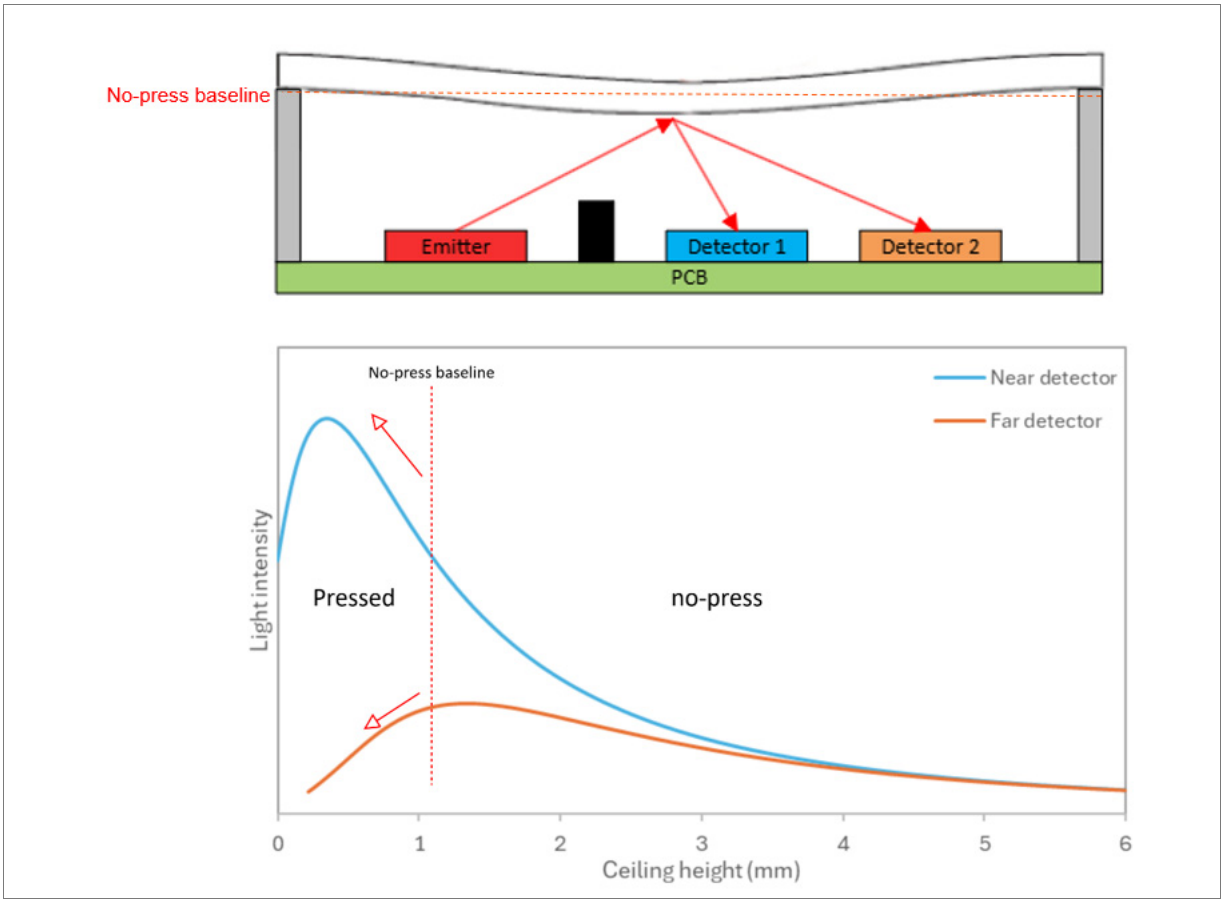
[1] Target size: 100x100mm, 90% reflective

3.2.1 Increasing the OFS signal resolution with OFS-D

As described in chapter 3.1, Equation 1 defines the OFS system resolution. Therefore, increasing the slope results in a lower value and better system resolution.

If the “no-press” distance (i.e. the surface distance without an external force) between the reflective ceiling surface and the emitter-detector is chosen to be in the middle of both sensor peaks, when the surface is pressed, the light intensity on one detector will be higher while the intensity on the other detector will be lower, as shown in Figure 8. If the signal from these two detectors is subtracted, it results in a signal with a higher slope, better resolution, and similar SNR (Signal-to-noise ratio) performance to OFS-S.

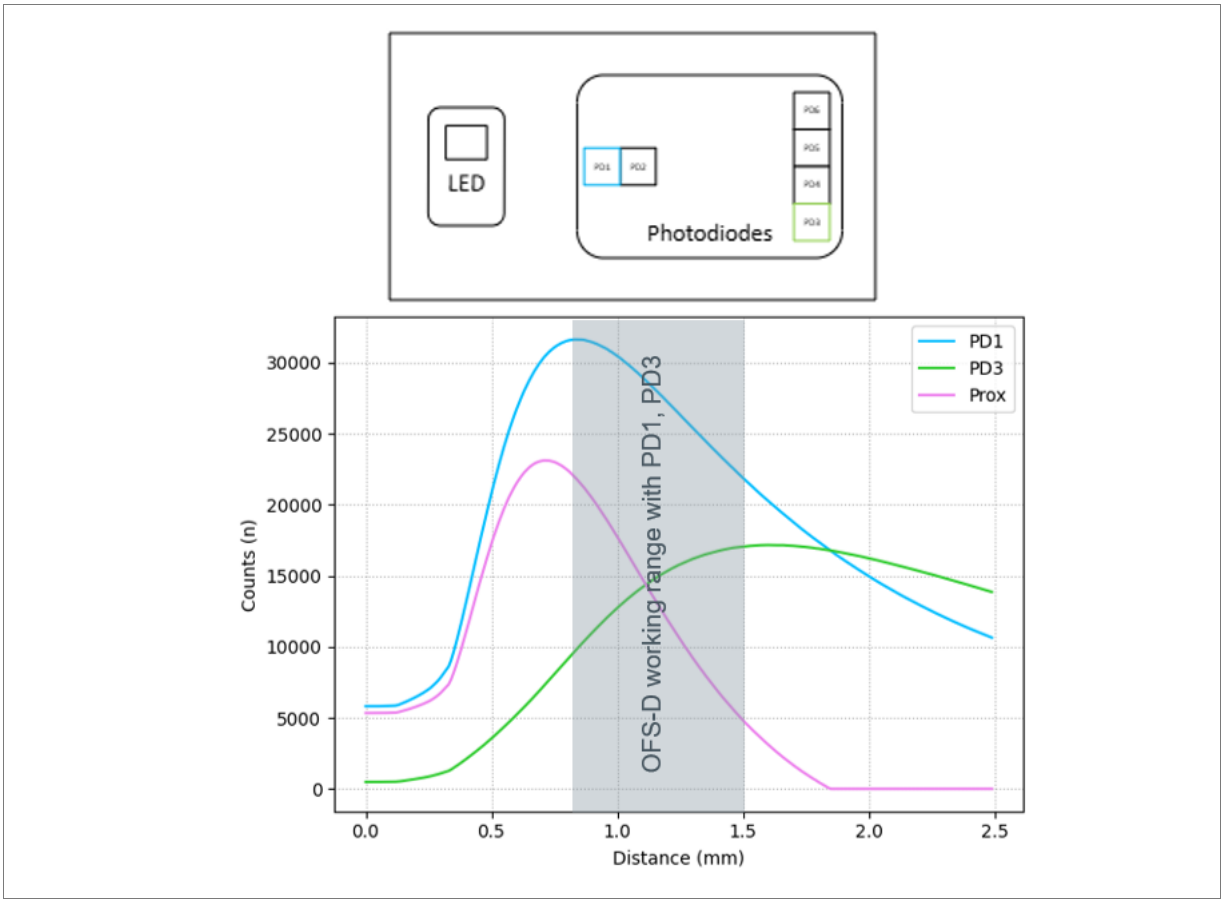
Figure 8: OFS-D system in pressed state



OFS-D is a built-in feature of the AS7100. Thus, in an OFS-D configuration of near and far photodiodes, the sensor outputs a differential signal along with its components. These additional individual signals can be used to develop advanced off-chip algorithms.

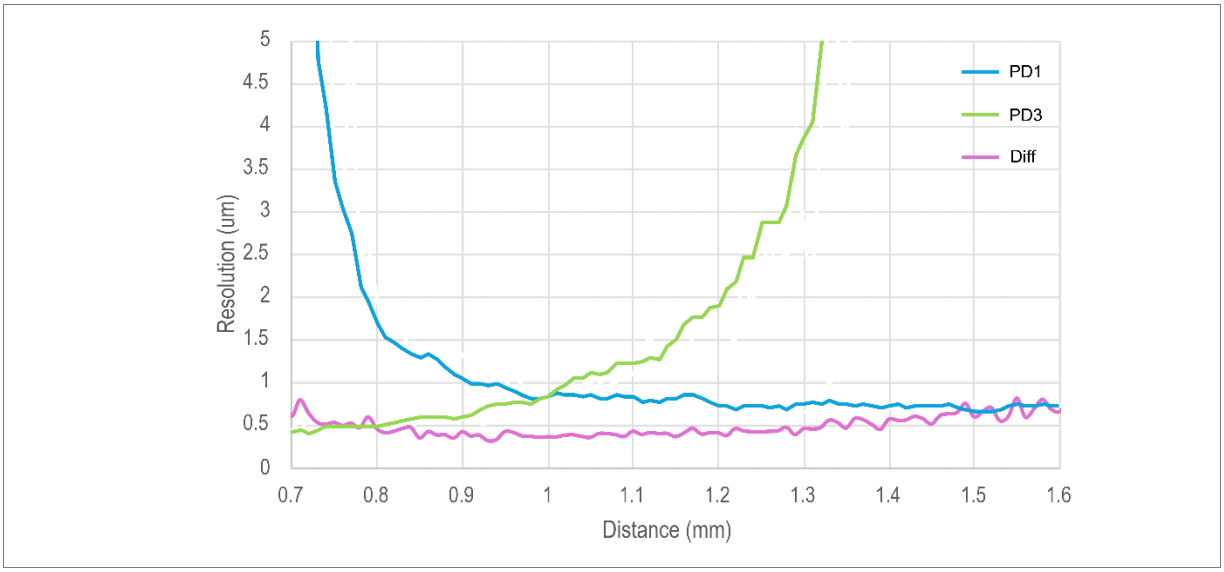
For example, if one near and one far photodiode (PD1, PD3) are used in the AS7100 for OFS-D, the corresponding ADC count-distance curves will look as shown in Figure 9, along with the calculated differential signal. From the graph, the working range of OFS-D is estimated to be from (0.7 - 1.48) ± 0.1 mm.

Figure 9: AS7100 OFS-D signal



The calculated resolution for this distance range is about 0.5 µm, which is better than the individual signals shown in Figure 10.

Figure 10: AS7100 OFS-D resolution



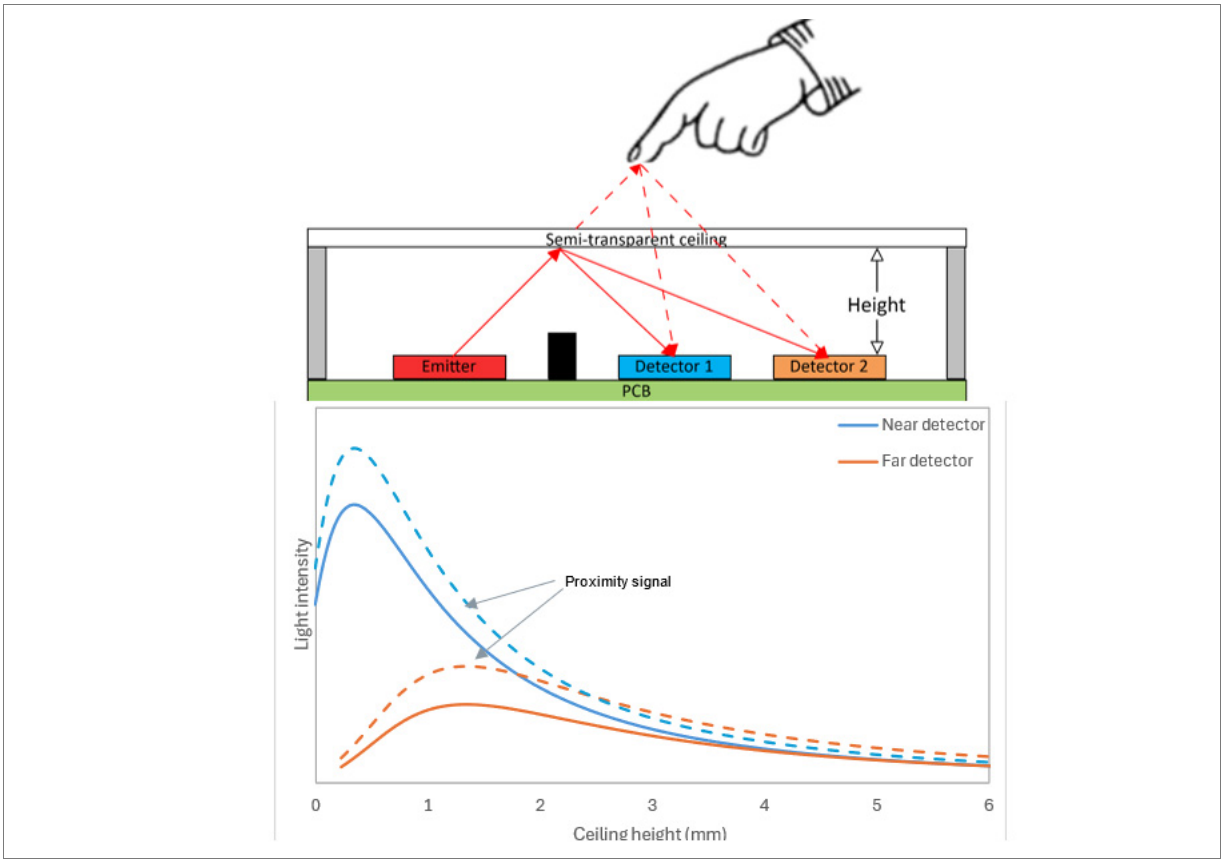
3.2.2 OFS extension with proximity using OFS-D

If the OFS ceiling surface is semi-transparent to infrared light, the same system can also be used for proximity detection to enhance the user experience e.g. lighting up the button for an approaching finger.

The OFS-D signal can also be used to increase proximity detection accuracy. As shown in Chapter 3.2.1, if the no-press distance between the ceiling surface and the emitter-detector is set in the middle of both sensor peaks, the approaching finger will cause the reflected light intensity to increase on both photodiodes. In contrast, the reflection from the surface will remain the same. Therefore, both detector signals will increase, as shown in Figure 11. This can be used for better proximity detection.

The increase in the reflected signal depends on various factors such as surface transparency, LED current, finger distance, number of active photodiodes, ambient light influence, etc.

Figure 11: OFS-D signal for proximity detection



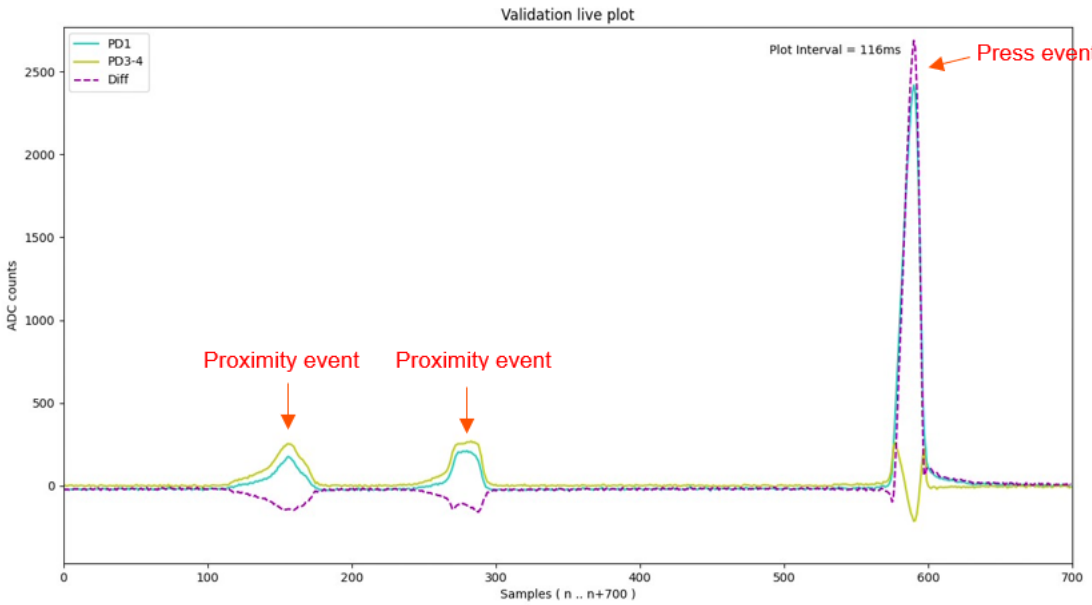
If the AS7100 EVM is fitted with a semi-IR-transparent surface and a combination of near (PD1) and far (PD3-4) photodiodes are used, the different responses for different actions can be identified.

When a finger approaches the button, the differential signal is decreased from the baseline because both OFS signals increase during the proximity detection phase (unpressed surface). When the finger presses the button, the differential signal is increased in the positive direction from the baseline because OFS-S1 increases while OFS-S2 decreases, as shown in Figure 13.

Figure 12: AS7100 EVM with semi-IR transparent surface



Figure 13: AS7100 EVM response for proximity and OFS-D



4 Comparison of OFS-S & OFS-D

Table 1 below shows a comparison between the OFS-S and OFS-D solutions.

Table 1: OFS-S and OFS-D comparison

OFS method	Single-channel OFS (OFS-S)	Differential OFS (OFS-D)
Implementation range	Short - Long	Short
Displacement	Medium - High	Low - Medium
Accuracy	High	Highest
Implementation effort	Low	Medium
Proximity detection	Possible	Possible
In-device support	All ams OSRAM OFS sensors	AS7100, AS7150

5 Summary

OFS-D compliments single-channel OFS (OFS-S) and provides a higher resolution in cases where a higher performance is required. Although it lacks native support on all devices, it can be implemented off-chip when required.

If the device supports on-chip OFS-D like the AS7100, it can help reduce the overall system power consumption when it is combined with the on-chip interrupt and signal processing capabilities.

6 Revision information

Changes from previous released version to current revision v3-00	Page
Document security class is updated “PUBLIC” in the footer	

- Page and figure numbers for the previous version may differ from page and figure numbers in the current revision.
- Correction of typographical errors is not explicitly mentioned.

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