AN5231

Application note

Cover window guidelines for the VL53L1X long-distance ranging Time-of-Flight sensor

Introduction

The aim of this application note is to provide guidelines for industrial designers on how to improve cover window quality. This document gives ST’s recommendations on cover window selection and details the design requirements for optimizing the system.

Figure 1. VL53L1X device

1 Acronyms and abbreviations

The main acronyms and abbreviations used in this document are listed below.

Table 1. Acronyms and abbreviations

Acronym/abbreviation	Definition
AFC	Anti-fingerprint coating
ARC	Anti-reflective coating
cps	Count per second
ID	Industrial design
IR	Infrared
PMMA	Polymethyl methacrylate
SNR	Signal-to-noise ratio
SPAD	Single photon avalanche diode
ToF	Time-of-Flight

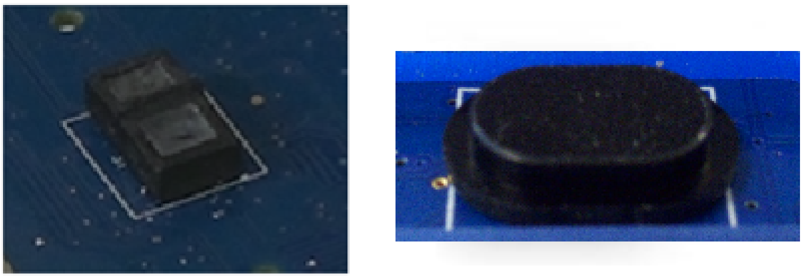
2 Overview

The VL53L1X ranging module is typically used in conjunction with a window covering. This "cover window" serves two main purposes:
- It provides physical protection for the module, including dust ingress prevention
- It provides additional optical filtering for the module

This application note presents information which allows the user to select the performance level of the cover window and the best topology for his use case.

There are two options for building the cover window:
- **Two-glass adapter:** This option seperates the emitter and receiver optical paths. It is the best solution as it provides high-ranging performances and limits calibration requirements.
- **Plain cover window**: When the above solution is not possible (for aesthetic reasons or when the material used cannot be split) a plain cover window can be selected.

Figure 2. **Two-glass adapter cover window (left) and plain cover window (right)**



3 Two-glass adapter (ideal solution)

The two-glass adapter is the only topology that allows the sensor to:

- Eliminate the impact of dust or fingerprints
- Improve ranging performance
- Suppress some calibration steps

Dust typically reduces the maximum working distance depending on its concentration. However, in the first figure below, we can see that the maximum ranging distance remains more than 2 m, thanks to the use of a two-glass cover window. In the second figure below, the target can still be seen despite the fact that both the emitter and receiver are fully covered in dust.

Figure 3. Two-glass adapter showing dust immunity

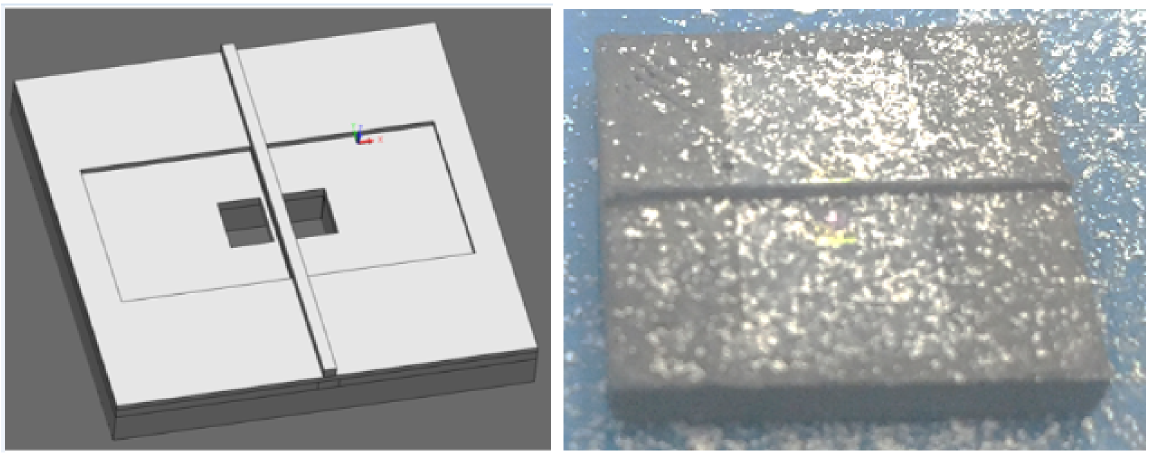
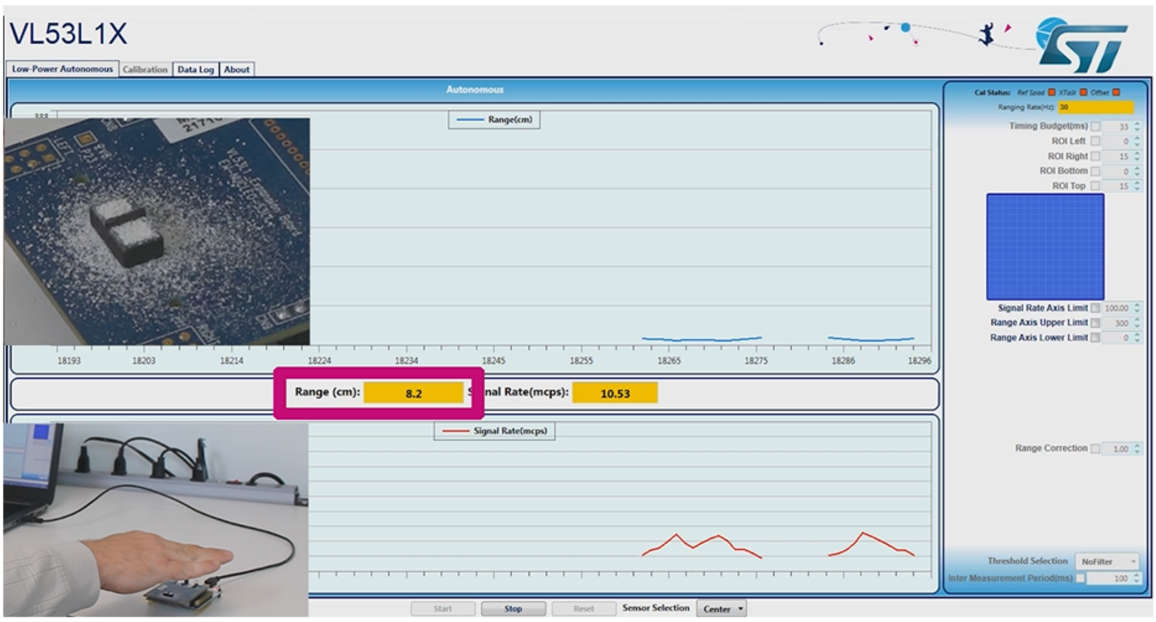


Figure 4. Two-glass adapter still working in dusty conditions



A step file of the two-glass adaptor (see following figure) is available on st.com/VL53L1X page.

Figure 5. **ST's two-glass adapter step file (3D view)**

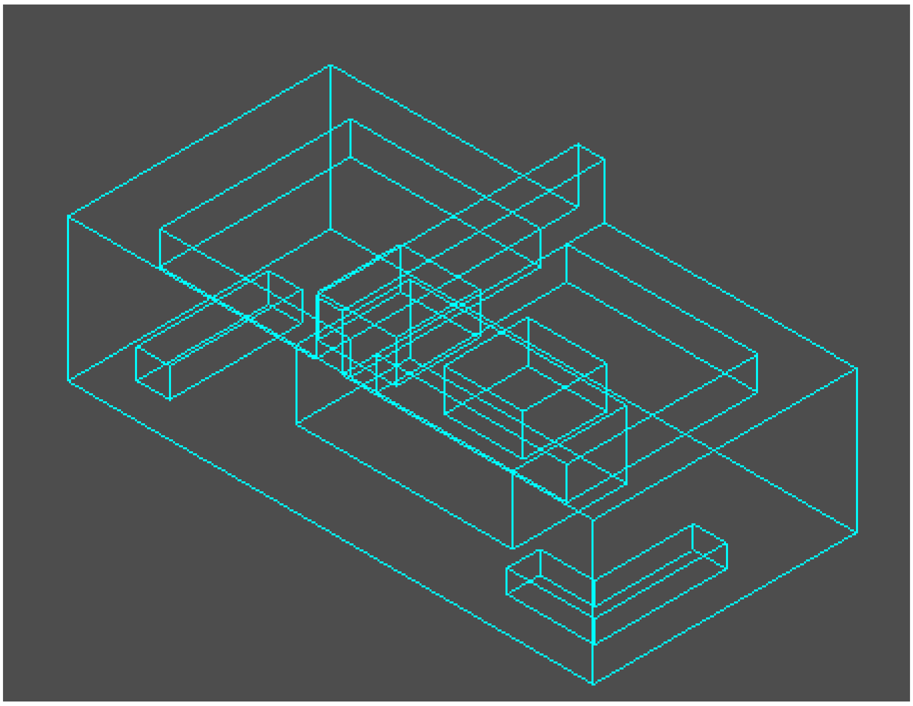
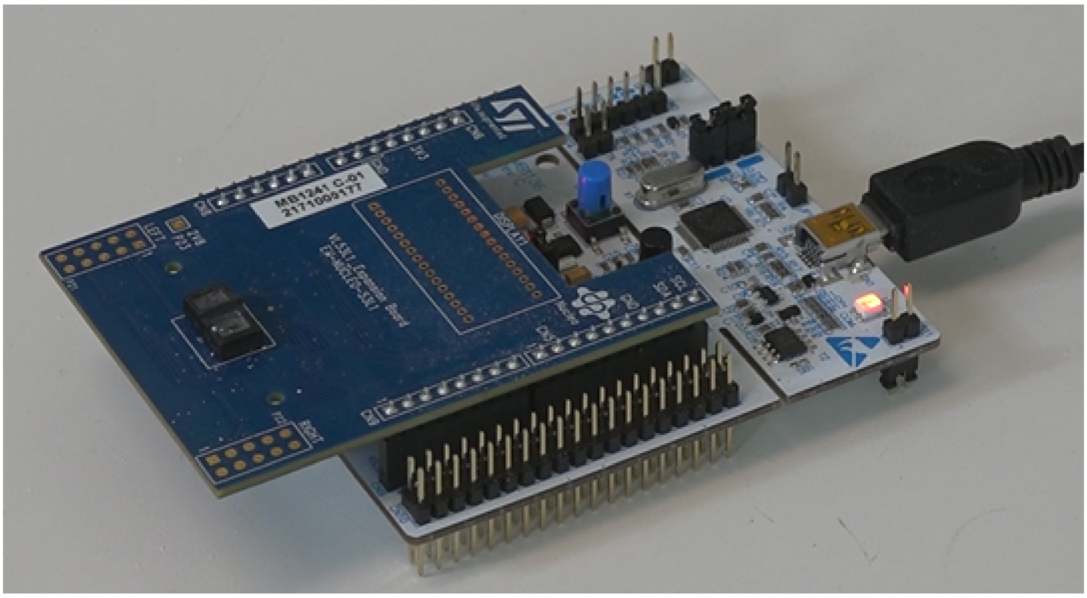


Figure 6. **Two-glass adapter used on VL53L1X nucleo evaluation kit**



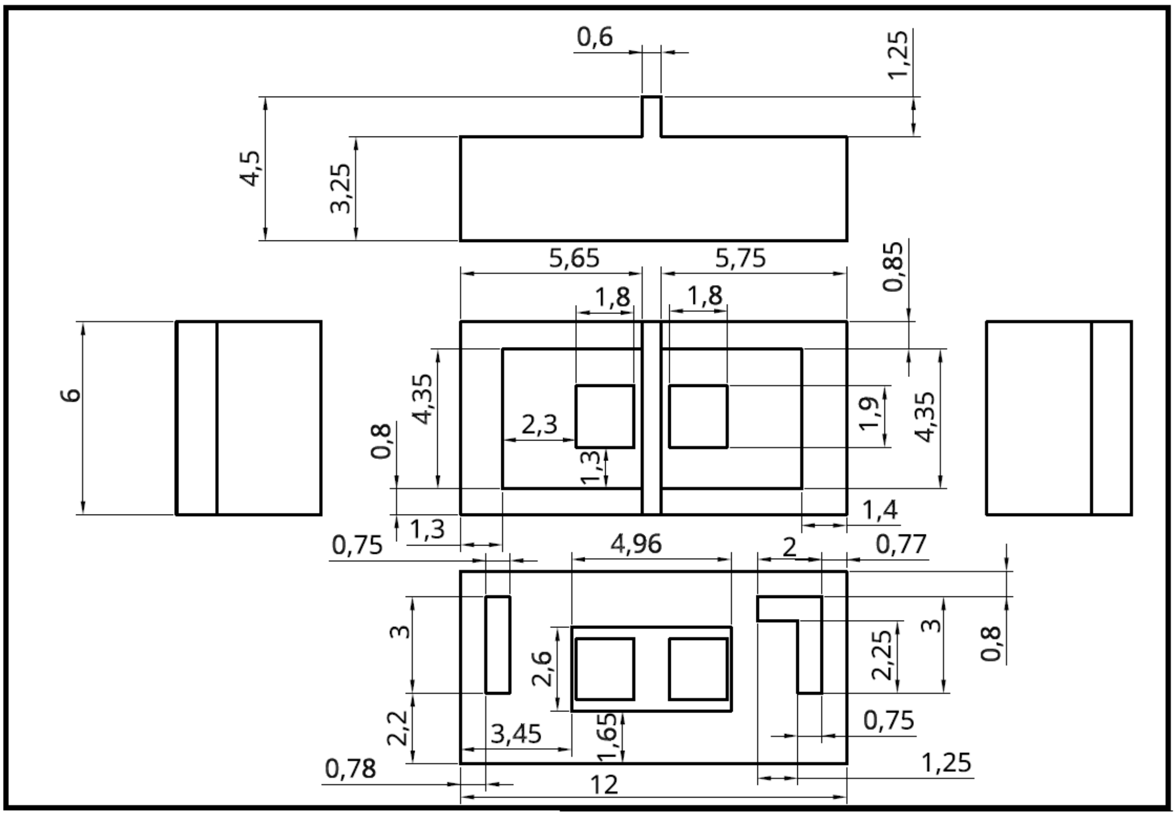


Figure 7. Two-glass adapter drawing (2D view)

A video of the two-glass adapter performance can be downloaded on the st.com/VL53L1X page of the ST website (shortcut name: VL53L1X cover glass solution; title name: VL53L1X cover glass, calibration free).

Figure 8. Video of two-glass adapter solution

4 Plain cover window

For aesthetic reasons, a two-glass adapter may not always be possible for ID products. In other cases, some manufacturers using specific cover window materials (e.g. Corning Gorilla Glass) are not able to split the cover window into two pieces. In both situations above, a plain cover window may be used. ST recommends that the cover window be opaque. IR ink can be used over exclusion areas (see Section 6 Cover window artwork for more details).

Note that by using a plain cover window, the VL53L1X is subject to crosstalk which is generated by the cover window itself. ST recommends that crosstalk be minimized so as to achieve the best ranging performance. The section below, Section 5 Crosstalk, describes the main contributors to crosstalk and suggests recommendations for reducing their affect. This section also looks at the impact of crosstalk on ranging performance and how crosstalk can be compensated.

5 Crosstalk

5.1 Definition

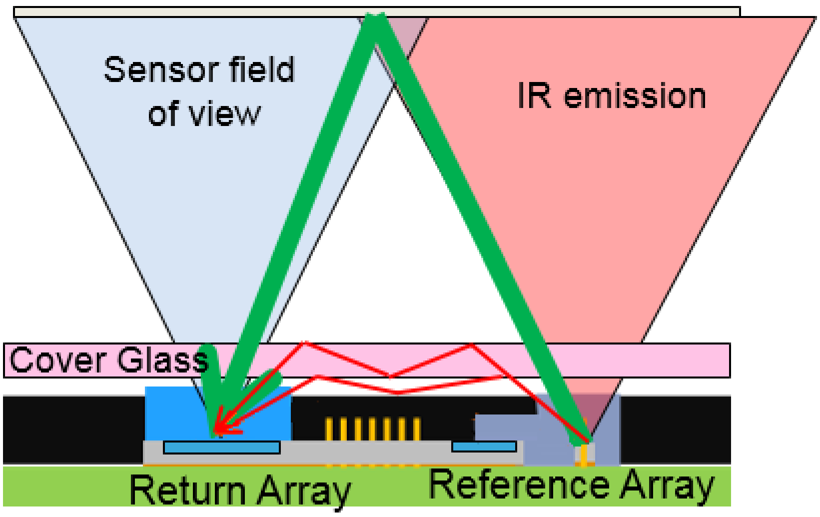
In electronics, crosstalk is any phenomenon by which a signal transmitted on one circuit or channel of a transmission system creates an undesired effect in another circuit or channel. Crosstalk is usually caused by undesired capacitive, inductive, or conductive coupling from one circuit or channel to another. In imaging, crosstalk is the interference caused by the ranging laser light that is reflected by a cover glass and not the intended target, which therefore distorts ToF data.

When using plain glass, there are two direct paths for the photons between the emitter and the receiver (see red curves in figure below).

- Path 1: The bottom surface of the cover window which partially reflects the beam. This is a big contributor to crosstalk. The bigger the airgap, the higher the crosstalk.
- Path 2: The top surface of the cover window which also reflects light towards the return receiver, and may bounce multiple times inside the cover window before reaching the receiver. The thicker the cover window, the higher its contribution to crosstalk.

These two paths lead the receiver to detect photons with a very short optical path, and so, they slightly degrades the ranging distance measured by the VL53L1X.

Figure 9. Crosstalk paths (red lines)



5.2 Crosstalk contributing factors and recommendations to reduce them

5.2.1 Cover window optical transmission

The VL53L1X is based on an optical technology using 940 nm wavelength. It is then mandatory to optimize photon transmission through the cover window in the 930-950 nm bandwidth.

ST transmission recommendations are as follows:

- Material transmission should be greater than 85 %.
  - PMMA (94 % transmission) and acrylic (92 % transmission)
  - Tempered glass or polycarbonate are acceptable (85 - 88 % transmission)
  - PET is not recommended (80 % transmission)
- Additional coatings are not recommended. The impact of coatings (ARC or AFC) on system performance should be assessed.
  - Bottom ARC
  - Top ARC or hard coating
  - AFC: carbon-fluorine (C-F=O) or silicon based AFC (Si-C-O-H) show better results than fluorosyl (Si-F4)

5.2.2 Cover window haze

ToF is an optical technology and the optical distortion impacts system performance. Haze is the best way to measure the different impacting parameters including embedded particles or trapped air, material manufacturing procedures, scattering, surface roughness, and surface thickness.

ST trecommends that haze should be less than 6 %.

Figure 10. **Example of optical distortion due to rough ink**

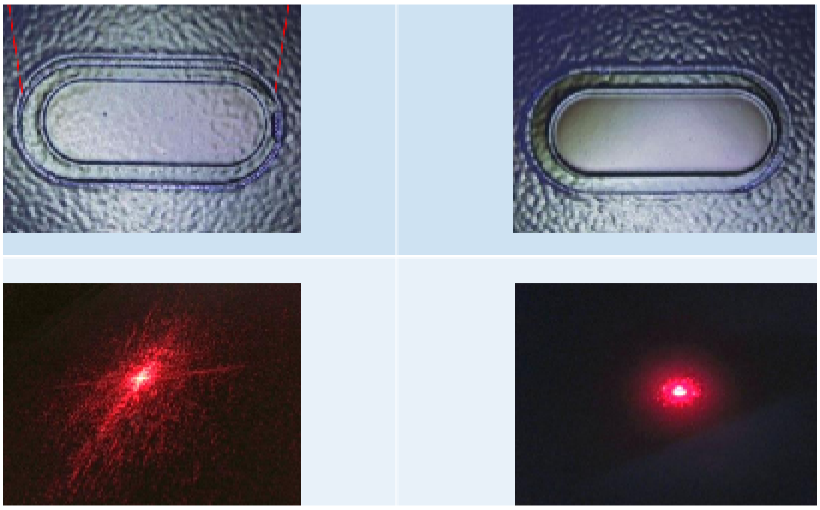
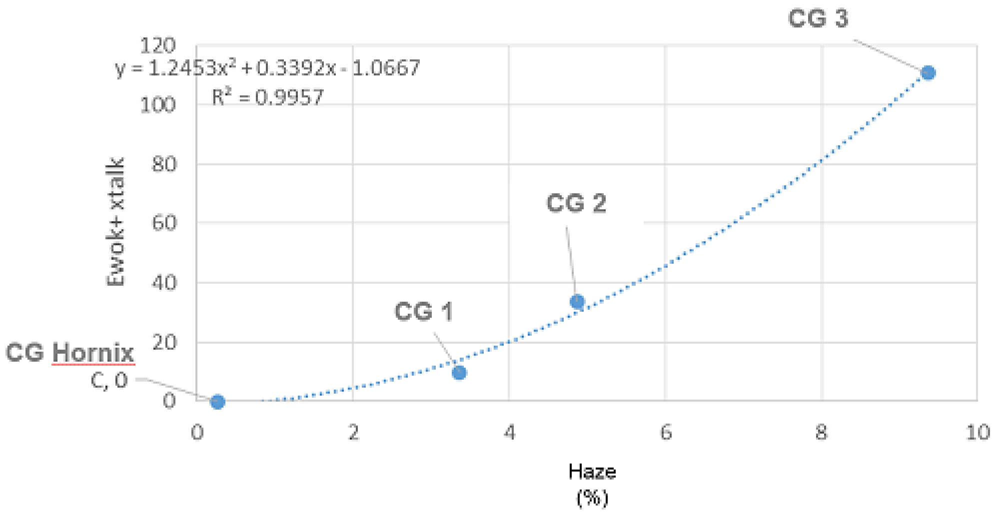


Figure 11. **Impact of haze on crosstalk**



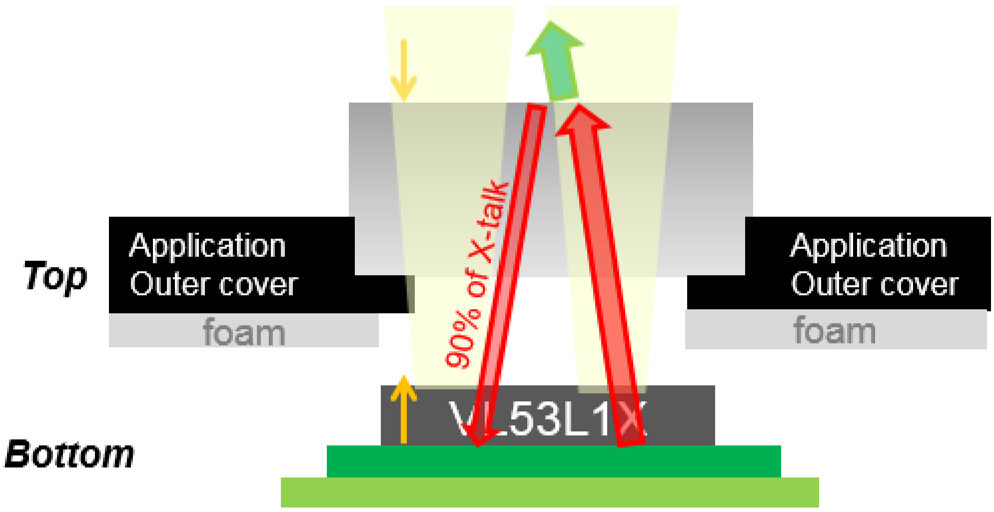
5.2.3 Cover window thickness

The thickness of the cover window contributes to crosstalk by reflecting photons towards the receiver.

A thin cover window means that the beam bounces internally many times before reaching the receiver. As the signal is attenuated at each bounce, the crosstalk is finally low.

However, due to its module dimensions, the air gap thickness of the VL53L1X is about 6 mm (see distance between orange arrows in the figure below). Consequently, there is a one-bounce path between the emitter and the receiver and crosstalk is at a maximum.

Figure 12. **Thick cover window introducing big crosstalk**



5.2.4 Cover window smudge

Smudge is the term used to describe dirt on the cover window. Smudge can be caused by fingerprints, grease, dust or anything that lies on top of the cover window and optically interferes with the sensor.

Any protective film/coating with high surface tensile strength on top of the cover window may be considered sensitive for ToF technology. Such materials can affect optical scattering.

Smudge sensitivity depends on the cover window material and manufacturing process. ST recommends that cover window smudge sensitivity be assessed.

Note: Smudge increases system crosstalk. If the system has a clean cover window and high crosstalk, it is likely that the smudge contribution to crosstalk is also high.

Consequently, if the product environment is full of dust, the two-glass adapter option is the ONLY working solution.

5.2.5 Cover window angle

Minimum crosstalk is achieved when the angle between the VL53L1X and the cover window is less than 10 °.

If a higher angle is required, the VL53L1X is still functional but, the ranging performance may be affected.

Figure 13. Crosstalk versus tilt of the cover window

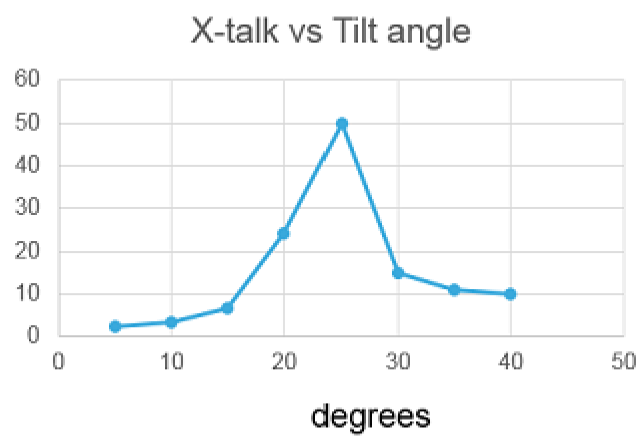
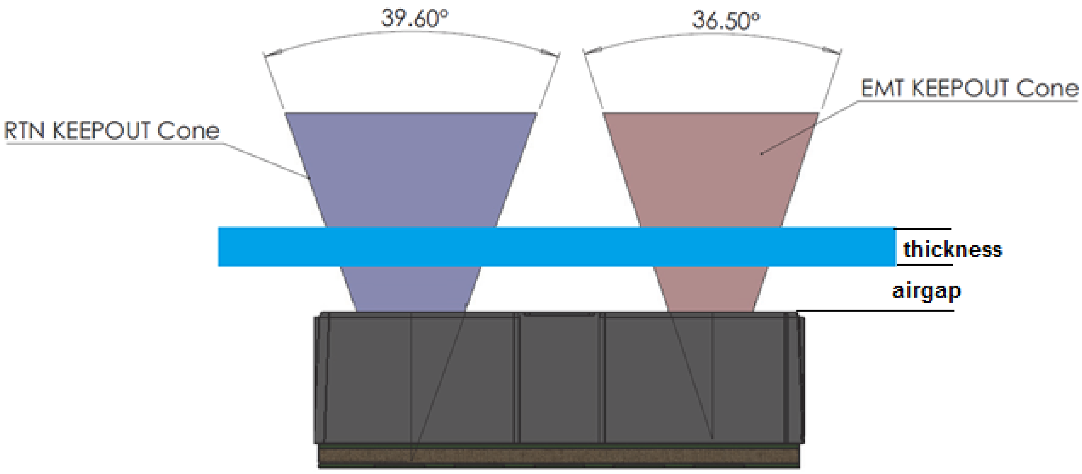


Figure 14. Cover window tilt requirement

5.2.6 Cover window air gap

As shown in the figure below, the distance between the top of the cap of the VL53L1X and the bottom surface of the cover window is referred to as the air gap.

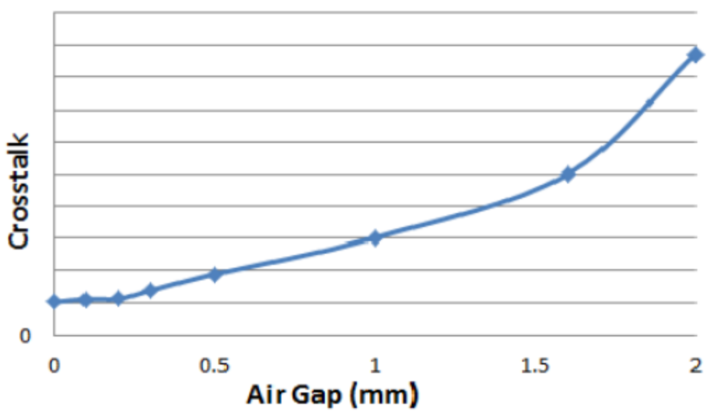
Figure 15. **Standard cover window showing air gap**



As the air gap increases, the amount of crosstalk also increases.

For optimum ranging performance, the air gap should be kep as small as possible (see figure below which shows an example of crosstalk variation vesrus air gap size.

Figure 16. **Example of crosstalk variation vs. air gap size**



The ID rules of thumb listed below can be applied:

- For fast and high-accuracy long ranging (>2000 mm):
  - Total air gap and cover window thickness = 1 mm maximum
  - Cover window thickness <0.6 mm and air gap <0.4 mm
  - Gasket and/or light blocker enhances performance (see Section 5.2.7 Use of a gasket)
- For sub 1000 mm ranging:
  - Total air gap and cover window thickness = 2 mm maximum
  - Cover window thickness <1.5 mm and air gap <0.5 mm
  - Gasket is required

- For sub 600 mm ranging (no specific accuracy requirement) with an air gap and cover window thickness > 2.0 mm:
  – A dedicated ID study is required to optimize ranging and system performance

For all use cases above, the assembly tolerances have to be accounted for when considering air gap and cover window thickness.

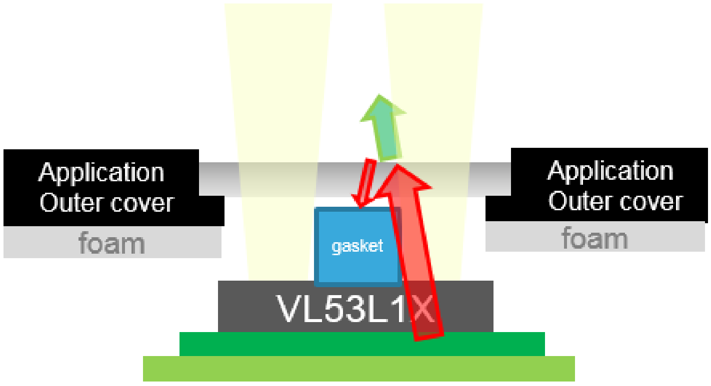
Note: The variation in the amount of crosstalk compensation required can be important if the air gap is likely to change throughout the lifetime of the system.

5.2.7 Use of a gasket

Placing a gasket between the VL53L1X and the cover window:

- Removes direct crosstalk from the bottom of the cover window
- Limits the residual crosstalk due to the thickness of the cover window

Figure 17. Gasket cancelling bottom crosstalk and reducing internal crosstalk



5.2.8 External contributors

Any external source of 930-950 nm light may impact the performance of the VL53L1X . Such sources of light increase the ambient light and so impact the SNR of each measurement. Consequently, the user should ensure that the design is set up to minimize optical interference from other IR sensors emitting in the same wavelength, or, even better, that the other sensors are not activated at the same time as the VL53L1X.

5.2.9 Crosstalk contributing factors summary

The figure below summarizes the main contributers to crosstalk.

Figure 18. Some of the major contributors to crosstalk and their consequences

Contributor	Trend	Impact on Xtalk
Cover Window Transmission	↗	↘
Cover Window Scattering / Haze	↗	↗
Cover Window Thickness	↗	↗
Cover Window Angle	↗	↗ up to 25° then ↘
Airgap	↗	↗
Gasket Presence	Yes	↘

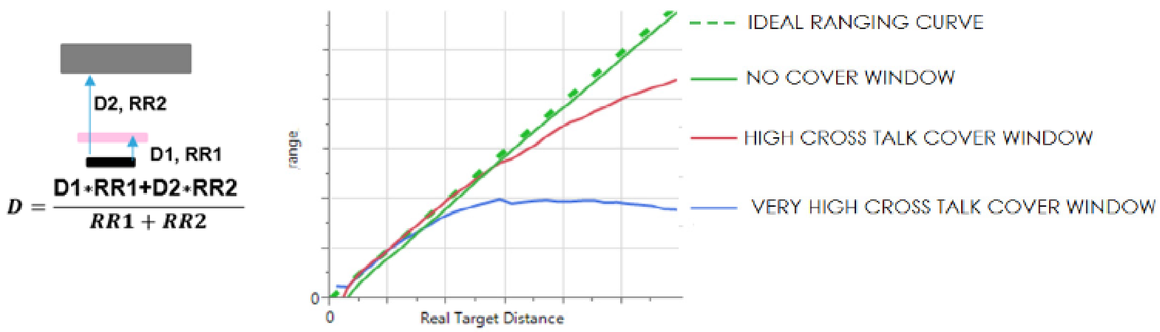
5.3 Crosstalk impact on ranging performance

The ranging result is a ToF weighted average of all the photons emitted by the emitter and reflected back to the sensor (the weight of each target being the return rate).

The photons reflected by the cover window (i.e. the crosstalk) are then averaged with the photons reflected by the target, which impact the ranging value when distance increases (see figure below).

The higher the crosstalk, the bigger the error as distance increases.

Figure 19. Crosstalk imapct on ranging measurement

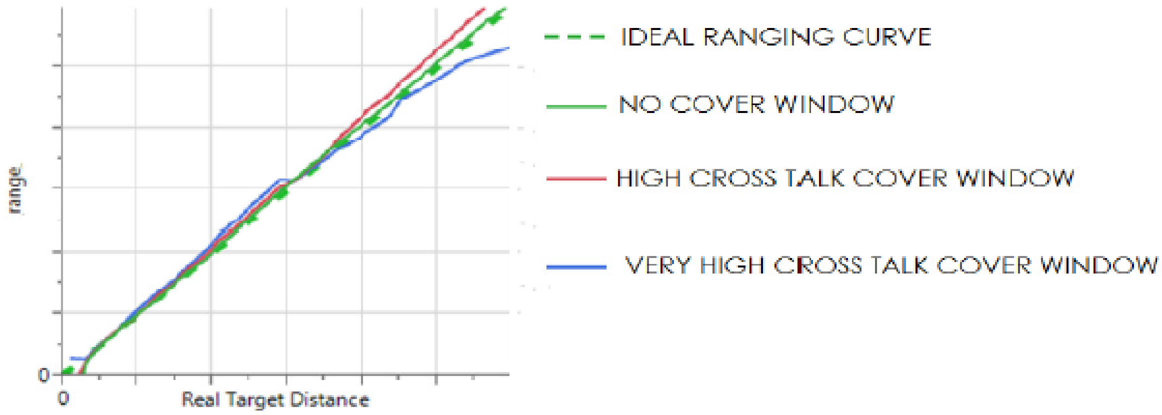


5.4 Crosstalk compensation

The device is able to compensate for crosstalk as long as crosstalk remains below or in the same range as the target signal (see Section 3.3 "Crosstalk calibration" in the UM2356 which can be downloaded from the VL53L1X web page on st.com). Such compensation means that the maximum ranging distance is shorter when crosstalk is higher.

In applications where the ranging distance must be around the maximum capabilities of the device (i.e. around 4 m in the dark), it is then necessary to minimize crosstalk.

Figure 20. VL53L1X crosstalk compensation capabilities



Note: The air gap thickness and cover window tilt must be minimized to reduce crosstalk using a standard cover window.

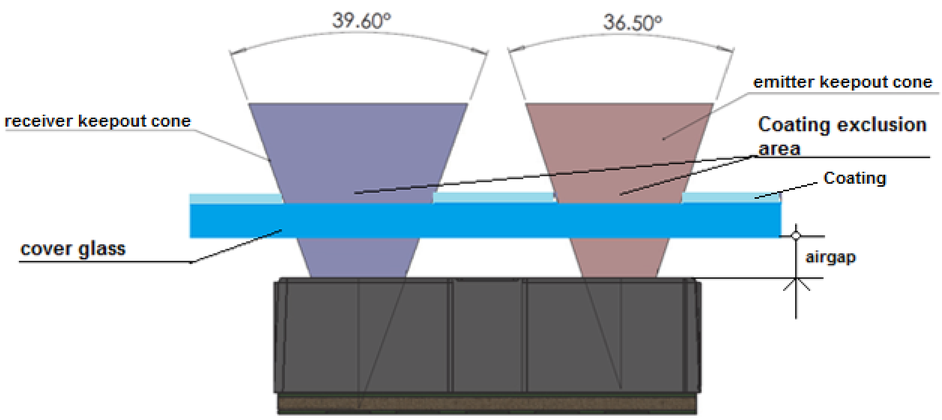
6 Cover window artwork

For aesthetic reasons, the customer may want to add a coating with different optical properties (color, glass finishing, etc.) to the cover window.

Exclusion areas are defined as the areas where there must be NO coating.

Exclusion cones provided in the VL53L1X datasheet (see figure below) take into account the ST assembly margins. The customer assembly margins must be considered to define the exclusion area sizes.

Figure 21. VL53L1X exclusion cones



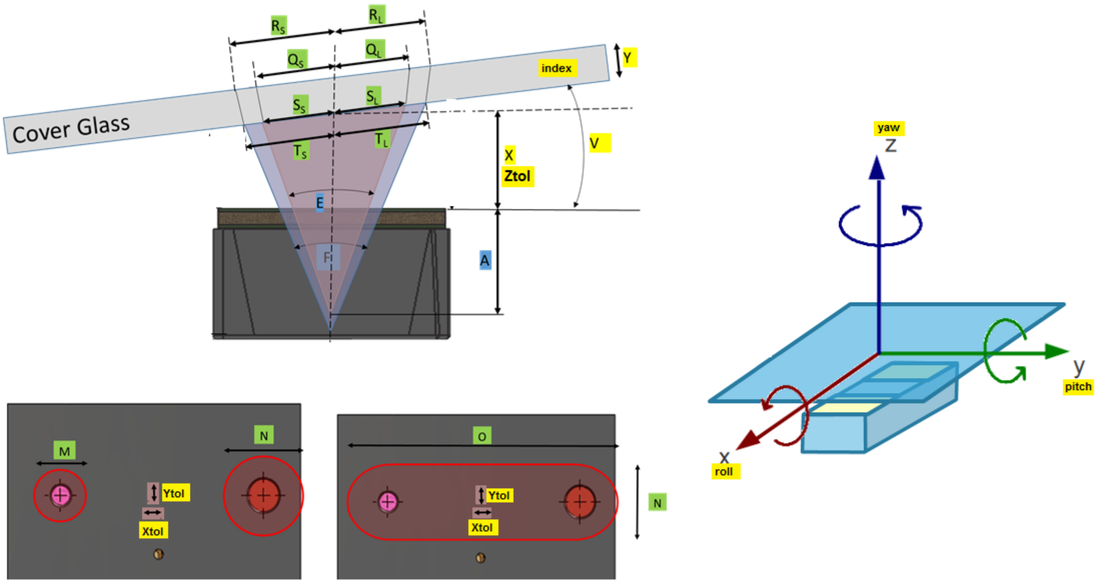
An Excel sheet is available on request from ST to calculate the exclusion areas. The following input parameters are taken into account:

- Cover window refractive index (index)
- Cover window thickness (Y)
- Air gap (X)
- Cover window tilt (V)
- Customer manufacturing assembly tolerance:
  - X, Y positioning (Xtol, Ytol)
  - Z-height positioning (Ztol)
  - Assembly pitch tilt (pitch)
  - Assembly roll tilt (roll)

Two topologies are taken into account:

- Oval exclusion area including both emitter and receiver
- Two-hole exclusion area, one for the emitter and one for the receiver

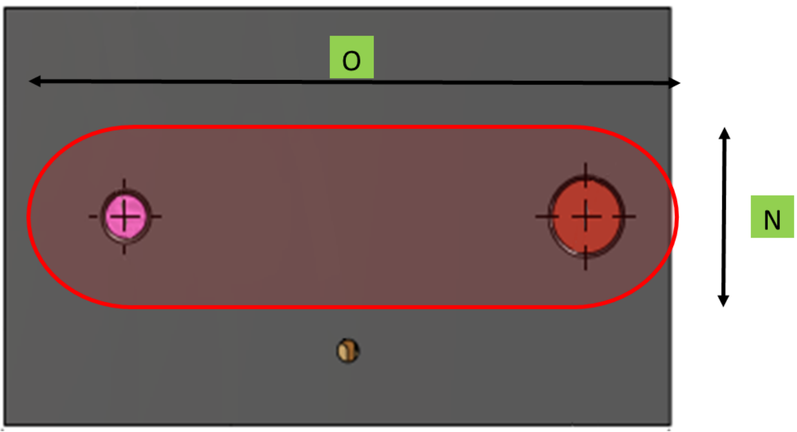
Figure 22. **Inputs (in yellow) for excel sheet**



6.1 Oval exclusion area

The figure below shows the design of the oval exclusion area. The exclusion zone is a single oval area covering both the emitter and the receiver.

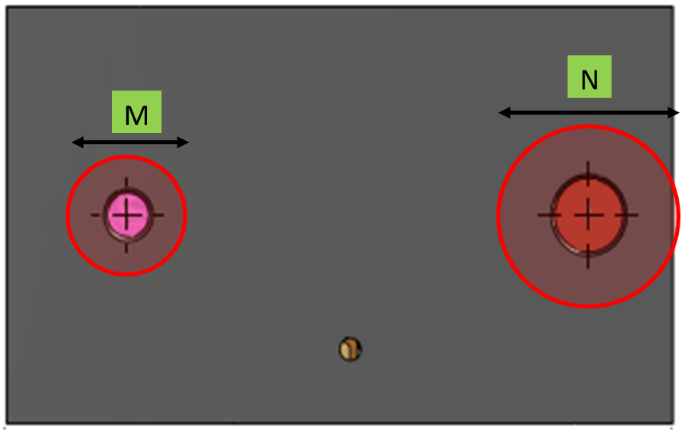
Figure 23. **Oval exclusion area**



6.2 Two-hole exclusion area

The figure below shows the design of the two-hole exclusion area. The exclusion zone is composed of two holes, one on the emitter and one on the receiver.

Figure 24. Two holes exclusion area



7 Off-the-shelf solution: Hornix cover window

ST recommends a Hornix cover window as an example of a very low crosstalk cover window. However, the final cover window selection depends on the individual customer requirements.

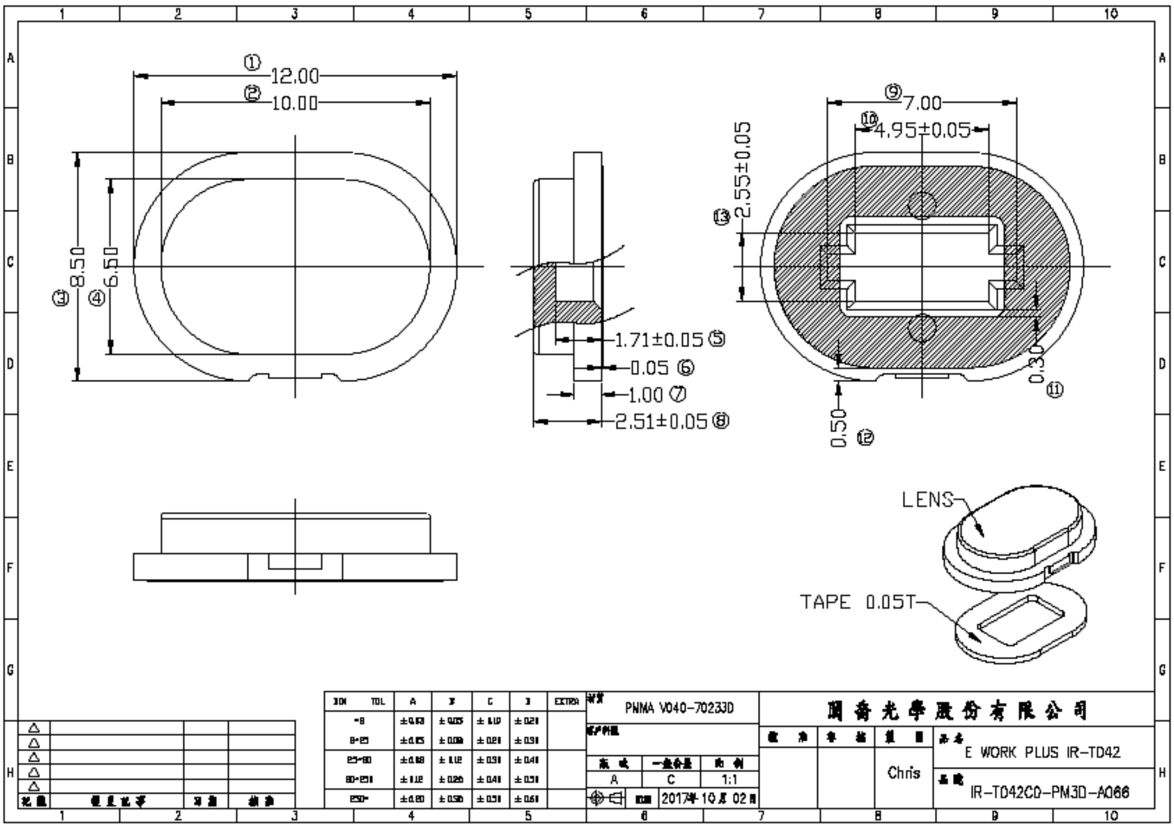
Hornix offers a standalone cover window, without a light blocker, called IR-T042C0-PM3D-A066. Its parameters include:

- Air gap: 0.2 mm (1.71 + 0.05 - 1.56)
- Cover window
  - Thickness: 0.8 mm (2.51 - 1.71)
  - Transmission: > 90 %
  - Haze: < 6 %
  - Angle: 0 °
- Typical crosstalk: < 0.2 kcps/SPAD

Note: Hornix has also developed cover windows with light blockers

For further details, contact: Hornix at sales@hornix.com.tw

Figure 25. IR-T042C0-PM3D-A066 Hornix cover window without light blocker



For a cover window with a light blocker, please contact Hornix Optical Technology Inc.

Revision history

Table 2. **Document revision history**

Date	Version	Changes
15-Nov-2018	1	Initial release

Contents