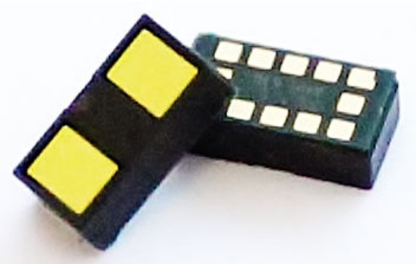
VL53L1

Datasheet

Time-of-Flight long-distance ranging sensor with advanced multizone and multiobject detection



Product status link
VL53L1

Features

Fully integrated miniature module

- 940 nm invisible laser VCSEL (vertical-cavity surface-emitting laser) emitter and its analog driver
- Receiving array with integrated lens
- Low power microcontroller running advanced digital firmware
- 4.9 x 2.5 x 1.56 mm

Fast, accurate distance ranging

- Up to 800 cm ranging
- A comprehensive application note (AN5573) providing detailed technical guidance
- 60 Hz ranging capability up to 300 cm
- Immunity to cover glass crosstalk and fingerprint smudge at long distances with patented dToF (direct Time-of-Flight) algorithms
- Multiobject detection capability
- Multizone scanning and selectable array (2x2, 3x3, 4x4, or defined by the user through software)

Eye safety

- Class 1 laser device compliant with latest standard IEC 60825-1:2014 - 3rd edition

Easy integration

- Keystone correction example code for projectors available with STSW-IMG047
- Single reflowable component
- Single power supply 2v8
- Works with many types of cover glass material
- I²C interface (up to 1 MHz)
- Xshutdown (reset) and interrupt GPIO (general-purpose input/output)
- Full set of software drivers (Linux® and Android compatible) for turnkey ranging

Application

- Laser assisted autofocus (AF): enhances the camera AF system speed and robustness, especially in difficult scenes (low light and low contrast). Ideal companion for PDAF sensors.
- Video focus tracking assistance at 60 Hz
- Scene understanding with multiobject detection: “choose the focus point”
- Dual camera stereoscopy and 3D depth assistance thanks to multizone measurements
- Presence detection (autonomous timed mode), typically to lock/unlock and power on/off devices like notebooks, tablets, or white goods

Description

The VL53L1 is a laser-ranging ToF sensor. It covers applications requiring long distance ranging up to 800 cm (ranging mode), multizone ranging (scanning mode), and low-power (autonomous mode). A comprehensive application note (AN5573) provides technical details on the programming interface including its bare driver. The API (application programming interface) enables the device to be controlled and managed in these three modes, to meet the requirements of all applications.

With patented algorithms and ingenious module construction, the VL53L1 is also able to detect different objects within the FoV (field of view). Its depth information (histogram) is at 60 Hz.

Scene browsing and multizone detection are now possible with the VL53L1, thanks to a software customizable detection array. This provides a quicker “touch-to-focus”, or minidepth map use cases.

1 Acronyms and abbreviations

Table 1. Acronym and abbreviations

Acronym/abbreviation	Definition
AMR	absolute maximum rating
API	application programming interface
ESD	electrostatic discharge
FoV	field of view
FW BOOT	firmware boot
HW STANDBY	hardware standby
I²C	inter-integrated circuit (serial bus)
MSB	most significant bit
NVM	nonvolatile memory
PCB	printed circuit board
PVT	power, voltage, and temperature
SCL	serial clock line
SDA	serial data line
SW STANDBY	software standby
SPAD	single photon avalanche diode
STG	storage
T	temperature
t	time
ToF	Time-of-Flight
VCSEL	vertical-cavity surface-emitting laser

2 Overview

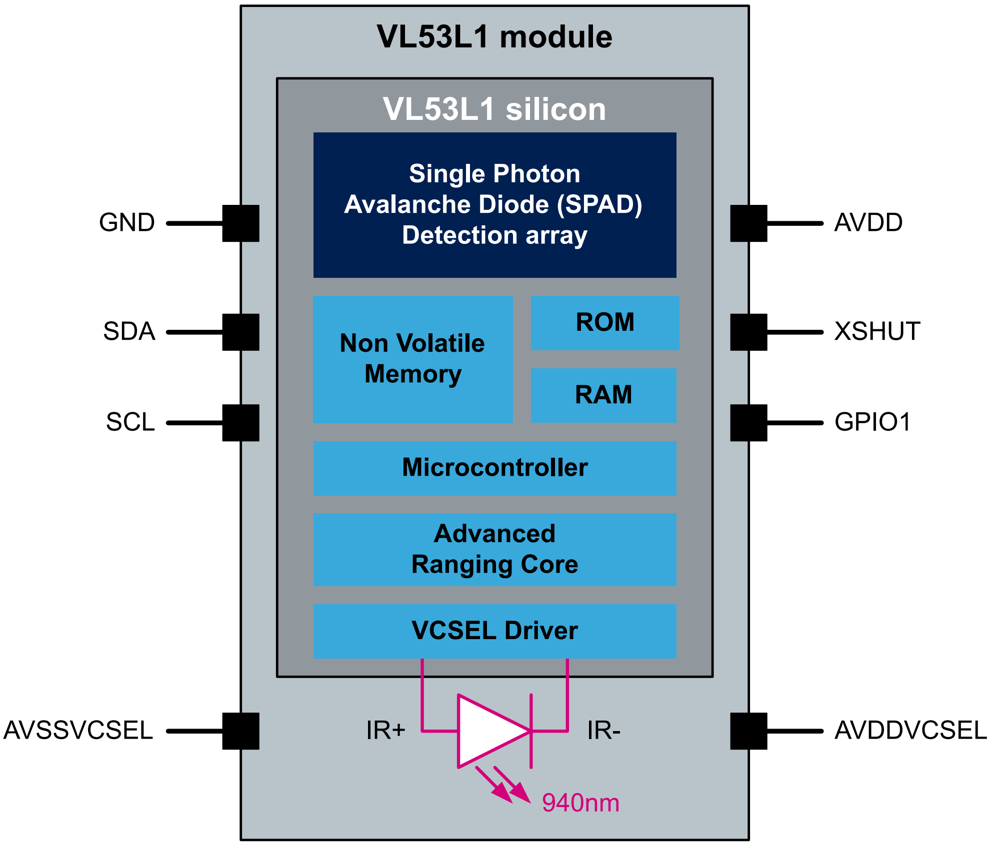
2.1 Technical specification

Table 2. **Technical specification**

Feature	Detail
Package	Optical LGA12
Size	4.4 x 2.5 x 1.56 mm
Operating voltage	2.6 to 3.5 V
Operating temperature	-20 to 85°C
Infrared emitter	940 nm
I²C	Up to 1 MHz (fast mode plus) serial bus Address: 0x52

2.2 System block diagram

Figure 1. **VL53L1 block diagram**



2.3 Device pinout

The following figure shows the pinout of the VL53L1 (see also Section 8: Outline drawings).

Figure 2. **VL53L1 pinout (bottom view)**

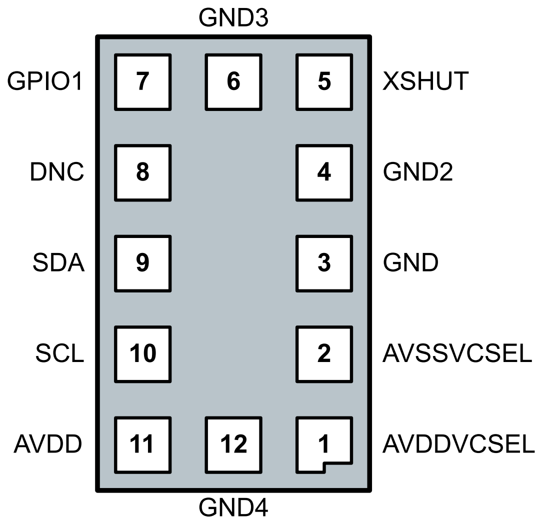


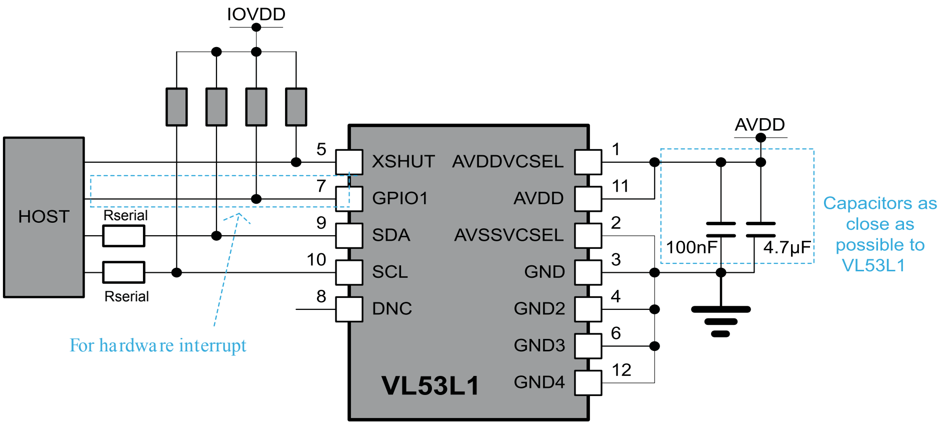
Table 3. **VL53L1 pin description**

Pin number	Signal name	Signal type	Signal description
1	AVDDVCSEL	Supply	VCSEL supply, connect to main supply
2	AVSSVCSEL	Ground	VCSEL ground, connect to main ground
3	GND		Connect to the main ground
4	GND2		
5	XSHUT	Digital input	Xshutdown pin, active low
6	GND3	Ground	Connect to the main ground
7	GPIO1	Digital output	Interrupt output. Open drain output
8	DNC	Digital input	Do not connect, must be left floating
9	SDA	Digital input/output	I²C serial data
10	SCL	Digital input	I²C serial clock input
11	AVDD	Supply	Supply, connect to the main supply
12	GND4	Ground	Connect to the main ground

2.4 Application schematic

The following figure shows the application schematic of the VL53L1.

Figure 3. VL53L1 schematic



Note: Place the capacitors on the external supply AVDD as close as possible to the AVDDVCSEL and AVSSVCSEL module pins.

Note: The external pull-up resistor values can be found in the I²C-bus specification. Pull-ups are typically fitted only once per bus, near the host. See Table 4. Suggested pull-up and series resistors for I²C fast mode and Table 5. Suggested pull-up and series resistors for I²C fast mode plus for suggested values.

Note: The XSHUT pin must always be driven to avoid leakage current. A pull-up is needed if the host state is not known. XSHUT is needed to use hardware standby mode (there is no I²C communication).

Note: The recommended value of the XSHUT and GPIO1 pull-ups is 10 kOhms.

Note: Leave the GPIO1 unconnected if not used.

Table 4 and Table 5 show recommended values for pull-up and series resistors for an AVDD of 1.8 V to 2.8 V in I²C fast mode (up to 400 kHz) and fast mode plus (up to 1 MHz).

Table 4. Suggested pull-up and series resistors for I²C fast mode

I²C load capacitance (C_L) (1)	Pull-up resistor (Ohms)	Series resistor (Ohms)
$C_L \leq$ 90 pF	3.6 k	0
90 pF < $C_L \leq$ 140 pF	2.4 k	0
140 pF < $C_L \leq$ 270 pF	1.2 k	0
270 pF < $C_L \leq$ 400 pF	0.8 k	0

1. *For each bus line, C_L is measured in the application PCB by the customer.*

Table 5. Suggested pull-up and series resistors for I²C fast mode plus

I²C load capacitance (C_L) (1)	Pull-up resistor (Ohms)	Series resistor (Ohms)
$C_L \leq$ 90 pF	1.5 k	100
90 pF < $C_L \leq$ 140 pF	1 k	50
140 pF < $C_L \leq$ 270 pF	0.5 k	50
270 pF < $C_L \leq$ 400 pF	0.3 k	50

1. *For each bus line, C_L is measured in the application PCB by the customer.*

3 Functional description

3.1 System functional description

Figure 4. VL53L1 system functional description shows the system level functional description. The host customer application controls the VL53L1 device using an API (application programming interface). The API implementation is delivered to the customer as a driver (Bare C code, or Linux/Android driver).

The driver shares with the customer application a set of high level functions that allow control of the VL53L1 firmware. Functions include initialization, ranging start/stop, setting the system accuracy, and choice of ranging mode.

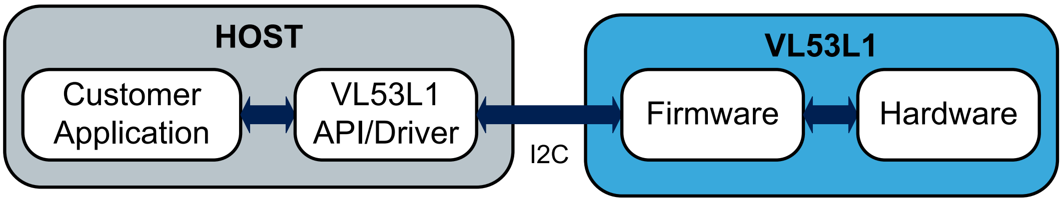
The driver is a turnkey solution consisting of a set of “C” functions that enables fast development of end user applications without the complication of direct multiple register access. The driver is structured in a way that it can be compiled on any kind of platform through a well abstracted platform layer. The driver package allows the user to take full advantage of the VL53L1 capabilities.

A detailed description of the driver is available in the VL53L1 driver user manual(UM2133).

The VL53L1 firmware fully manages the hardware register accesses.

Section 3.2: Firmware state machine description details the firmware state machine.

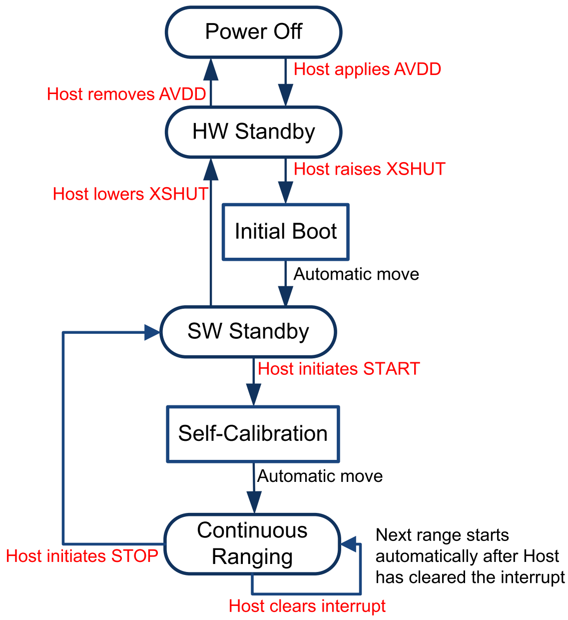
Figure 4. VL53L1 system functional description



3.2 Firmware state machine description

The following figure shows the device state machine.

Figure 5. Firmware state machine



3.3 Customer manufacturing calibration flow

The detailed procedure is provided in the VL53L1 driver user manual (UM2133).

3.4 Device programming and control

The VL53L1 physical control interface is the I^2C, with is described in Section 4: Control interface.

A software layer (driver) is provided to control the device. This avoids complex I^2C register operations with turnkey functions to start, stop, and read the ranging values.

The driver structure and functions are described in the VL53L1 driver user manual (UM2133).

3.5 Description of operating “preset” modes

The VL53L1 software driver proposes four turnkey operating modes (called “preset”) to allow fast and easy ranging in all customer applications:

- Ranging mode
- Multizone scanning mode
- Lite ranging mode
- Autonomous mode

Ranging mode is the default (recommended) configuration to the get the best of the VL53L1 functionalities.

- Ranging mode is natively immune to cover glass crosstalk and smudge beyond 80 cm. With patented dToF algorithms, temporal filtering is possible to distinguish crosstalk from an object signal over long distances > 80 cm. Best-in-the-class ranging performances of 300 cm+ with the cover glass in place are now possible. They can be reached with any computation unlike other sensors on the market.
- Ranging mode can detect several objects concurrently within the FoV. Up to four ranges can be output simultaneously by the software driver, to indicate objects range. Check the latest software driver manual for further details.
- Ranging mode is compatible with the ROI (region of interest) selection. The user may chose a custom FoV by software, from 4x4 SPADs (minimum size) up to 16x16 SPADs (full FoV). This gives full flexibility to support “touch-to-focus” or custom ranging.
- Ranging operation is performed by default at 60 Hz once the driver function is called (typical ranging operation lasts 16 ms). It includes internal housekeeping, ranging, and postprocessing.

Multizone scanning mode provides ranging results of all the selected ROIs sequentially. The ROIs include quadrant (four zones), nine zones, 16 zones, or custom numbers of zones and location. In each ROI, the VL53L1 system can also detect multiple objects, and the software driver returns a ranging quality level and signal, in addition to the distance in millimeters.

Lite ranging mode is recommended to minimize postprocessing with a low-performance host (microcontroller or low frequency CPU).

Autonomous mode triggers ranging interrupts under certain conditions. The user can set distance thresholds, signal thresholds, and a timing interval between two consecutive ranging operations.

Note: *Ranging, multizone scanning, and lite ranging modes require a handshake between the host and the VL53L1, at each ranging operation. This handshake is mandatory to ensure the right result is read by the host to continue the ranging operation.*

Refer to Section 3.10: Handshake management for further details.

3.6 Digital processing and reading the results

The digital processing is the final operation of the ranging sequence that computes, validates, or rejects a ranging measurement. Part of this processing is performed by the VL53L1 internal firmware. It is completed on the host processor running the software driver.

At the end of the digital processing, the ranging distance is computed by the VL53L1 itself. If the distance cannot be measured (no target or weak signal), a corresponding status error code is generated and can be read by the host.

3.7 Reading the results

The VL53L1 software driver provides turnkey functions to read the following output results after the measurement:

- Signal rate
- Ranging distance per object detected
- Min. and max. distances where object is located
- Dmax and range quality level

A full description is provided in the VL53L1 driver user manual (UM2133).

3.8 Power sequence

Two options are available for device power-up/boot.

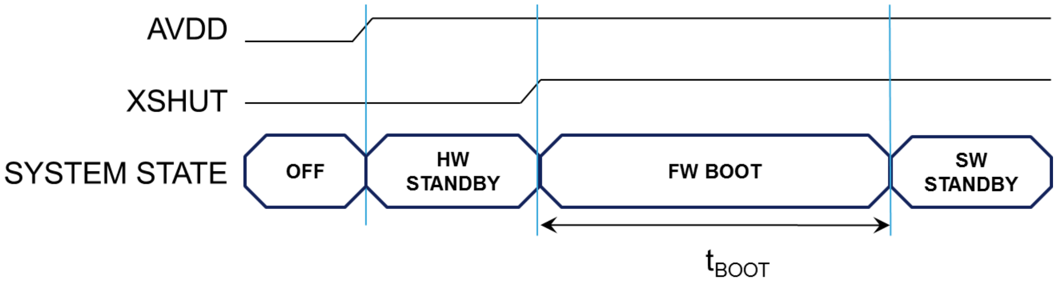
Option 1

The XSHUT pin is connected and controlled from the host.

This option optimizes power consumption. The device can be completely powered off when not used, and then woken up through the host GPIO (using the XSHUT pin).

Hardware standby mode is the period when the AVDD is present and the XSHUT is low.

Figure 6. Power-up and boot sequence



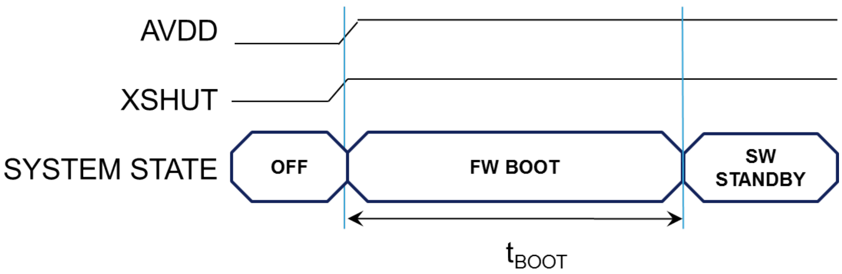
Note: t_{BOOT} is 1.2 ms maximum.

Option 2

The host does not control the XSHUT pin. This pin is tied to AVDD through a pull-up resistor.

When the XSHUT pin is not controlled, the power-up sequence is as shown in the following figure. In this case, the device goes automatically to software standby after a firmware boot, without entering hardware standby.

Figure 7. Power-up and boot sequence with XSHUT not controlled

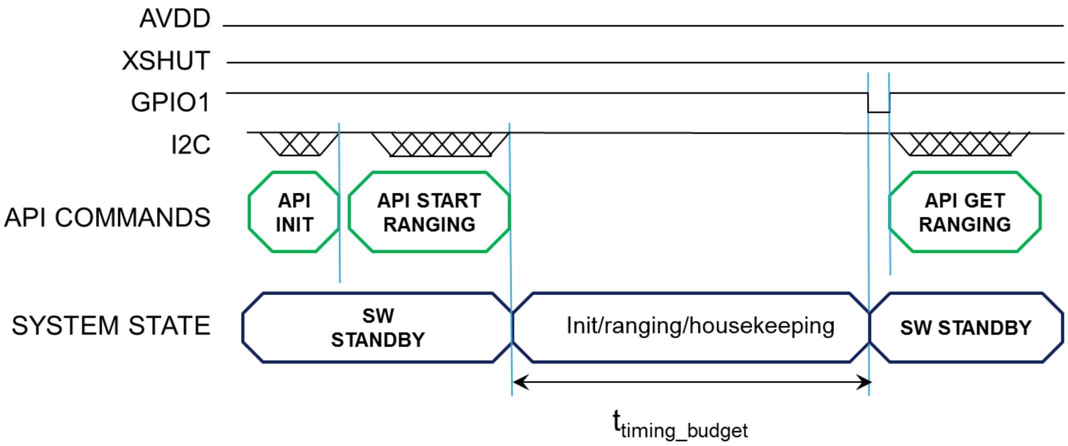


Note: t_{BOOT} is 1.2 ms maximum.

Note: In all cases, XSHUT has to be raised only when AVDD is tied on.

3.9 Ranging sequence

Figure 8. Ranging sequence



Note: The t_{timing_budget} is a parameter set by the user, using a dedicated driver function.

3.10 Handshake management

For all ranging modes described above, every time a ranging measurement is available, an interrupt is generated. The GPIO1 pin of the VL53L1 is then driven high. Once the host reads the result, the interrupt is cleared and the ranging sequence can repeat. If the interrupt is not cleared, the ranging operation of the VL53L1 is on hold. It allows a good synchronization between the VL53L1 and the host, avoids loosing results in case of delay on the I^2C bus, and is mandatory for multizone scanning operations.

It is strongly recommended to use the hardware interrupt pin to manage this handshake. But if not possible a software polling mode remains available.

For more details, refer to the VL53L1 user manual (UM2133).

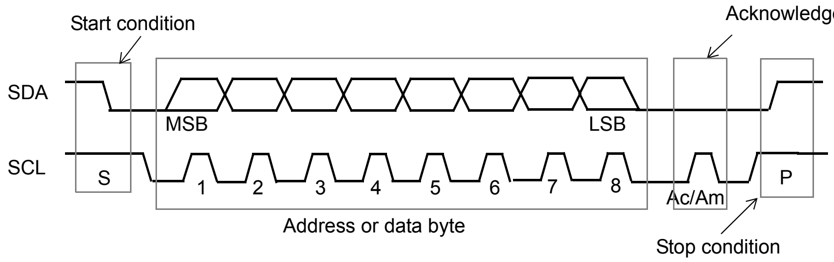
4 Control interface

This section specifies the control interface. The I²C interface uses two signals: serial data line (SDA) and serial clock line (SCL). Each device connected to the bus uses a unique address and a simple controller/target relationship exists.

Both SDA and SCL lines are connected to a positive supply voltage using pull-up resistors located on the host. Lines are only actively driven low. A high condition occurs when lines are floating and the pull-up resistors pull lines up. When no data are transmitted both lines are high.

Clock signal generation is performed by the controller device. The controller device initiates data transfer. The I²C bus on the VL53L1 has a maximum speed of 1 Mbits/s and uses a default device address of 0x52.

Figure 9. Data transfer protocol



Information is packed in 8-bit packets (bytes) and is always followed by an acknowledge bit, Ac for the VL53L1 acknowledge and Am for the controller acknowledge (host bus controller). The internal data are produced by sampling SDA at a rising edge of SCL. The external data must be stable during the high period of SCL. The exceptions to this are start (S) or stop (P) conditions when SDA falls or rises respectively, while SCL is high.

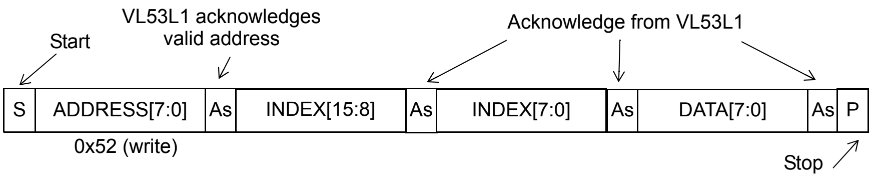
A message contains a series of bytes preceded by a start condition, and followed by either a stop or repeated start (another start condition but without a preceding stop condition), followed by another message. The first byte contains the device address (0x52) and also specifies the data direction. If the least significant bit is low (that is, 0x52) the message is a controller write-to-the-target. If the LSB is set (that is, 0x53) then the message is a controller read-from-the-target.

Figure 10. I²C device address: 0x52

MSBit							LSBit
0	1	0	1	0	0	1	R/W

All serial interface communications with the ToF sensor must begin with a start condition. The VL53L1 module acknowledges the receipt of a valid address by driving the SDA wire low. The state of the read/write bit (LSB of the address byte) is stored and the next byte of data, sampled from SDA, can be interpreted. During a write sequence, the second byte received provides a 16-bit index, which points to one of the internal 8-bit registers.

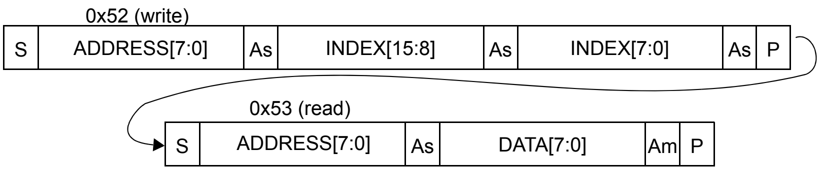
Figure 11. Data format (write)



As data are received by the target, they are written bit by bit to a serial/parallel register. After each data byte has been received by the target, an acknowledge is generated, the data are then stored in the internal register addressed by the current index.

During a read message, the contents of the register addressed by the current index is read out in the byte following the device address byte. The contents of this register are parallel loaded into the serial/parallel register and clocked out of the device by the falling edge of SCL.

Figure 12. Data format (read)



At the end of each byte, in both read and write message sequences, an acknowledge is issued by the receiving device (that is, the VL53L1 for a write, and the host for a read).

A message can only be terminated by the bus controller, either by issuing a stop condition or by a negative acknowledge (that is, not pulling the SDA line low) after reading a complete byte during a read operation.

The interface also supports auto increment indexing. After the first data byte has been transferred, the index is automatically incremented by 1. The controller can therefore send data bytes continuously to the target until the target fails to provide an acknowledge, or the controller terminates the write communication with a stop condition. If the auto increment feature is used, the controller does not have to send address indexes to accompany the data bytes.

Figure 13. Data format (sequential write)

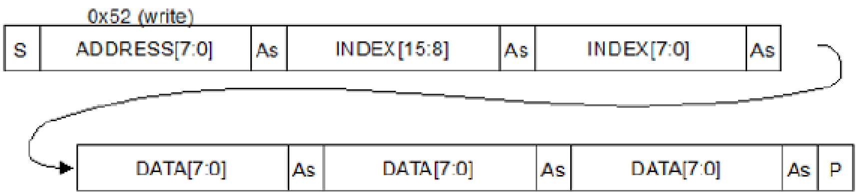
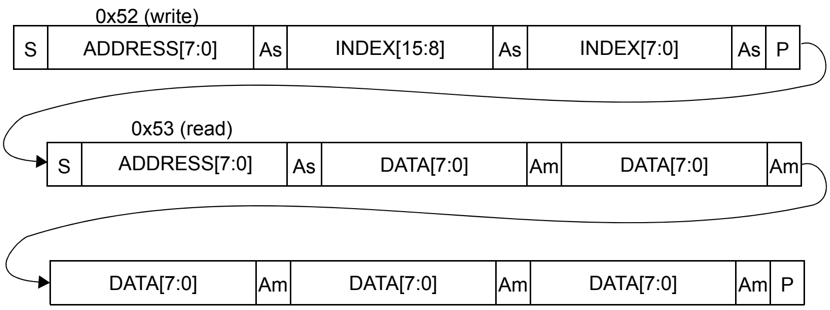


Figure 14. **Data format (sequential read)**



4.1 I²C interface - timing characteristics

Timing characteristics are shown in the following tables. Refer to Figure 15. I²C timing characteristics for an explanation of the parameters used.

Timings are given for all PVT conditions.

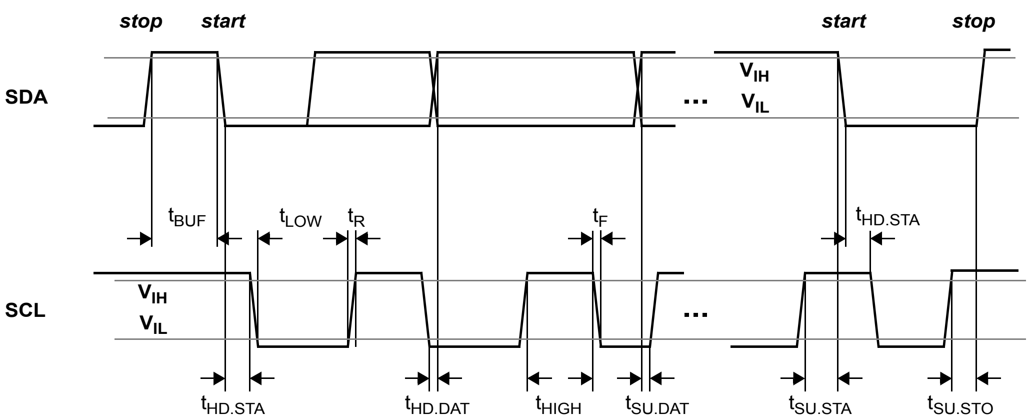
Table 6. **I²C interface - timing characteristics for fast mode plus (1 MHz)**

Symbol	Parameter	Minimum	Typical	Maximum	Unit
F_{I2C}	Operating frequency	0	—	1000	kHz
t_{LOW}	Clock pulse width low	0.5	—	—	µs
t_{HIGH}	Clock pulse width high	0.26	—	—	
t_{SP}	Pulse width of spikes that are suppressed by the input filter	—	—	50	ns
t_{BUF}	Bus free time between transmissions	0.5	—	—	µs
$t_{HD.STA}$	Start hold time	0.26	—	—	µs
$t_{SU.STA}$	Start setup time	0.26	—	—	
$t_{HD.DAT}$	Data in hold time	0	—	0.9	
$t_{SU.DAT}$	Data in setup time	50	—	—	ns
t_R	SCL/SDA rise time	—	—	120	
t_F	SCL/SDA fall time	—	—	120	
$t_{SU.STO}$	Stop setup time	0.26	—	—	µs
Ci/o	Input/output capacitance (SDA)	—	—	10	pF
Cin	Input capacitance (SCL)	—	—	4	
C_L	Load capacitance	—	140	550	

Table 7. I²C interface - timing characteristics for fast mode (400 kHz)

Symbol	Parameter	Minimum	Typical	Maximum	Unit
F_{I2C}	Operating frequency	0	—	400	kHz
t_{LOW}	Clock pulse width low	1.3	—	—	µs
t_{HIGH}	Clock pulse width high	0.6	—	—	
t_{SP}	Pulse width of spikes that are suppressed by the input filter	—	—	50	ns
t_{BUF}	Bus free time between transmissions	1.3	—	—	µs
$t_{HD.STA}$	Start hold time	0.26	—	—	µs
$t_{SU.STA}$	Start setup time	0.26	—	—	
$t_{HD.DAT}$	Data in hold time	0	—	0.9	
$t_{SU.DAT}$	Data in setup time	50	—	—	ns
t_R	SCL/SDA rise time	—	—	300	
t_F	SCL/SDA fall time	—	—	300	
$t_{SU.STO}$	Stop setup time	0.6	—	—	µs
Ci/o	Input/output capacitance (SDA)	—	—	10	pF
Cin	Input capacitance (SCL)	—	—	4	
C_L	Load capacitance	—	125	400	

Figure 15. I²C timing characteristics



All timings are measured from either V_{IL} or V_{IH}.

4.2 I²C interface - reference registers

The registers shown in the table below can be used to validate the user I²C interface.

Table 8. Reference registers

Address	After fresh reset, without the API loaded
0xC0	0xEE
0xC1	0xAA
0xC2	0x10
0X51	0x0099
0x61	0x0000

Note: The I²C read/writes can be 8, 16, or 32-bit. Multibyte read/writes are always addressed in ascending order with the MSB first as shown in the following table.

Table 9. 32-bit register example

Register address	Byte
Address	MSB
Address + 1	...
Address + 2	...
Address + 3	LSB

5 Thermal characteristics

5.1 Absolute maximum rating (TSTG)

Warning: *Stresses above those listed in the following table may cause permanent damage to the device. These are stress ratings only. Functional operation of the device is not implied at these or any other conditions above those indicated in the operational sections of the specification. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

The storage temperature (T_{STG}) is the ambient temperature at which the device can be stored with no voltage applied.

Table 10. Absolute maximum rating conditions

Parameter	Min.	Max.	Unit
Storage temperature (T_{STG})	-40	125	°C

5.2 Ambient operating temperature

The ambient operating temperature is the temperature at which the device may be powered and can operate without any damage.

Table 11. Recommended operating temperature

Parameter	Min.	Max.	Unit
Ambient operating temperature	-20	85	°C

6 Electrical characteristics

6.1 Absolute maximum ratings

Warning: *Stresses above those listed in the following table may cause permanent damage to the device. These are stress ratings only. Functional operation of the device is not implied at these or any other conditions above those indicated in the operational sections of the specification. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

Table 12. Absolute maximum ratings

Parameter	Min.	Typ.	Max.	Unit
AVDD	-0.5	—	3.6	V
SCL, SDA, XSHUT, and GPIO1				

6.2 Recommended operating conditions

Table 13. Recommended operating conditions

There are no power supply sequencing requirements. The I/Os may be high, low, or floating when AVDD is applied. The I/Os are internally failsafe with no diode connecting them to AVDD.

Parameter		Min.	Typ.	Max.	Unit
Voltage (AVDD)		2.6	2.8	3.5	V
IO (IOVDD) (1)	Standard mode	1.6	1.8	1.9	
	2V8 mode (2) (3)	2.6	2.8	3.5	

1. *XSHUT should be high only when AVDD is on.*
2. *SDA, SCL, XSHUT, and GPIO1 high levels have to be equal to AVDD in 2V8 mode.*
3. *The default driver mode is 1V8. 2V8 mode is programmable using the device settings loaded by the driver. For more details, refer to the VL53L1 driver user manual (UM2133).*

6.3 Electrostatic discharge

The VL53L1 is compliant with the ESD values presented in the following table.

Table 14. ESD performances

Parameter	Specification	Conditions
Human body model	JS-001-2012	± 2 kV, 1500 ohms, 100 pF
Charged device model	JESD22-C101	± 500 V

6.4 Current consumption

Table 15. Power consumption at ambient temperature

All current consumption values include silicon process variations. Temperature and voltage are nominal conditions (23°C and 2.8 V).

<table>
<tr><th>Parameter</th><th>Min.</th><th>Typ.</th><th>Max.</th><th>Unit</th></tr>
<tr><td>HW STANDBY</td><td>3</td><td>5</td><td>7</td><td rowspan="3">µA</td></tr>
<tr><td>SW STANDBY (2V8 mode) (1)</td><td>4</td><td>6</td><td>9</td></tr>
<tr><td>Timed ranging intermeasurement</td><td>—</td><td>20</td><td>—</td></tr>
<tr><td>Active ranging average consumption (including VCSEL) (2) (3)</td><td>—</td><td>16</td><td>18</td><td>mA</td></tr>
<tr><td>Average power consumption at 10 Hz with 33 ms ranging sequence</td><td>—</td><td>—</td><td>20</td><td>mW</td></tr>
</table>

1. *In standard mode (1V8), pull-ups have to be modified. Then the SW STANDBY consumption is increased by 0.6 µA.*
2. *Active ranging is an average value, measured using the default driver settings: Ranging mode with the default settings at a 16 ms timing budget.*
3. *Peak current (including VCSEL) can reach 40 mA.*

6.5 Digital input and output

Table 16. Digital I/O electrical characteristics

<table>
<tr><th>Symbol</th><th>Parameter</th><th>Min.</th><th>Typ.</th><th>Max.</th><th>Unit</th></tr>
<tr><td colspan="6">Interrupt pin (GPIO1)</td></tr>
<tr><td>V_{IL}</td><td>Low level input voltage</td><td>—</td><td rowspan="5">—</td><td>0.3 IOVDD</td><td rowspan="4">V</td></tr>
<tr><td>V_{IH}</td><td>High level input voltage</td><td>0.7 IOVDD</td><td>—</td></tr>
<tr><td>V_{OL}</td><td>Low level output voltage (I_{OUT} = 4 mA)</td><td>—</td><td>0.4</td></tr>
<tr><td>V_{OH}</td><td>High level output voltage (I_{OUT} = 4 mA)</td><td>IOVDD-0.4</td><td>—</td></tr>
<tr><td>F_{GPIO}</td><td>Operating frequency (C_{LOAD} = 20 pF)</td><td>0</td><td>108</td><td>MHz</td></tr>
<tr><td colspan="6">I²C interface (SDA/SCL)</td></tr>
<tr><td>V_{IL}</td><td>Low level input voltage</td><td>-0.5</td><td rowspan="5">—</td><td>0.6</td><td rowspan="3">V</td></tr>
<tr><td>V_{IH}</td><td>High level input voltage</td><td>1.12</td><td>3.5</td></tr>
<tr><td>V_{OL}</td><td>Low level output voltage (I_{OUT} = 4 mA)</td><td>—</td><td>0.4</td></tr>
<tr><td rowspan="2">$I_{IL/IH}$</td><td>Leakage current (1)</td><td>—</td><td>10</td><td rowspan="2">µA</td></tr>
<tr><td>Leakage current (2)</td><td>—</td><td>0.15</td></tr>
</table>

1. *AVDD = 0 V*
2. *AVDD = 2.85 V, and I/O voltage = 1.8 V*

7 Ranging performance

7.1 Measurement conditions

In all the measurement tables of this document, it is considered that:

1. The full FoV is covered (typically at 27°). Alternatively, a partial FoV is covered after a specific ROI definition by the user. The array size of the partial FoV is from 4x4 SPADs to 16x16 SPADs.
2. The charts used as targets are:
   - Gray with a reflectance of 17% and a Munsell of N4.74.
   - White with a reflectance of 88% and a Munsell of N9.5.
3. The nominal voltage is 2.8 V and the temperature is 23°C.
4. Unless mentioned, the device is controlled through the driver using the default settings. Refer to the user manual for driver setting descriptions.
5. The detection rate is considered as 94%.
6. Indoor (no IR) means that there is no light contribution in the band 940 nm ± 30 nm. Outdoor overcast conditions mean an illumination level of 0.7 W/m² back on the sensor, in the band 940 nm ± 30 nm.
7. No cover glass is present.
8. A gain correction is available in the driver. The performance assumes that an average gain correction has been applied.

7.2 Minimum ranging distance

The minimum ranging distance ensured is 4 cm. This is valid for all modes: Ranging, scanning, lite, and autonomous.

7.3 Ranging and scanning modes: Multiobject detection

Thanks to the direct Time-of-Flight principle and ST patents, the VL53L1 is able to detect up to four objects in a FoV.

The typical depth separation between objects has to be at least 80 cm.

7.4 Ranging and scanning modes: Full FoV performance

Table 17. Ranging accuracy shows the performance with a full FoV (gray and white targets), a 16 ms timing budget, and the default software driver settings.

Table 17. Ranging accuracy

Applicable to ranging and scanning modes		Dark or indoor (no infrared)			Outdoor overcast		
Target color	**Performances full FoV**	**Min.**	**Typ.**	**Max.**	**Min.**	**Typ.**	**Max.**
White target	Maximum distance detection	320 cm	320 cm	—	70 cm	90 cm	—
	Accuracy	—	—	1%	—	—	8.5%
	Ranging offset	—	—	±25 mm	—	—	±25 mm
Gray target	Maximum distance detection	180 cm	230 cm	—	70 cm	90 cm	—
	Accuracy	—	—	2.5%	—	—	8.5%
	Ranging offset	—	—	±25 mm	—	—	±25 mm

Note: It is assumed that an offset calibration is performed.

7.5 Range and scanning modes: Partial FoV performance

7.5.1 Optical center definition

The sensing array optical center specification considers the part-to-part variation in production.

The Xo, Yo coordinates define the optical center.

The optical center is measured for each part during a factory test at STMicroelectronics. The coordinates are stored in the VL53L1 nonvolatile memory and are readable by the customer through a software driver in the application. This helps optimize application design, and the alignment between the camera module and ranging performance of the application.

The green array in Figure 16. Optical center specification gives the possible location of the optical center. See also Table 18. Optical center specification.

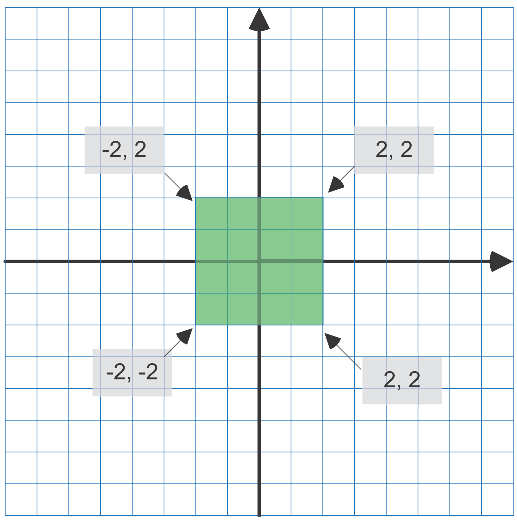
The user can define their own priorities. Example:

- Priority FoV: Full matrix 16x16 active and a maximum ranging distance on the corners, which may be smaller than in the center.
- Priority distance: Cropped matrix around the optical center. Refer to Table 19. Ranging and scanning modes: Performance with a partial FoV, which shows how to get the target performance.

Table 18. Optical center specification

Parameter	Min.	Typ.	Max.	Unit
Xo offset	-2	0	2	SPAD
Yo offset	-2	0	2	

Figure 16. Optical center specification



7.5.2 Partial FoV performance

Table 19. Ranging and scanning modes: Performance with a partial FoV shows the performance with a partial FoV (gray and white targets), a 16 ms timing budget per zone, and the default software driver settings.

Table 19. Ranging and scanning modes: Performance with a partial FoV

Applicable to ranging and scanning modes		8x8 SPAD ROI array		4x4 SPAD ROI array	
		In corner	Centered	In corner	Centered
Target color	ROI center location	Max. 4 SPADs from optical center	ROI center = optical center	Max. 6 SPADs from optical center	ROI center = optical center
White target	Maximum distance detection	Typ. = 250 cm Min. = 190 cm	Typ. = 250 cm Min. = 250 cm	Typ. = 110 cm Min. = 50 cm	Typ. = 170 cm Min. =150 cm
	Accuracy	2%	2%	2%	2%
	Ranging offset	±25 mm	±25 mm	±25 mm	±25 mm
Gray target	Maximum distance detection	Typ. =125 cm Min. = 70 cm	Typ. = 155 cm Min. = 100 cm	Typ. = 50 cm Min. = 20 cm	Typ. = 90 cm Min. = 50 cm
	Accuracy	5%	5%	5%	5%
	Ranging offset	±25 mm	±25 mm	±25 mm	±25 mm

Note: *It is assumed that an ROI offset calibration is performed.*

Note: *The above performance table is specified after optical centering of the VL53L1 defined in the user manual. The optical center of the VL53L1 is stored in the VL53L1 NVM and can be read by the user through the software driver.*

7.6 Lite mode performance

Performance for lite mode, as defined in the software driver, is provided in Table 20. Lite mode: Performance with a full FoV.

Table 20. Lite mode: Performance with a full FoV

Applicable to lite mode with default settings		Dark or indoor (no infrared)		
		15 Hz (default, recommended)		
Target color	Performance	Min.	Typ.	Max.
White target	Maximum distance detection	330 cm	410 cm	—
	Accuracy	—	—	2.5%
	Ranging offset	—	—	±25 mm
Gray target	Maximum distance detection	130 cm	170 cm	—
	Accuracy	—	—	2.5%
	Ranging offset	—	—	±25 mm

7.7 Autonomous mode performance

Performance for autonomous mode, as defined in the software driver, is provided in Table 21. Autonomous mode: Performance with a full FoV.

Table 21. Autonomous mode: Performance with a full FoV

Applicable to autonomous mode with default settings		Dark or indoor (no infrared)		
Target color	Performance	76 ms timing budget		
		Min.	Typ.	Max.
White target	Maximum distance detection	—	280 cm	—
	Accuracy		—	1.5%
	Ranging offset		—	±25 mm
Gray target	Maximum distance detection		180 cm	—
	Accuracy		—	2.5%
	Ranging offset		—	±25 mm

Note: The accuracy of the ranging thresholds programmed by user in autonomous mode are compliant with the values described the above table.

8 Outline drawings

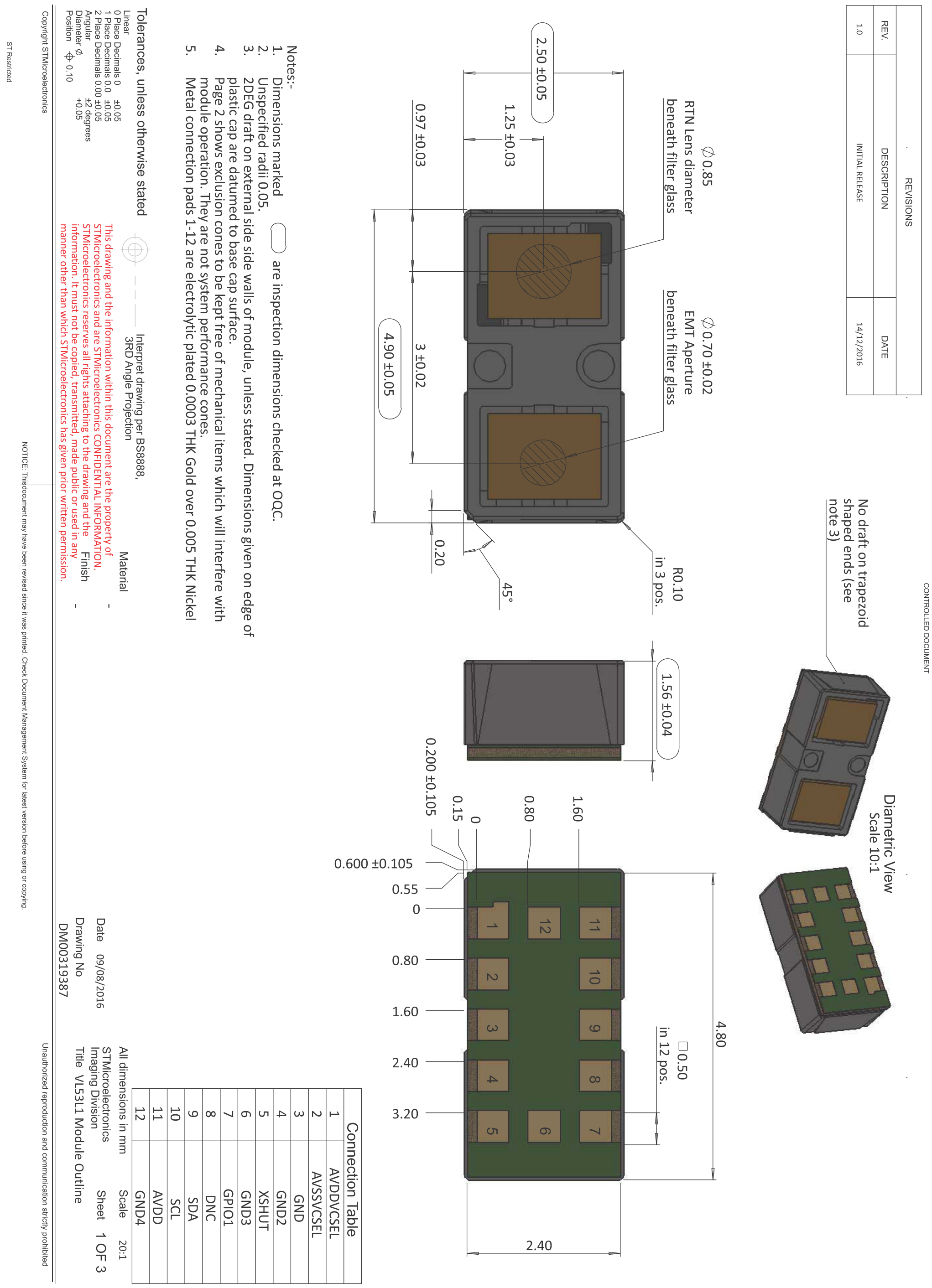


Figure 17. Outline drawing (1/3)

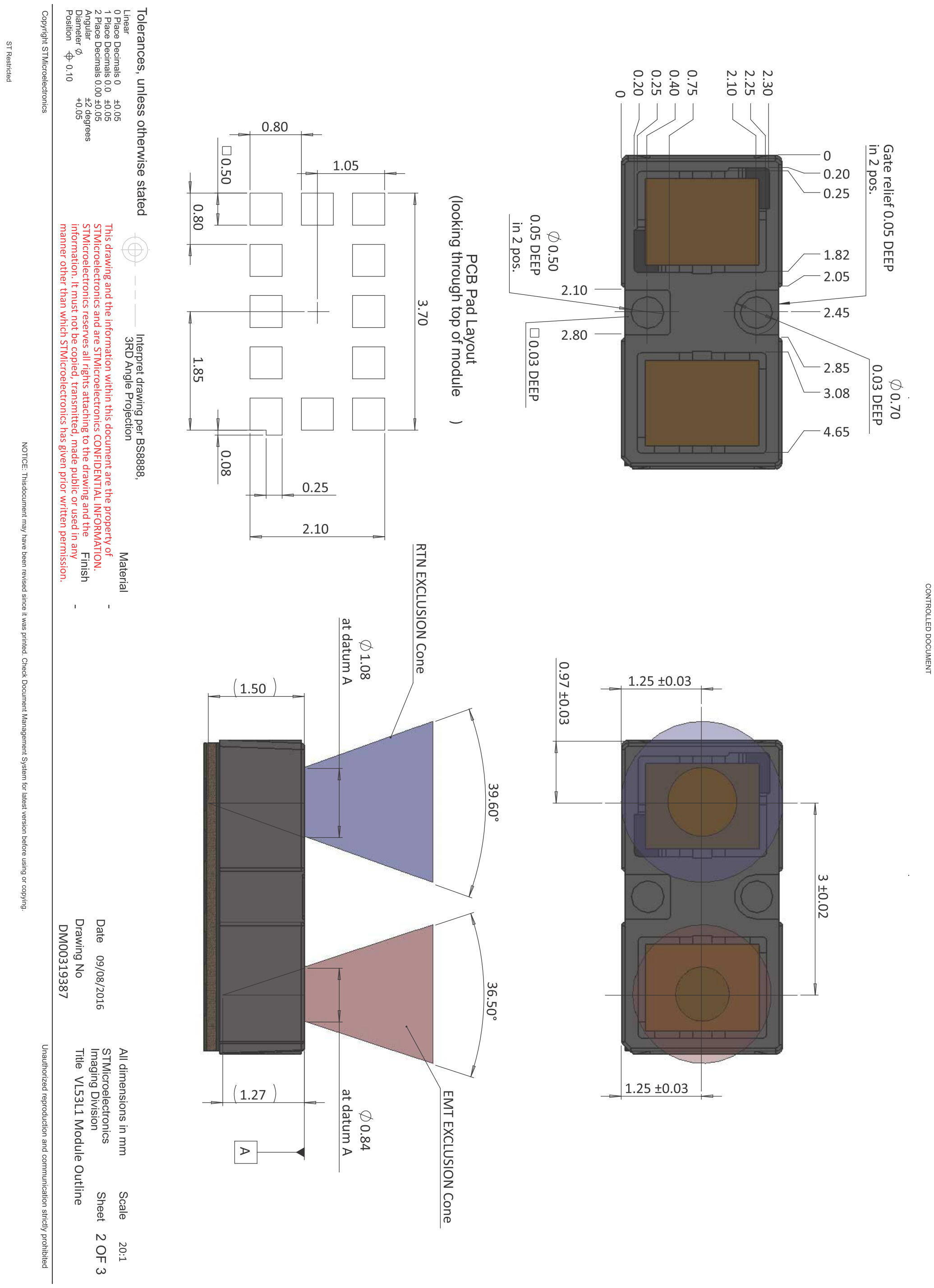
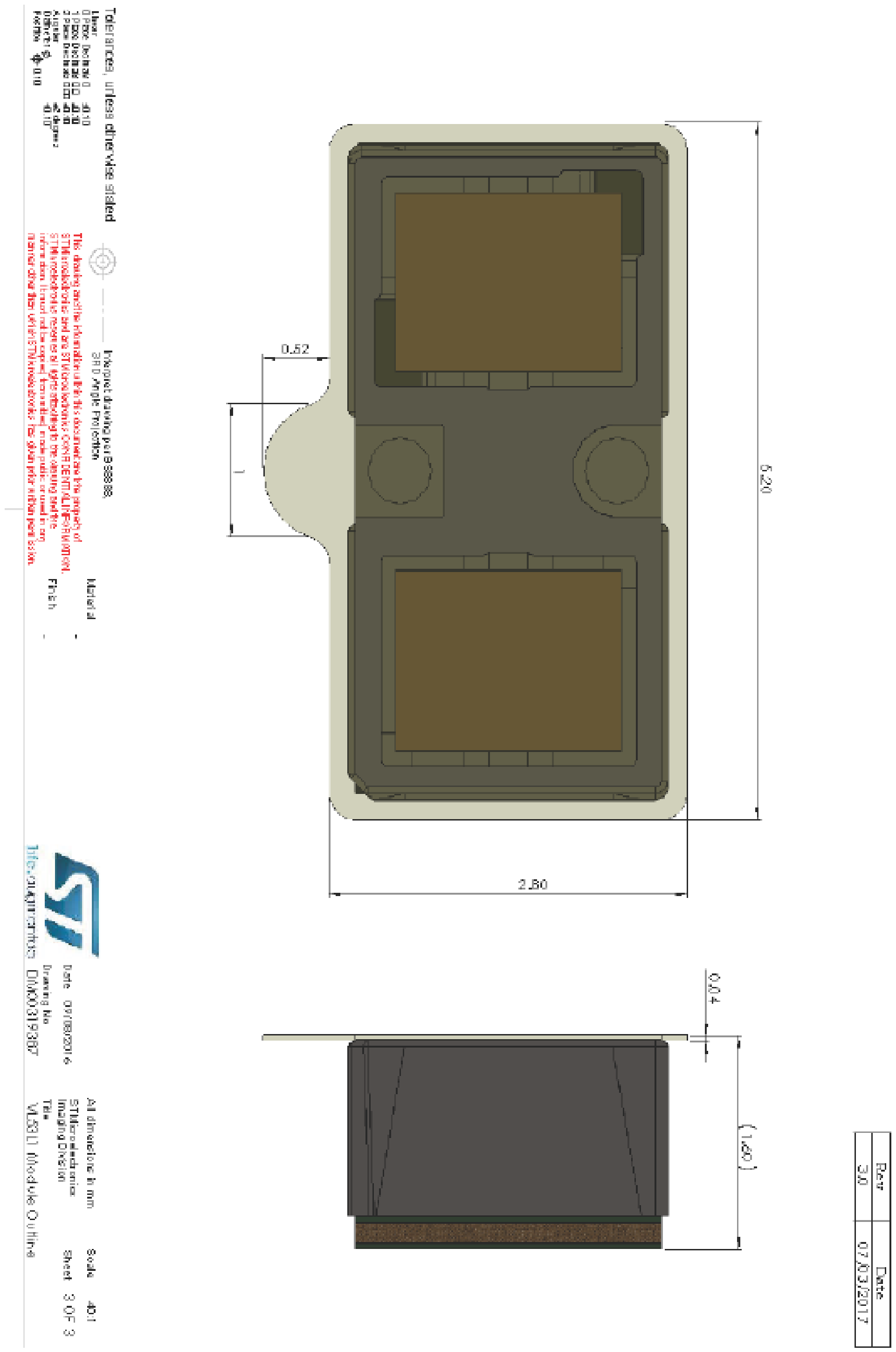


Figure 18. **Outline drawing (2/3)**

Figure 19. Outline drawing (3/3)



Caution: The VL53L1 module is delivered with a protective liner covering the top of the cap to protect the sensor from foreign material during the assembly process. It must be removed by the customer just before mounting the cover glass.

9 Laser safety

This product contains a laser emitter and corresponding drive circuitry. The laser output is designed to meet Class 1 laser safety limits under all reasonably foreseeable conditions including single faults in compliance with IEC 60825-1:2014.

Do not increase the laser output power by any means. Do not use any optics to focus the laser beam.

Caution: Use of controls or adjustments, or performance of procedures other than those specified herein may result in hazardous radiation exposure.

Figure 20. Class 1 laser label

This product complies with:

- IEC 60825-1:2014
- 21 CFR 1040.10 and 1040.11, except for conformance with IEC 60825-1:2014 as described in the laser notice number 56, dated May 8, 2019.
- EN 60825-1:2014 including EN 60825-1:2014/A11:2021
- EN 50689:2021, however STMicroelectronics does not guarantee compliance with the requirement of clause 5 from EN50689 regarding child appealing products. If designing a child appealing product, contact STMicroelectronics' technical application support.

10 Packing and labeling

10.1 Product marking

A two line product marking is applied on the backside of the module (on the substrate). The first line is the silicon product code, and the second line, the internal tracking code.

10.2 Inner box labeling

The labeling follows the STMicroelectronics' standard packing acceptance specification.

The following information is on the inner box label:

- Assembly site
- Sales type
- Quantity
- Trace code
- Marking
- Bulk ID number

10.3 Packing

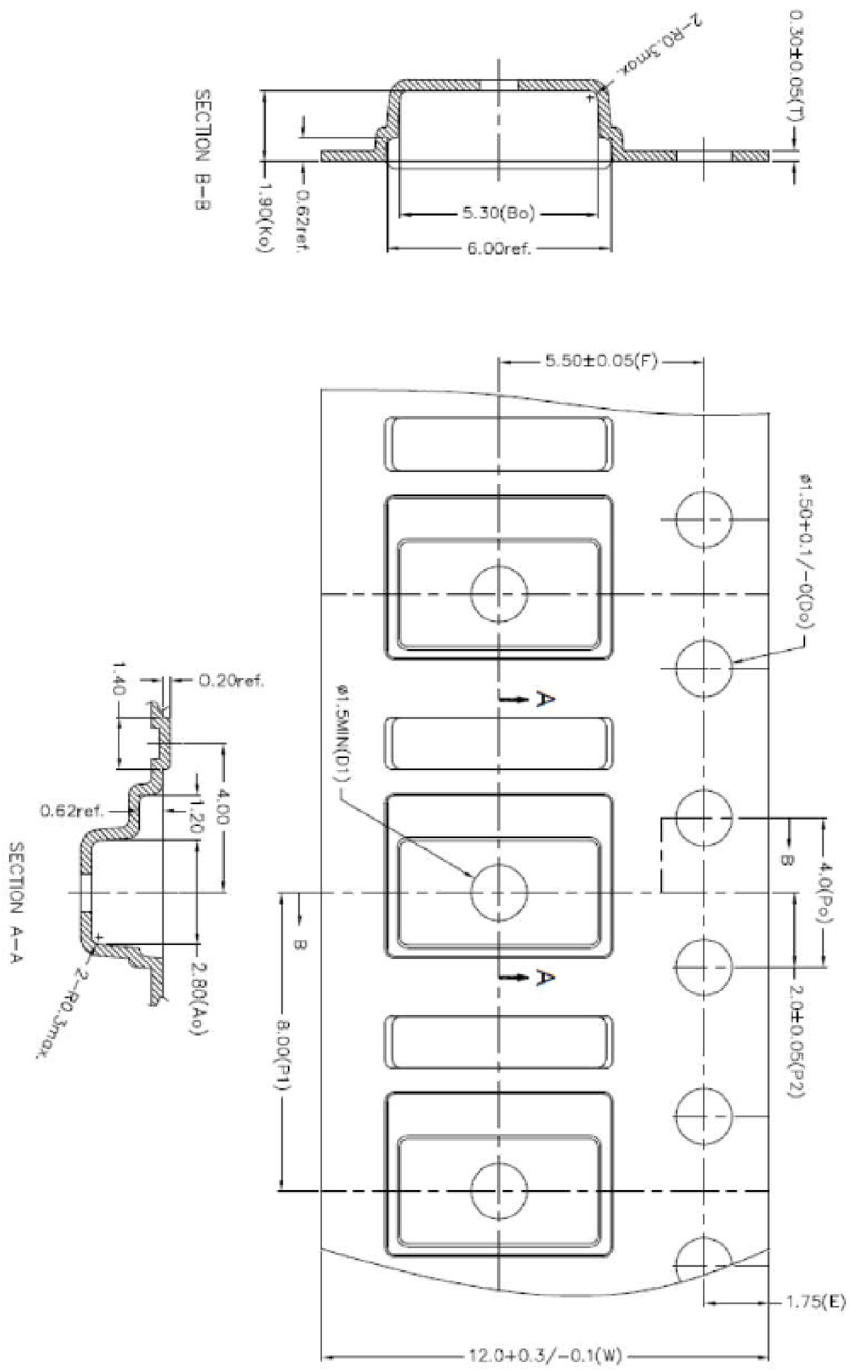
At the customer/subcontractor level, it is recommended to mount the device in a clean environment to avoid foreign material deposition.

To help avoid any foreign material contamination at product assembly level the modules are shipped in a tape and reel format with a protective liner, starting from production version (cut1.1).

The packing is vacuum-sealed and includes a desiccant.

10.4 Tape outline drawing

Figure 21. Tape outline drawing



11 Handling, moisture, and reflow precautions

11.1 Shock precaution

Sensor modules house numerous internal components that are susceptible to shock damage. If a unit is subject to excessive shock, it must be rejected even if no apparent damage is visible. For example, if it is dropped on the floor, or if a tray/reel of units is dropped on the floor.

11.2 Part handling

Handling must be done with nonmarring, ESD, safe carbon, plastic, or Teflon™ tweezers. Ranging modules are susceptible to damage or contamination. The customer is advised to use a clean assembly process after removing the tape from the parts, and until a protective cover glass is mounted.

11.3 Compression force

A maximum compressive load of 25 N should be applied on the module.

11.4 Moisture sensitivity level

Moisture sensitivity is level 3 (MSL) as described in JEDEC JSTD-020-C.

For devices that are classified to the levels defined in JEDEC JSTD-020-C, JEDEC JSTD-033-C provides:

- Manufacturers and users with standardized methods for handling, packing, and shipping.
- Standardized methods for using moisture/reflow and process sensitive devices.

11.5 Pb-free solder reflow process

Table 22. Recommended solder profile and Figure 22. Solder profile show the recommended and maximum values for the solder profile.

Customers have to tune the reflow profile depending on the PCB, solder paste, and material used. We expect customers to follow the recommended reflow profile, which is specifically tuned for the VL53L1 package.

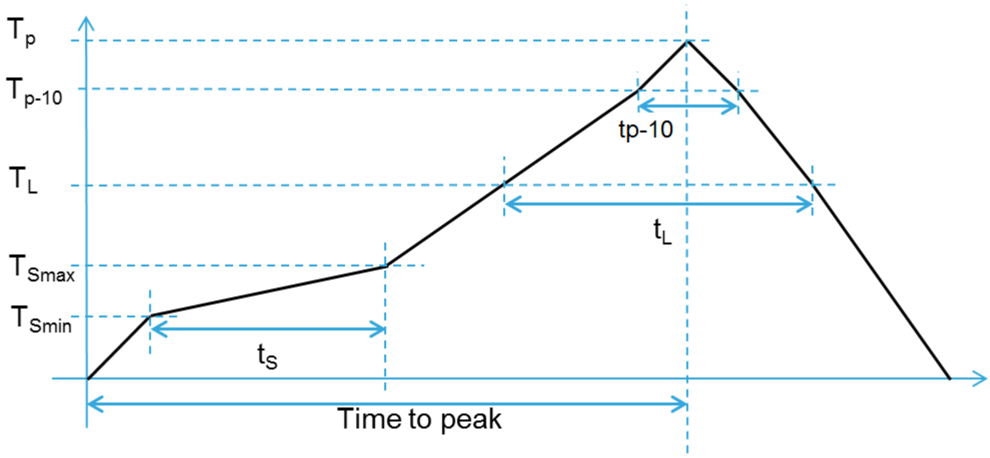
If a customer must perform a reflow profile, which is different from the recommended one, the new profile must be qualified by the customer at their own risk. This is especially true for peaks >240°C. In any case, the profile must be within the “maximum” profile limit described in JEDEC JSTD-020-C and in Table 22. Recommended solder profile.

Note: Temperatures mentioned in the table below are measured at the top of the VL53L1 package.

Table 22. Recommended solder profile

Parameters	Recommended	Maximum	Unit
Minimum temperature (T_S min)	130	150	°C
Maximum temperature (T_S max)	200	200	
Time t_s (T_S min to T_S max)	90-110	60-120	s
Temperature (T_L)	217	217	°C
Time (t_L)	55-65	55-65	s
Ramp up	2	3	°C/s
Temperature (T_{p-10})	—	250	°C
Time (t_{p-10})		10	s
Ramp up		3	°C/s
Peak temperature (Tp)	240	245	°C
Time to peak	300	300	s
Ramp down (peak to T_L)	-4	-6	°C/s

Figure 22. Solder profile



Note: The component should be limited to a maximum of three passes through this solder profile.

Note: As the VL53L1 package is not sealed, only a dry reflow process should be used (such as convection reflow). Vapor phase reflow is not suitable for this type of optical component.

Note: The VL53L1 is an optical component and should be treated carefully. This would typically include using a ‘no-wash’ assembly process.

12 Package information

In order to meet environmental requirements, ST offers these devices in different grades of ECOPACK packages, depending on their level of environmental compliance. ECOPACK specifications, grade definitions and product status are available at: www.st.com. ECOPACK is an ST trademark.

13 Ordering information

Table 23. Order codes

Order codes	Package	Packing	Minimum order quantity
VL53L1CBV0FY/1	Optical LGA12 with liner	Tape and reel	3600 pcs

Revision history

Table 24. Document revision history

Date	Version	Changes
29-Nov-2022	13	Updated Figure 17. Outline drawing (1/3), Figure 18. Outline drawing (2/3), and Figure 19. Outline drawing (3/3). Updated Section 10.4: Tape outline drawing. Added a note at the end of Section 11.5: Pb-free solder reflow process.
25-Apr-2024	14	Updated Features and Description sections. Updated maximum value of V_{IH} in Section 6.5: Digital input and output. Updated Section 9: Laser safety.
09-Aug-2024	15	Features section: Added "eye safety". Updated master/slave to controller/target. Added Section 5: Thermal characteristics, including a maximum AMR of 125°C. Table 13. Recommended operating conditions: Removed ambient temperature data. Updated Section 10: Packing and labeling. Added Section 11: Handling, moisture, and reflow precautions.

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