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## Guidelines for the cover glass of the VL53L9CX Time-of-Flight 2K zones

### Introduction

The aim of this application note is to provide guidelines for industrial design and how to assess cover glass quality. It details ST's recommendations on cover glass selection and design requirements for minimizing the crosstalk and optimizing the system.

**Figure 1. VL53L9CX ranging sensor module**



# 1 Acronyms and abbreviations

**Table 1. Acronyms and abbreviations**

Acronym/abbreviation	Definition
AFC	antifingerprint coating
ARC	antireflective coating
cps	photon count per second
FoV	field of view
FWHM	full width at half maximum
IR	infrared
PMMA	polymethyl methacrylate
Rx	receiver
SPAD	single photon avalanche diode
TNR	temporal noise reduction
ToF	Time-of-Flight
Tx	transmitter
VCSEL	vertical-cavity surface-emitting laser

## 2 General information

The VL53L9CX is a state of the art, dToF 3D lidar (light detection and ranging) module with market leading resolution of up to 2.3k zones enhancing the ST FlightSense product family.

The cover glass is normally an opaque window with a coating layer that presents apertures to allow the emission and reception of IR light. The apertures can be either one oval aperture or two circular apertures. Often cover glasses are coated with filter film that is generally deposited on the underside of the window.

The cover glass serves two main purposes:

- Physical protection of the device, including dust ingress prevention
- Optical filtering

The cover glass may also be used for aesthetic purposes. For this reason, on the coating layer, it is possible to create two equal-sized holes, placed on the top of the transmitter and the receiver. However, the receiver hole can be made smaller if required (see [Section 5: Cover glass mechanical guidelines](#)). [Figure 2. Crosstalk critical paths](#) presents the VL53L9CX system in a typical application. The cover glass is placed on the top of the module and a space is left between the two. This space is generally called the air gap and is measured in mm.

Experimental data shows that increasing the air gap size leads to an increase of:

- Crosstalk signal
- Signal loss

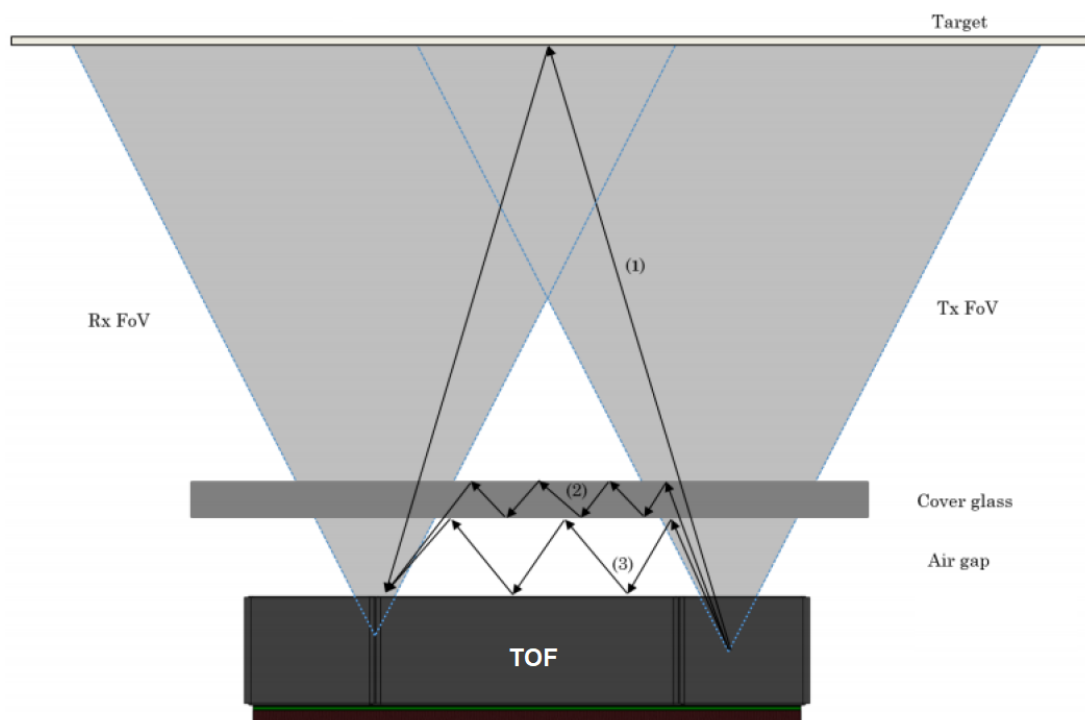
### 2.1 System crosstalk

The VL53L9CX is a device with a standard FoV that allows high signal reception coming from the target. At the same time, crosstalk signals are present in the receiver array.

The crosstalk is defined as light coming from the module emitter and not reflected by the target, but that follows alternative, undesirable paths to reach the the receiver. If the crosstalk is too significant, it could impact performance, notably the maximum distance. This document describes some procedures to ensure the crosstalk is sufficiently low to have minimal impact.

The crosstalk optical path is short, so the crosstalk pulse appears close to zero distance/delay. The amount of crosstalk depends on the optical setup, cover glass geometry, and properties. Crosstalk can also vary during the life of the product due to scratches or dirt on the cover glass.

**Figure 2. Crosstalk critical paths**



The figure above highlights the typical optical paths that the light, shot by the emitter, may follow before reaching the receiver array.

The main paths represented are:

- Target signal path, marked with 1 in the figure above
- Crosstalk signal path inside the cover glass, marked with 2 in the figure above
- Crosstalk signal path inside the air gap, marked with 3 in the figure above

The aim of the final application design is to minimize the crosstalk signals and maximize the target signal avoiding any obstacles or attenuation along its path.

In general, the crosstalk signal increases with the thickness of the cover glass. To minimize the crosstalk signal, it is recommended to use the thinnest cover glass choice available. To break the crosstalk path propagating through the cover glass, it is recommended to use a light-blocker as shown in the figure below.

The crosstalk signal decreases when the air gap size is reduced, see Conclusion and summary table for more details. Therefore, it is recommended to have the smallest air gap possible.

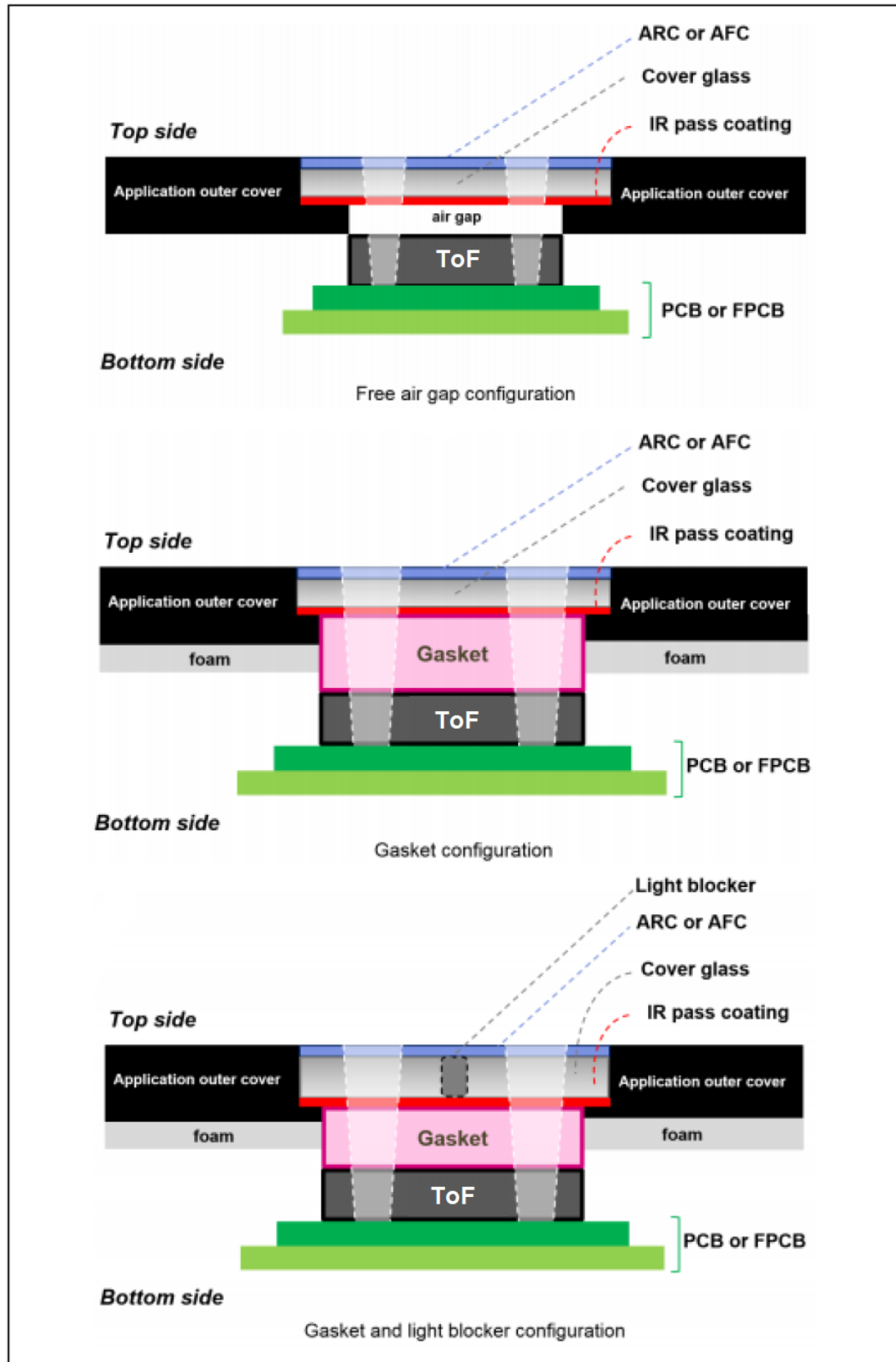
To break the crosstalk path propagating through the air gap, it is recommended to use a gasket. Specific dark materials like neoprene can be placed in the middle of the air gap space to break the crosstalk light path.

The crosstalk effect has several negative impacts, such as an increase in:

- Signal loss
- Ranging nonlinearity
- Ranging standard deviation

Moreover, the crosstalk signal is temperature dependent as well as the target signal. In general, the crosstalk signal increases as the temperature rises.

Figure 3. VL53L9CX final application configuration



### 3 VL53L9CX crosstalk immunity

The VL53L9CX is designed to range even with high crosstalk. **Crosstalk calibration is not required** by customers. ST delivers a tool to measure the crosstalk, and recommends using this tool during design to select the best cover glass material, coating, and mechanical design. The tool can also be used in production to identify incorrectly assembled parts.

#### 3.1 Crosstalk impact on ranging distance

**Table 2. Evolution of maximum ranging distance vs crosstalk**

Configuration	ROI	Crosstalk (MCps)	Estimated maximum ranging distance [m] (1)	Estimated distance reduction vs no cover glass
PMMA 0.75 mm air gap	Left	2.0	4.4	8% (2)
PMMA 0.75 mm air gap	Right	0.9	4.4	10% (2)
PMMA 1.0 mm air gap	Left	5.9	3.2	35%
PMMA 1.0 mm air gap	Right	2.3	4.4	10% (2)

1. Example of precision mode (4 ms), 0 klx ambient conditions, gray 17% target reflectance, 30 Hz ranging frequency, with default driver settings without TNR (temporal noise reduction)
2. The maximum distance reduction linked to the cover glass transmittance only, the crosstalk impact is marginal or ignored by the system.

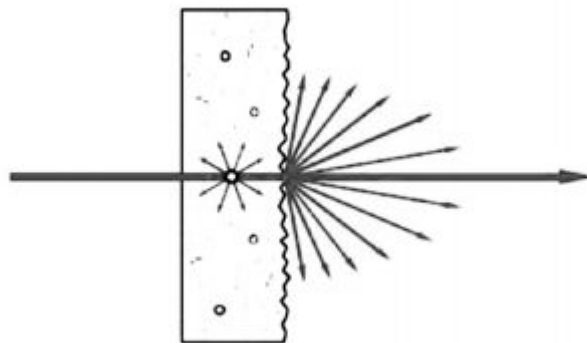
## 4 Cover glass design

The crosstalk signal is very sensitive to the cover glass design and structure. The manufacturing properties of the cover glass affect the light scattering phenomena and consequently the crosstalk as shown in the figure below. For instance, particles and crystal defects embedded inside the cover glass increase light scattering. Similarly, the cover glass surface topography and the surface roughness affect crosstalk.

In order to avoid the light scattering effect and reduce the crosstalk signal, the cover glass should be manufactured to have:

- No defects in the crystal structure or on the top of the surface layer
- No impurities or dislocation inside the structure
- No smudge or superficial artifacts

**Figure 4. Light scattering examples due to internal defects or superficial roughness**



### 4.1 Optical transmission

From the optical point of view, the cover glass must allow transmission of IR light emitted by the module VCSEL at 940 nm with 1.6 nm at full width at half maximum (FWHM), and received by the SPAD array embedded inside the module. It is required to have the optical transmission of the cover glass higher than 87% in this bandwidth.

The table below shows the estimated evolution of maximum ranging distance over the transmittance:

**Table 3. Evolution of maximum ranging distance vs optical transmission**

Transmittance [%]	Estimated maximum ranging distance [m] <sup>(1)</sup>
100	4.8
90	4.3
80	3.8
70	3.4
50	2.4
20	1.0

1. Example of precision mode (4 ms), dark conditions, gray 13% target reflectance, 30 Hz ranging frequency, with default driver settings.

**Note:** All the signals not transmitted by the cover glass are lost or can potentially turn into crosstalk. Loss of signal directly affects the performance of the VL53L9CX module, and the maximum ranging distance. It is recommended to have the highest cover glass transmittance possible.

## 4.2 Cover glass coating

The cover glasses are normally coated with different material for different purposes.

- Colored ink for aesthetic reasons
- IR filter to cut off all the unwanted light in the IR transmission. Normally the filter coating is deposited on the back side of the window.
- ARC: antireflective coating to reduce the surface reflectance.
- AFC: antifingerprint coating to increase the fingerprint protection.

It is important to note that superficial coating may generate additional crosstalk signals. In fact, any transmissive layer deposited on the cover glass could act as an optical path to guide the crosstalk light from the emitter to the receiver.

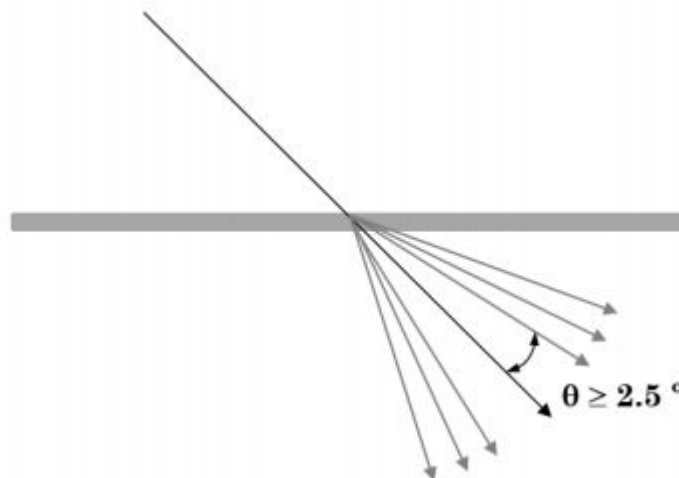
*Note: Whenever possible, avoid the use of any cover glass coating, at least in the exclusion areas defined in section Cover glass mechanical guidelines. Use outer coatings that do not degrade the immunity to the fingerprint (for example, antifingerprint or antireflective coatings with the antifingerprint feature) in order to reduce a smudge effect or loss of signal.*

## 4.3 Haze

Haze is defined as the percentage of light that, when passing through a certain material, deviates from the incident beam, on average, by an angle greater than 2.5 degrees.

The crosstalk signal increases with the square of the haze percentile. It is recommended to ensure that haze represents less than 2% of the total light emitted (1%, 940 nm IR).

Figure 5. Representation of light haze definition



## 4.4 Cover glass tilt and surface parallelism

The cover glass top and bottom surfaces must both be parallel to the device surface. Ideally, any cover glass tilt must be avoided to reduce the crosstalk signals.

The recommended maximum tilt is given in Table 7. Cover glass guidelines and summary table.

## 4.5 Cover glass materials

A single material is recommended for the cover glass design. This is because multimaterials may alter the performance or increase the internal light scattering effect. Materials suggested are:

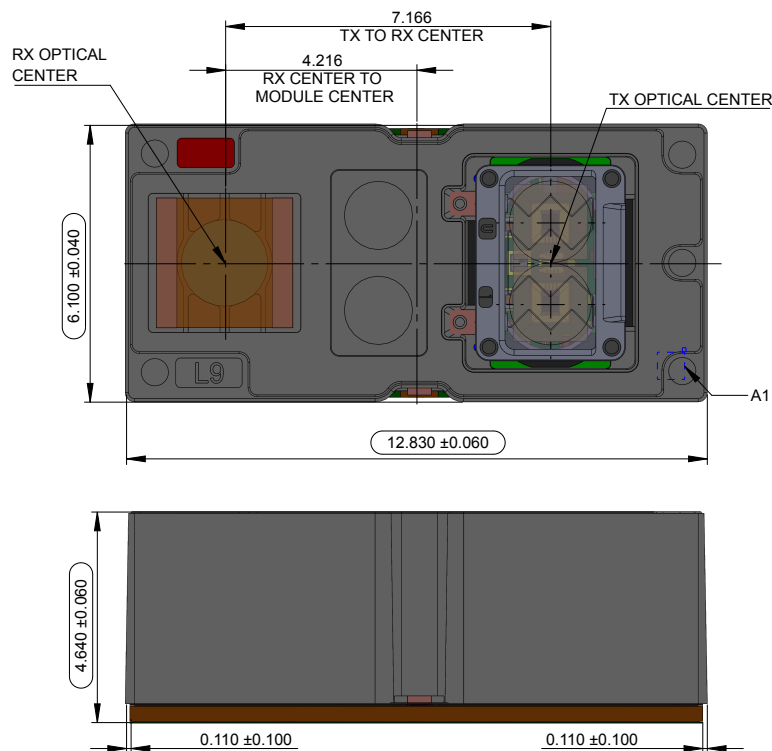
- Glass
- Sapphire glass
- Polymethyl methacrylate (PMMA)
- Polycarbonate

## 5 Cover glass mechanical guidelines

This section provides information on the VL53L9CX module geometrical dimensions necessary to calculate the minimal aperture dimensions of the cover glass coating layer. See the figure below.

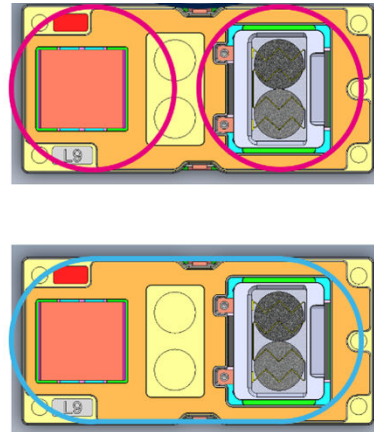
- The receiver mechanical aperture is rectangular with a width of 3.35 mm and high 3.55 mm (area 11.9 mm<sup>2</sup>).
- The emitter mechanical aperture is rectangular with a width of 3.67 mm and high 4.69 mm (area 17.6 mm<sup>2</sup>).
- The distance between the optical emitter center and the optical receiver center is 7.166 mm as reported in the figure below.
- It is optional to have one large cover glass aperture or two separate apertures. The final decision is partly aesthetic, partly functional. Two apertures may offer better crosstalk immunity, particularly in designs with no gasket.

Figure 6. VL53L9CX mechanical dimensions



**Note:** It is important to align the apertures with the optical centers of the VCSEL, as above. They are not the same as the mechanical centers. Further mechanical details can be found in the datasheet.

Figure 7. Example of cover glass coating with dual or single apertures

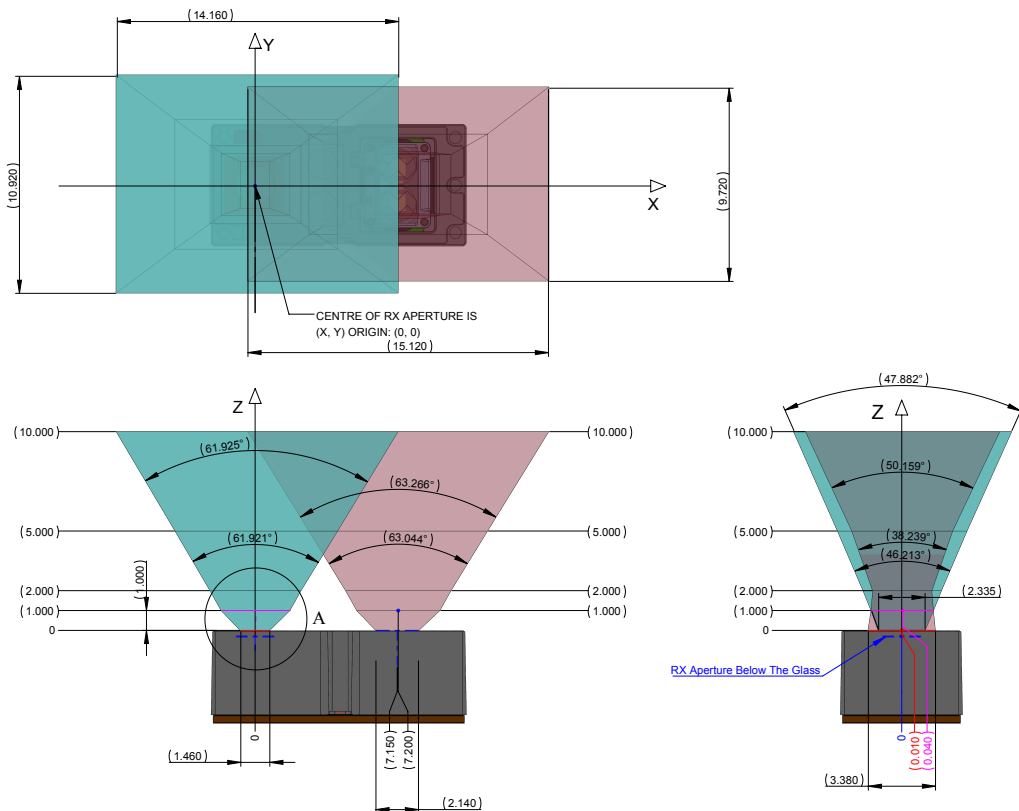


XY planes are tabulated at varying Z positions (where Z=0 is the top surface of the module). At each Z position, XY planes are specified as exclusion areas, which should remain clear to ensure no clipping of the optical signal for the module. An angle in 'X' or 'Y' at a given 'Z' position can be calculated from the reference dimensions included in the exclusion area tables.

For Z positions larger than 1000 mm, the angle can be the same as between the previous two planes.

It is possible to calculate the minimum apertures of the cover glass using the following formulae. See the figures below as a reference for the calculation.

Figure 8. Exclusion cones



ST delivers an aperture calculation tool. Refer to [How to calculate the dimensions of the Cover-Window exclusion zone above a Multizone ToF sensor](#).

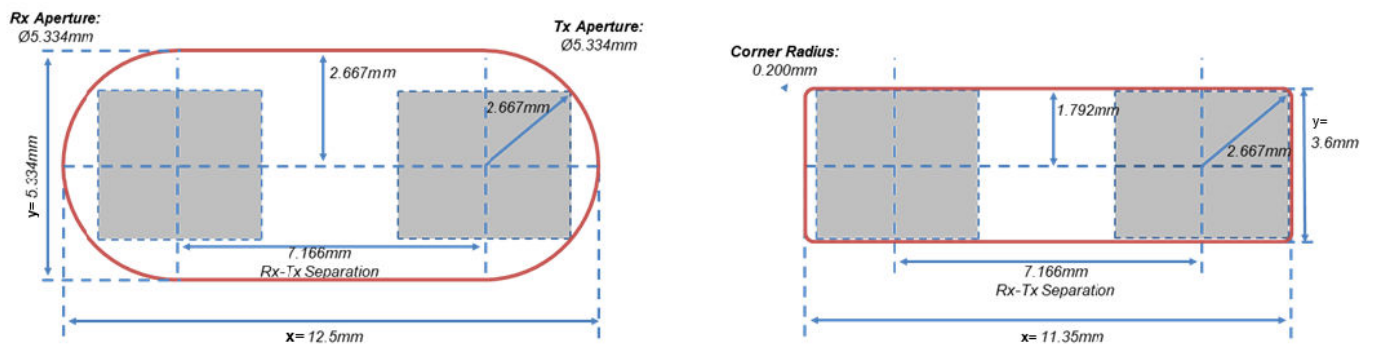
**Table 4. Rx and Tx exclusion zones**

Rx exclusion zone rectangle					Tx exclusion zone rectangle				
Z	Centroid coordinates		Edge length along axis		Z	Centroid coordinates		Edge length along axis	
	X	Y	X	Y		X	Y	X	Y
0	0.01	0.01	1.46	2.34	0	7.15	0.01	2.14	3.38
1	0.04	0.04	3.44	3.12	1	7.20	0.04	4.16	3.12
2	0.04	0.04	4.56	3.92	2	7.20	0.04	5.28	2.96
5	0.08	0.04	8.16	6.48	5	7.20	0.04	8.96	5.04
10	0.12	0.06	14.16	10.92	10	7.20	0.06	15.12	9.72
100	1.00	0.25	129.00	97.50	100	7.25	0.25	132.50	98.50
1000	10.00	4.00	1308.00	992.00	1000	12.00	4.00	1320.00	992.00

## 5.1 Continuous aperture example

### Assumptions:

- Cover glass air gap: 0.3 mm
- Cover glass thickness = 0.4 mm
- Module placement (dX/dY/dZ and rX/rY)

**Figure 9. Continuous aperture guidelines**

**Table 5. Continuous aperture - CG aperture design guidelines**

Component	Tolerances	Values	Comments
Module	dX	±50 µm	
	dY	±40 µm	
	dZ	±100 µm	
	rX	±0.45°	10 µm tilt along 12.8 mm module length
	rY	±0.94°	10 µm tilt along 5.8 mm module width
	rZ	±1	

## 5.2 Decoupled apertures example

### Assumptions:

- Cover glass air gap: 0.3 mm
- Cover glass thickness = 0.4 mm
- Module placement (dX/dY/dZ and rX/rY)

Note: Rx and Tx aperture dimensions are identical. Both apertures are centered on respective optics.

**Table 6. Decoupled apertures - CG aperture design guidelines**

Component	Tolerances	Values	Comments
Module	dX	$\pm 50 \mu\text{m}$	
	dY	$\pm 40 \mu\text{m}$	
	dZ	$\pm 100 \mu\text{m}$	
	rX	$\pm 0.45^\circ$	10 $\mu\text{m}$ tilt along 12.8 mm module length
	rY	$\pm 0.94^\circ$	10 $\mu\text{m}$ tilt along 5.8 mm module width
	rZ	$\pm 1$	

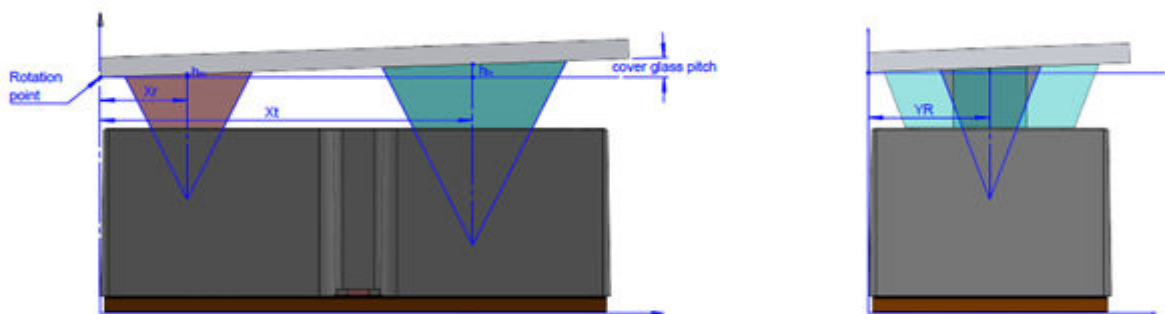
**Figure 10. Cover glass pitch or roll rotation**



In case of pitch and roll rotation of the cover glass, the size and shape of the apertures change as shown below and must be recalculated.

The calculation can be provided in a separate document if required. Contact the ST customer support office for more information.

**Figure 11. Aperture shapes with cover glass rotation**



## 6 Crosstalk mitigation

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### 6.1 Gaskets

Gaskets reduce the crosstalk between the true signal and spurious reflections from the transmitted signal. The ideal gasket should be thick enough to fill the full air gap between the device and the cover glass. The gasket should contain two apertures large enough to allow the full Tx or Rx cone to pass through unimpeded. The gasket should also form a light barrier between the Rx and Tx channels. The gasket should cover the maximum area between the Rx and Tx channels possible without impeding the keepout zones.

## 7 Conclusion and summary table

Air-gap size and cover glass properties influence the level of crosstalk signals.

Experimental results show that an air gap smaller than 0.5 mm is recommended. If a larger air gap is used, a gasket may be required to reduce crosstalk.

Cover glass recommendation details are reported in the summary table below.

**Table 7. Cover glass guidelines and summary table**

	Parameter		Recommended spec for maximum performances
Optical parameter	Maximum crosstalk signal level		2000 kcps
	Transmittance at 940 nm		> 87%
	Transmittance haze (visible)		< 1%
	Transmittance haze (IR)		< 6%
	Roughness, Ra		Optical grade (<20 nm)
	Wettability		< 60°
Mechanical parameter	Air gap <sup>(1)</sup>	Without gasket	< 0.5 mm
		With gasket	< 1 mm
	Cover glass thickness		< 1 mm (thinnest possible recommended) <sup>(2)</sup>
	Cover glass tilt		< 1° (not recommended)
	Cover glass coating		Not affect the transmittance, haze, wettability, roughness requirements.
Number of cover glass apertures		One capsule shape (a circular opening is not an efficient use of space for an aperture opening)	

1. Increased air gap potentially adds crosstalk. The crosstalk may be limited with the use of a gasket. Air gaps <0.5 mm keeps crosstalk below the recommended limits.

2. If designing a product outside of these guidelines contact ST technical support.

**Note:** The figures above are for the final cover glass including any coatings applied.

**Note:** Limits are given as a recommendation. Customers should try to maximize the transmittance, and reduce the crosstalk as much as possible. Both increase the ranging distance and the low reflectance target detection. Smudge and dust may reduce the transmittance and increase the crosstalk, which negatively impacts the performance.

**Note:** For a particular turnkey cover glass made by a third-party, contact your ST sales office.

## Revision history

Table 8. Document revision history

Date	Version	Changes
18-May-2026	1	Initial release

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