LIÈGE université

Hawkseye

Time of flight distance sensor

Based on the VL53L0X from STMicroelectronics

Datasheet - Rev. B

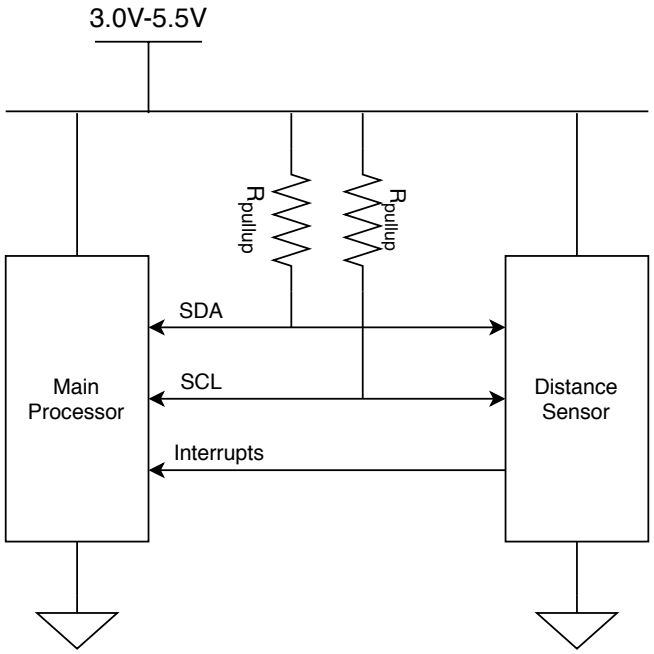
1 Introduction

This fully open-source sensor is a time-of-flight based distance sensor based on two VL53L0X from STMicroelectronics. It is aimed at providing accurate distance measurements at a high sampling rate which can go up to 50Hz. It is also largely configurable and offers an external interrupt functionality. It accepts a wide input voltage range and will adapt the I^2C voltages and interrupt signal to the input power.

1.1 Features

- Fully open-source. Adapt it to your needs
- Input voltage from 3.0V to 5.5V
- Low power consumption
- Distance sensing from 0 to 150 cm
- I^2C communication bus
- Programmable I^2C address
- External interrupts functionality
- DIP switches for boot configuration
- Embedded calibration routines

1.2 Typical application



2 Layout

2.1 Front

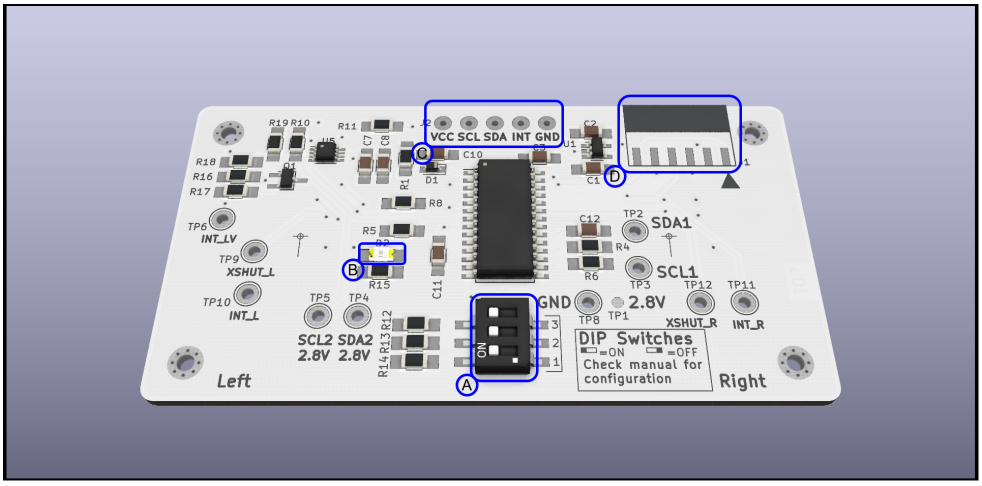


Figure 1: Annotated picture of the front of the sensor

A Boot configuration DIP Switches.

B LED indicator

C Main connector (Power, I^2C , Interrupts)

D ICSP connector to program the PIC controller

Note: *On PCB V1.0 the* `XSHUT` *and* `INT` *test points labels have been swapped for the right and left sensors.*

2.2 Back

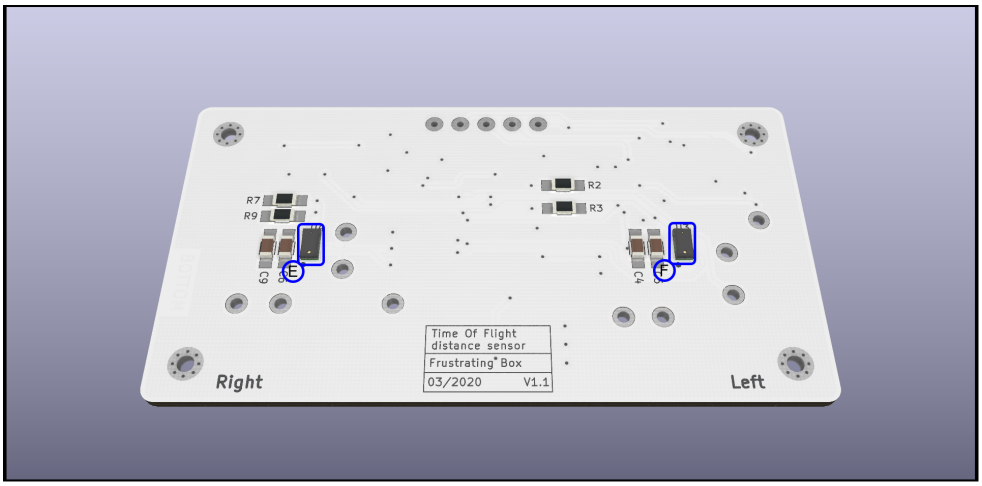


Figure 2: Annotated picture of the back of the sensor

E Right sensor

F Left sensor

3 Interfacing With the Sensor

The sensor contains two interfaces. One for using the sensor and one for programming the sensor.

3.1 Main interface

The main interface is used for powering the sensor, communication (I^2C) and interrupts.

Power (Pins `VCC` and `GND`)
Sensor can be powered from any source ranging from 3.0V to 5.5V connected to `VCC`. Connect `GND` to ground.

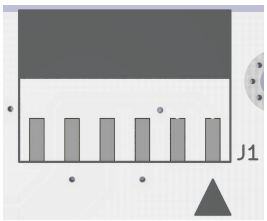
I^2C (Pins `SCL` and `SDA`)
I^2C port. Connect sensor `SCL` to master `SCL` and sensor `SDA` to master `SDA`.
Compatibility : [1] [2]

- standard mode (100kbit/s)
- fast mode (400kbit/s)

Interrupts (Pin `INT`)
Interrupts output. Pin is driven low when an interrupt is triggered and reset to high when a data register is read.

Note: *On PCB V1.0 interrupts only works if the sensor is powered with 3.0V-3.3V.*

3.2 Programming interface



That is the `ICSP` header used to reprogram the PIC firmware.

Note: *On PCB V1.0 the connector is not keyed. VPP is connected to the pin on the right of the picture.*

Note: *On PCB V1.0 the `VCC` pin is directly connected to the internal power rail of the sensor. Components on the board are rated to 3.3V and will not tolerate more. Caution must be used when reprogramming the board to not apply more than 3.3V. Advice is to configure the programmer so that it does not power the sensor. Provide the required power via the main interface `J2`.*

4 Registers

Description of the I^2C registers.

4.1 Configuration Registers

4.1.1 `CONFIG_L`: Configuration register (low part)

CONFIG_L (0x00)							
BIT 7	BIT 6	BIT 5	BIT 4	BIT 3	BIT 2	BIT 1	BIT 0
L_EN	R_EN	XTALK	AUTO_INC	CONT_MODE	CONV	CONV_FINISHED	unused

Description of the content of the register:

`L_EN` **Readable / Writeable / Initialize at 1**
Set this bit to 1 to enable the left sensor.
Set this bit to 0 to disable the left sensor.

R_EN **Readable / Writeable / Initialize at 1**

Set this bit to 1 to enable the right sensor.
Set this bit to 0 to disable the right sensor.

XTALK **Readable / Writeable / Initialize at 0**

Set this bit to 1 to enable crosstalk compensation on both sensors.
Set this bit to 0 to disable crosstalk compensation on both sensors.
More information on crosstalk can be found in the VL53L0X API manual. [3]

AUTO_INC **Readable / Writeable / Initialize at 0**

Set this bit to 1 to enable I^2C auto incrementation of the registers.
Set this bit to 0 to disable I^2C auto incrementation of the registers.
Auto incrementation of the registers will automatically increment the internal register pointer after a read or a write. The pointer will cycle through the configuration registers if it was initially pointing to a configuration register (and go back to the first config register if it reached the last config register). The pointer will cycle through the data registers if it was initially pointing to a data register (and go back to the first data register if reached the last data register).

CONT_MODE **Readable / Writeable / Initialize at 0**

Set this bit to 1 to enable continuous measurement mode.
Set this bit to 0 to disable continuous measurement mode.
Continuous measurement mode will start a new measurement as soon as the last measurement is over. It will also raise the interrupt after each measurement (depending on the interrupt setting) if the interrupt was reset.

CONV **Readable / Writeable / Hardware clearable / Initialize at 0**

Set this bit to 1 to start a measurement or start continuous measurement.
Set this bit to 0 to stop continuous measurement. If CONT_MODE is disabled the sensor will automatically clear this bit once the measurement is over.

CONF_FINISHED **Read-only / Hardware settable / Hardware clearable / Initialize at 0**

Hardware set to 1 once the conversion is over.
Hardware set to 0 after an I^2C read of a data register.

4.1.2 CONFIG_H: Configuration register (high part)

CONFIG_H (0x01)							
BIT 7	BIT 6	BIT 5	BIT 4	BIT 3	BIT 2	BIT 1	BIT 0
INT_MODE		DURATION					

Description of the content of the register:

INT_MODE **Readable / Writeable / Initialize at 0b00**

00 No interrupts. Interrupts are disabled.

01 Full Interrupt. Generates an interrupt everytime a sensor gets a new measurement.

10 Half Interrupt. Generates an interrupt once all enabled sensors got a new measurement.
Note : *If only one sensor is enabled the behavior is equivalent to 0b01.*

11 Unused.

DURATION **Readable / Writeable / Initialize at 0b000011**
Controls the time budget allocated to each sensor for it's measurement. The final value is

$$\texttt{DURATION} * 3 + 20 \ [ms]$$

4.1.3 ADDRESS: I²C Slave Address

ADDRESS (0x02)							
BIT 7	BIT 6	BIT 5	BIT 4	BIT 3	BIT 2	BIT 1	BIT 0
ADDRESS							

Description of the content of the register:

ADDRESS **Readable / Writeable / Initialize at 0x42**
I²C Address of the device

Note: *If you change the I²C address of the sensor while in backup address mode the change will only be effective at the next boot in normal I²C address mode.*

4.2 Data Registers

All the data registers contains the distance sensed by the two VL53L0X chips. The data are formatted on one byte, unsigned integer representing the distance in centimeters. All these sensors are read-only.

Right (0x10) Distance measured by the right sensor.

Left (0x11) Distance measured by the left sensor.

Min (0x12) Minimum distance measured by the sensors.

Max (0x13) Maximal distance measured by the sensors.

AVG (0x14) Average distance measured by the sensors.

5 Boot Configuration and Calibration Routines

3 boot configuration switches are available on the board to select the boot mode of the sensor.

5.1 Boot Modes

The first switch controls the main operation mode. Either RUN mode or CAL mode.

In RUN mode the second switch control the LED behaviour.
The third switch control the I²C address.

In CAL mode the second and third switches control the calibration to perform. The led always displays the status.

All the boot modes available are shown in table 1.

5.2 Calibration routines

When booting in calibration mode the status LED will blink a few times (0.5s ON, 0.5s OFF) indicating the calibration routine performed. The LED will then be kept lit until the calibration is over. The LED will then be kept lit off and the sensor can then be safely powered off. For detailed informations on the calibration requirements check the chapter 2 of the VL53L0X API User Manual [3].

5.2.1 SPAD Calibration

Status LED blinks 2 times. Optimize the dynamics of the system. It lasts for approximately

10ms. Nothing special is required to perform this calibration. It must be performed with the protective glass cover if you use one.

5.2.2 Offset Calibration

Status LED blinks 3 times. Corrects the mean offset of the measurement compared to the real distance. It lasts for approximately 300ms. To perform this calibration you must place a white target (if possible 88% reflectance) at precisely 10 cm in front of the sensor in a dark environment. It must be performed with the protective glass cover if you use one.

5.2.3 Crosstalk Calibration

Status LED blinks 4 times. If using a protective window in front of the sensor a sometimes significant fraction of the emitted signal goes back to the sensor after having been reflected by the protective window instead of the target. This leads to false measurements with a non-linear behaviour. This calibration routine tries to correct those errors and lasts approximately 1sec. To perform this calibration you must place a grey (17% reflectance) target 50 cm in front of the target. This should be able to correct the crosstalk due to a good quality window. If the window you use produces too much crosstalk this might not suffice to correct the error and you might have to edit the crosstalk calibration parameters in the firmware (`config.h`).

5.2.4 Reset

Status LED blinks 5 times. All the calibration parameters will be reset to default.

Switch 1	Switch 2	Switch 3	Behaviour
OFF	OFF	OFF	RUN mode. Status led is always OFF. I^2C address is the programmed address (default to 0x42).
OFF	OFF	ON	RUN mode. Status led is always OFF. I^2C address is the backup address (0x44).
OFF	ON	OFF	RUN mode. Status led displays status and errors. I^2C address is the programmed address (default to 0x42).
OFF	ON	ON	RUN mode. Status led displays status and errors. I^2C address is the backup address (0x44).
ON	OFF	OFF	CAL mode. SPADs calibration routine.
ON	OFF	ON	CAL mode. Offset calibration routine.
ON	ON	OFF	CAL mode. Crosstalk calibration routine.
ON	ON	ON	CAL mode. Resets the calibration parameters to the default parameters factory programmed in the VL53L0X chips.

Table 1: The different boot modes available.

6 Measurement modes

Depending on the configuration of the `CONFIG_H`(Section 4.1.2) the sensor will be in one of 3 possible measurement modes.

Standard mode This is the default configuration and is enabled for a time budget allocated of 29ms (included) up to 50ms (excluded). That is

$$3 \leq \texttt{DURATION} < 20$$

. The measurement range can go up to 120cm in correct conditions with a reasonable error on the measurement.

Fast mode This mode is enabled when the time budget allocated is between 20ms and 29ms. That is

$$0 \leq \texttt{DURATION} < 3$$

. The measurement range is reduced and the error on the measurement is increased.

Long Range mode This mode is enabled for a time budget allocated from 50ms and up. That is

$$50 \leq \texttt{DURATION} \leq 63$$

. The measurement range is increased and can go up to 200cm in dark environments. The error will increase with the measured distance.

7 Error codes

In RUN mode if the LED is not forced off (see section 5.1) the sensor might indicate an error code by blinking the status LED a few times. This should normally not happen during normal operation and is mainly used for debug purposes. The error codes are displayed in table 2.

Number of blinks	Reason
1	Sensor related error during the main execution loop.
2	Sensor related error while configuring the sensor. (RUN mode only)
3	Could not perform device initialization.
4	Could not load device specific settings.
5	In SPAD calibration mode: could not perform SPAD calibration. In reset mod: could not get SPAD calibration data. Otherwise: could load SPAD calibration data.
6	Could not perform reference calibration.
7	In offset calibration mode: could not perform offset calibration. In reset mod: could not get offset calibration data. Otherwise: could not load offset calibration data.
8	In crosstalk calibration mode: could not perform crosstalk calibration. In reset mod: could not get crosstalk calibration data. Otherwise: could not load crosstalk calibration data.

Table 2: List of error codes

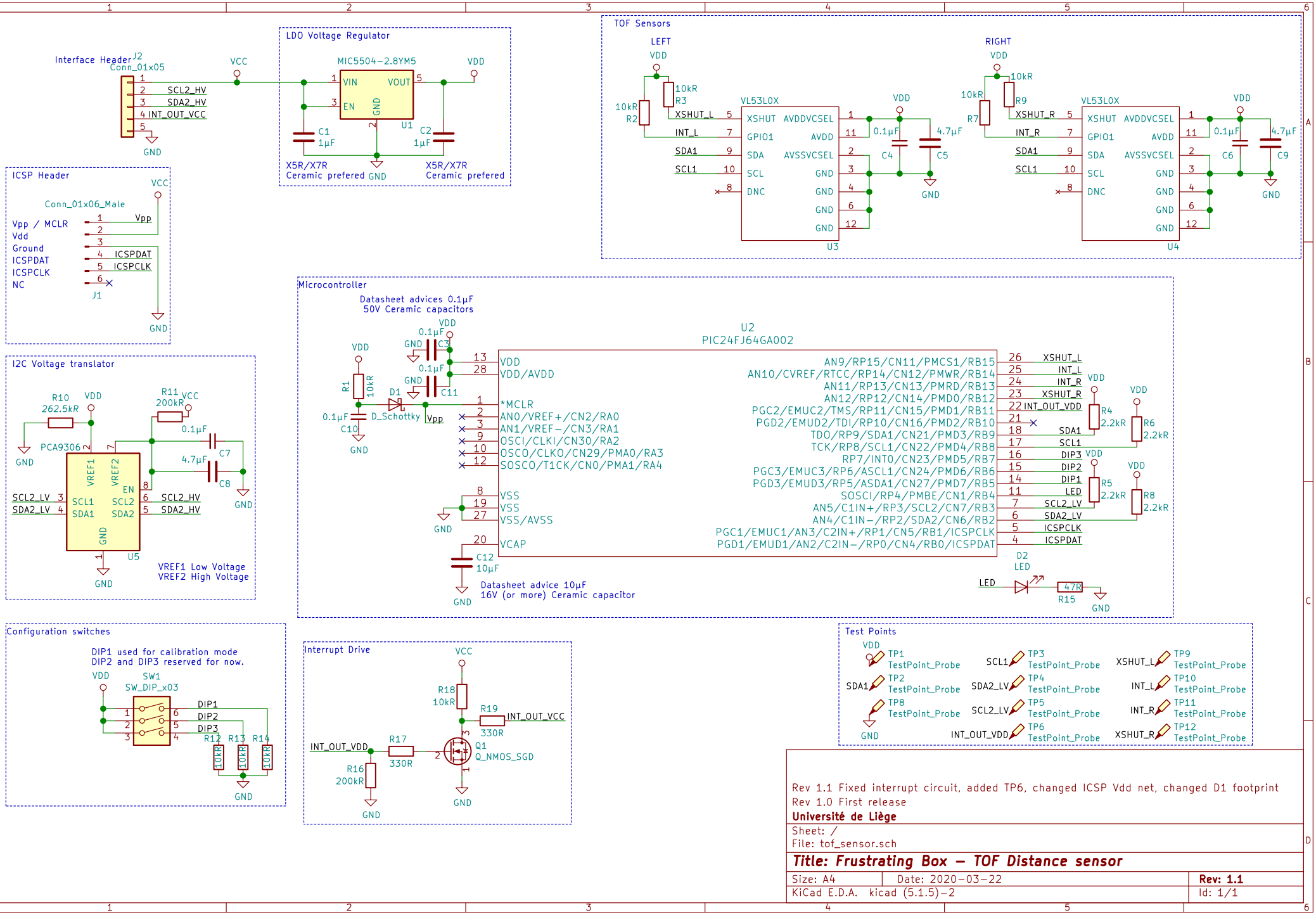
A Bill Of Material

Component	Quantity	PCB Locations	Reference used
PIC24FxxGA702	1	U2	PIC24FJ256GA702-I/SO
VL53L0X	2	U3, U4	VL53L0CXV0DH/1
2.8 LDO Regulator	1	U1	MIC5504-2.8YM5-TR
I^2C Voltage Translator	1	U5	PCA9306DCTR
ICSP Header [Optional]	1	J1	10129380-906001ALF
Canal N Ench. MOSFET	1	Q1	2N7002K-7 [1]
DIP Switches (3)	1	SW1	219-3LPS
Shottky diode	1	D1	1PS76SB10,115
1μF Capacitor (X5R/X7R)	2	C1, C2	*Any 1206 package capacitor*
0.1μF Capacitor	6	C3, C4, C6, C7, C10, C11	*Any 1206 package capacitor*
4.7μF Capacitor	3	C5, C8, C9	*Any 1206 package capacitor*
10μF Capacitor	1	C12	*Any 1206 package capacitor*
10kΩ Resistor	9	R1, R2, R3, R7, R9, R12, R13, R14, R18	*Any 1206 package resistor*
2.2kΩ Resistor	4	R4, R5, R6, R8	*Any 1206 package resistor*
262.5kΩ Resistor	1	R10	*Any 1206 package resistor*
200kΩ Resistor	2	R11, R16	*Any 1206 package resistor*
330Ω Resistor	3	R15, R17, R19	*Any 1206 package resistor*
LED	1	D2	*Any 1206 package LED*

Table 3: Bill of material

B Electric Diagram

[1] On PCB V1.0 a P Mosfet is used. That part of the circuit was badly designed and PCB V1.0 should not be used.


Interface Header
J2
Conn_01x05
SCL2_HV
SDA2_HV
INT_OUT_VCC
GND
VCC
LDO Voltage Regulator
MIC5504-2.8YM5
VIN
VOUT
EN
GND
VDD
C1
1µF
C2
1µF
X5R/X7R
Ceramic prefered
TOF Sensors
LEFT
RIGHT
VL53L0X
XSHUT
GPIO1
SDA
SCL
DNC
AVDDVCSEL
AVDD
AVSSVCSEL
U3
U4
10kR
R2
R3
R7
R9
0.1µF
4.7µF
C4
C5
C6
C9
XSHUT_L
INT_L
XSHUT_R
INT_R
SDA1
SCL1
ICSP Header
Conn_01x06_Male
Vpp / MCLR
Vdd
Ground
ICSPDAT
ICSPCLK
NC
Vpp
J1
Microcontroller
Datasheet advices 0.1µF
50V Ceramic capacitors
U2
PIC24FJ64GA002
*MCLR
AN0/VREF+/CN2/RA0
AN1/VREF-/CN3/RA1
OSCI/CLKI/CN30/RA2
OSCO/CLKO/CN29/PMA0/RA3
SOSCO/T1CK/CN0/PMA1/RA4
VDD
VDD/AVDD
VSS
VSS/AVSS
VCAP
AN9/RP15/CN11/PMCS1/RB15
AN10/CVREF/RTCC/RP14/CN12/PMWR/RB14
AN11/RP13/CN13/PMRD/RB13
AN12/RP12/CN14/PMD0/RB12
PGC2/EMUC2/TMS/RP11/CN15/PMD1/RB11
PGD2/EMUD2/TDI/RP10/CN16/PMD2/RB10
TDO/RP9/SDA1/CN21/PMD3/RB9
TCK/RP8/SCL1/CN22/PMD4/RB8
RP7/INT0/CN23/PMD5/RB7
PGC3/EMUC3/RP6/ASCL1/CN24/PMD6/RB6
PGD3/EMUD3/RP5/ASDA1/CN27/PMD7/RB5
SOSCI/RP4/PMBE/CN1/RB4
AN5/C1IN+/RP3/SCL2/CN7/RB3
AN4/C1IN-/RP2/SDA2/CN6/RB2
PGC1/EMUC1/AN3/C2IN+/RP1/CN5/RB1/ICSPCLK
PGD1/EMUD1/AN2/C2IN-/RP0/CN4/RB0/ICSPDAT
D_Schottky
C12
10µF
Datasheet advice 10µF
16V (or more) Ceramic capacitor
D2
LED
47R
R15
I2C Voltage translator
PCA9306
VREF1
VREF2
EN
SCL1
SDA1
SCL2
SDA2
U5
R10
262.5kR
R11
200kR
C7
4.7µF
C8
SCL2_LV
SDA2_LV
SCL2_HV
SDA2_HV
VREF1 Low Voltage
VREF2 High Voltage
Configuration switches
DIP1 used for calibration mode
DIP2 and DIP3 reserved for now.
SW1
SW_DIP_x03
DIP1
DIP2
DIP3
R12
R13
R14
Interrupt Drive
R18
10kR
R19
330R
INT_OUT_VCC
INT_OUT_VDD
R17
330R
R16
200kR
Q1
Q_NMOS_SGD
Test Points
TP1
TestPoint_Probe
TP2
TP3
TP4
TP5
TP6
TP8
TP9
TP10
TP11
TP12
Rev 1.1 Fixed interrupt circuit, added TP6, changed ICSP Vdd net, changed D1 footprint
Rev 1.0 First release
Université de Liège
Sheet: /
File: tof_sensor.sch
Title: Frustrating Box – TOF Distance sensor
Size: A4
Date: 2020-03-22
Rev: 1.1
KiCad E.D.A. kicad (5.1.5)-2
Id: 1/1

Revision History

Revision	Date	Author(s)	Description
Rev. A	03 April 2020	Morgan Diepart	First release
Rev. B	04 April 2020	Morgan Diepart	Updated to PCB V1.1, added section for the measurement modes

References

[1] *I2C-bus specification and user manual*, NXP Semiconductors, April 2014, rev. 6. [Online]. Available: https://www.nxp.com/docs/en/user-guide/UM10204.pdf

[2] *PIC24FJ256GA705 FAMILY*, Microchip Technology Inc., March 2020, rev. E. [Online]. Available: http://ww1.microchip.com/downloads/en/DeviceDoc/PIC24FJ256GA705-Family-Data-Sheet-DS30010118E.pdf

[3] *VL53L0X Application Programming Interface User Manual*, STMicrolectronics, June 2016, rev. 1. [Online]. Available: https://www.st.com/en/embedded-software/stsw-img005.html

[4] *VL53L0X Datasheet - production data*, STMicrolectronics, April 2018, rev. 2. [Online]. Available: https://www.st.com/resource/en/datasheet/vl53l0x.pdf

[5] *Inter-Integrated Circuit™ (I2C™)*, Microchip Technology Inc., February 2014, rev. F. [Online]. Available: http://ww1.microchip.com/downloads/en/devicedoc/70000195f.pdf