Application note

Description of the fields of view of STMicroelectronics' Time-of-Flight sensors

Introduction

This document describes how STMicroelectronics defines the different fields of view (FoVs) of its Time-of-Flight (ToF) sensors.

By definition, a system FoV corresponds to a solid angle through which a detector is sensitive. However, in the context of ToF sensors, this common definition cannot be applied due to the following constraints:

- The system is composed of two FoVs: one for an emitter (VCSEL) and one for a receiver (SPAD). Each FoV has its own specific characteristics.
- The quantity of signal received by the SPAD array depends on testing conditions, such as target distance, ambient rate, and integration time.
- From a customer point-of-view, ToF sensors are used to measure a distance, and not a quantity of signal.

These points have encouraged STMicroelectronics to propose different definitions for describing the FoVs. Each definition is used for specific use-cases, which are described in this document.

Figure 1. STMicroelectronics' ToF sensor module

1 Acronyms and abbreviations

Table 1. Acronyms and abbreviations

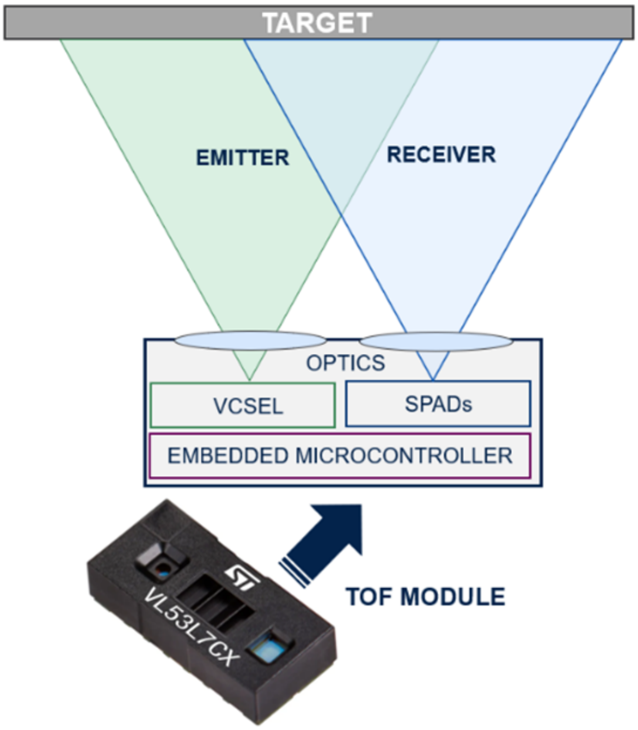
Acronym/abbreviation	Definition
FoI	field of illumination
FoV	field of view
FWHM	full width at half maximum
SPAD	single photon avalanche diode
ToF	Time-of-Flight
VCSEL	vertical cavity surface emitting laser

2 Circular and square fields of view

2.1 STMicroelectronics' Time-of-Flight sensors

STMicroelectronics' ToF sensors are all-in-one modules that include a VCSEL, optics, an embedded microcontroller, and SPAD arrays. They are used to measure a distance at fast speed, with a low-power consumption.

Figure 2. ToF module overview



STMicroelectronics develops and produces two types of ToF sensors:

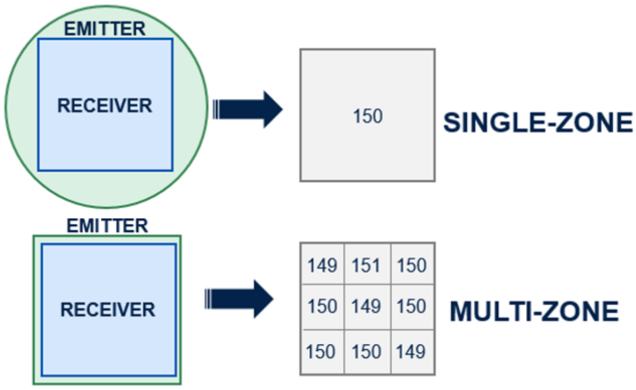
- Single-zone: Sensors used to measure a single distance within the FoV. Some sensors can also measure multitargets within the FoV. Several distances are returned, but it is not possible to have the co-ordinates of the detected target. Examples of single-zone sensors include the VL53L1CB and VL53L4CD.
- Multizone: Sensors used for depth-mapping. Such sensors can split the SPAD array into multiple zones. Each zone reports its own distance. Consequently, it is possible to have a mini depth-map. Examples of multizone sensors include the VL53L5CX and VL53L7CX.

2.2 Field of view construction

By construction, some sensors have a circular FoV, and others have a square FoV. This effect is due to the optics that are present in the module. Standard optics gives circular FoVs, whereas diffractive optics allows a square FoV.

Most single-zone sensors have standard optics, and most multizone sensors have diffractive optics. See Figure 3. Example of measurements for single-zone and a multizone sensor, which has a target at 150 mm.

Figure 3. Example of measurements for single-zone and a multizone sensor



Consequently, the angle given by STMicroelectronics to describe the FoV can be different for a single-zone and a multizone product. For a multizone product, STMicroelectronics gives the diagonal of the receiver, and the angle at each side of the FoV. For single-zone products, only the diagonal of the receiver is given.

Example: For the VL53L4CD, the FoV is specified in diagonal (18° diagonal). For the VL53L5CX, the FoV is specified in diagonal (65° diagonal) and by side (45°x45° side).

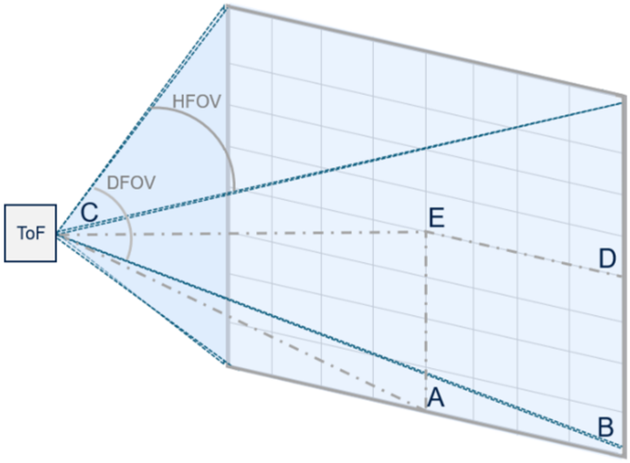
Note: The conversion from side to diagonal cannot be applied using Pythagoras' theorem (see Section 2.3 Computing the diagonal field of view of a multizone sensor.

2.3 Computing the diagonal field of view of a multizone sensor

A common error when computing the diagonal FoV is caused by converting the given X and Y angles using Pythagoras' theorem. However, this theorem can only be applied for distances. It cannot be applied for angles.

The computation used by STMicroelectronics is demonstrated below. Distances used for the demonstration are described in Figure 4. Points used for computing diagonal FoVs.

Figure 4. Points used for computing diagonal FoVs



For the calculation, it is assumed that:

- The SPAD array is square
- The sensor is perpendicular to the target, so each zone is a square
- The distance [AC] is equal to 1. This value is arbitrary and does not interfere with any results at the end.

By construction, it is also assumed that:

$$[AB] = [EA] = [AC] \times \tan\left(\frac{HFoV}{2}\right) \quad \textit{Equation 1}$$

$$[EB] = \sqrt{[EA]^2 + [AB]^2} \quad \textit{Equation 2}$$

$$[BC] = \sqrt{[AB]^2 + [AC]^2} \quad \textit{Equation 3}$$

If we consider that: [AC] = 1, then:

$$[EB] = \sqrt{2 \times \left[\tan\left(\frac{HFoV}{2}\right)\right]^2} \quad \textit{Equation 2 + Equation1}$$

$$[BC] = \sqrt{\left[\tan\left(\frac{HFoV}{2}\right)\right]^2 + 1} \quad \textit{Equation 3 + Equation1}$$

The diagonal FoV can be extracted by:

$$[DFoV] = 2 \times \left(\frac{[EB]}{[BC]}\right) = 2 \times asin\left(\frac{\sqrt{2 \times \left[\tan\left(\frac{HFoV}{2}\right)\right]^2}}{\sqrt{\left[\tan\left(\frac{HFoV}{2}\right)\right]^2 + 1}}\right) \quad \textit{Equation 4}$$

Example for the VL53L7CX

The detection volume is 60° x 60°. By applying Pythagoras' theorem, the result is 84.5°. The solid angle given by this computation gives 90°.

3 Field of view definitions

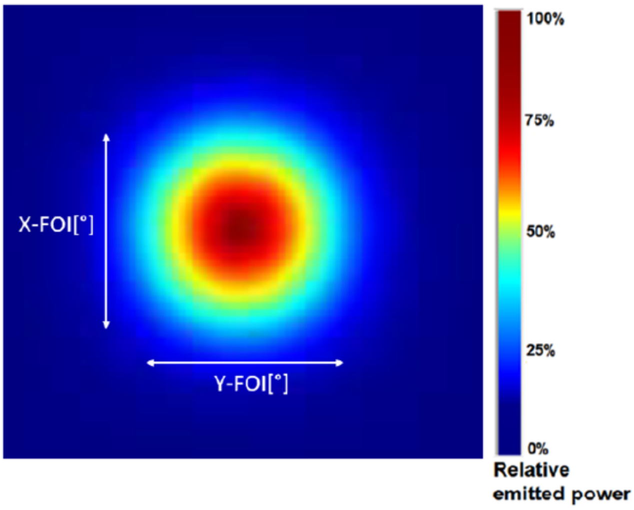
3.1 System field of view

The system FoV is the volume given for nominal performances. It is composed of an emitter called the field of illumination (FoI), and a receiver called the nominal FoV. From a user point of-view, the system FoV gives an idea of where the signal is emitted, and where it can be detected.

3.1.1 Field of illumination

The FoI is used to describe the intensity profile emitted by the VCSEL. STMicroelectronics gives the illumination profile (see Figure 5. Example of the VL53L4CD FoI), and angles for specific intensity values.

Figure 5. Example of the VL53L4CD FoI



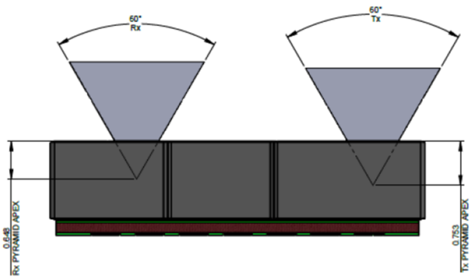
- For single-zone products, the FoI angle is given for an intensity of $1/e^2$, or FWHM
- For multizone products, the FoI angle is given for two different intensities: the 75% and 10% relative signals from the maxima.

3.1.2 Nominal field of view

The nominal FoV is used to describe the area where the signal can be detected for nominal performances. Standard STMicroelectronics' reflectances are detected within this area. Angles are given for the X and Y orientations of the module.

The nominal FoV is applicable for Lambertian targets only. For specular targets, please refer to Section 3.3 Keep-out cone.

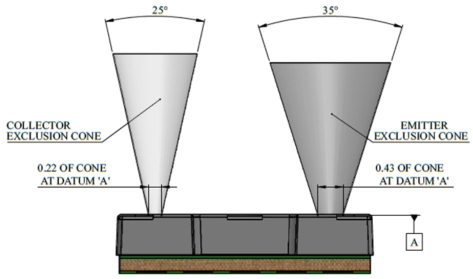
Figure 6. VL53L7CX nominal FoV example



3.2 Exclusion cone

The exclusion cone is a region used for design integration. It is based on the system FoV tolerances. There is one exclusion cone for the emitter and one for the receiver. Customers should ensure that there are no materials within this region to avoid parasitic crosstalk. Exclusion cones are given in the product datasheet drawings. They should be considered for the design of both the cover glass and the application apertures. Cover glass integration guides and aperture calculator tools are also available on st.com.

Figure 7. Example of the VL53L3CX exclusion cones



3.3 Keep-out cone

The keep-out cone is another region used for design integration. It is based on the irradiance detection. A keep-out cone guarantees that there is no light outside the region (emitted or received), even if a mirror, or a high reflective surface is used. This cone can be used to define the detection limit whatever the conditions. Consequently, keep-out cones are very large compared to detection volumes or system FoVs.

Keep-out cones do not feature in the datasheets of STMicroelectronics. However, they can be shared by contacting st.com support.

Note: For a major part of single-zone sensors, the keep-out cone is the same as the exclusion cone.

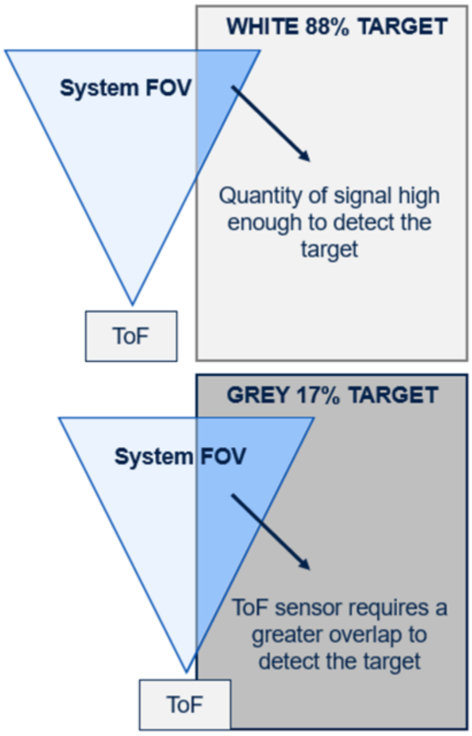
3.4 Detection volume

From a customer point-of-view, the detection volume is the most important area. It corresponds to the region where it is possible to extract a valid ranging distance. A target outside the detection volume could be detected by the sensor, but the signal strength may be too low to extract a valid ranging distance.

As the detection volume is based on valid ranging distance measurements, it is strongly impacted by the surrounding environment. The signal-to-noise ratio should be high enough to extract a distance.

For example, for two targets located at the same distance, the detection volume is lower on a gray 17% target than on a white 88% target. This is due to the different quantity of signal reflected by the target, and measured by the sensor.

Figure 8. Impact of the reflectance on the detection volume

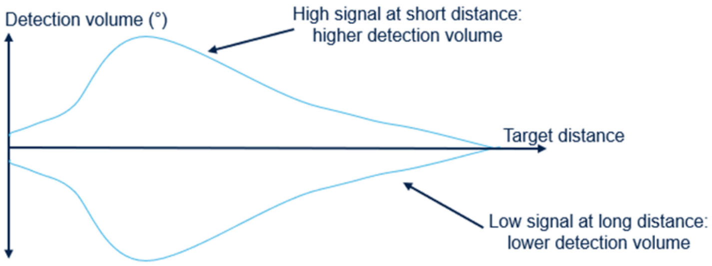


The reflectance is not the only factor that has an impact on the detection volume. Everything influencing the signal-to-noise ratio can change the detection volume. The main factors are:

- Target reflectance: A higher reflectance gives a higher detection volume. This is because the target is detected even with a small overlap between the target and the ToF system FoV.
- Ambient light level: A high ambient rate reduces the detection volume. This is because ambient noise parasitizes the sensor.
- The integration time/timing budget: Sensor settings define the quantity of time used to integrate the light. A higher value causes a higher detection volume.
- Target distance: The detection volume evolves with the quantity of signal received.

As the detection volume depends on a target distance, the detection volume profile is not linear. It looks like a spade (see Figure 8. Impact of the reflectance on the detection volume).

Figure 9. **Impact of the distance on the detection volume**



In STMicroelectronics' technical documentation, the detection volume is given for one or two different distances with fixed settings. It is measured for the X and Y orientations of the module. An example is given in Table 2. Example of the detection volume given for the VL53L4CX.

Table 2. **Example of the detection volume given for the VL53L4CX**

Setting	Target at 100 mm (white88%)	Target at 1000 mm (white88%)
Detection volume (°)	22°	18°

Note: *For the system FoV, the detection volume is specified in diagonal for single-zone modules (example, 22° diagonal for the VL53L4CX), and by side for multizone products (example 60°x60° side for the VL53L7CX). For more information, please go to Section 2.2 Field of view construction.*

3.5 Summary

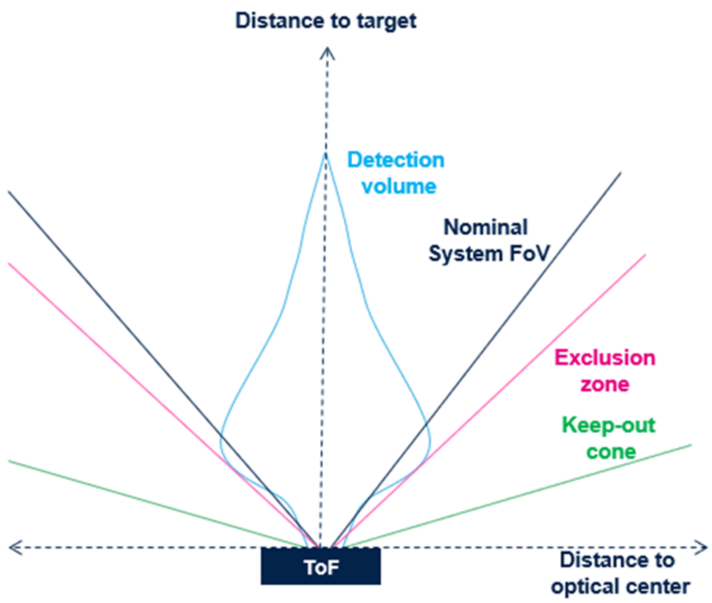
Table 3. FoV summary table outlines the different definitions of the FoVs given in this application note.

Table 3. FoV summary table

Definition		Name	Usage for customer
System FoV	FoI (emitter)	Typical signal emitted by the sensor	Region where the signal is emitted, and where it can be detected
	Nominal FoV (receiver)	Typical signal that can be detected by the sensor using a Lambertian reflectance	
Detection volume		Region where a valid distance can be measured	Sensor working area (recommended for evaluation)
Exclusion cone		Region based on system FoV tolerances	Design integration using a Lambertian surface (recommended for integration)
Keep-out cone		Region based on very high illumination	Design integration using a highly reflective surface

Figure 10. Schematic of all STMicroelectronics ToF field of view definitions gives a simplified view of all the different FoVs.

Figure 10. Schematic of all STMicroelectronics ToF field of view definitions



4 STMicroelectronics' recommendations for customers

To compare the performances of products, it is recommended to rely on the detection volume as it is based on valid distance measurements.

For design integration, it is recommended to use the exclusion cones. Information on them is provided in the product datasheets, and also in the dedicated calculator tools on st.com. If your materials have reflective surface that is too high, you can use the keep-out cone. However, please note that keep-out cones are not recommended by default as they require larger apertures.

All other FoV descriptions given in this application note are purely for information purposes.

Revision history

Table 4. **Document revision history**

Date	Version	Changes
18-Jan-2023	1	Initial release

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