Time of Flight: Principles, Challenges, and Performance

ST Technology Tour 2017

John Kvam

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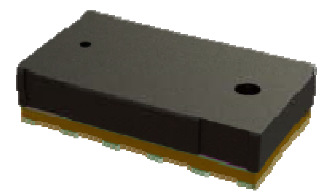
Agenda

- Time of Flight Principles and Design Choices
- Performance
- Application Examples
- Design Challenges
- Calibration
- Evaluation kit : HW & GUI
- Hardware Considerations
- Development & Support

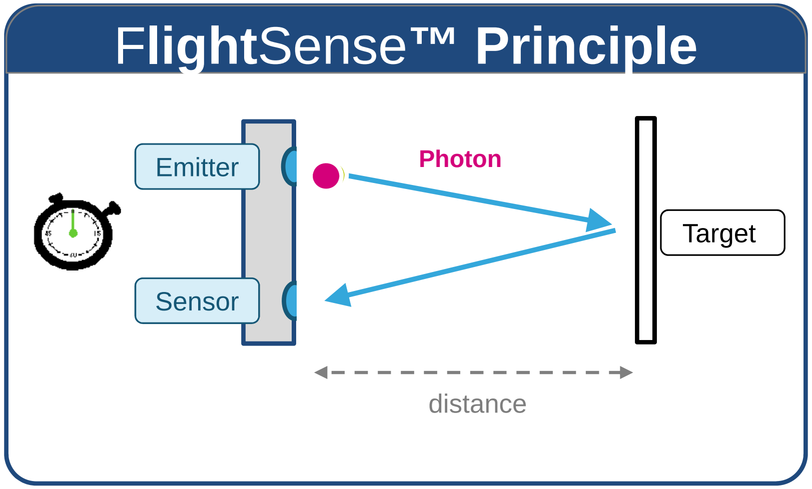


ToF Principles

Time of Flight Basics

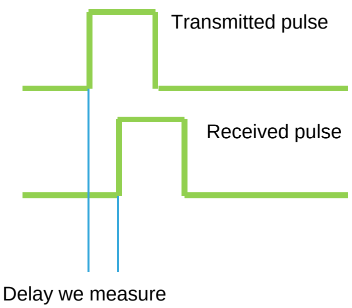
Active illumination system:

- Laser emits light (photons) towards a target
- Light (partially) reflected from the target
- Sensor area determines when light (photons) arrives
- ToF is translated into distance



Distance Value = Photon travel time/2 x by speed of light

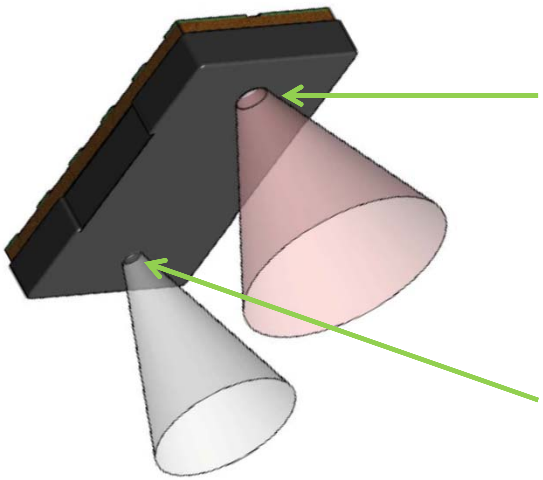
Allowing 1mm high resolution (time discrimination of 6.6ps!)



Photon travel time NOT affected by target reflectance

Measured Time is Measured Distance

ToF – Order of Operation



VCSEL - Emitter:
Vertical Cavity, Surface Emitting Laser

SPAD - Receiver:
Single Photon Avalanche Diode
IR notch filter

Proximity Sensor operation description:

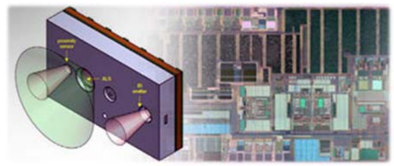
- VCSEL emits a pulse of photons towards a target
- Photons are partially reflected from the target to the SPAD
- The SPAD array generates a small pulse for each detected photon
- Time between initial and received pulse is measured
- Time is converted in distance

FlightSense™ Technology Advantages

True Distance

INVISIBLE

Color independent



Fully integrated

Gesture capable

Eye Safe

Texture independent

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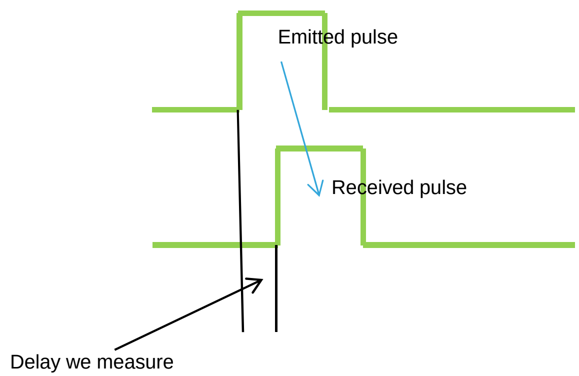
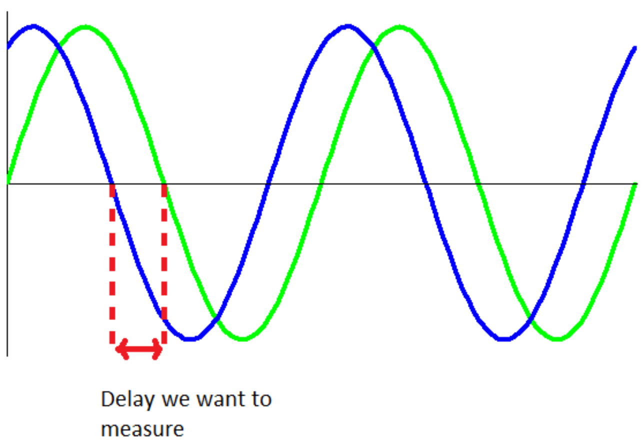
ToF – Direct vs Indirect

- Two ways to measure the Time of Flight (ToF):
- In the direct method, the time difference between the emitted pulse, and a received signal.
- In indirect, a continuous modulated sinusoidal light wave is emitted and the phase difference between outgoing and incoming signals is measured.



Direct – Used by ST



Indirect

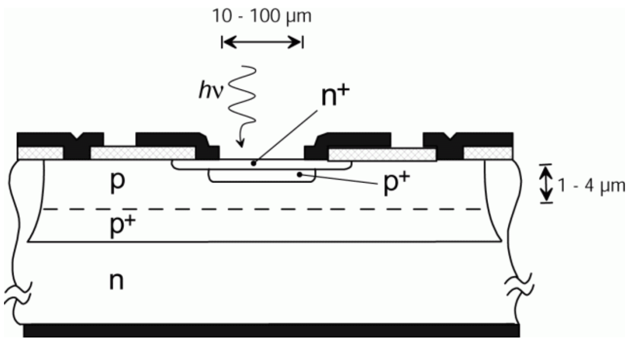
Single Photon Avalanche Diode- SPAD

- From Wikipedia:

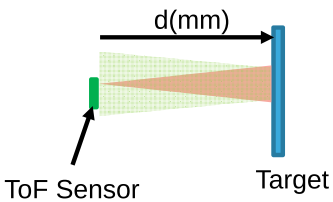
- “SPADs are semiconductor devices based on a p-n junction reverse-biased at a voltage V_a that exceeds breakdown voltage V_B of the junction.”

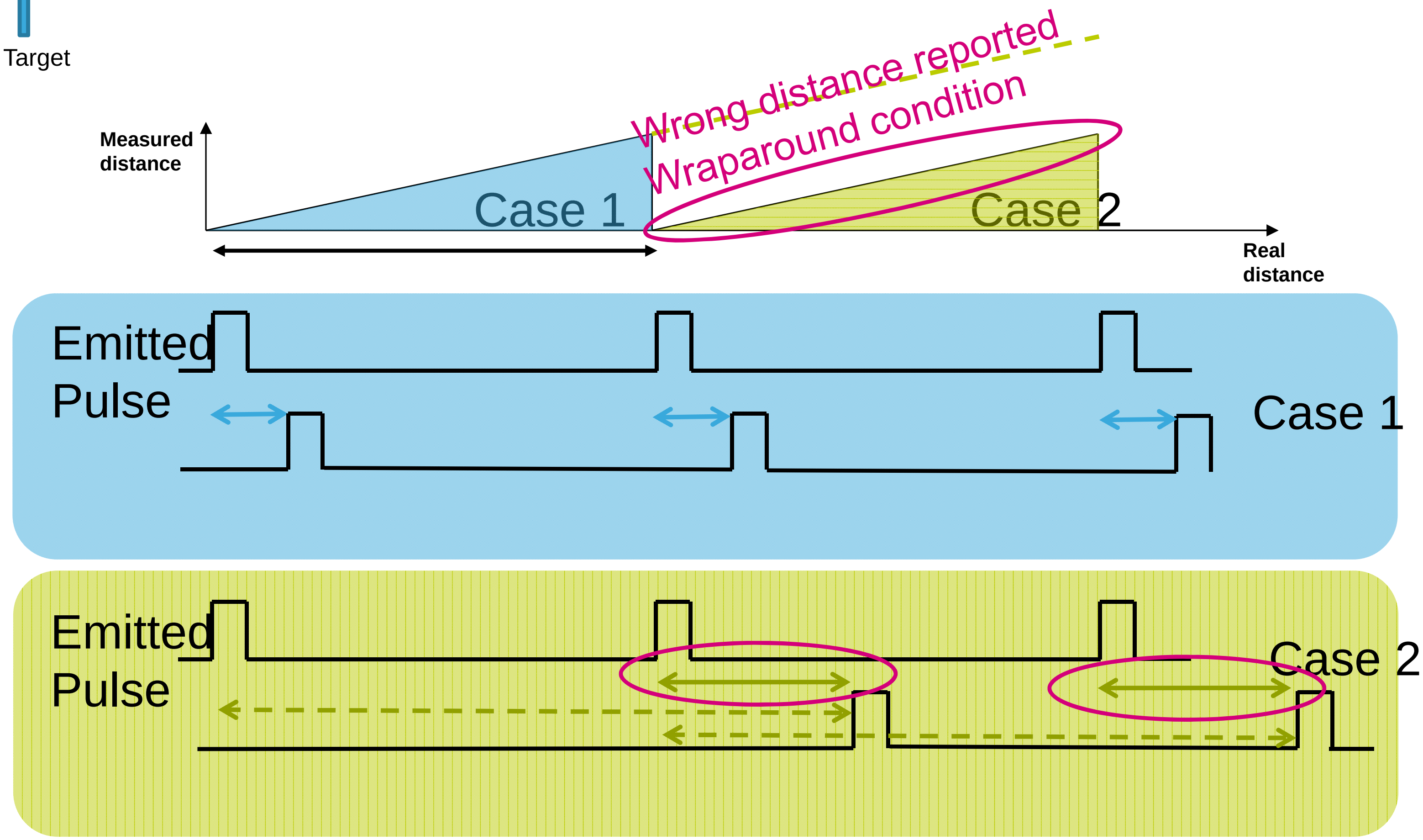
- The trick is to make them small and low-power.

- ST uses a standard CMOS process

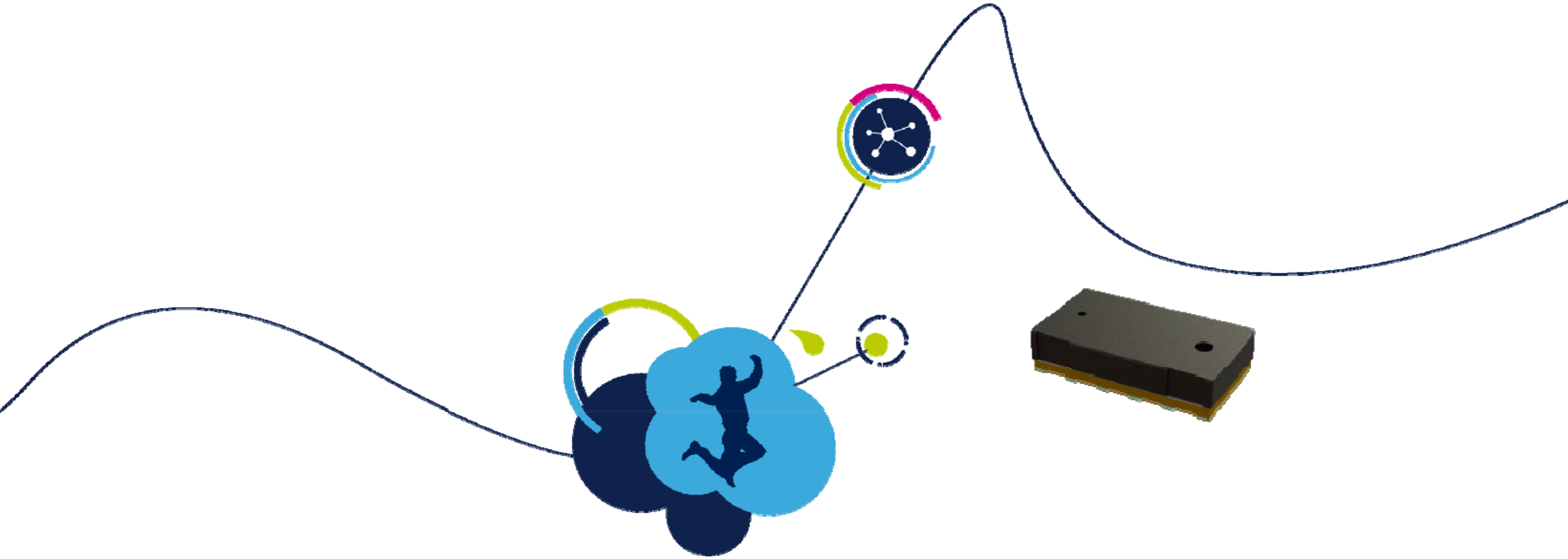


Maximum Measurable Distance





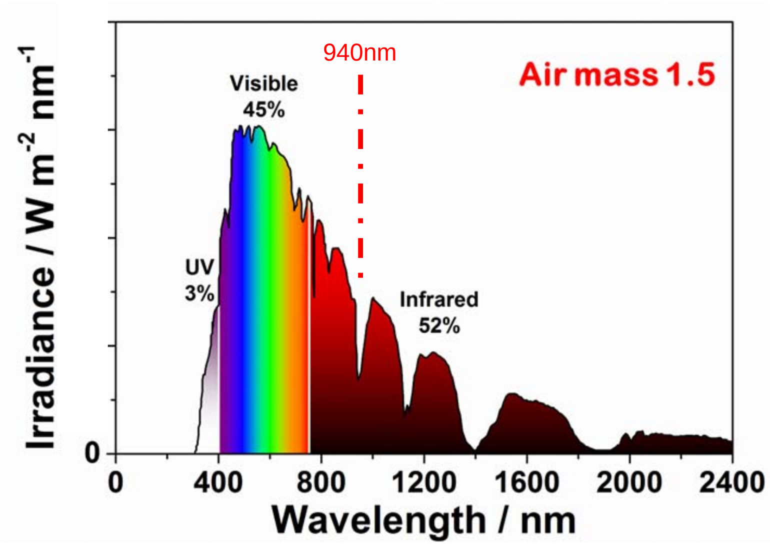
Emitted pulse period = Maximum measurable distance



ToF Performance: Distance, Accuracy, Ranging Rate, and Power Consumption

Lux vs IR

- Solar spectrum at sea level : AM 1.5 standard
- Outdoor = 5kLux equivalent IR
- Indoor = 0kLux (AM1.5) or NO IR emitting light



FlightSense^{TM} product benefits

	VL6180X	VL53L0X
Distance measurement	Proximity up to 40cm (*)	Ranging up to 2 meters (*)
Performance under strong ambient light		+++
FoV	25 degrees	25 degrees
ALS	Yes (0 to 100klux)	No
Laser emitter (Class1)	850nm	940nm (no red glow)
Speed for Distance acquisition	Few ms (*)	up to x2 faster (programmable)
Accuracy	+/- 10mm (*)	+/-3 % (*)
Programmable modes	No	3 modes in API (High-speed, long distance, high accuracy)
Small all-in-one module	2.8 x 4.8 x 1 mm	2.4 x 4.4 x 1 mm
Low power consumption	HW stdby <5uA Ranging: 20mW (average at 10Hz with 33ms ranging sequence)	
Power supply - functional operating (Absolute maximum rating)	2.6V to 3V (-0.5 to 3.6V)	2.6V to 3.5V (-0.5 to 3.6V)

(*) Depending on conditions like Ambient light, target reflectance and product settings

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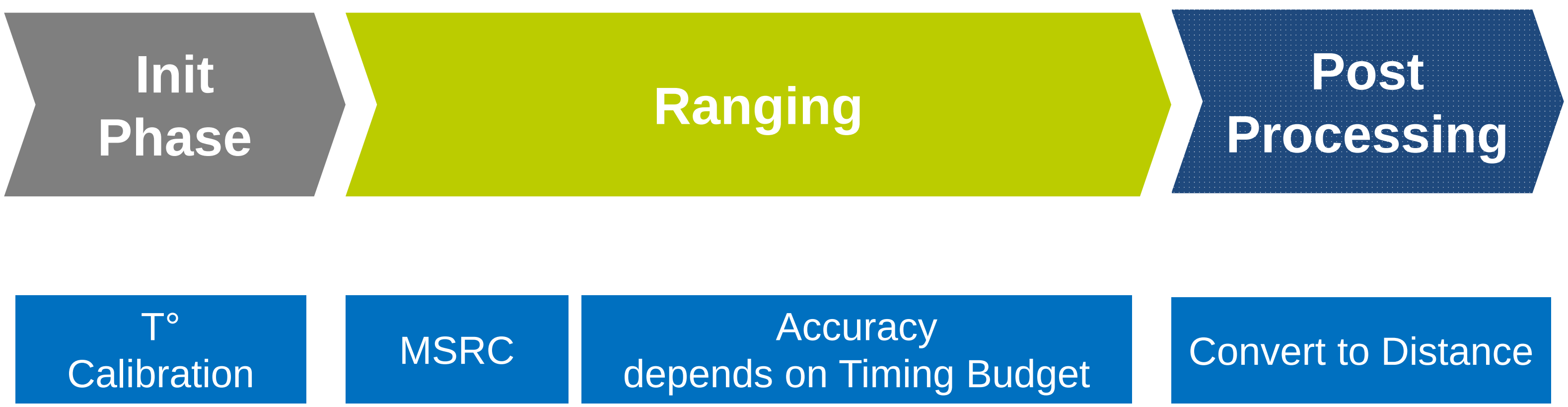
VL53L0X Internal Sequencing

- Temperature autocalibration is automatically done when starting
- Timing budget is generally 30ms, then **33Hz**
- MSRC will quit ranging if NO Target is present
- 4x Timing Budget implies 2x accuracy



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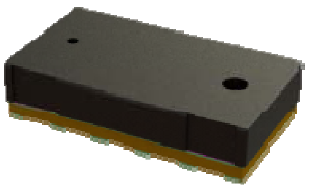
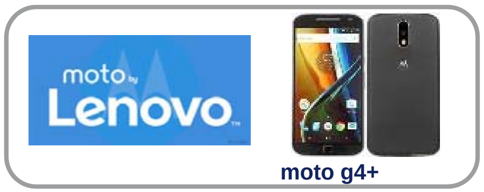
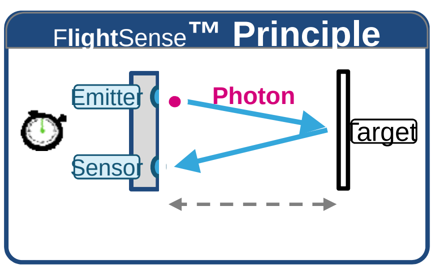


Application Examples

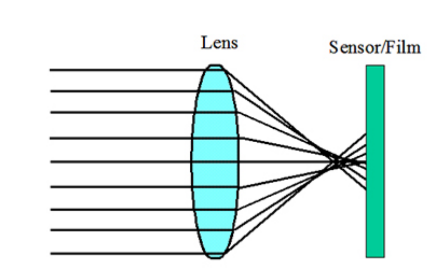
VL53L0 AF Assist Worldwide Adoption

….250 Million sold and many more to follow





Distance



Focal length

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Power Saving

- Waking up on target / Presence detection

Faucet

Hand dryer

urinal / toilet flusher

Soap dispenser

Reliable User Detection

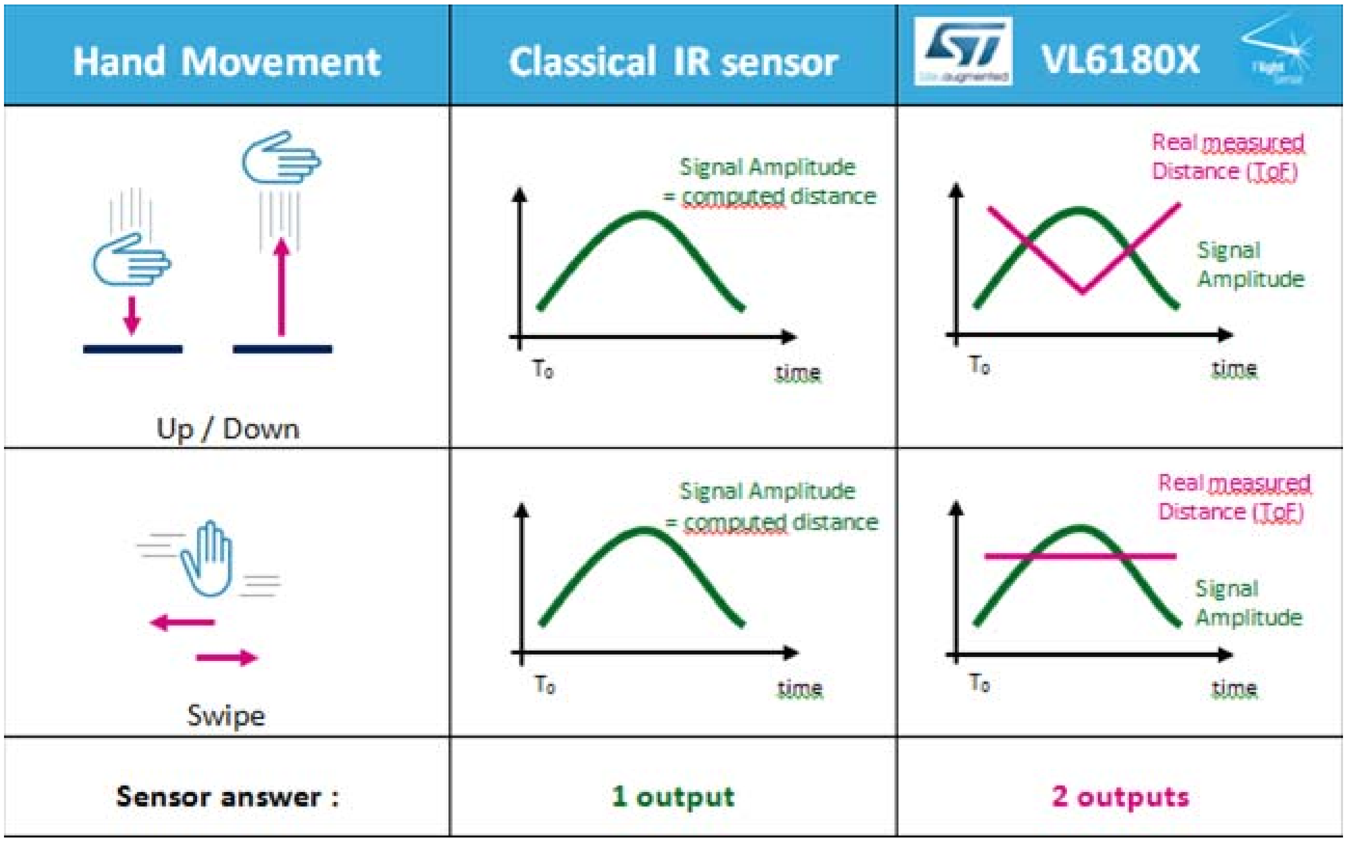
True distance measurement independent of target size and color allows more reliable detection

Reliable Coin Detection

ToF sensor allows system to detect coin when coin inserted much more reliably than conventional IR solutions. Thus user experience improves from significantly decreased coin re-inserting rate

FlightSense™ benefits versus traditional IR

- **Flight**Sense™ allows to discriminate vertical gesture from horizontal gesture while traditional IR sensor cannot



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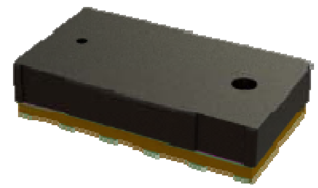
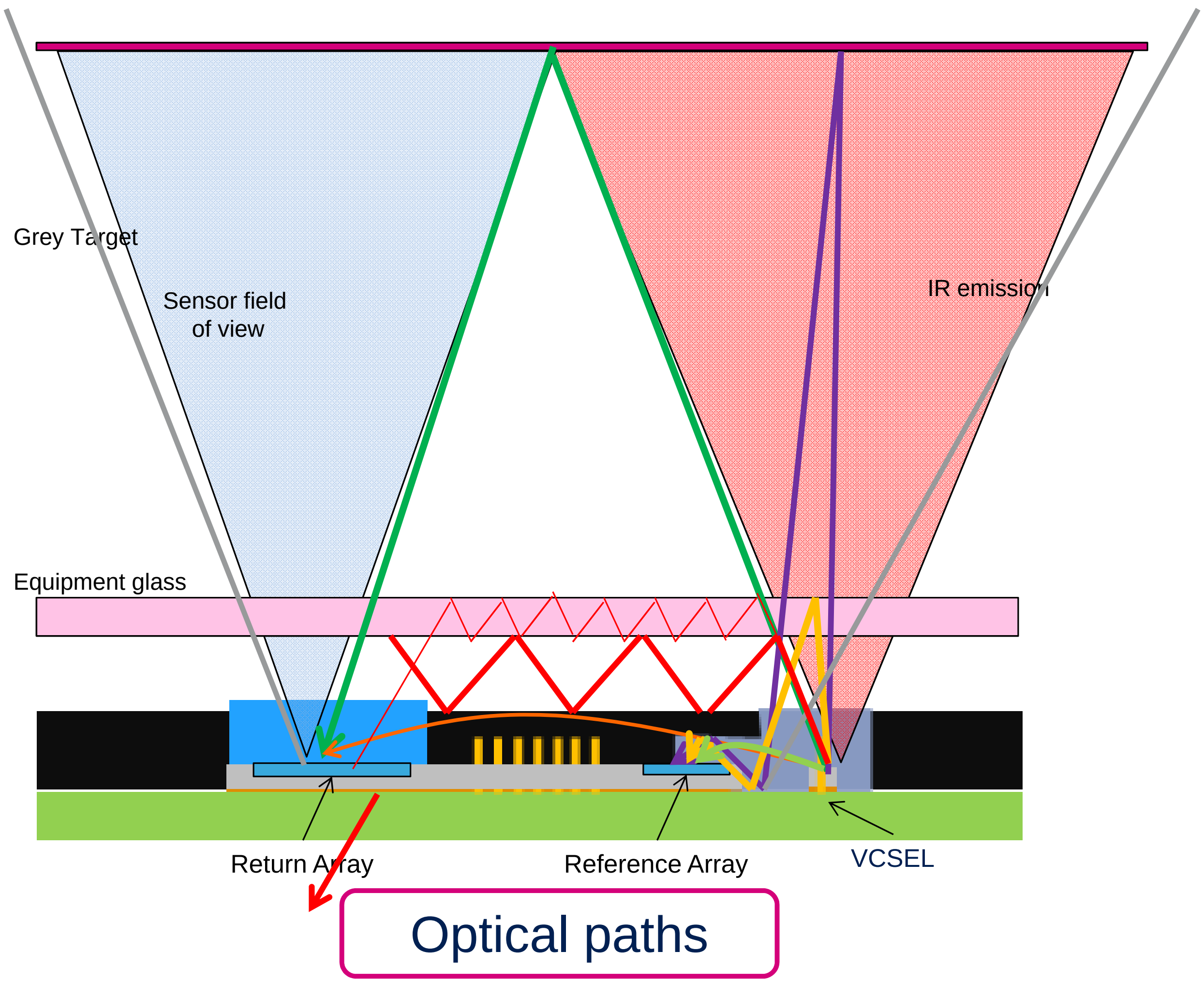


ToF Sensor Challenges

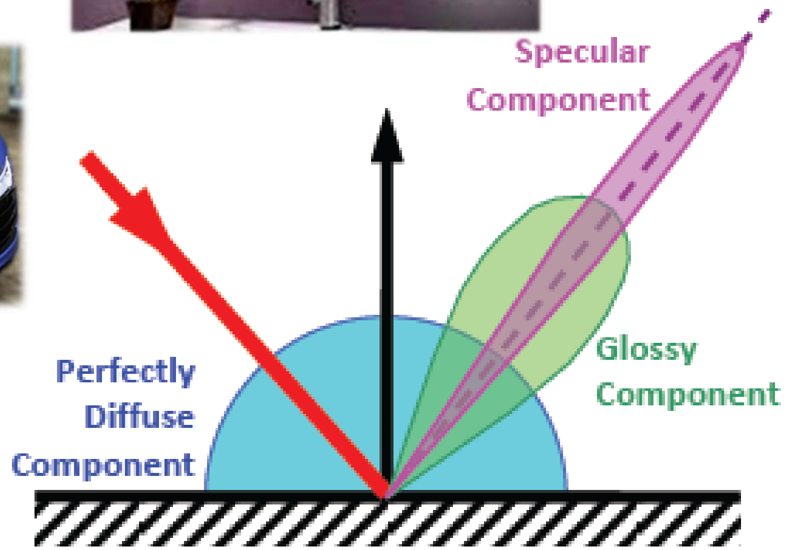
Light Interferers



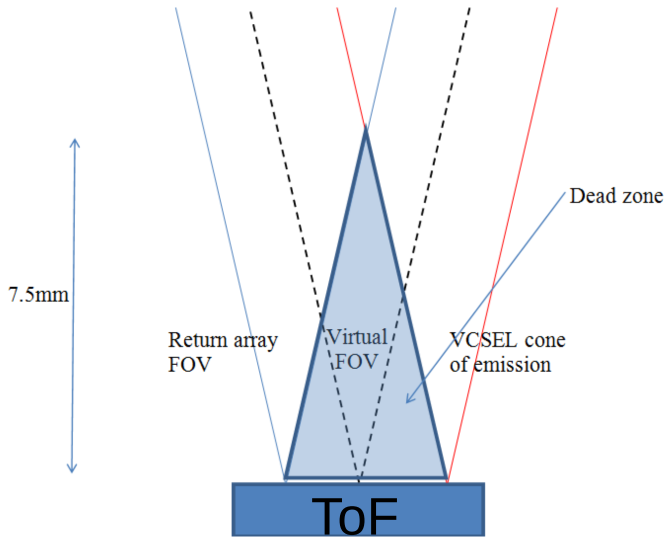
Signal
- Returns
- Coupling

Noise
- Crosstalk on reference
- Returns on reference
- Leakage
- Crosstalk on return
- Ambient on Reference
- Ambient on Return

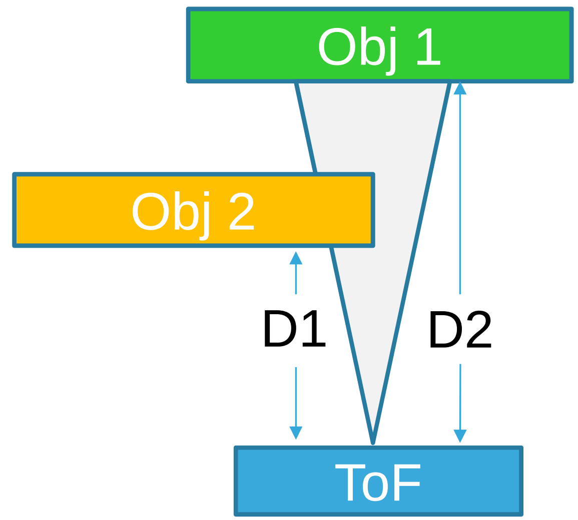
Impact of Surface Finish



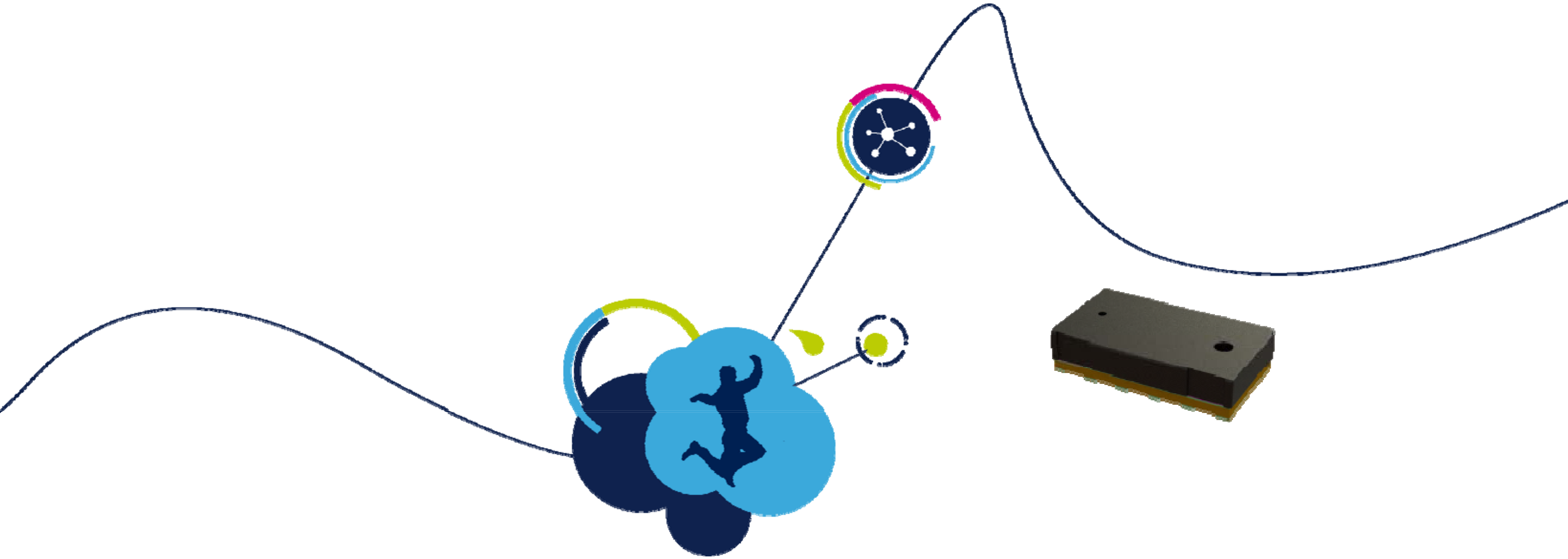
Field of View Issues



Due to distance between VCSEL and SPAD, there is A deadzone where the target can be considered out of FoV



If two objects are present in the FoV, the measured distance will be a weighted average



ToF Sensor Offset and Crosstalk Calibrations

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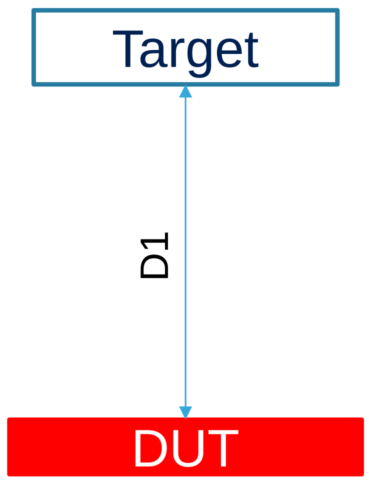
Offset Calibration Procedure

- Range Offset Calibration
  - The Offset changes slightly during re-flow
  - Perform the P2P offset calibration at manufacture is recommended.
- Range Offset Calibration Procedure
  - With a known distance D1, typical 10 cm.
  - Range several time to get an averaged distance (avD).
  - Offset = D1 - avD.
  - Store the Offset in the host memory to be program at each device boot.



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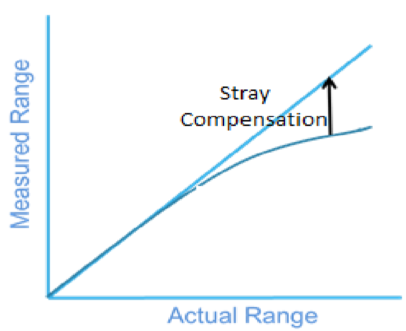
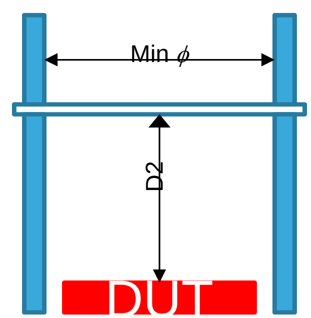
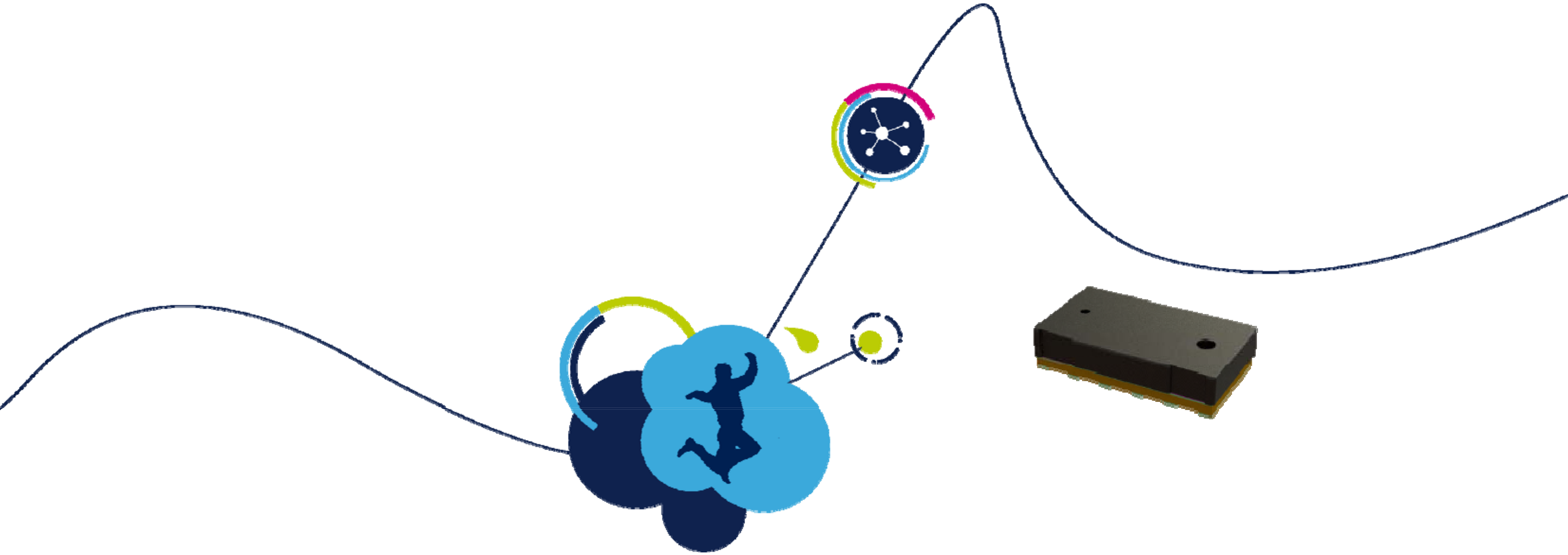
Crosstalk Calibration

- Crosstalk is induced by the photons reflected by the cover glass.
- The magnitude of the cross talk is dependent on the thickness of glass, material and the air gap
- Crosstalk affects longer range measurements where the reflected photon by the target becomes
- Procedure
  - With a known D2 (60 cm typical)
  - Range several times to get an average
  - API software provides the compensation coefficient, which is stored in the host memory to be programmed in the ToF at each system boost.

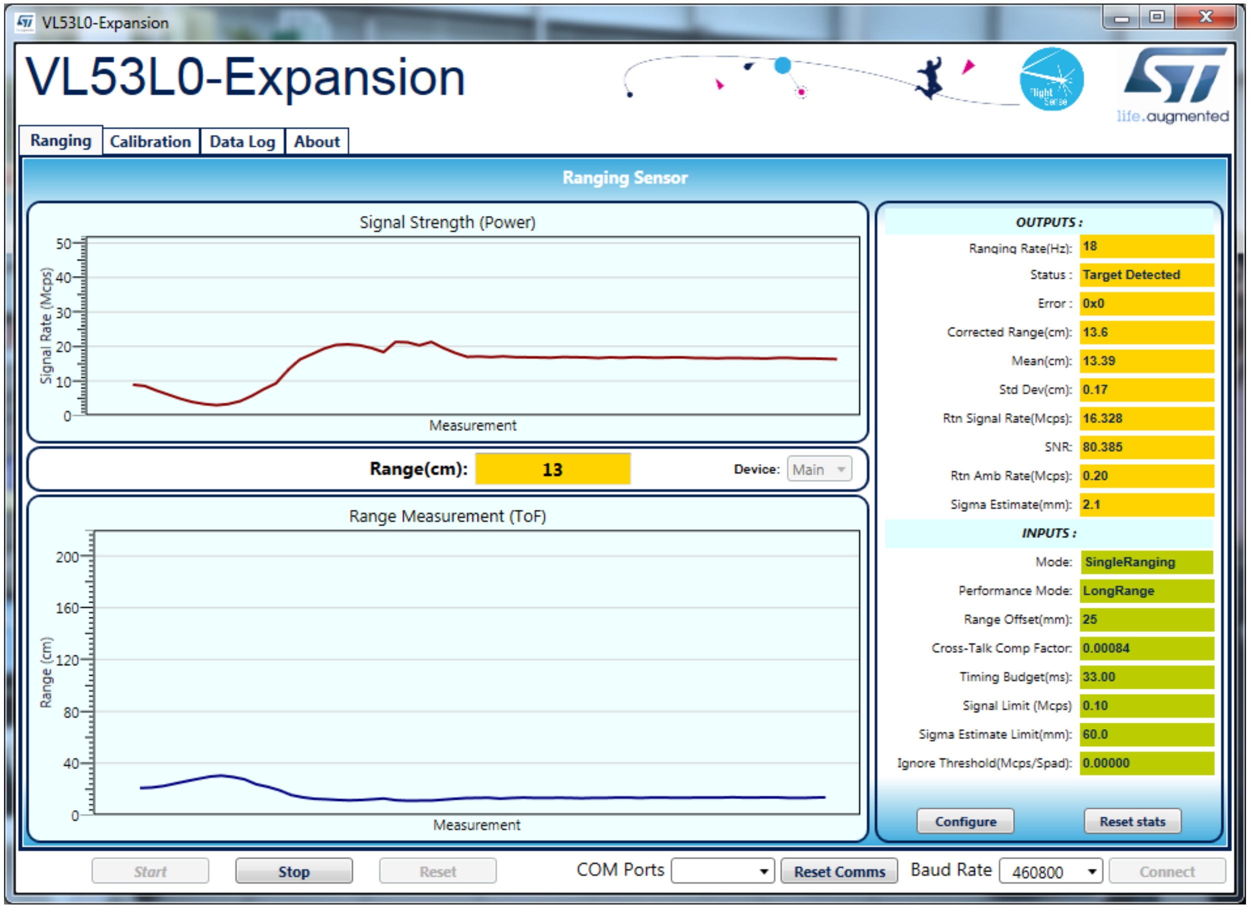






GUI Explanation – Practical Application

VL53L0X Expansion GUI



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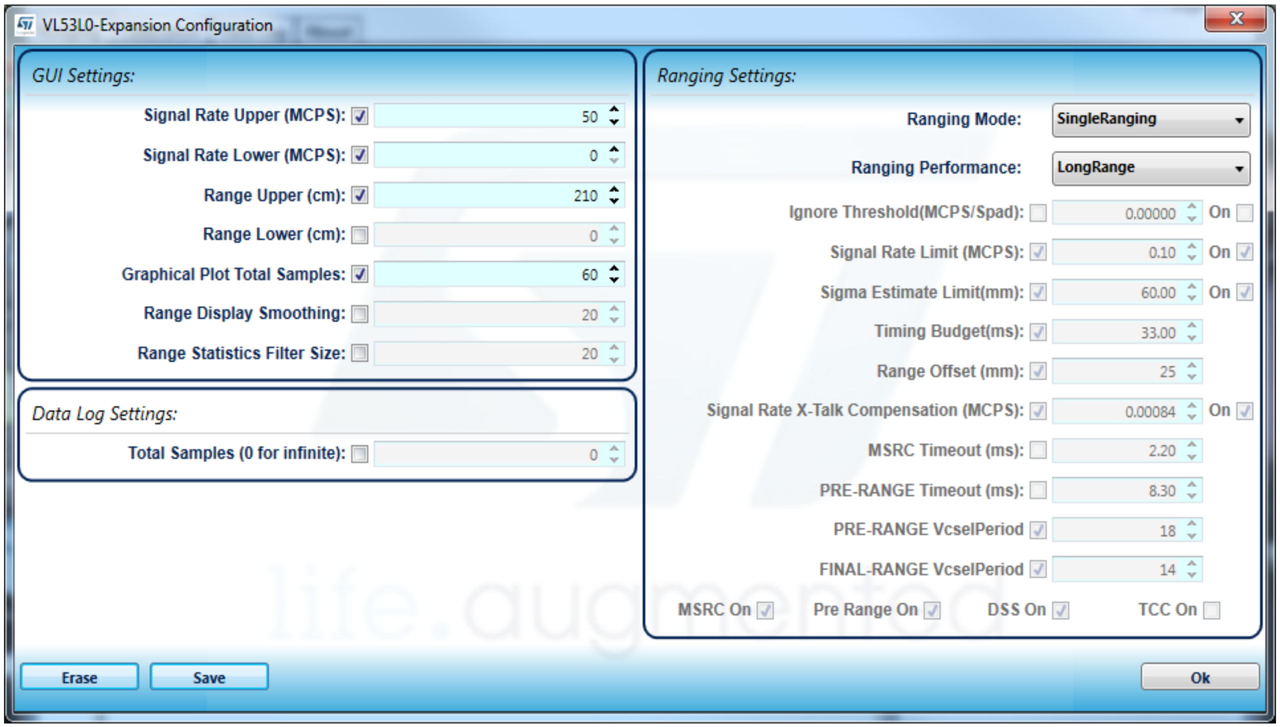
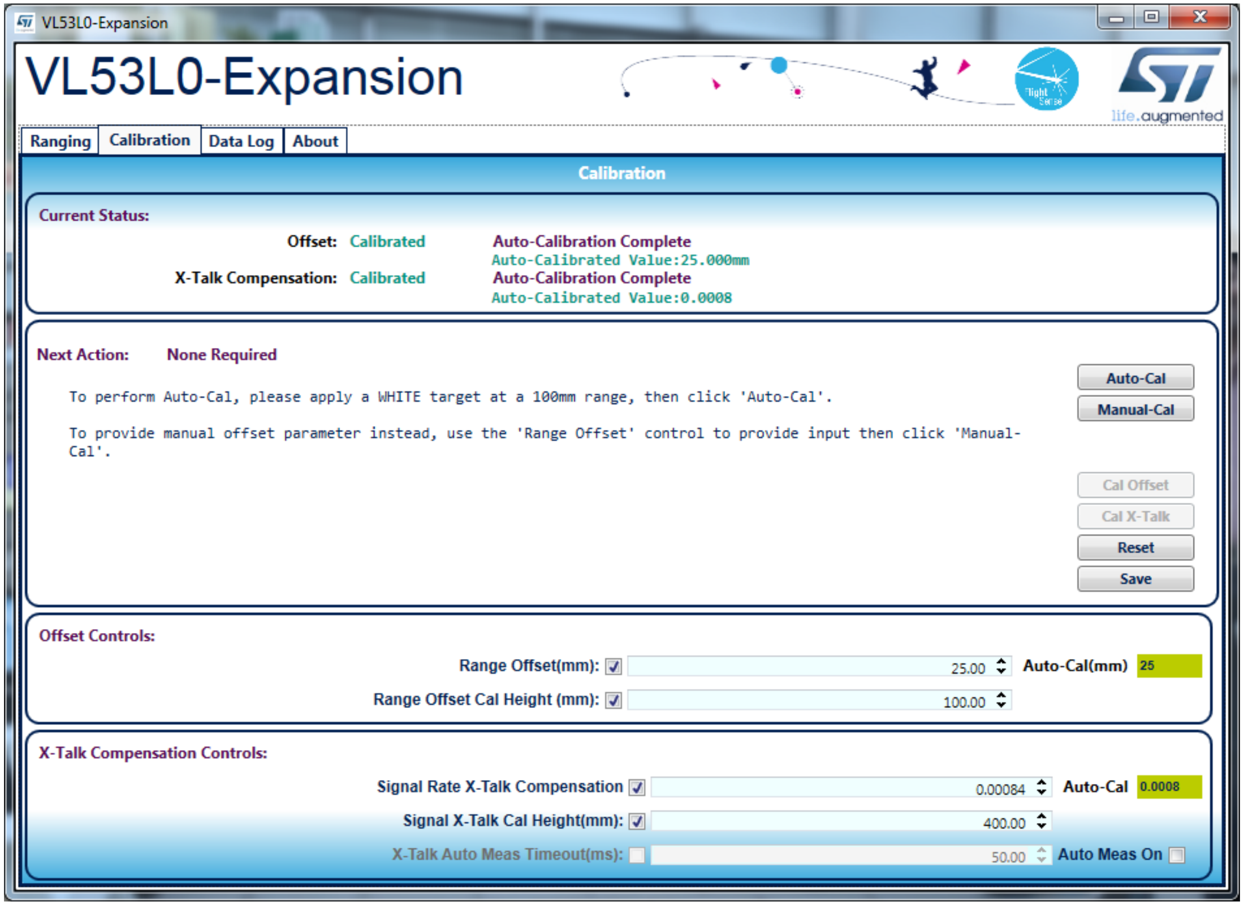
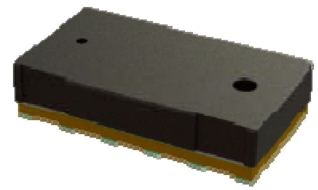
VL53L0X Expansion GUI Settings



- GUI Settings Panel

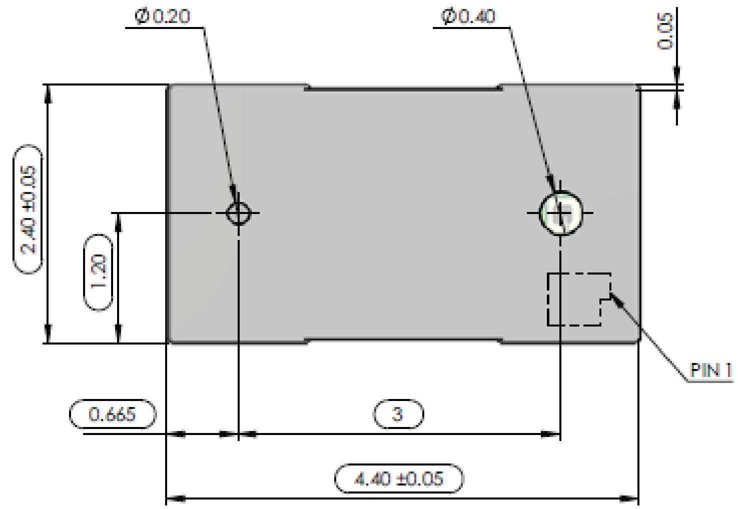
VL53L0X Expansion GUI Calibration

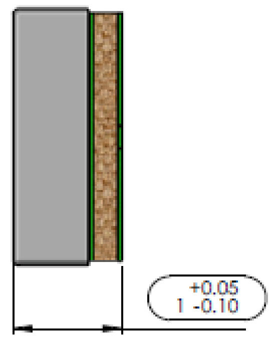


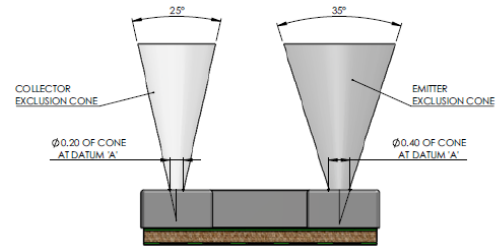


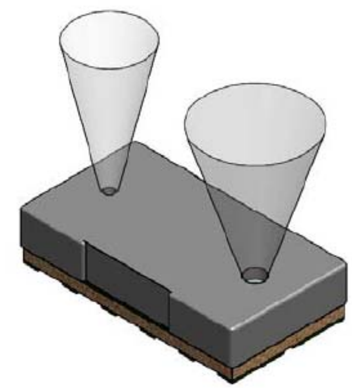
Hardware Description

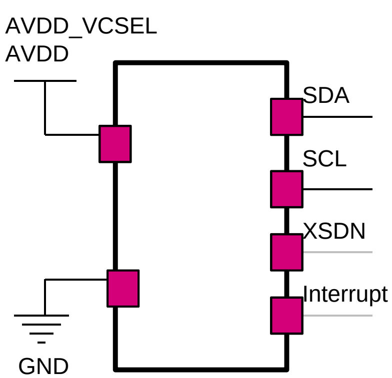
VL53L0X: Electrical/Mechanical

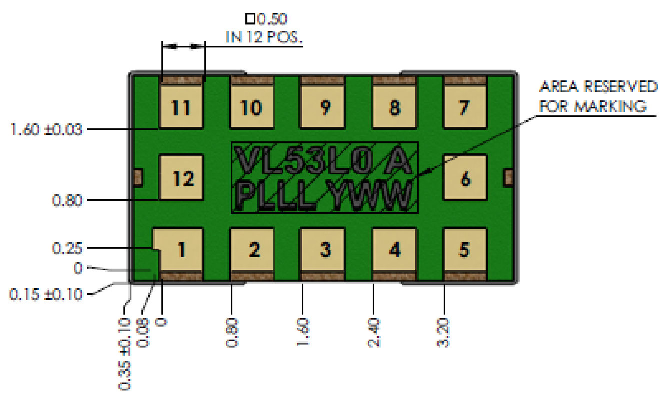












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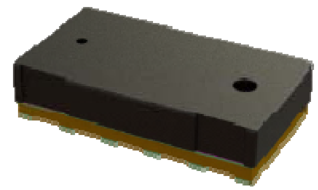

VL53L0X Development Tools and Technical Support

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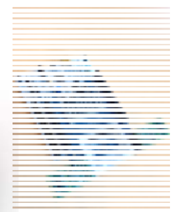
Let’s Start!

VL53L0X
module

Nucleo pack (EVK)



- Complete documentation and beginners guide
- API
- Samples available via distributors Worldwide
- Delivered with protective liner

- PC software interface (GUI) + stand-alone mode (4-digit display)
- Nucleo / Arduino™ compatible
- Available as stand-alone Expansion board, or Nucleo pack
- Source code examples and doc.
- Can accept up to two external VL53L0X satellites

More on **www.st.com/VL53L0X** for support and buy-on-line

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Hardware Description

- VL53L0X Evaluation tools are all based on the same hardware pack composed of
  - Nucleo F401RE board
  - X-NUCLEO-53L0A1 Nucleo Expansion board
  - Optional two VL53L0X satellites
  - Several gap spacers and cover glass

- Search for ***P-NUCLEO-53L0A1*** on st.com to order the pack and get documentation

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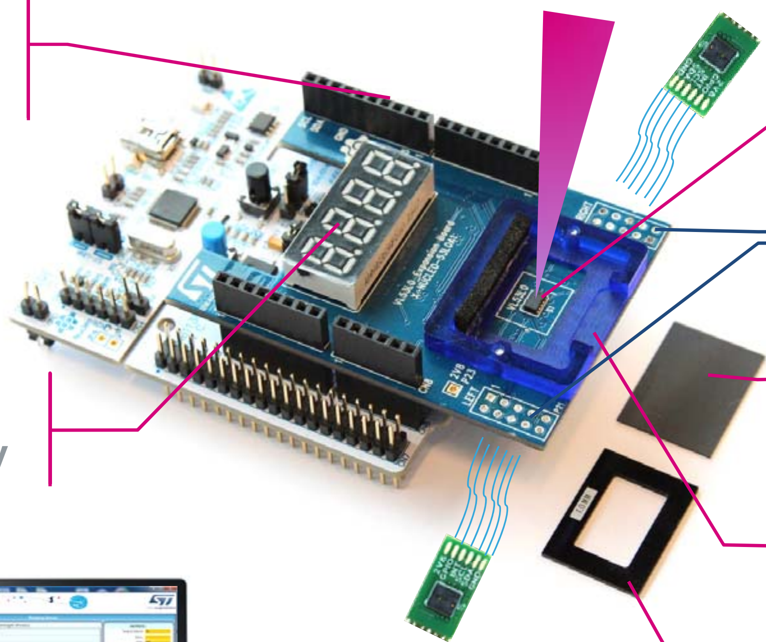
VL53L0X Nucleo pack

X-NUCLEO-53L0A1 works with STM32F401RE

Arduino
Connectors

Autonomous
4-digit display



VL53L0X
Ranging sensor

2 connections for external VL53L0X satellites

Cover Glass sample
(PMMA material. Low XTalk)

Cover Glass holder
(Can hold Cover Glass and spacers)

Spacers
3 spacers 0.25/0.5/1mm to create various air gaps below CG

PC GUI interface

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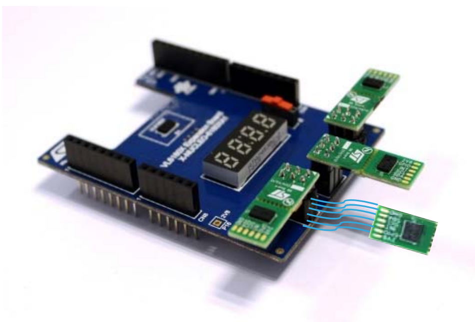
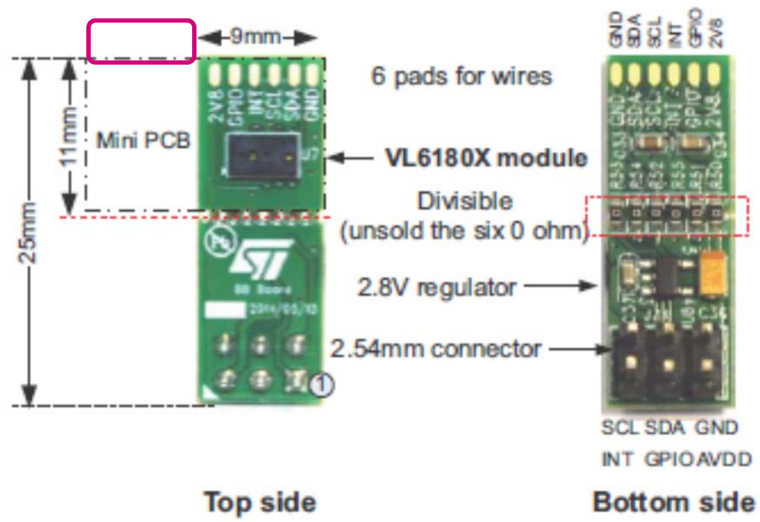
How to use ToF Satellites

- The ToF expansion board can accept “satellites”, through connectors, or flying wires



- For 2.8V supply application, the satellite board can be separated, in order to use only the “mini PCB”, easier to integrate into a customer device



Install STM32 IDE of Your Choice

- Pre-configured projects are available for
  - Keil : http://www.keil.com/
  - IAR : https://www.iar.com/
  - STM32 Workbench (Eclipse-based) : http://www.openstm32.org/HomePage

  - Lots of example code – just Google VL53L0X

ToF VL53L0: How to place orders?

Go to **www.st.com/VL53L0x**




Product	Order code
VL53L0 proximity sensor	VL53L0CXV0DH/1
Nucleo VL53L0X Expansion board	X-NUCLEO-53L0A1
Nucleo Pack: VL53L0X expansion board + STM32F410 “Full features” Nucleo board	P-NUCLEO-53L0X1
ToF VL53L0 satellite	53L0-SATEL-I2

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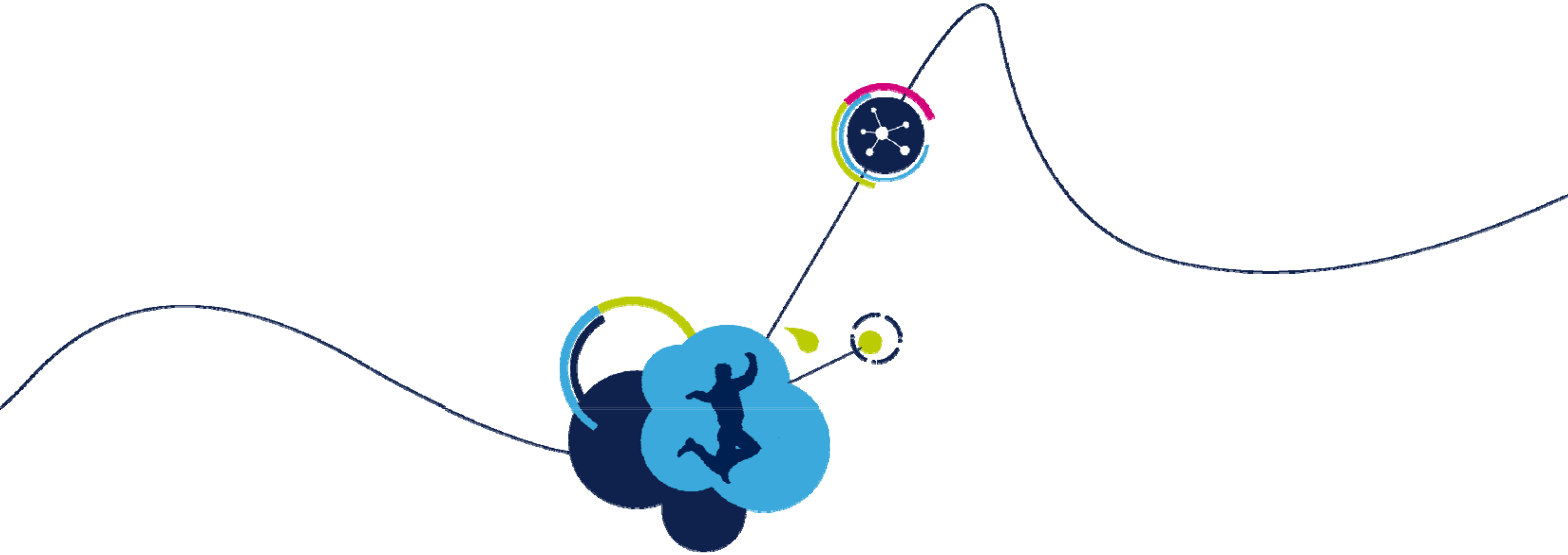
ToF VL6180: How to place orders?

Go to **www.st.com/VL6180X**

	Product	Order code
	VL6180x proximity sensor	VL6180XV0NR/1
	Nucleo VL6180X Expansion board (Gen2)	X-NUCLEO-6180XA1
	Nucleo Pack: VL6180X expansion board + STM32F410 “Full features” Nucleo board	P-NUCLEO-6180X1
	ToF VL6180 Satellites	VL6180X-SATEL



Thank You !

Back up

ToF vs other Proximity Sensing Technologies

	Capacitive	Ultra-Sonic	Conventional IR	ST FlightSense™
Size/Weight	Small/light	2xToF/Heavy	Small/Light	Small/Light
Mechanical integration	Complex (antenna)	Complex (large module)	Easy (if all-in-one)	**Easy (all in one, reflowable)**
Signal Amplitude	No	Yes	Yes	**Yes**
Real distance output	No Very un-precise	No (computed)	No (computed)	**Real distance in mm** (readable thru i²C)
Minimum distance	0cm	10cm	0cm	0cm
Maximum distance	Few cms	Up to 1.5m	20cm	up to **2 meters** (1)
Reliable (Vs objects color and reflectance)	No. May detect target in all directions around antenna	No, impacted	No, impacted	**Yes** even black (3%), gloves, …
Reliable (Vs material finish/roughness)	No. Sensitive to body or object charge	No. Isotropic, impacted by wide Sound	No. Angular dependency	**Yes**, with angular dependency
Gesture control Tap vs Swipe		Yes	No	**Yes**

(1) depends on conditions

Laser Consideration

- VCSEL has shorter rise time compare to LED (ps instead ns)
- VCSEL has smaller beam than LED (35° instead 120°)
- VCSEL needs less current for same efficiency
- VCSEL can detect 6x longer with half the power
- VCSEL spectrum 10x narrower