ABSOLUTE PRESSURE SENSOR
WSEN-PADS
USER MANUAL

2511020213301
25110202133011

VERSION 2.2

MARCH 31, 2022

Revision history

Manual version	Notes	Date
0.1	• Initial release of the manual	April 2019
1.0	• Updated section 11: Interrupt functionality • Updated section 13: Register description	June 2019
1.1	• Updated flowchart in section 7.5 • Added note to section 9.3 • Updated section 11.2: Interrupt generation based on pressure threshold • Updated address of reserved registers and register type of REF_P_x in section 12: Register Map • Updated register name in section 13.6 • Updated register address to 0x7C in section 13.28	April 2020
2.0	• Added description of the SPI interface. • Updated pin description for the SPI interface in section 3.2 • Added 'SIM' bit for the SPI interface in section 12 and under register description in section 13.6	November 2020
2.1	• Added part number 2511020213301 1 to section 1.3: Ordering information	March 2021
2.2	• Added overview of helpful application notes • Updated test conditions in sections 2.3 and 2.5 • Added new chapter 15 added : MEMS sensor PCB design guidelines	March 2022

Abbreviations

Abbreviation	Description
ASIC	Application Specific Integrated Circuit
BDU	Block Data Update
DRDY	Data ready
ESD	Electrostatic Discharge
FIFO	First-In First-Out
HBM	Human Body Model
I^2C	Inter Integrated Circuit
LGA	Land Grid Array
LSB	Least Significant Bit
MEMS	Micro-Electro Mechanical System
MISO	Master In Slabe Out
MOSI	Master Out Slave In
MSB	Most Significant Bit
NVM	Non Volatile Memory
ODR	Output Data Rate
PCB	Printed Circuit Board
SPI	Serial Peripheral Interface

Contents

Overview of helpful application notes

Application note ANM003 - Pressure altimeter using absolute pressure sensor WSEN-PADS

http://www.we-online.com/ANM003

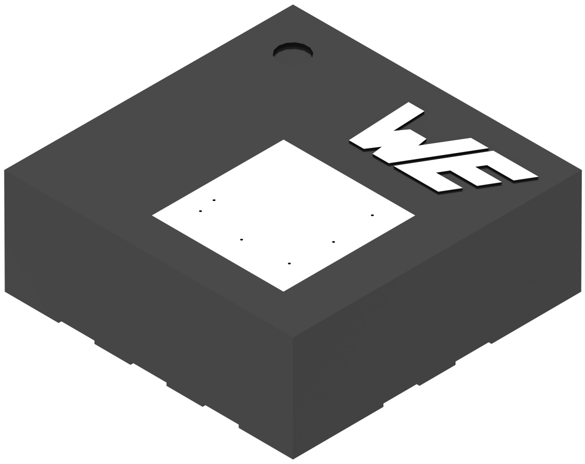
An altimeter is an instrument that measures the altitude above a fixed level. This document describes the altimeter functionality of the absolute pressure sensors from Würth Elektronik eiSos and how the built-in sensor features like filters, offset calibration, temperature compensation etc. help customers to implement the altimeter functionality with high accuracy.

1 Introduction

This device is a MEMS based piezo-resistive absolute pressure sensor. The sensor comprises of a pressure sensing cell and an analog and digital signal processing unit. The integrated ASIC with digital I^2C interface provides a digital signal to the host controller. The sensor has an embedded temperature sensor. A 128 level embedded FIFO buffer is available to store the pressure and temperature data. The sensor comes in fully molded holed land grid array package (LGA) having a form factor of 2.0 x 2.0 x 0.8 mm.

1.1 Application

- Altimeters and barometers
- Weather stations
- GPS navigation enhancement
- Indoor navigation
- White goods
- Wearable devices



1.2 Key features

- Absolute pressure range: 26 to 126 kPa
- Output data rate: 1 Hz to 200 Hz
- Integrated temperature sensor
- Pressure data: 24-bits and temperature data: 16-bits
- Low current consumption: 4 µA
- Digital interface: I^2C
- Embedded FIFO buffer: 128 levels
- Interrupt pin functionality: data-ready, pressure threshold

1.3 Ordering information

WE order code	Dimensions	Description
2511020213301	2.0 x 2.0 x 0.8 mm	Tape & reel packaging (1000 pcs.)
25110202133011	2.0 x 2.0 x 0.8 mm	Tape & reel packaging (8000 pcs.)
2511223013301	33 x 20 mm	Evaluation board

Table 1: Ordering information

1.4 Block diagram

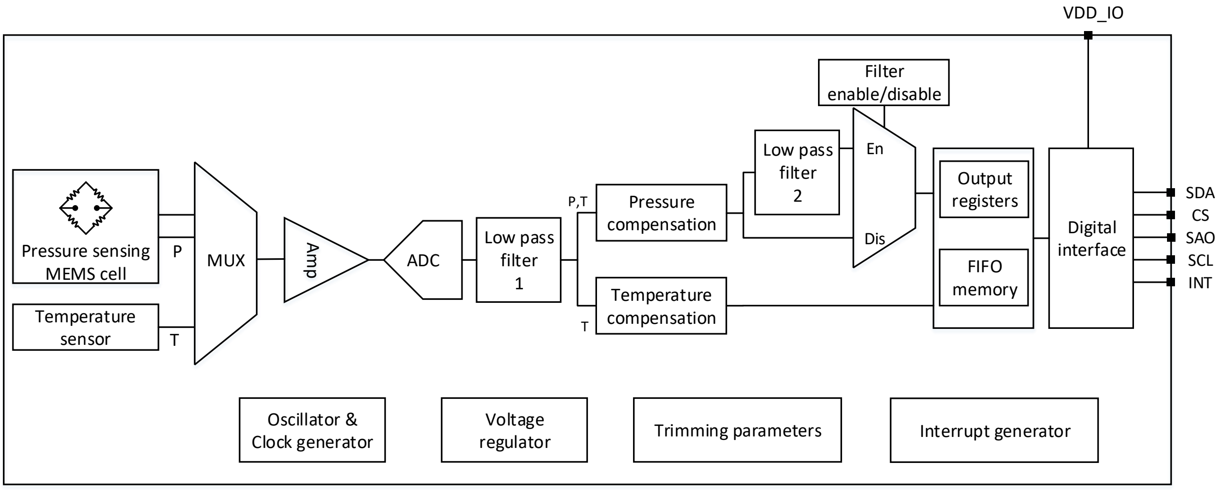


Figure 1: Block diagram

1.5 Operational functionality

1.5.1 MEMS Cell

The MEMS cell is the primary pressure sensing element. It contains piezo-resistors embedded on a suspended silicon membrane. The piezo-resistors are connected in a Wheatstone bridge configuration. When pressure is applied, the membrane is deflected and the bridge resistance changes. This change leads to a change of the Wheatstone output voltage proportional to the applied pressure. This analog signal is fed to the ASIC.

1.5.2 ASIC

The ASIC comprises of low-noise amplifier, analog-to-digital converter and other signal conditioning blocks that converts an uncompensated analog voltage equivalent to a 24-bit digital pressure value.

The ASIC embeds a high-resolution temperature sensor which is used for internal compensation of the pressure signal. The temperature information can also be read as a 16-bit digital value.

1.5.3 Calibration

The sensor is factory calibrated for both pressure and temperature measurements. The trimming parameters are stored on-chip in the non volatile memory (NVM). Every-time the sensor is powered on, these trimming parameters are copied from the NVM to the registers. In normal use, no further calibration is required from the user.

1.5.4 Digital filtering

The sensor has on-chip signal conditioning and embeds two digital low pass filters. The first filter LPF1 is applied to both pressure and temperature data. The second filter LPF2 can be optionally applied only to the pressure data. User can turn on or off this filter, depending on his requirements.

1.5.5 FIFO memory

The sensor has embedded FIFO buffer that can store up to 128 levels of pressure and temperature data. This can save host controller power, since the controller doesn't have to poll for data continuously.

1.6 Filtering chain and data path

Figure 2 shows detailed information about the functionality of the sensor. The sensor can be operated in various operating modes and filter setting which determines the pressure and temperature data path.

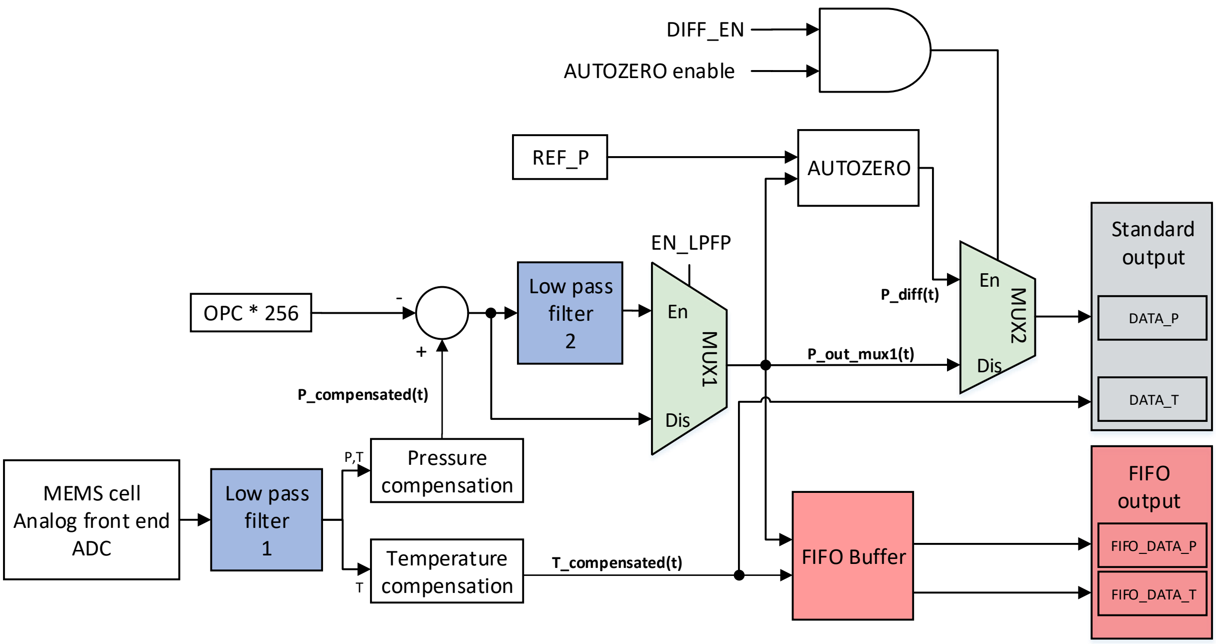


Figure 2: Filtering chain and data path

2 Sensor specifications

2.1 General information

Parameter	Value
Operating temperature	-40 up to +85 ℃
Storage conditions	< 40 ℃; < 90% RH
Communication interface	I^2C
Moisture sensitivity level (MSL)	3
Electrostatic discharge protection (HBM)	2.5 kV

Table 2: General information

2.2 Absolute maximum ratings

Absolute maximum ratings are the limits, the device can be exposed to without causing permanent damage. Exposure to absolute maximum conditions for extended periods may affect device reliability.

Parameter	Symbol	Value		Unit
		Min	Max	
Input voltage *VDD* pin	V_{DD_MAX}	-0.3	4.8	V
Input voltage *VDD_IO* pin	$V_{DD\_IO\_MAX}$	-0.3	4.8	V
Input voltage *SDA*, *SCL*, *CS* & *SAO* pins	V_{IN_MAX}	-0.3	V_{DD_IO}+0.3	V
Overpressure	P_{OVER}		2	Mpa

Table 3: Absolute maximum ratings

Supply voltage on any pin should never exceed 4.8 V.

The device is susceptible to be damaged by electrostatic discharge (ESD). Always use proper ESD precautions when handling. Improper handling of the device can cause performance degradation or permanent damage.

2.3 Pressure sensor specification

Unless otherwise stated, all the specified values were measured under the following conditions: T=25℃, V_{DD}=3.3 V. Sensor parameter values are measured after soldering the sensor on a PCB. The PCB design follows the MEMS sensor PCB design guidelines described in the chapter 15.

Parameter	Symbol	Test conditions	Value			Unit
			Min	Typ	Max	
Measurement range	P_{RANGE}		26		126	kPa
Absolute accuracy[1]	P_{ACC_ABS}	T= -20 to 80℃		±100		Pa
Relative accuracy[2]	P_{ACC_REL}	P= 80 to 110 kPa T= 25℃		±2.5		Pa
Resolution	RES_P			24		bit
Sensitivity	SEN_P			1/40960		kPa/digit
Output data rate	ODR		1		200	Hz
Noise (RMS)[3]	P_{NOISE}	Low pass filter enabled		0.75		Pa RMS
Offset change over temperature	P_{TCO}	P= 66 to 116 kPa T= -20 to 65℃		±65		Pa/℃
Long term drift	P_{DRIFT}			±33		Pa/Year

Table 4: Pressure sensor specifications

1. *Absolute accuracy includes the soldering drift effects.*
2. *Typical value is defined based on characterization data with 2kPa interval.*
3. *Pressure noise RMS is measured in a controlled environment.*

2.4 Temperature sensor specification

Parameter	Symbol	Test conditions	Value			Unit
			Min	Typ	Max	
Measurement range	T_{RANGE}		-40		+85	℃
Absolute accuracy	T_{ACC_ABS}	T= 0 to 80℃		±1.5		℃
Resolution	RES_T			16		bit
Sensitivity	SEN_T			0.01		℃/digit

Table 5: Temperature sensor specifications

2.5 Electrical specifications

Unless otherwise stated, all the specified values were measured under the following conditions: T=25℃, V_{DD}=3.3V. Electrical parameter values are measured after soldering the sensor on a PCB. The PCB design follows the MEMS sensor PCB design guidelines described in the chapter 15.

Parameter	Symbol	Test conditions	Value			Unit
			Min	Typ	Max	
Operating supply voltage	V_{DD}		1.7	3.3	3.6	V
Supply voltage for I/O pins	V_{DD_IO}		1.7		V_{DD} +0.1	V
Current consumption in low power mode	I_{DD_LP}	ODR= 1Hz		4		µA
Current consumption in low noise mode	I_{DD_LN}	ODR= 1Hz		12		µA
Current consumption in power down mode	I_{DD_PD}			0.9		µA
Digital input voltage - high-level	V_{IH}		0.8*V_{DD_IO}			V
Digital input voltage - low-level	V_{IL}				0.2*V_{DD_IO}	V
Digital output voltage - high-level	V_{OH}		V_{DD_IO}-0.2			V
Digital output voltage - low-level	V_{IL}				0.2	V

Table 6: Electrical specifications

3 Pinning information

3.1 Pin configuration

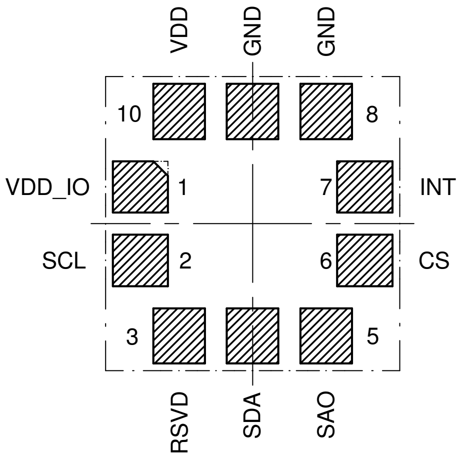


Figure 3: Pin specifications (top view)

3.2 Pin description

Pin No.	Name	Function	I/O	Comments
1	*VDD_IO*	Positive supply voltage for I/O pins	Supply	
2	*SCL*	I²C/ SPI serial clock	Input	Internal pull-up disconnected by default
3	*RSVD*	Reserved	Input	Connect to ground
4	*SDA*	I²C serial data; SPI serial data input	Input/Output	Internal pull-up disconnected by default
5	*SAO*	I²C device address selection; SPI chip select pin	Input/Output	High: device address LSB is 1 Low: device address LSB is 0
6	*CS*	I²C enable/disable	Input	High: I²C enable
7	*INT*	Interrupt	Input/Output	Do not connect if not used
8	*GND*	Negative supply voltage	Supply	
9	*GND*	Negative supply voltage	Supply	
10	*VDD*	Positive supply voltage	Supply	

Table 7: Pin description

4 Digital I²C interface

The sensor supports standard I²C (Inter-IC) bus protocol. Further information about the I²C interface can be found at *https://www.nxp.com/docs/en/user-guide/UM10204.pdf*. I²C is a serial 8-bit protocol with two-wire interface that supports communication between different ICs, for example, between microcontrollers and other peripheral devices.

4.1 General characteristics

A serial data line (*SDA*) and a serial clock line (*SCL*) are required for the communication between the devices connected via I²C bus. Both *SDA* and *SCL* lines are bidirectional. The output stages of devices connected to the bus must have an open-drain or open-collector. Hence, the *SDA* and *SCL* lines are connected to a positive supply voltage via pull-up resistors. In I²C protocol, the communication is realized through master-slave principle. A master device generates the clock pulse, a start command and a stop command for the data transfer. Each connected device on the bus is addressable via a unique address. Master and slave can act as a transmitter or a receiver depending upon whether the data needs to be sent or received.

> This sensor behaves like a slave device on the I²C bus

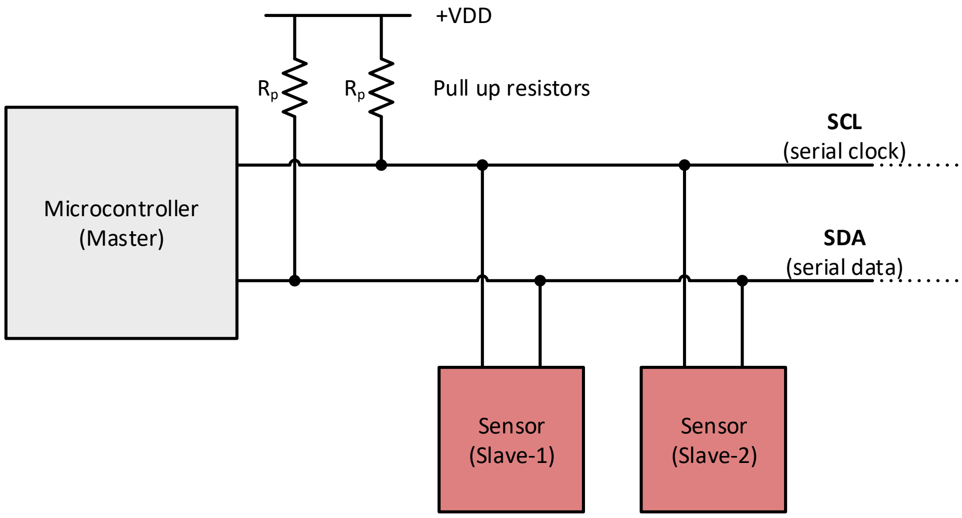


Figure 4: Master-slave concept

4.2 *SDA* and *SCL* logic levels

The positive supply voltage to which *SDA* and *SCL* lines are pulled up (through pull-up resistors), in turn determines the high level input for the slave devices. The sensor has separate supply voltage *VDD_IO* for the *SDA* and *SCL* lines. The logic high '1' and logic low '0' levels for the *SDA* and *SCL* lines then depend on the *VDD_IO*. Input reference levels for this sensor are set as 0.8 * *VDD_IO* (for logic high) and 0.2 * *VDD_IO* (for logic low). Explained in the figure 5.

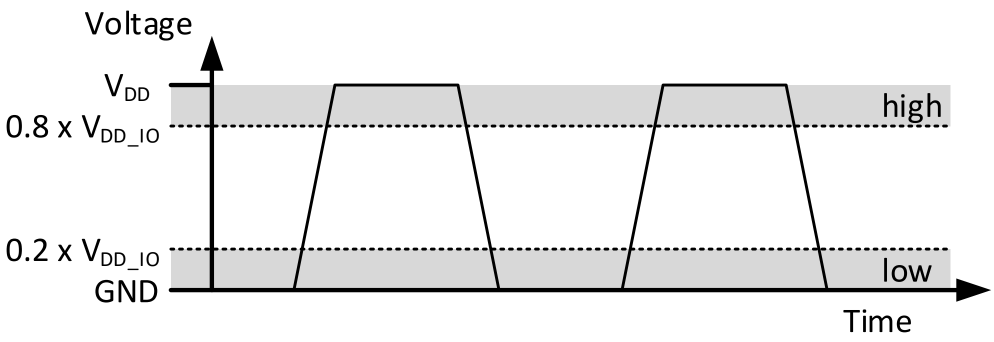


Figure 5: *SDA* and *SCL* logic levels

4.3 Communication phase

4.3.1 Idle state

During the idle state, the bus is free and both *SDA* and *SCL* lines are in logic high '1' state.

4.3.2 START(S) and STOP(P) condition

Data transfer on the bus starts with a START command, which is generated by the master. A start condition is defined as a high-to-low transition on the *SDA* line while the *SCL* line is held high. The bus is considered busy after the start condition.

Data transfer on the bus is terminated with a STOP command, which is also generated by the master. A low-to-high transition on the *SDA* line, while the *SCL* line being high is defined as a STOP condition. After the stop condition, the bus is again considered free and is in idle state. Figure 6 shows the I^2C bus START and STOP conditions.

Master can also send a REPEATED START (SR) command instead of STOP command. REPEATED START condition is the same as the START condition.

4.3.3 Data validity

After the start condition, one data bit is transferred with each clock pulse. The transmitted data is only valid when the *SDA* line data is stable (high or low) during the high period of the clock pulse. High or low state of the data line can only change when clock pulse is in low state.

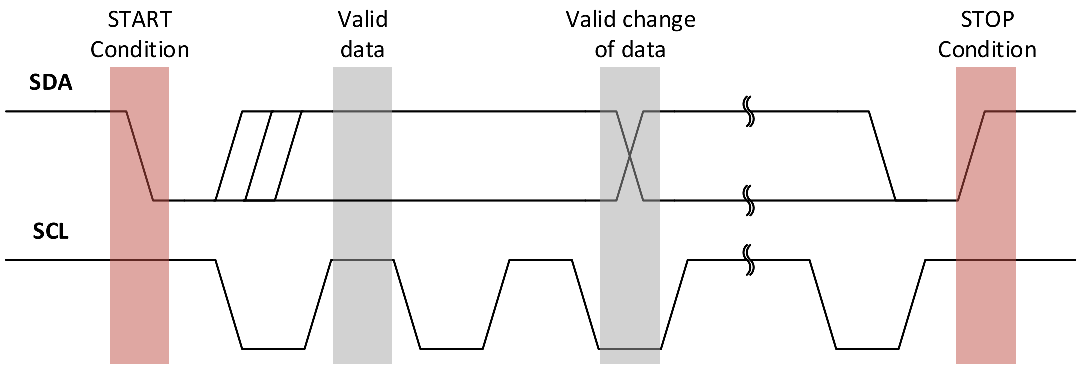


Figure 6: Data validity, START and STOP condition

4.3.4 Byte format

Data transmission on the *SDA* line is always done in bytes, with each byte being 8-bits long. Data is transferred with the most significant bit (MSB) followed by other bits.

If the slave cannot receive or transmit another complete byte of data, it can force the master into a wait state by holding *SCL* low. Data transfer continues when the slave is ready which is indicated by releasing the *SCL* line.

4.3.5 Acknowledge(ACK) and No-Acknowledge(NACK)

Each byte sent on the data line must be followed by an Acknowledge bit. The receiver (master or slave) generates an Acknowledge signal to indicate that the data byte was received successfully and another data byte could be sent.

After one byte is transmitted, the master generates an additional Acknowledge clock pulse to continue the data transfer. The transmitter releases the *SDA* line during this clock pulse so that the receiver can pull the *SDA* line to low state in such a way that the *SDA* line remains stable low during the entire high period of the clock pulse. This is considered as an Acknowledge signal.

In case the receiver does not want to receive any further byte, it does not pull down the *SDA* line and it remains in stable high state during the entire clock pulse. This is considered as a No-Acknowledge signal and the master can generate either a stop condition to terminate the data transfer or a repeated start condition to initiate a new data transfer.

4.3.6 Slave address for the sensor

The slave address is transmitted after the start condition. Each device on the I^2C bus has a unique address. Master selects the slave by sending corresponding address after the start condition. A slave address is 7 bits long followed by a Read/Write bit.

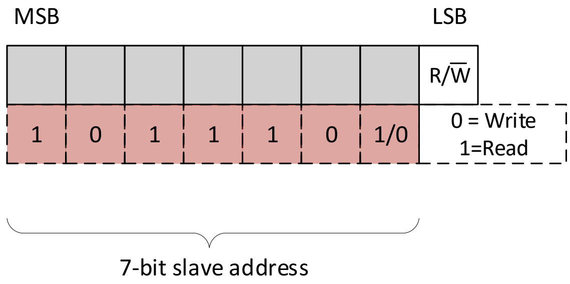


Figure 7: Slave address format

The 7-bit slave address for this sensor is 101110xb. LSB of the 7-bit slave address can be modified with the *SAO* pin. When SAO is connected to positive supply voltage, the LSB is '1', making 7-bit slave address 1011101b (0x5D). If SAO is connected to ground, the LSB is '0', making 7-bit address 1011100b (0x5C).

The R/W bit determines the data direction. A '0' indicates a write operation (transmission from master to slave) and a '1' indicates a read operation (data request from slave).

Slave address[6:1]	Slave address[0]	7-bit slave address	R/W	Slave address + R/W
101110	SAO=0	1011100b (0x5C)	0	10111000b (0xB8)
101110			1	10111001b (0xB9)
101110	SAO=1	1011101b (0x5D)	0	10111010b (0xBA)
101110			1	10111011b (0xBB)

Table 8: Slave address and Read/Write commands

4.3.7 Read/Write operation

Once the slave-address and data direction bit is sent, the slave acknowledges the master. The next byte sent by the master must be a register-address of the sensor. This indicates the address of the register where data needs to be written to or read from.

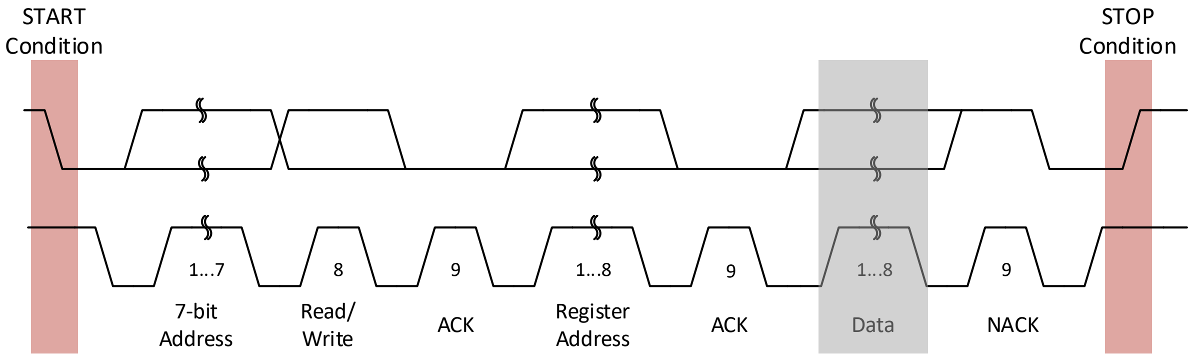


Figure 8: Complete data transfer

After receiving the register address, the slave sends an Acknowledgement (ACK). If the master is still writing to the slave (R/W bit = 0), it will transmit the data to slave in the same direction. If the master wants to read from the addressed register (R/W bit =1), a repeated start (SR) condition must be sent to the slave. Master acknowledges the slave after receiving each data byte. If the master no longer wants to receive further data from the slave, it would send No-Acknowledge (NACK). Afterwards, Master can send a STOP condition to terminate the data transfer. Figure 9 shows the writing and reading procedures between the master and the slave device (sensor).

7-bit slave address of this device is 101110xb. LSB of the 7-bit slave address depends on the *SAO* pin

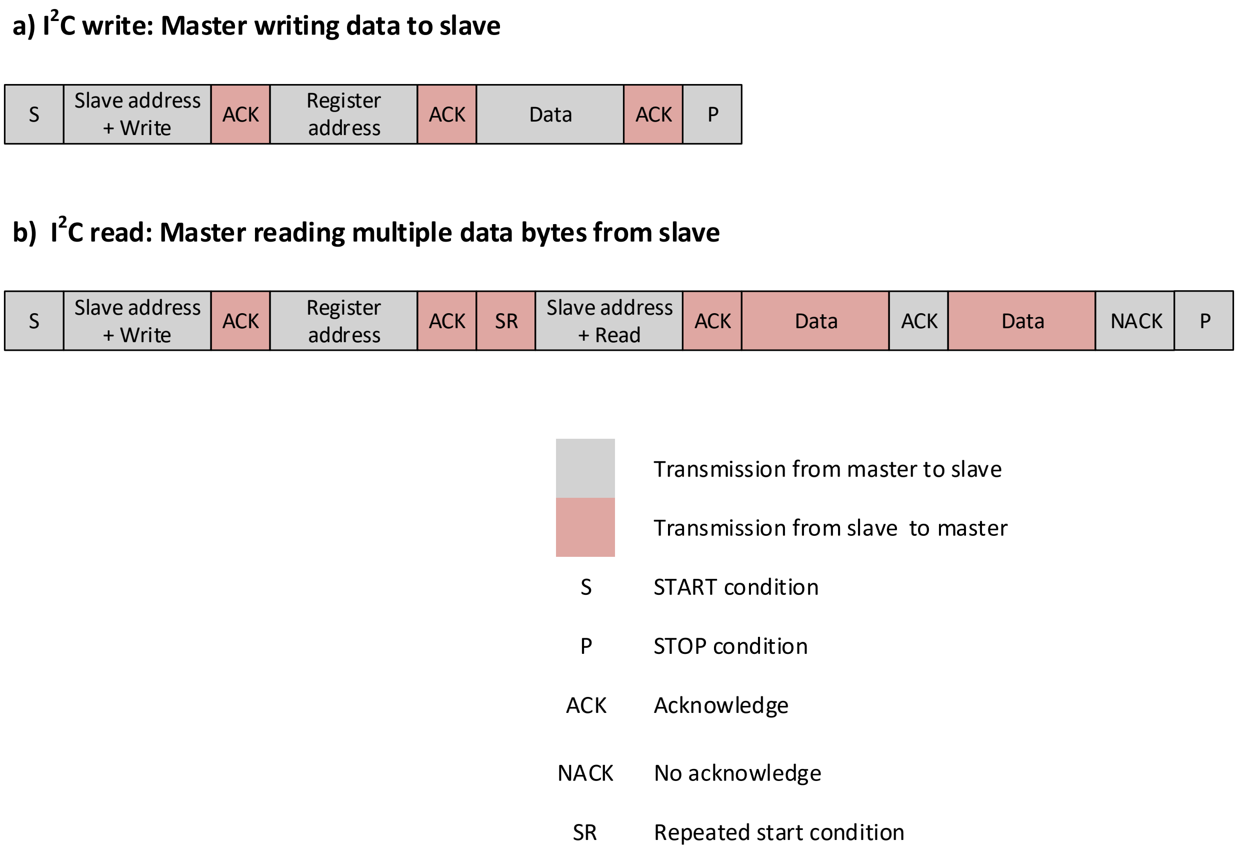


Figure 9: Write and read operations with the device

4.4 I²C timing parameters

Parameter	Symbol	Standard mode		Fast mode		Unit
		Min	Max	Min	Max	
SCL clock frequency	f_{SCL}	0	100	0	400	kHz
LOW period for *SCL* clock	t_{LOW_SCL}	4.7		1.3		µs
HIGH period for *SCL* clock	t_{HIGH_SCL}	4.0		0.6		µs
Hold time for START condition	t_{HD_S}	4		0.6		µs
Setup time for (repeated) START condition	f_{SCL}	4.7		0.6	400	µs
SDA setup time	t_{SU_SDA}	250		100		ns
SDA data hold time	t_{HD_SDA}	0	3.45	0	0.9	µs
Setup time for STOP condition	t_{SU_P}	4		0.6		µs
Bus free time between STOP and START condition	t_{BUF}	4.7		1.3		µs

Table 9: I²C timing parameters

5 Serial Peripheral Interface (SPI)

Serial Peripheral Interface (SPI) is a synchronous serial communication bus system for the communication between host microcontroller and other peripheral ICs such as ADCs, EEPROMs, sensors, etc. SPI is a full-duplex master-slave based interface allowing the communication to happen in both directions simultaneously. The data from the master or the slave is synchronized either on the rising or falling edge of clock pulse. SPI can be either 4-wire or 3-wire interface. 4-wire interface consists of two signal lines and two data lines. All of these bus lines are unidiretional.

1. Clock (SCL)
2. Chip select (CS)
3. Master out, slave in (MOSI)
4. Master in, slave out (MISO)

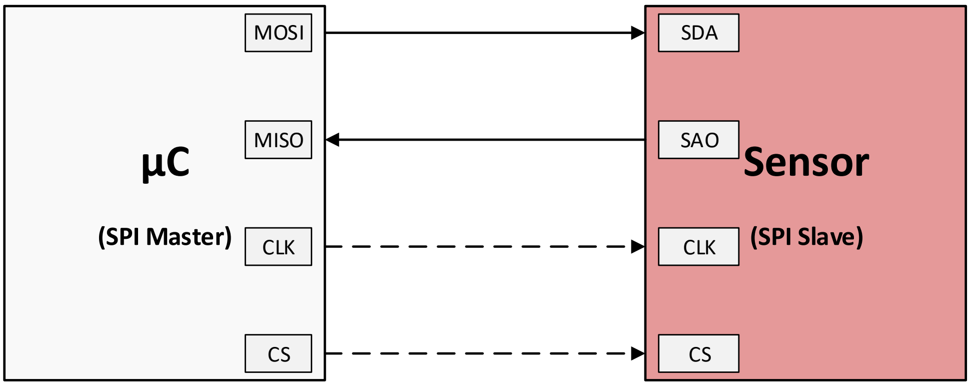


Figure 10: SPI Interface

Master generates the clock signal and is connected to all slave devices. Data transmission between the master and salves is synchronized to the clock signal generated by the master.

One master can be connected to one or more slave devices. Each slave device is addressed and controlled by the master via individual chip select (CS) signals. CS is controlled by the master and is normally an active low signal.

MOSI and MISO are data lines. MOSI transmits data from the master to the slave. MISO transmits data from the slave to the master.

This sensor supports both 3-wire and 4-wire SPI.

5.1 Data transfer

Communication begins when the master selects a slave device by pulling the CS line to LOW. The clock and data lines (MOSI/MISO) are available for the selected slave device. Data stored in the specific shift registers are exchanged synchronously between master and the slave through MISO and MOSI lines. The data transmission is over when the chip select line is pulled up to the HIGH state. 4-wire SPI uses both data lines for the synchronous data exchange in both the direction. 3-wire SPI shares a single data line for the data transfer, where the master and slave alternate their transmitter and receiver roles synchronously.

5.2 Communcation modes

In SPI, the master can select the clock polarity (CPOL) and clock phase (CPHA). The CPOL bit sets the polarity of the clock signal during the idle state. The CPHA bit selects the clock phase. Depending on the CPHA bit, the rising or falling clock edge is used to sample and shift the data. Depending on the CPOL and CPHA bit selection in the SPI control registers, four SPI modes are available as per table 10. In order to ensure proper communication, master and the slave must be set to same communication modes.

CPOL	CPHA	Desription
0	0	Clock polarity LOW in idle state; Data sampled on the rising clock edge
0	1	Clock polarity LOW in idle state; Data sampled on the falling clock edge
1	1	Clock polarity HIGH in idle state; Data sampled on the falling clock edge
1	0	Clock polarity HIGH in idle state; Data sampled on the rising clock edge

Table 10: SPI communication modes

5.3 Sensor SPI Communcation

4-Wire SPI of this sensor uses following lines: SDA (data input, MOSI), SAO (data output, MISO), SCL (serial clock) and CS (chip select). For more information, please refer to pin description in the section 3.2

CS is pulled LOW by the master at the start of communication. The SCL polarity is HIGH in the idle state (CPOL = 1). The data lines (SDA & SAO) are sampled at the falling clock edge and latched at the rising clock edge (CPHA = 1). Data is transmitted with MSB first and the LSB last.

SPI read and write operations are completed in 2 or more bytes (multiple of 16 or more clock pulses). Each block consits of a register address byte and a data byte. The first byte is the register address. In the SPI communication, the register address is specified in the 7-bits and the the MSB of the register address is used as an SPI read/write bit (Figure 11). When R/W is '0', the data is written on to the sensor. When '1', the data is read from the sensor.

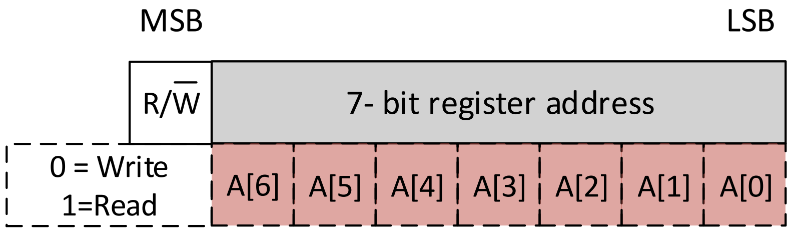


Figure 11: SPI register address

The next bytes of data, depending on the R/W bit, is either written to or read from the indexed register. Figure 12 shows the complete SPI data transfer protocol.

> The sensor also supports 3-wire SPI communication. *SDA* is used for both data read and write operations. Communication protocol remains the same.

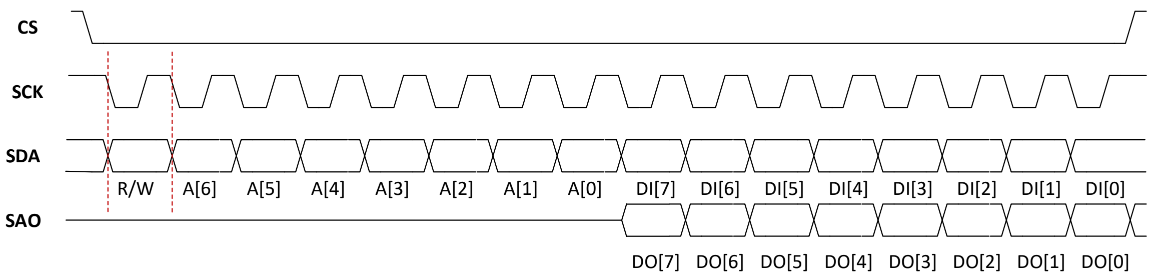


Figure 12: 4-wire SPI data transfer (CPOL = 1, CPHA = 1)

5.3.1 SPI write operation

The write operation starts with the CS = LOW and sending the 7-bit register address with R/W bit = ’0’ (write command). Next byte is the data byte that is the data to be written to the indexed register. Several write command pairs can be sent without raising the CS back to HIGH. The operation is ended with CS = HIGH. The SPI write protocol is shown in the figure 13.

Start	R/$\overline{W}$	Register address							Data to be written								Stop
CS = LOW	**0**	A[6]	A[5]	A[4]	A[3]	A[2]	A[1]	A[0]	DI [7]	DI [6]	DI [5]	DI [4]	DI [3]	DI [2]	DI [1]	DI [0]	CS = HIGH

Figure 13: SPI write protocol

5.3.2 SPI read operation

The read operation starts with the CS = LOW and sending the 7-bit register address with R/W bit = ’1’ (read command). Data is sent out from the sensor through the SAO line. The SPI read protocol is shown in the figure 14.

If 3-wire SPI is used, the data is sent out through the SDA line.

Start	R/$\overline{W}$	Register address							Data from indexed register								Stop
CS = LOW	**1**	A[6]	A[5]	A[4]	A[3]	A[2]	A[1]	A[0]	DI [7]	DI [6]	DI [5]	DI [4]	DI [3]	DI [2]	DI [1]	DI [0]	CS = HIGH

Figure 14: SPI read protocol

During multiple read/write operation, the register address is automatically incremented after each block. This feature is enabled by default with the bit IF_ADD_INC set to ’1’ in the *CTRL_2* register.

3-wire SPI can be enabled by setting bit SIM to ’1’ in the *CTRL_1* register.

5.3.3 SPI timing parameters

Table 11 shows general SPI timing parameters. They are subject to VDD and the operating temperature.

Parameter	Symbol	Min	Max	Unit
SCL clock frequency	f_{SCL}		10 (1)	MHz
SPI clock cycle	t_{SCL}	100		ns
CS setup time	t_{SU_CS}	6		ns
CS hold time	t_{h_CS}	6		ns
SDA input setup time	t_{SU_SDA}	5		ns
SDA input hold time	t_{h_SDA}	15		ns
SAO valid output time	t_{v_SAO}		50	ns
SAO output hold time	t_{h_SAO}	9		ns
SAO output disable time	t_{dis_SAO}		50	ns

Table 11: SPI timing parameters

1. *Recommended maximum SPI clock frequency for ODR $\leq$ 50 Hz is 8 MHz*

6 Application circuit

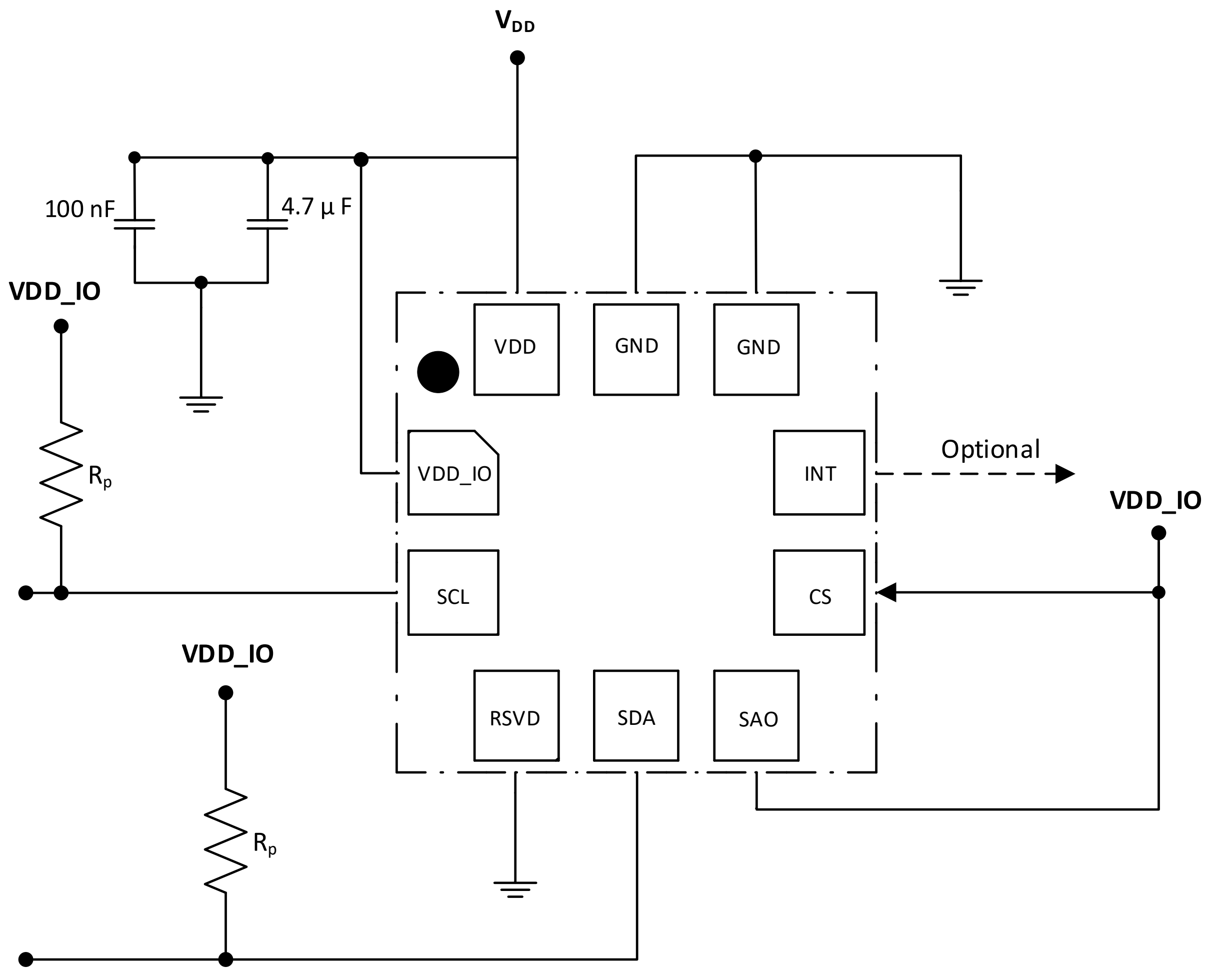


Figure 15: Application circuit with I²C interface (top view)

The sensor has two separate supply pins: *VDD* and *VDD_IO*. *VDD* pin is the central supply pin for the MEMS cell and internal circuits. *VDD_IO* provides the supply to the digital interface.

VDD_IO voltage level must be equal to or lower than V_{DD}+0.1 V.

In order to prevent ripple from the power supply, a decoupling capacitor of 100 nF must be placed as close to the *VDD* pad of the sensor as possible. An optional decoupling capacitor (4.7 µF) could placed as shown in the figure 15. If *VDD_IO* is not connected to the *VDD* line, a separate decoupling capacitor of 10nF should be added on the *VDD_IO* line.

Figure 15 shows a typical application circuit for I²C communication. For proper I²C functionality, the *CS* pin must be connected to *VDD*. Least significant bit of the 7-bit slave address can be modified based on the status of the *SAO* pin. In order to optimize the power consumption, it is recommended to connect *SAO* pin to *VDD* (*SAO* = 1) if only one sensor is used on the I²C line. This sets the 7 bit slave address as 0x5D (1011101b). *SCL* and *SDA* must be connected to *VDD_IO* through the pull-up resistors. Proper value of the pull-up resistors must be chosen depending on the I²C bus speed and load.

Pins *SDA* and *SCL* have internal pull up resistors. By default they are disabled and can be enabled through bits SDA_PU_EN and SAO_PU_EN in *InNTERFACE_CTRL* register (0x0E). Value of the internal pull up varies between 30kΩ 50kΩ, depending on *VDD_IO*.

Sensor communication with the master controller remains active even if *VDD* is disconnected while *VDD_IO* is maintained. However, in this situation, the internal measurement cycle is turned off.

7 Quick start guide

7.1 Power-up sequence

The sensor is powered up when supply voltage is applied to *VDD* and *VDD_IO* pins. During the power up sequence, it is recommended to keep the I^2C interface pins in the high impedance state from the host controller side.

During the power up sequence of the sensor, the sensor performs a boot process. During this process, trimming parameters and calibration coefficients are loaded to the internal registers from the embedded non-volatile memory. The booting process lasts for a maximum of 4.5 milliseconds. During this period, the internal registers are not accessible to read or write the data. However, the status of the boot procedure can be checked by reading the BOOT bit in the *INT_SOURCE* register (0x24). This bit is set to '1' during the boot procedure and automatically goes back to '0' once it has ended. At the end of the power-up sequence the sensor automatically enters into power-down mode and is ready for data measurements.

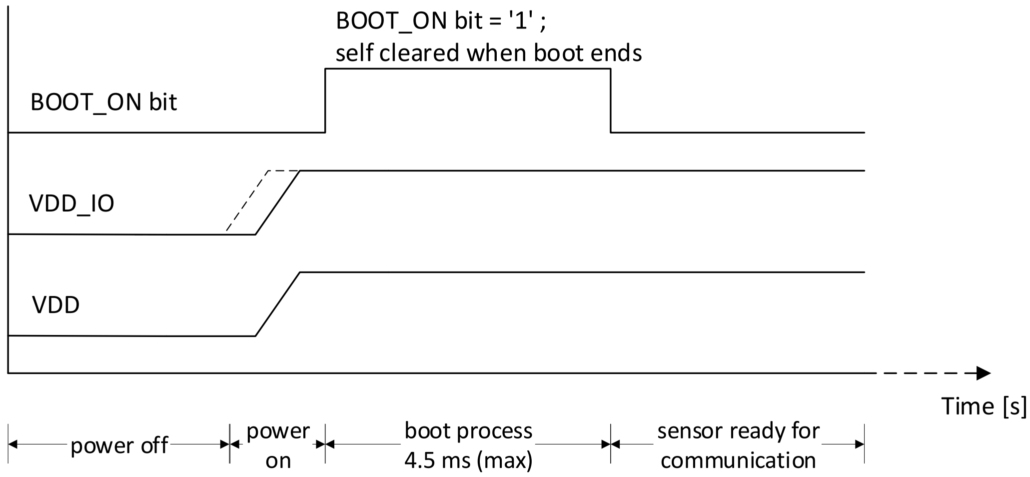


Figure 16: Power-up sequence

7.2 Communication with host controller

Communication with the host controller via I²C interface can be checked by reading the *DEVICE_ID* register (0x0F). Device ID for this sensor is 0xB3.

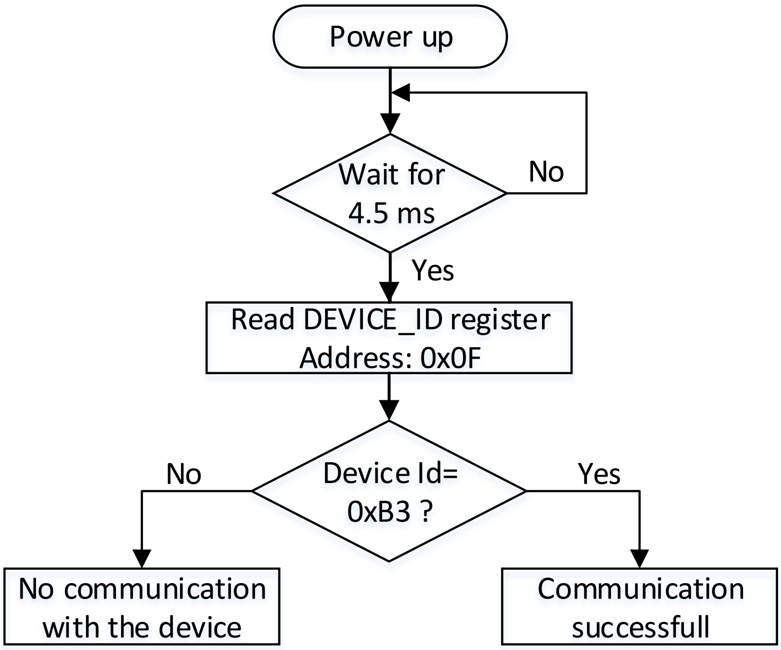


Figure 17: Communication check with host controller

7.3 Reboot

Reboot procedure can be also performed by the user in case the trimming parameters are somehow modified during operations. The Reboot procedure restores the correct values and resets the offset calibration registers *OPC_L* (0x18) and *OPC_H* (0x19) to '0'

When the BOOT bit in the *CTRL_2* register (0x11) is set to '1', the trimming parameters are copied to the corresponding internal registers and are used to calibrate the device. At the end of the reboot process the BOOT bit is self cleared to '0'.

Status of the reboot procedure can be checked by the BOOT_ON bit as mentioned in the section `7.1`

7.4 Software reset

To set the internal registers to the default values, software reset can be performed. It is done by setting the SWRESET bit in the *CTRL_2* register (0x11) to '1'. Following registers are reset to their default values during the software reset.

- *INTERRUPT_CFG* (0x0B)
- *THR_P_L* (0x0C)
- *THR_P_H* (0x0C)

- *INTERFACE_CTRL* (0x0E)
- *CTRL_1* (0x10)
- *CTRL_2* (0x11)
- *CTRL_3* (0x12)
- *FIFO_CTRL* (0x13)
- *FIFO_WTM* (0x14)
- *INT_SOURCE* (0x24)
- FIFO_STATUS1 (0x25)
- FIFO_STATUS2 (0x26)
- *STATUS* (0x27)

The software reset procedure lasts for a maximum of 50 µs. At the end of the software reset, the SWRESET bit in *CTRL_2* register (0x11) is automatically set back to '0'.

The reboot and software reset procedure must not be executed simultaneously. Both processes can be executed serially as shown in Figure 18

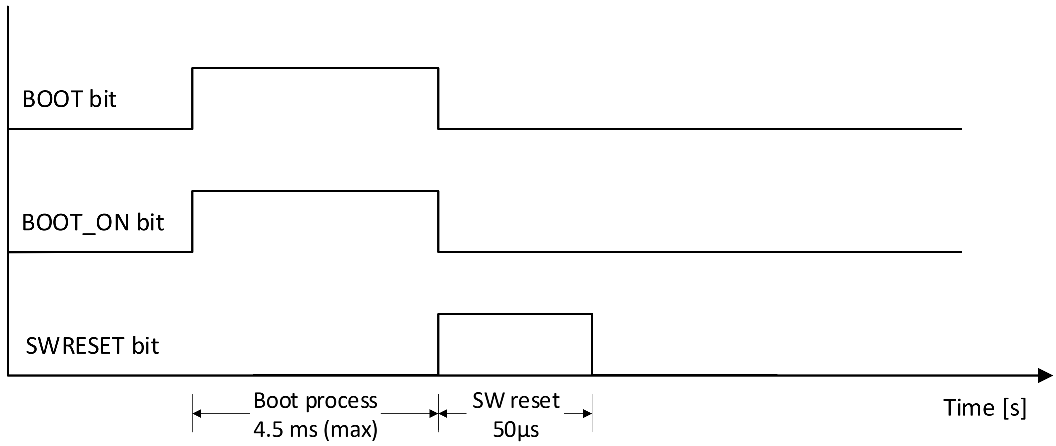


Figure 18: Reboot and software reset sequence

Do not set BOOT and SWRESET bits to '1' at the same time.

7.5 Sensor operation: single conversion mode

Flow chart shows sensor operation in the single conversion mode.

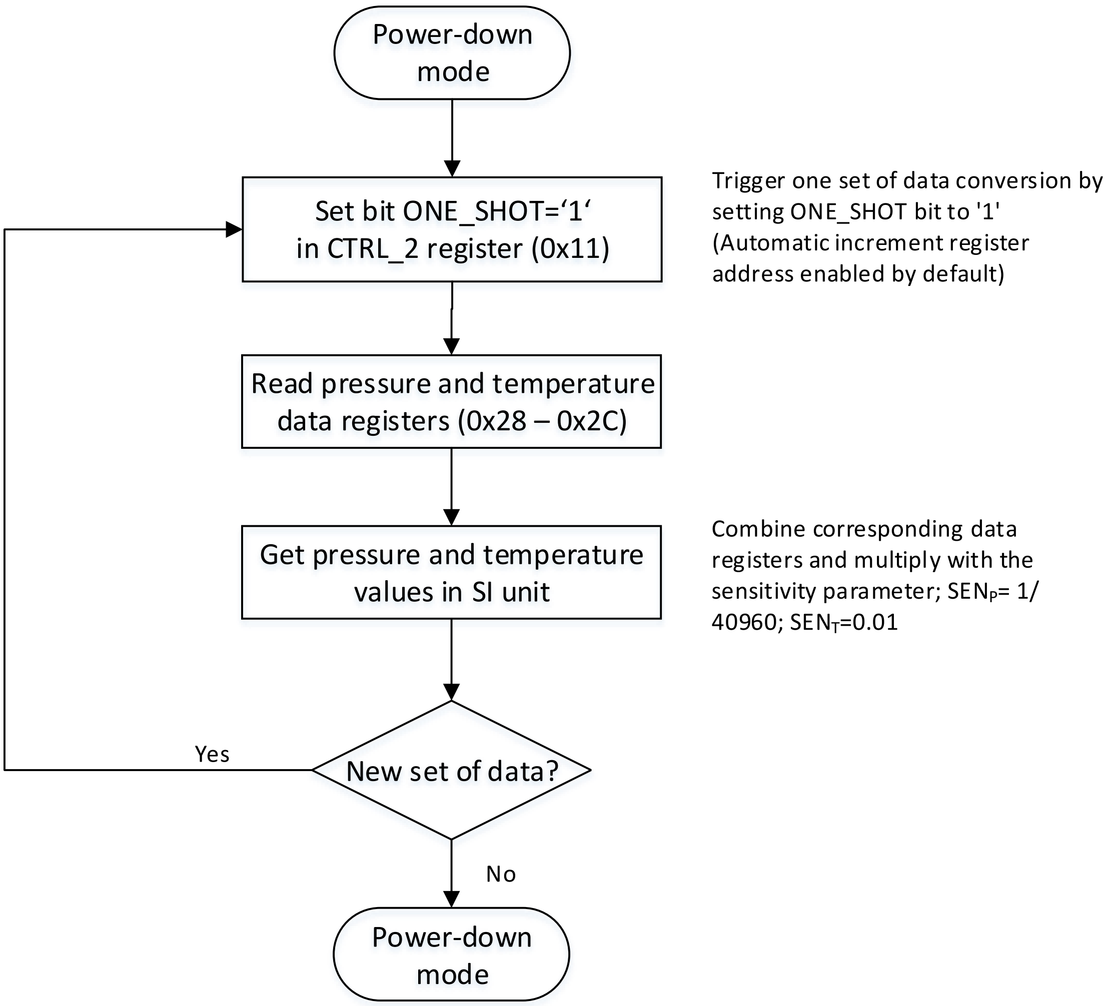


Figure 19: Sensor operation: single-conversion mode

7.6 Sensor operation: continuous mode

Flow chart shows sensor operation in continuous mode with 50Hz ODR and low-noise configuration enabled.

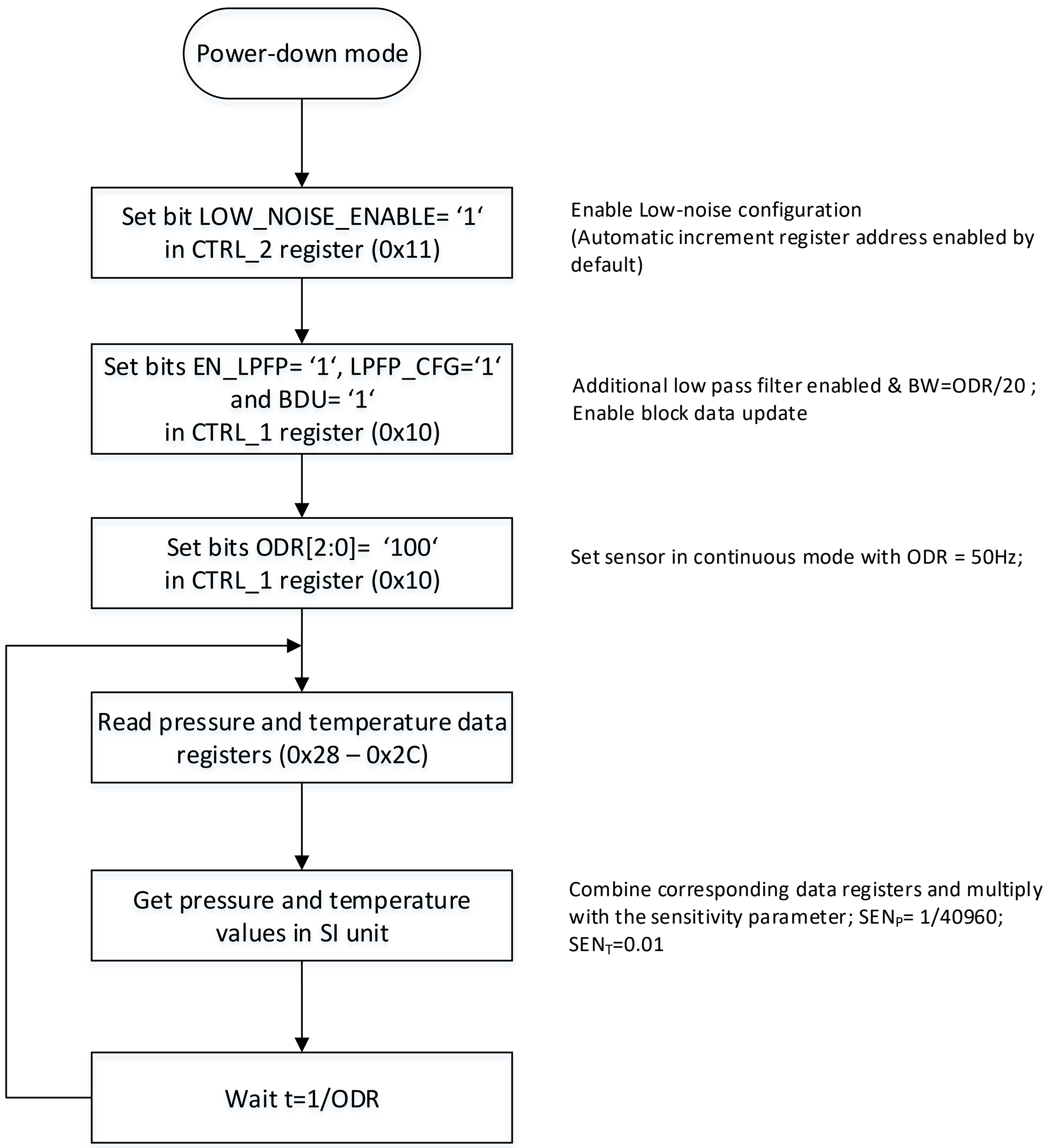


Figure 20: Sensor operation: continuous mode

7.7 Power-off sequence

VDD rise/fall time for the sensor varies between 10 µs and 100 ms. For proper device power off, it is recommended to drive the *VDD* pin to *GND* or less than 0.2 V and keep it stable at this level for at least 10 ms.

This procedure is also necessary to guarantee the next power-on and boot procedure to be successful.

8 Modes of operation

The sensor can be configured to be used in the following 3 different modes.

1. Power-down mode
2. Single conversion mode
3. Continuous mode

Additionally, the device can be operated in either low-power or low-noise configuration. Transition to/from one of the operating modes and configurations can be executed by writing to specific registers.

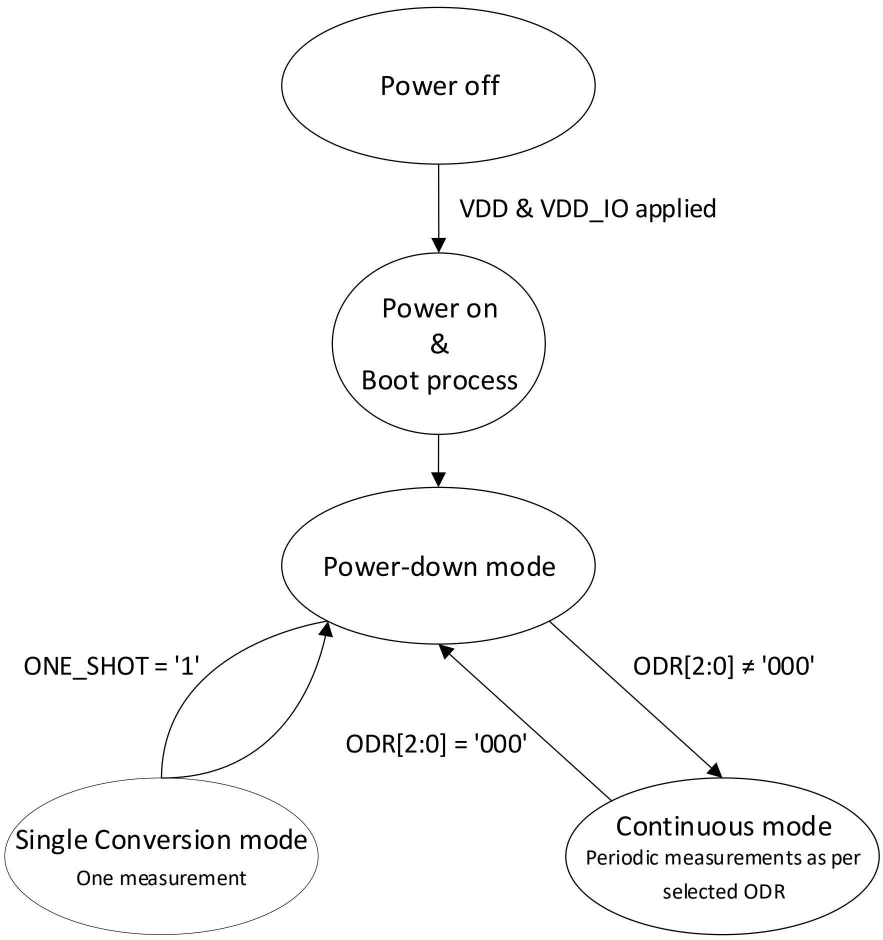


Figure 21: Operating modes

8.1 Power-down mode

The power-down mode can be configured by setting the ODR[2:0] bits of *CTRL_1* register (0x10) to '000'.

In power-down mode the digital chain that samples the pressure and temperature values is turned off. No new measurement is performed during this mode. Hence, the data registers containing pressure and temperature values are not updated. The data registers contain the last sampled pressure and temperature data before going into power-down mode. Current consumption is at the minimum during this mode.

However, serial communication with the host controller via I^2C bus is still possible. This allows the user to configure the device by accessing the configuration/control registers. Data of the control registers remains unaffected when the sensor is configured to power-down mode from another mode.

Sensor is in power-down mode by default after the power-up sequence.

8.2 Single conversion mode

In this mode single measurement of pressure and temperature is performed according to the request of the host controller. This mode can be activated only when the sensor is in the power-down mode. When ONE_SHOT bit of *CTRL_2* register (0x11) is set to ’1’, the digital chain is turned on, data conversion starts and a single measurement of pressure and temperature is acquired. This measurement data is written in the respective pressure and temperature data registers. Afterwards, the digital chain is turned off again and the sensor enters the power-down mode. The ONE_SHOT bit of *CTRL_2* register (0x11) automatically returns to ’0’ (default value). The data registers are not updated until another data acquisition is requested by the host controller. This mode is useful when the application demands reduced power consumption.

During this mode the output data rate (ODR) of new measurement depends on the new measurement request from the host controller (frequency at which the ONE_SHOT bit is set to ’1’).

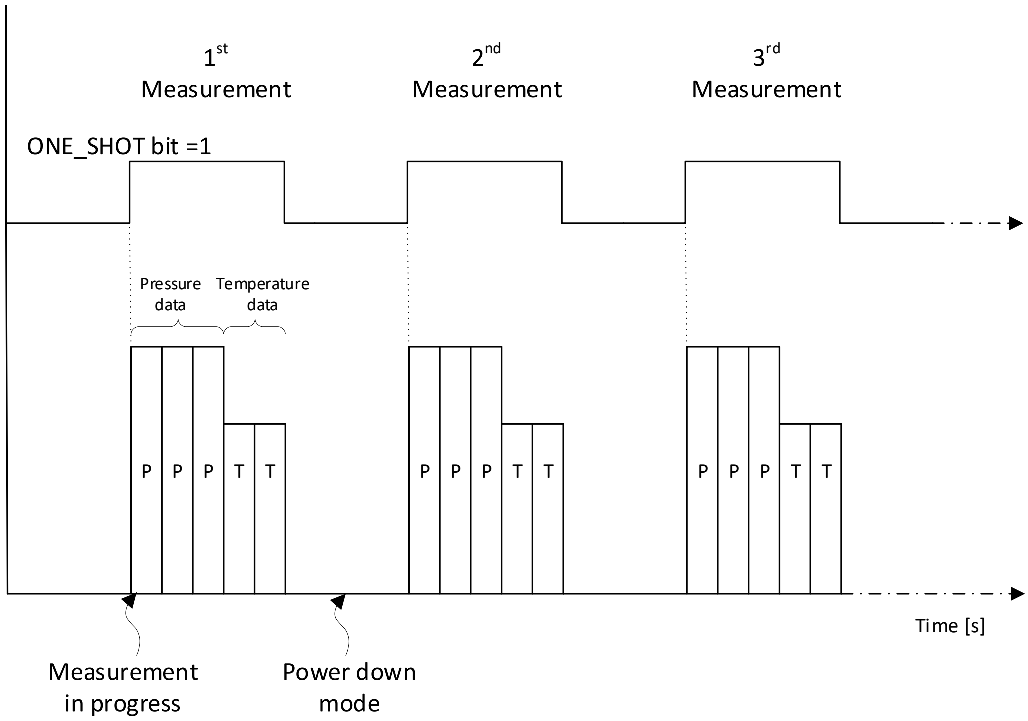


Figure 22: Single conversion mode

Figure 12 shows typical data conversion time in low-power and low-noise configuration.

Configuration	Conversion time [ms]
Low-power	4.7
Low-noise	13.2

Table 12: Data conversion time

8.3 Continuous mode

The sensor is configured in the continuous mode when the ODR[2:0] bits of CTR_1 register (0x10) are set to a value other than '000'. The continuous mode constantly samples new pressure and temperature measurements and writes the data to the corresponding data registers. The measurement rate is defined by the user selectable output data rate (ODR) which can be set by ODR[2:0] bits of *CTRL_1* register. Selectable ODR and corresponding register settings are shown in the table 13

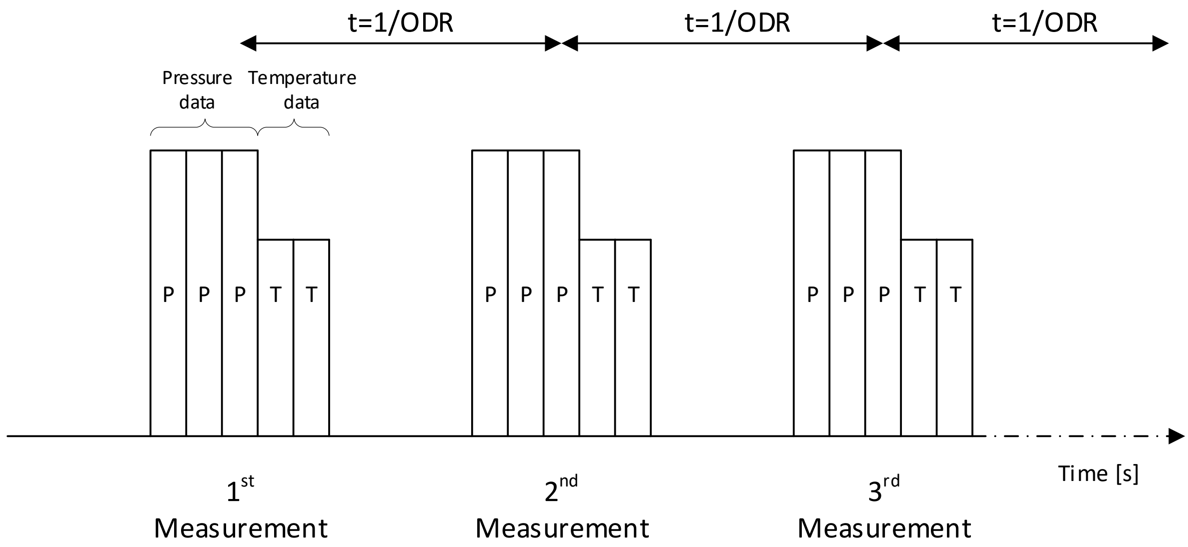


Figure 23: Continuous mode

ODR[2:0]	Output data rate [Hz]
000	Power-down mode / One-shot mode
001	1
010	10
011	25
100	50
101	75
110	100
111	200

Table 13: Output data rate selection

8.4 Additional configurations

During continuous mode and single conversion mode, additional configurations can be selected. These include enabling the additional low pass filter; selecting either low-power or low-noise configuration.

8.4.1 Low-power or low-noise configuration

In the low-power configuration, the device is configured to minimize the current consumption. In the low-noise configuration, the device is configured to reduce the noise. During the continuous mode and single conversion mode, either one of these configurations can be selected as shown in Table 14. By default the sensor operates in the low-power configuration.

Address	Register	Bit	Bit value	Configuration
0x11	*CTRL_2*	LOW_NOISE_EN	0	Low-power (default)
0x11	*CTRL_2*	LOW_NOISE_EN	1	Low-noise

Table 14: Low-power/low-noise configuration

To ensure the proper behaviour of the device, LOW_NOISE_EN bit must changed only when it is in the power-down mode.

Table 15 shows typical conversion time and maximum allowable ODR in each operating mode.

Configuration	Typical data conversion time [ms]	Maximum ODR [Hz]	
		Single conversion mode	Continuous mode
Low-power	4.7	200	200
Low-noise	13.2	50	75

Table 15: Typical conversion time and maximum ODR

Low-noise configuration is not available at ODR 100 Hz or 200Hz. If ODR is set to 100Hz or 200Hz, LOW_NOISE_EN bit must be set to '0'.

8.4.2 Enabling additional low-pass filter

The sensor embeds two digital low-pass filters. First low-pass filter LPF1 is always applied to the pressure and temperature data. The second low-pass filter LPF2 can be optionally enabled and applied to the pressure data. This configuration is available for both continuous mode and single conversion mode.

The second low-pass filter LPF2 can be enabled by setting the EN_LPFP bit in the *CTRL_1* register (0x10) to '1'. Further, overall device bandwidth can also be configured by changing LPFP_CFG bit of the *CTRL_1* (0x10) register. LPF2 is applied only to the pressure data.

EN_LPFP	LPFP_CFG	LPF2 status	Device Bandwidth	Samples to be discarded
0	x	Disabled/reset filter	ODR/2	0
1	0	Enabled	ODR/9	2
1	1	Enabled	ODR/20	2

Table 16: Additional low-pass filter setting

When EN_LPF bit in the *CTRL_1* (0x10) is changed from '1' to '0', the filter is reset. The filter is also reset when the ODR or device bandwidth is changed. Table 16 indicates the number of samples to be discarded when the filter is enabled or reset. The output data is not considered meaningful before the filter reaches the settling condition.

9 Reading output data

Once the device is configured in one of the operating modes, pressure and temperature values are sampled and stored in the respective data registers, available for the user to read.

> It is recommended to read the data registers starting from the lower address to the higher address.

9.1 Reading pressure values

Pressure values are stored in the three data registers: *DATA_P_XL*, *DATA_P_L* and *DATA_P_H*. Each register contains 8-bits data. The complete pressure data is represented as a 24-bit signed 2's complement word. This can be obtained by concatenating the three 8-bit pressure data registers: *DATA_P_H*, *DATA_P_L* & *DATA_P_XL*, with *DATA_P_H* being most significant byte and *DATA_P_XL* being least significant byte.

After calculating the 24-bit digital pressure value, it must be multiplied with the sensitivity parameter, SEN_P (see table 4) in order to obtain the corresponding pressure in SI unit (Pa).

Step 1: Reading raw data from the three pressure data registers

1. *DATA_P_XL* (0x28)
2. *DATA_P_L* (0x29)
3. *DATA_P_H* (0x2A)

Step 2: Concatenating pressure data registers to obtain complete 24-bit pressure value

$$P_{24bit} = DATA\_P\_H \,\&\, DATA\_P\_L \,\&\, DATA\_P\_XL$$

Step 3: Obtaining pressure value in SI unit (Pa) by multiplying with sensitivity parameter

$$\text{Pressure [Pa]} = P_{24bit}\,\text{[digit]} \times \frac{1}{40960}\,\text{[Pa/digit]}$$

Example:

If values obtained from pressure data registers are:

DATA_P_XL = 0x00
DATA_P_L = 0x54
DATA_P_H = 0x3F

Concatenating these 3 registers (0x3F5400) to obtain 24-bit signed decimal value and multiplying with the sensitivity parameter

$$P_{24bit}\text{[digit]} = 4150272 \text{ [digit]}$$

$$P\text{[kPa]} = 4150272 \text{ [digit]} * 1/40960 \text{ [kPa/digit]} = 101.325 \text{ kPa}$$

9.2 Reading temperature values

Temperature values are stored in the two data registers: *DATA_T_L* and *DATA_P_H*. Each register contains 8-bits data. The complete temperature data is a 16-bit signed 2's complement word. This can be obtained by concatenating the two 8-bit temperature data registers: *DATA_T_H* & *DATA_P_L*, with *DATA_T_H* being most significant byte and *DATA_T_L* being least significant byte.

After calculating the 16-bit digital temperature value, it must be multiplied with the sensitivity parameter, SEN_T (see table 5) in order to obtain the corresponding temperature in SI unit (℃).

Step 1: Reading raw data from the two temperature data registers

1. *DATA_T_L* (0x2B)
2. *DATA_T_H* (0x2C)

Step 2: Concatenating the temperature data registers to obtain complete 16-bit temperature value

$$T_{16bit} = DATA\_T\_H \ \& \ DATA\_T\_L$$

Step 3: Obtaining temperature value in SI unit [℃] by multiplying with sensitivity parameter

$$\text{Temperature [℃]} = T_{16bit} \text{ [digit]} \times 0.01 \text{ [℃/digit]}$$

Example:

If values obtained from temperature data registers are:

DATA_T_L = 0x42
DATA_T_H = 0x0E

Concatenating these 2 registers (0x0E42)to obtain 16-bit signed decimal value and multiplying with sensitivity parameter

$$T_{16bit}\text{[digit]} = 3650 \text{ [digit]}$$

$$T\text{[℃]} = 3650 \text{ [digit]} * 0.01 \text{ [℃/digit]} = 36.50 \text{ ℃}$$

9.3 Status register for reading the data

The sensor has a *STATUS* register (0x27) that can be used to check when a new set of pressure or temperature data is available in the corresponding data register.

P_DA bit is set to '1' whenever a new sample is available in the pressure data registers. P_DA bit is self cleared and set back to '0' when the corresponding pressure data (most significant byte, *DATA_P_H*) has been read.

Same way, T_DA bit is set to '1' whenever a new set of data is available in the temperature data registers. T_DA bit is self cleared and set back to '0' when the corresponding temperature data (Most significant byte, *DATA_T_H*) has been read.

Bits P_OR and T_OR of the *STATUS* register (0x27) are overrun flags for pressure and temperature data respectively. Whenever a previous pressure or temperature sample in the data register is overwritten without being read by the user, P_OR and T_OR bits are set to '1', indicating that previous value has been lost. P_OR and T_OR bit will be set to '1' in case a new pressure or temperature data is measured while the corresponding x_DA bit is still '1'. They are automatically set to '0' when all data from the corresponding data registers have been read and no new measurement is generated in the meantime.

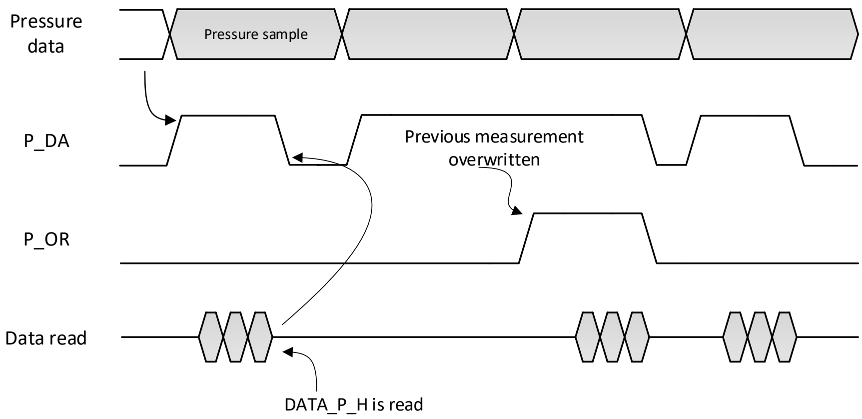


Figure 24: Reading pressure data using *STATUS* register

Since, pressure and temperature data are synchronously generated, P_DA and T_DA synchronously rises to '1' (unless one of the bit is already one). However, they would not synchronously reset to '0' as it depends on when the corresponding data is read.

Reading the data registers (pressure and temperature) before 1/ODR time period allows acquisition of all data and resetting P_DA and T_DA before the overrun flags are set.

If the sensor is configured in the single conversion mode, the STATUS register will not be updated after the first measurement because the sensor goes to power down mode after the first acquisition.

10 FIFO buffer

The sensor has an embedded first-in, first-out (FIFO) buffer that can store upto 128 sets of pressure and temperature data. Each data set consists of 5 bytes of data (3 bytes pressure and 2 bytes temperature). This allows considerable power saving of the system because the host controller does not have to continuously poll for new data from the sensor. The host controller can be notified via the *INT* pin when it is required to read the data from FIFO buffer. FIFO events can be used to generate interrupt via *INT* pin.

FIFO can be operated in six different user selectable modes.

- Bypass mode
- FIFO mode
- Continuous mode
- Bypass-to-FIFO mode
- Bypass-to-continuous mode
- Continuous-to-FIFO mode

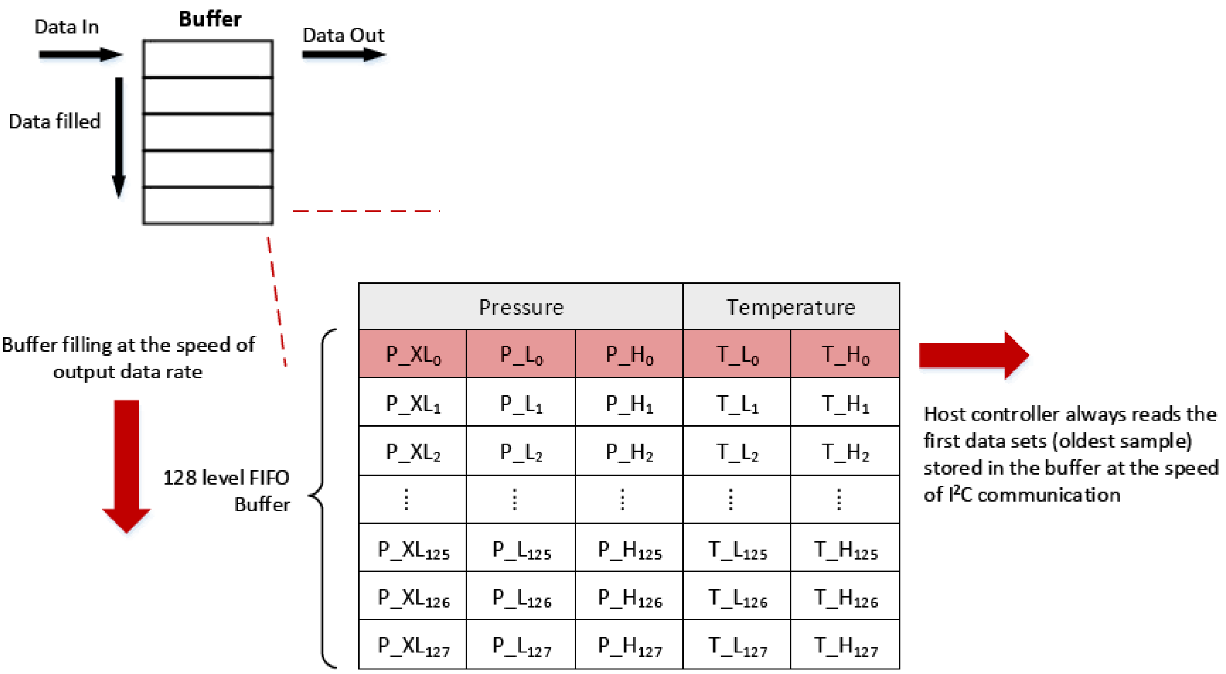


Figure 25: First-In-First-Out buffer

FIFO behaves as a circular buffer. The buffer is filled with new data set (pressure and temperature) in the first available empty slot. Once the buffer is full, FIFO either stops filling the new data sets or the oldest data set is replaced by the new data sets.

When FIFO is enabled, pressure and temperature data is sent to the FIFO buffer at the selected ODR in the *CTRL_1* register. The host controller can read the data stored in FIFO buffer. The oldest data set is always read first. FIFO modes can be configured from *FIFO_CTRL* register. (0x13).

FIFO_CTRL [2:0]			FIFO Mode
TRIG_MODE	F_MODE[1]	F_MODE[0]	
x	0	0	Bypass mode
0	0	1	FIFO mode
0	1	x	Continuous mode
1	0	1	Bypass-to-FIFO mode
1	1	0	Bypass-to-Continuous mode
1	1	1	Continuous-to-FIFO mode

Table 17: FIFO mode settings

10.1 Bypass mode

FIFO buffer is not in operation in the bypass mode. By default the FIFO buffer is in bypass mode and FIFO remains empty. Each new data set is directly available in the respective data (DATA_P_x, DATA_T_x) registers (See Figure 26)

The device can be configured in the bypass mode by writing '000' or '100' to register FIFO_CTRL[2:0].

Enabling bypass mode clears the FIFO buffer and must be used while switching between other FIFO modes.

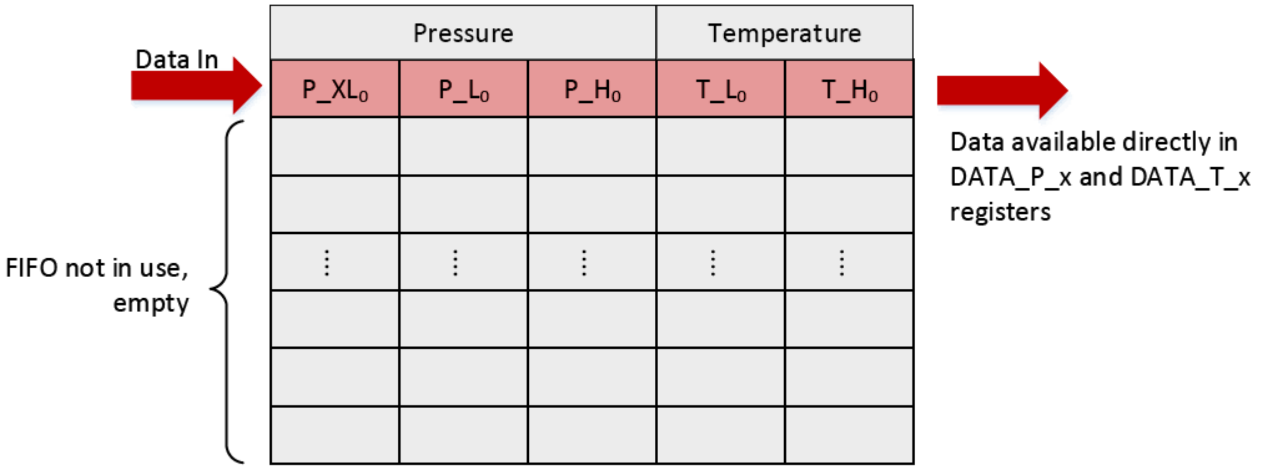


Figure 26: Bypass mode

10.2 FIFO mode

This mode is enabled by settings bits [2:0] of *FIFO_CTRL* (0x13) to '001'.

In this mode, each data set (pressure and temperature) is stored in the FIFO buffer at selected ODR. The FIFO buffer keeps filling untill it is full or reaches the user-defined FIFO threshold (see section 10.7.1).

FSS[7:0] bits in *FIFO_STATUS_1* register (0x25) shows the number of data sets stored in FIFO buffer. This register is updated every 1/ODR period.

Once the FIFO is full, bit FIFO_FULL_IA or FIFO_WTM_IA (if user defined FIFO threshold level is enabled) in the *FIFO_STATUS_2* register (0x26) will be set to '1', and buffer stops storing new data sets. At this point data in the FIFO buffer will remain unchanged and further measured data sets will be lost. Data stored in FIFO buffer can be read from five FIFO_DATA_x_x registers(0x78-0x7C). See section (see section 10.7.2)

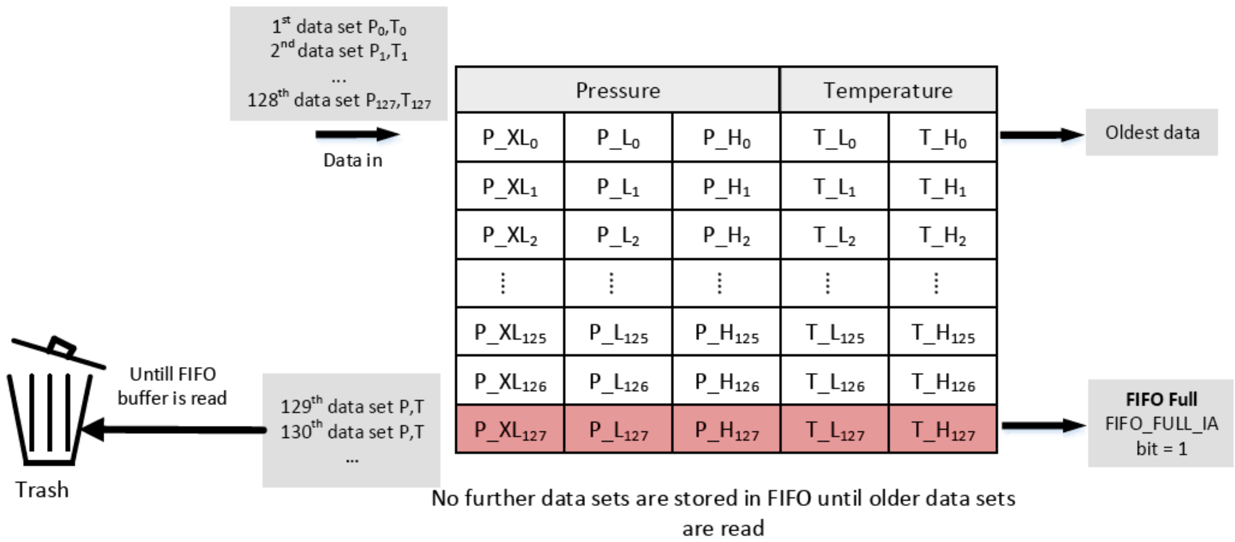


Figure 27: FIFO mode

In order to fill the FIFO buffer with new sets of measurement data, the device must be first configured in the bypass mode to reset the FIFO buffer and then again in the FIFO mode.

10.3 Continuous mode

This mode is enabled by settings bits [2:0] of *FIFO_CTRL* (0x13) to ’010’ or ’011’.

In this mode, each data set (pressure and temperature) is stored in the FIFO buffer at selected ODR. Once the FIFO buffer is full or reaches the user-defined FIFO threshold, oldest data sets will be overwritten by the new data sets, meaning older data sets will be lost.

FSS[7:0] bits in *FIFO_STATUS_1* register (0x25) indicate the number of data sets stored in FIFO buffer. This register is updated every 1/ODR period.

Once the FIFO is full, bit FIFO_FULL_IA or FIFO_WTM_IA (if user defined FIFO threshold level is enabled) in the *FIFO_STATUS_2* register (0x26) will be set to ’1’. At this point, older data sets are replaced by new data sets and FIFO_OVR_IA bit in the *FIFO_STATUS_2* register (0x26) goes to ’1’, indicating that at least one data set has been overwritten.

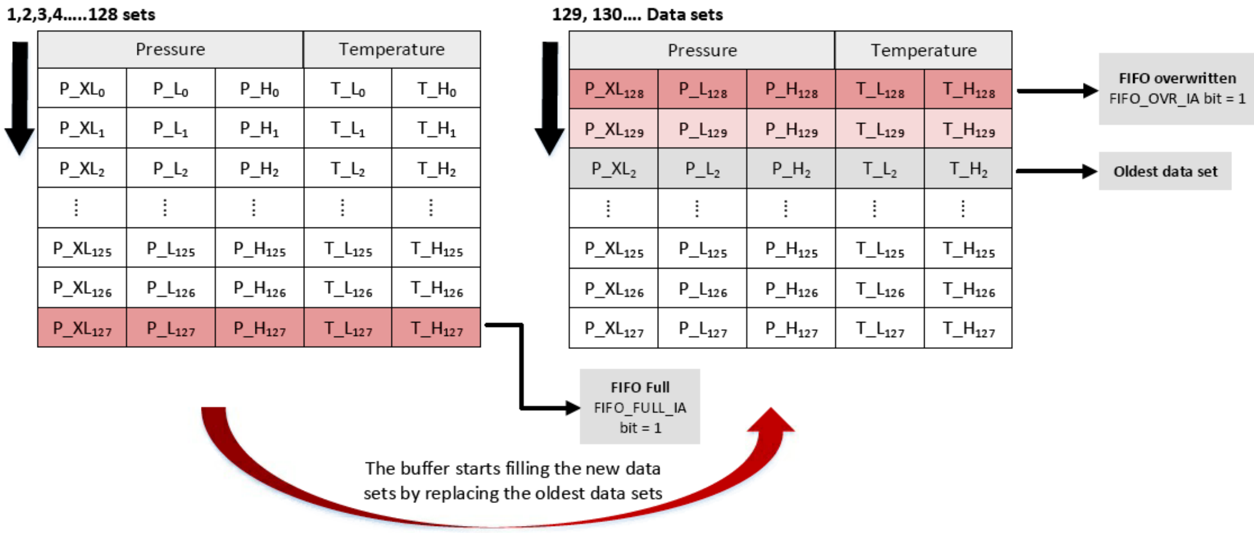


Figure 28: Continuous mode

If FIFO buffer is overwritten without a read operation, bits FIFO_FULL_IA and FIFO_WTM_IA are set back to ’0’ after the first data set is overwritten.

New data sets will continue to overwrite the old data sets until a read operation is initiated by the host controller or the FIFO is reset. In order to avoid losing the older data sets, data must be read faster than the ODR. Host controller can be alerted about FIFO full or FIFO overwritten event by routing the status of FIFO_FULL_IA, FIFO_WTM_IA or FIFO_OVR_IA to the *INT* pin of the device through corresponding bits of *CTRL_3* register (0x12).

10.4 Bypass-to-FIFO mode

This mode is enabled by settings bits [2:0] of *FIFO_CTRL* (0x13) to '101'.

In this mode, initially FIFO buffer is in bypass mode. When an interrupt trigger event is generated, FIFO switches from bypass mode to FIFO mode and starts filling the slots with measurement data sets until the buffer is full.

Switching from the bypass mode to the FIFO mode can be triggered by an interrupt event selected by user through *INT_CFG* (0x0B) register. The selected event generation leads IA bit of *INT_SOURCE* (0x24) register to rise to '1'. When this bit rises to '1' for the first time, the buffer switches to FIFO mode.

When the IA bit goes back to '0', FIFO does not switch back to bypass mode.

10.5 Bypass-to-continuous mode

This mode is enabled by settings bits [2:0] of *FIFO_CTRL* (0x13) to '110'.

In this mode, initially FIFO buffer is in bypass mode. When an interrupt trigger event is generated, FIFO switches from bypass mode to continuous mode and starts filling the slots with measurement data sets; once FIFO is full, it will overwrite old data sets with the new data.

Switching from the bypass mode to the continuous mode can be triggered by an interrupt event selected by the user through *INT_CFG* (0x0B) register. The selected event generation leads IA bit of *INT_SOURCE* (0x24) register to rise to '1'. When this bit rises to '1' for the first time, FIFO switches to continuous mode.

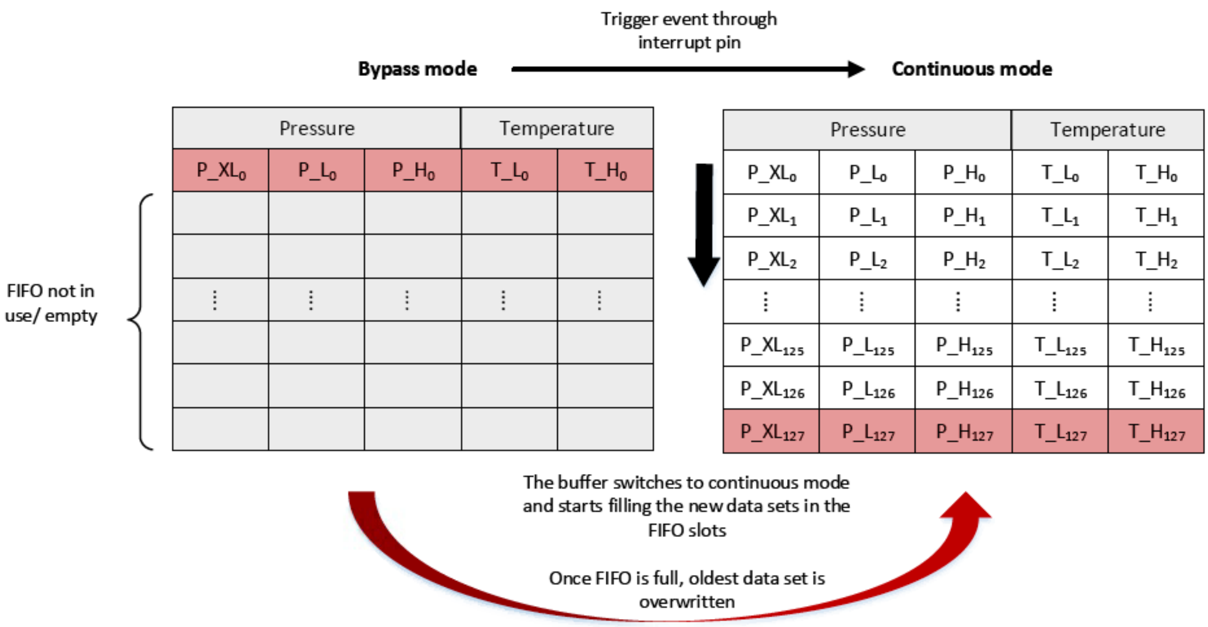


Figure 29: Bypass-to-Continuous mode

When the IA bit goes back to '0', FIFO does not switch back to bypass mode.

10.6 Continuous-to-FIFO mode

This mode is enabled by settings bits [2:0] of *FIFO_CTRL* (0x13) to '111'.

In this mode, initially FIFO buffer is in continuous mode. When an interrupt trigger event is generated, FIFO switches from continuous mode to FIFO mode and continues to fill the slots with the data sets; once FIFO is full, it will stop storing the data in the FIFO buffer.

Switching from continuous to FIFO mode can be triggered by an interrupt event selected by the user through *INT_CFG* (0x0B) register. The selected event generation leads IA bit of *INT_SOURCE* (0x24) register to rise to '1'. When this bit rises to '1' for the first time, the buffer switches to FIFO mode.

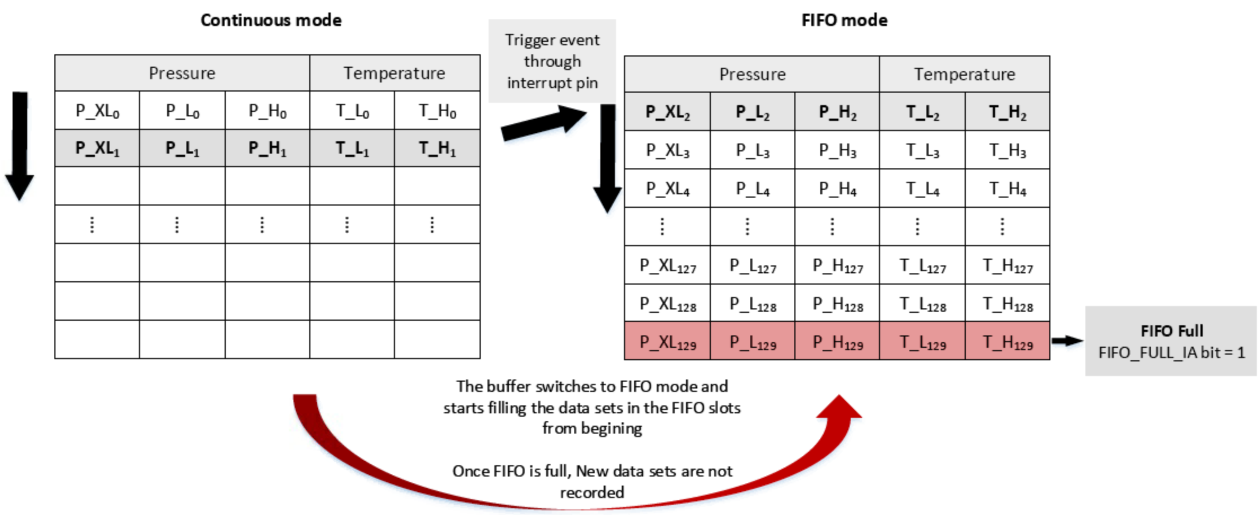


Figure 30: Continuous-to-FIFO mode

When the IA bit goes back to '0', FIFO does not switch back to continuous mode.

10.7 FIFO status monitoring and control

When FIFO is in operation, its status can be monitored by reading two registers, *FIFO_STATUS_1* (0x25) and *FIFO_STATUS_2* (0x26).

FIFO_STATUS_1 register shows the current number of data sets stored in the FIFO buffer. 0000000b indicates FIFO is empty and 1000000b indicates FIFO is full with 128 data sets.

FIFO_STATUS_2 register has 3 FIFO buffer flags.

- FIFO_WTM_IA flag indicates when FIFO buffer is equal to or higher than user defined FIFO threshold level (only if this feature is enabled through *FIFO_CTRL* register). The status of this flag can be routed to *INT* pad of the sensor via *CTRL_3* register by setting INT_F_WTM bit to '1'.
- FIFO_OVER_IA flag indicates when FIFO is full and at least one data set is overwritten with a new one. The status of this flag can be routed to *INT* pad of the sensor via *CTRL_3* register by setting INT_F_OVR bit to '1'.
- FIFO_FULL_IA flag indicates when FIFO is completely filled with 128 data sets. The status of this flag can be routed to *INT* pad of the sensor via *CTRL_3* register by setting INT_F_FULL bit to '1'.

10.7.1 User-defined FIFO threshold

Normally, FIFO can be filled with 128 sets of data. However, user can limit the FIFO buffer depth with *FIFO_WTM* (0x14) register. The user can define the required FIFO threshold level by setting bits WTM[6:0] of *FIFO_WTM* registers to the corresponding value. Maximum allowable value in this register is 0x7F.

The user-defined FIFO threshold has to be enabled by setting STOP_ON_WTM bit of *FIFO_CTRL* (0x13) register to '1'. When enabled, the FIFO level size will be considered as the value defined im the *FIFO_WTM* register.

STOP User-defined FIFO threshold level can not be changed when FIFO is already in operation.

10.7.2 Reading data from FIFO buffer

When FIFO buffer is in operation, the data stored in FIFO is available to read from dedicated FIFO data registers. Pressure values can be read from FIFO_P_x (0x78 to 0x7A) and temperature values can be read from FIFO_T_x (0x7B to 0x7C) registers. Every time a data set is read, remaining oldest entry in the FIFO buffer is placed in the FIFO data registers, available to be read. FIFO status registers *FIFO_STATUS_1* (0x0x25) and *FIFO_STATUS_2* (0x0x26) are also updated accordingly.

FIFO data registers (0x78-0x7C) can be read with multi read/write feature which is enabled by default. Number of read operations can be determined based on the number of data sets stored in the FIFO buffer. The current number of data sets stored in the FIFO buffer can be known by reading *FIFO_STATUS_1* (0x0x25) register.

STOP If differential interrupt is enabled (bit DIFF_EN = '1') with AUTOZERO mode (bit AUTOZERO = '1'), then FIFO buffer will contain values other than the standard pressure data registers.

11 Interrupt functionality

The sensor has a dedicated interrupt generator which generates various interrupt events. The interrupt events can be monitored via dedicated status registers. Available interrupt events and their dedicated status registers are listed below.

- Pressure data ready event (*STATUS* register (0x27))
- Based on pressure threshold (*INT_SOURCE* register (0x24))
  - Pressure high
  - Pressure low
  - Pressure high or low
- FIFO status (*FIFO_STATUS_2* register (0x26))
  - FIFO full
  - FIFO overrun
  - FIFO threshold

11.1 Interrupt generation on pressure data-ready

It is possible to generate a hardware signal through the *INT* pin of the sensor when a new set of measurement data is available. This feature can be used to trigger an external action synchronously as soon as a new set of data is available.

As mentioned in the section 9.3, P_DA bit in the *STATUS* register goes to '1', whenever a new set of pressure data is generated. This can be routed to the *INT* pin of the device by setting bit DRDY = 1 and INT_S[1:0] = 00 of *CTRL_3* register (0x12).

P_DA bit and the data-ready signal on *INT* resets after the most significant byte of pressure data is read.

Data-ready interrupt generation is only available for pressure data.

11.2 Interrupt generation based on pressure threshold

Interrupt can be generated on the differential pressure signal when DIFF_EN bit is set to ’1’. When differential pressure is above or below user-defined threshold pressure, an interrupt signal on the *INT* pin can be generated.

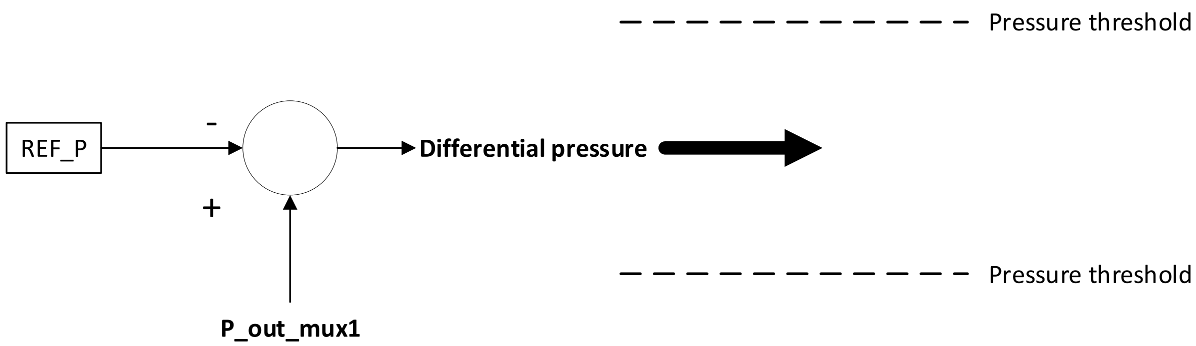


Figure 31: Differential pressure interrupt

DIFF_EN is used with either AUTOZERO or AUTOREFP configuration. When one of these configuration is enabled, the measured pressure is automatically stored in the REF_P (0x15-0x16) as a 16-bit signed value.

Measured pressure is a 3-byte long signed value, but REF_P contains the 2 most significant bytes of the measured pressure value

If AUTOZERO mode is engaged, the pressure data registers DATA_P_x (0x28-0x2A) are updated with the difference between the measured pressure and REF_P value. The differential pressure value is also updated with the difference between the measured pressure and REF_P value. During AUTOZERO configuration, DATA_P_x registers contain the differential pressure value and not the standard absolute pressure value.

- Differential pressure = measured pressured-REF_P
- Data_P_x = measured pressure-REF_P

To obtain the absolute pressure in kPa from the DATA_P_x registers in the AUTOZERO configuration, the DATA_P_x[digits] has to be divided by a factor of 160 [digits/kPa]

Bit AUTOZERO is set back to ’0’ after the first conversion but the configuration still remains active. To disable, bit RESET_AZ needs to be set to ’1’. RESET_AZ bit is set back to ’0’ automatically. This resets the REF_P registers to default value ’0’ and the pressure data registers DATA_P_x show default pressure data.

If AUTOREFP mode is engaged, the pressure data registers DATA_P_x (0x28-0x2A) will contain the measured pressured but the the differential pressure value will still be updated with the difference between the measured pressured and REF_P value.

- Differential pressure = measured pressured-REF_P
- Data_P_x = measured pressure

Bit AUTOREFP is set back to '0' after the first conversion but the configuration still remains active. To disable, bit RESET_ARP needs to be set to '1'. RESET_AZ bit is set back to '0' automatically. This resets the REF_P registers to default value '0'.

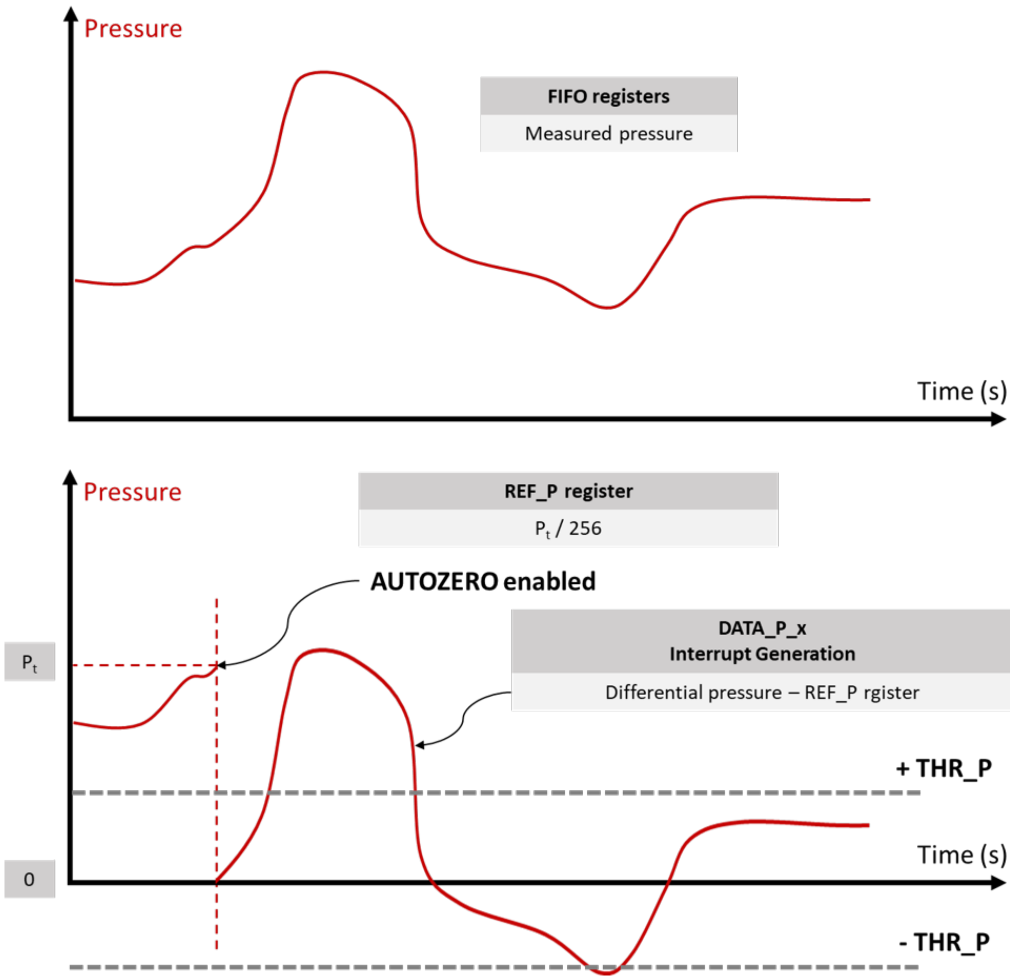


Figure 32: Interrupt generation with AUTOZERO enabled

The sensor has dedicated pressure threshold registers *THR_P_L* and *THR_P_H*, where user-defined pressure can be stored as a 15 bit unsigned value. Desired pressure threshold value can be stored in the THR_P_x registers as shown below.

$$\text{Pressure threshold [digit]} = \frac{\text{Pressure threshold [kPa]}}{SEN_P\text{[kPa/digit]} \times 256 \text{ [kPa/digit]}}$$

SEN_P = 1/40960 [kPa/digit]

Example:

If the pressure threshold for the interrupt is 10 kPa.
Pressure threshold = 10 [kPa] / (256/40960) [kPa/digit] = 1600 [digits]

Threshold pressure value is 0x0640

THR_P_L = 0x40
THR_P_H = 0x06

User defined pressure threshold is a 15-bit unsigned value which represents a differential pressure and not absolute pressure value.

When, bits PHE = '1' or PLE = '1' or both are set to '1', the differential pressure is compared to the user defined pressure value at each new sample generation and an interrupt signal is generated accordingly. Based on the status of the PHE and PLE bits, interrupt signals can be generated on the *INT* pin of the sensor.

PHE	PLE	Interrupt Event
1	0	Differential pressure is above the THR_P value (+THR)
0	1	Differential pressure is below the THR_P value (-THR)
1	1	Differential pressure is above or below the THR_P vlaue

Table 18: Interrupt based on pressure threshold

To enable the differential pressure interrupt with AUTOZERO configuration, bits AUTOZERO, DIFF_EN, PLE and/or PHE have to be set to '1'.

11.2.1 Interrupt latching

The interrupt generated based on the pressure threshold, can be also latched. Interrupt flags (PH, PL or IA) in the *INT_SOURCE* registers can be latched to their 'high' states, even if the condition that triggered their rise is not valid anymore. The interrupt flags only get reset when *INT_SOURCE* (0x24) register has been read.

Interrupt latching is enabled by setting LIR bit of *INT_CFG* (0x0B) register to '1'. In this case, when the IA bit rises to '1' it will remain in the same state until the *INT_SOURCE* is read.

Interrupt latching is also routed to the *INT* pin of the sensor if IA or PH or PL flags are routed to generate an interrupt.

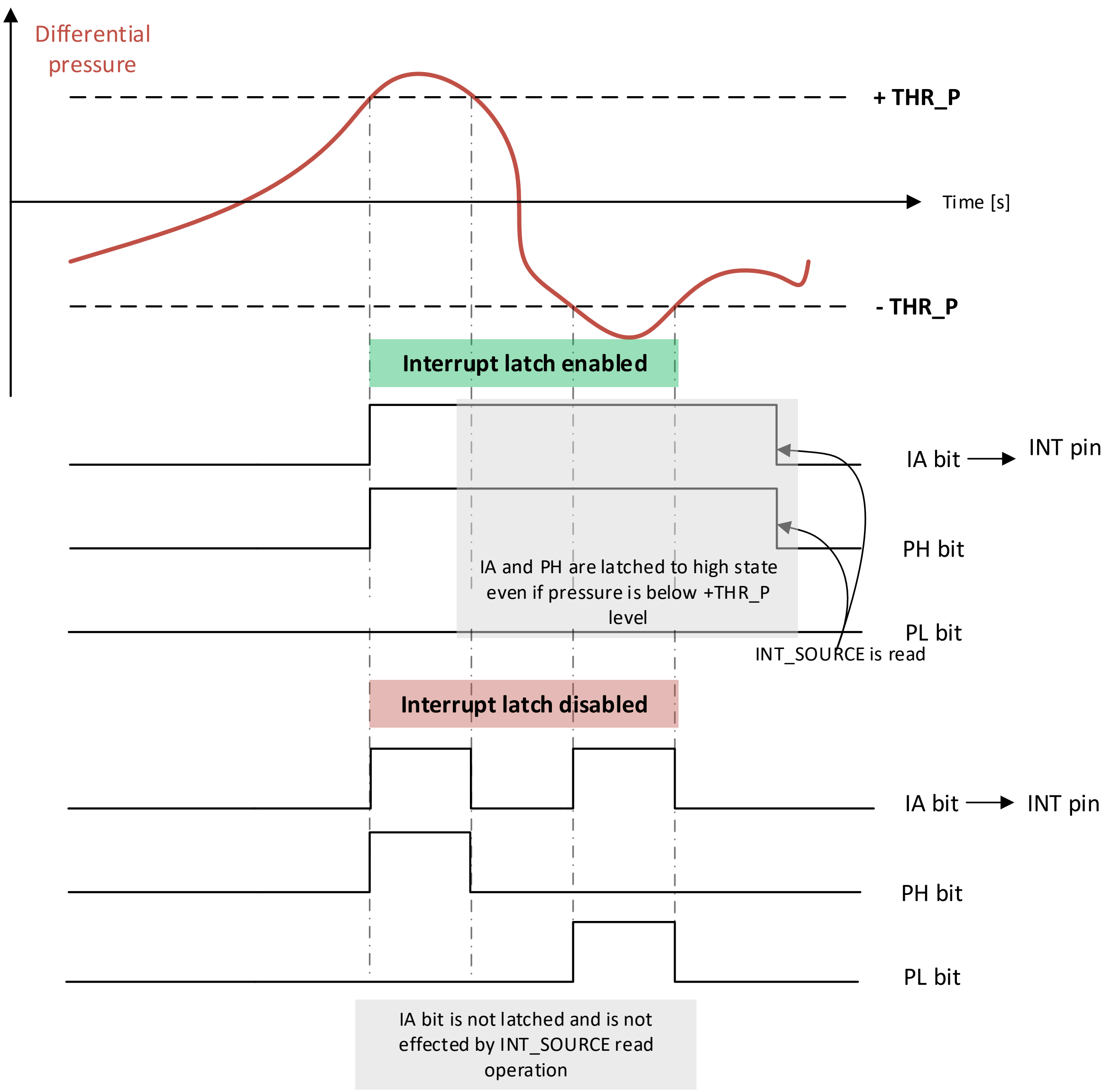


Figure 33: Interrupt latching

11.3 FIFO status based interrupt events

When FIFO is active, interrupt event can be generated based on the status of FIFO registers. Status of FIFO registers can be checked from *FIFO_STATUS_2* (0x26) register. By configuring the *CTRL_3* register, it is possible to route the event to the *INT* pin.

Bit	Bit value	Event
INT_F_FULL	1	FIFO is full
INT_F_WTM	1	User-defined FIFO threshold level is reached
INT_F_OVR	1	FIFO is full and at least one measurement is overwritten

Table 19: FIFO interrupts

FIFO modes can also be triggered from the interrupt events. When the bit IA in the *INT_SOURCE* register 0x24 is set to '1', following FIFO buffer mode can be triggered.

- Bypass-to-FIFO mode (when *FIFO_CTRL* bits [2:0] are set to '101')
- Bypass-to-Continuous mode (when *FIFO_CTRL* bits [2:0] are set to '110')
- Continuous-to-FIFO mode (when *FIFO_CTRL* bits [2:0] are set to '111')

11.4 Routing interrupt events to the *INT* pin

All the interrupt events can be individually selected and routed to the *INT* pin of the sensor from *CTRL_3* register.

Interrupt Event	Routing to *INT* pin
Pressure data ready	Bit DRDY = '1' and bits INT_S[1:0] = '00'
FIFO full	Bit INT_F_FULL = '1' and bits INT_S[1:0] = '00'
FIFO Overrun	Bit INT_F_OVR = '1' and bits INT_S[1:0] = '00'
FIFO threshold	Bit INT_F_WTM = '1' and bits INT_S[1:0] = '00'
Pressure high or low	Bit PLE or PHE= '1' and bits INT_S[1:0] = '11'
Pressure high	Bit PLE= '1' and bits INT_S[1:0] = '01'
Pressure low	Bit PLE= '1' and bits INT_S[1:0] = '10'

Table 20: Routing interrupt events to *INT* pin

It is also possible to route multiple interrupt events to the *INT*. The interrupt events are connected via logical OR operation and multiplexed to the *INT* pin (see figure 34). To know which interrupt event triggered the interrupt signal on *INT* pin, the corresponding status registers have to be read.

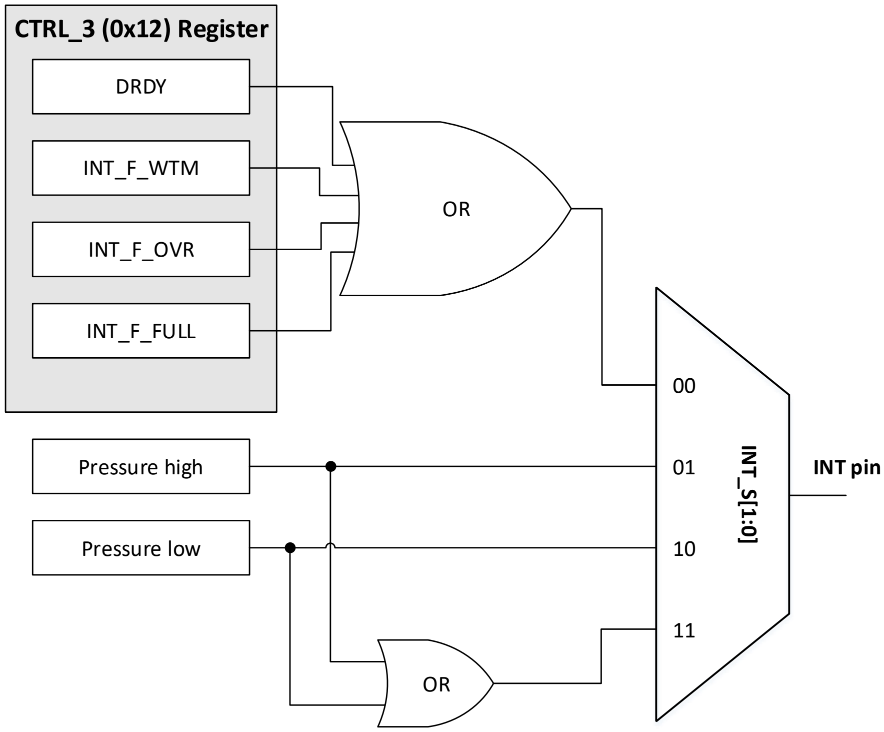


Figure 34: Routing interrupt events to *INT* pin

INT_S[1]	INT_S[0]	*INT* pin configuration
0	0	Data signal (priority order: DRDY or INT_F_WTM or INT_F_OVER or INT_F_FULL)
0	1	Pressure high event
1	0	Pressure low event
1	1	Pressure low or high event

Table 21: INT pin configuration

12 Register map

Addr.	Register Name	Type	Bits								Comments
			7	6	5	4	3	2	1	0	
0x0B	*INT_CFG*	R/W	AUTO REFP	RESET_ ARP	AUTO ZERO	RESET_ AZ	DIFF_ EN	LIR	PLE	PHE	Interrupt configuration register
0x0C	*THR_P_L*	R/W	THR[7:0]								Pressure threshold register
0x0D	*THR_P_H*	R/W	THR[15:8]								
0x0E	*INTERFACE_CTRL*	R/W	0	0	0	SDA_ PU_EN	SAO_ PU_EN	PD_ DIS_INT	0	I2C_ DIS- ABLE	Interface control register
0x0F	*DEVICE_ID*	R	1	0	1	1	0	0	1	1	Device ID register
0x10	*CTRL_1*	R/W	0	ODR[2:0]			EN_ LPFP	LPFP_ CFG	BDU	SIM	Control register-1
0x11	*CTRL_2*	R/W	BOOT	INT_H_L	PP_OD	IF_ADD_ INC	0	SW RESET	LOW_ NOISE_ ENABLE	ONE_ SHOT	Control register-2
0x12	*CTRL_3*	R/W	0	0	INT_F_ FULL	INT_F_ WTM	INT_F_ OVR	DRDY	INT_S[1:0]		Control register-3
0x13	*FIFO_CTRL*	R/W	0	0	0	0	STOP_ ON_WTM	TRIG_ MODES	F_MODE[1:0]		FIFO control register
0x14	*FIFO_WTM*	R/W	0	WTM[6:0]							FIFO threshold level
0x15	*REF_P_L*	R	REFL[7:0]								Reference pressure register
0x16	*REF_P_H*	R	REFH[15:8]								
0x18	*OPC_P_L*	R/W	OPCP[7:0]								Reference pressure register
0x19	*OPC_P_H*	R/W	OPCP[15:8]								
0x1A-0x23	Reserved		-								Reserved
0x24	*INT_SOURCE*	R	BOOT_ ON	0	0	0	0	IA	PL	PH	Interrupt register
0x25	*FIFO_STATUS_1*	R	FSS[7:0]								FIFO status registers
0x26	*FIFO_STATUS_2*	R	FIFO_ WTM_IA	FIFO_ OVR_IA	FIFO_ FULL_IA	0	0	0	0	0	
0x27	*STATUS*	R	0	0	T_OR	P_OR	0	0	T_DA	P_DA	Status register
0x28	*DATA_P_XL*	R	DATA_P[7:0]								Pressure output registers
0x29	*DATA_P_L*	R	DATA_P[15:8]								
0x2A	*DATA_P_H*	R	DATA_P[23:16]								
0x2B	*DATA_T_L*	R	DATA_T[7:0]								Temperature output registers
0x2C	*DATA_T_H*	R	DATA_T[15:8]								
0x2D-0x77	Reserved		-								Reserved
0x78	*FIFO_DATA_P_XL*	R	FIFO_P[7:0]								Pressure output registers
0x79	*FIFO_DATA_P_L*	R	FIFO_P[15:8]								
0x7A	*FIFO_DATA_P_H*	R	FIFO_P[23:15]								
0x7B	*FIFO_DATA_T_L*	R	FIFO_T[7:0]								Temperature output registers
0x7C	*FIFO_DATA_T_H*	R	FIFO_P[15:8]								

Writing to reserved registers may cause permanent damage to the device. Register addresses not listed in the above table, must not be accessed and content must not be modified.

Register contents that are loaded during the boot process should not be changed. They contain factory calibration values and their content is automatically restored at the power up.

13 Register description

13.1 INT_CFG (0x0B)

Address: 0x0B
Type: R/W
Default Value: 00000000b

7	6	5	4	3	2	1	0
AUTO REFP	RESET_ ARP	AUTO ZERO	RESET_ AZ	DIFF_EN	LIR	PLE	PHE

AUTOREFP — Enable AUTOREFP function. Measured pressure value is stored in REF_P_x registers (0x15-0x16). Pressure data registers, DATA_P_x show actual measured values

0: AUTOREFP is disabled 1: AUTOREFP is enabled

RESET_ARP — Reset AUTOREFP function. Resets REF_P_x register values

0: normal mode 1: reset AUTOREFP

AUTOZERO — Enable AUTOZERO mode. Measured pressure value is stored in REF_P_x registers (0x15-0x16) and used as reference for measured data. Pressure data registers DATA_P_x contain the difference between measured pressure and REF_P registers.

0: AUTOZERO is disabled 1: AUTOZERO is enabled

RESET_AZ — Reset AUTOZERO function; Resets REF_P_x register values

0: normal mode 1: reset AUTOZERO

DIFF_EN — Enable differential interrupt generation. To be used with AUTOREFP and AUTOZERO mode

0: differential interrupt disabled; 1: differential interrupt is enabled

LIR — Interrupt request is latched to the *INT_SOURCE* register (0x24)

0: interrupt is not latched; 1: interrupt is latched

PLE — Enable differential pressure interrupt generation when pressure value is lower than the user-defined threshold value set in register THR_P_x (0x0c-0x0D)

0: interrupt is inactive; 1: interrupt active on pressure low event

PHE	Enable differential pressure interrupt generation when pressure value is higher than the user-defined threshold value set in register THR_P_x (0x0c-0x0D) 0: interrupt is inactive; 1: interrupt active on pressure high event

AUTOZERO or AUTOREFP mode must be enabled when differential pressure interrupt is desired.

AUTOZERO and AUTOREFP bits are set back to ’0’ after the first measurement and two most significant bytes of the measured value are stored in *REF_P_H* and *REF_P_L* registers. In order to return to normal mode, RESET_AZ or RESET_ARP must be set to ’1’.

13.2 THR_P_L (0x0C)

Address: 0x0C
Type: R/W
Default Value: 00000000b

7	6	5	4	3	2	1	0
THR[7:0]							

THR[7:0] LSB of the user defined pressure threshold value to generate a pressure based interrupt event.

13.3 THR_P_H (0x0D)

Address: 0x0D
Type: R/W
Default Value: 00000000b

7	6	5	4	3	2	1	0
-	THR[14:8]						

THR[15:8] MSB of the user defined pressure threshold value to generate a pressure based interrupt event.

User-defined pressure threshold value is expressed in 15-bit unsigned right-justified value stored in *THR_P_H* and *THR_P_L* registers. It can be calculated as follows:

$$\text{Pressure threshold value (kPa)} \times 16 = \text{THR\_P}[15:0]$$

STOP THR_P value is a differential pressure threshold and not absolute pressure threshold.

Enable interrupt based on user-defined pressure threshold

1. Set DIFF_EN bit to '1' in *INT_CFG* register (0x0B)
2. Set PHE or PLE (or both) = '1', based on the user application

13.4 INTERFACE_CTRL (0x0E)

Address: 0x0E
Type: R/W
Default Value: 00000000b

7	6	5	4	3	2	1	0
0	0	0	SDA_PU_EN	SAO_PU_EN	PD_DIS_INT	0	I2C_DISABLE

SDA_PU_EN — Enable internal pull-up resistors on the *SDA* pin
0: internal pull-up not connected; 1: internal pull-up is connected

SAO_PU_EN — Enable internal pull-up resistors on the *SAO* pin
0: internal pull-up not connected; 1: internal pull-up is connected

PD_DIS_INT — Disable internal pull-down on *INT* pin
0: *INT* pin pull-down connected; 1: *INT* pin pull-down is disconnected

I2C_DISABLE — Disable I^2C digital interface
0: I^2C enabled; 1: I^2C disabled

13.5 DEVICE_ID (0x0F)

Address: 0x0F
Type: R
Default Value: 10110011b (0xB3)

7	6	5	4	3	2	1	0
1	0	1	1	0	0	1	1

Device ID for this device is a fixed number (0xB3) which is stored in this register.

13.6 CTRL_1 (0x10)

Address: 0x10
Type: R/W
Default Value: 00000000b

7	6	5	4	3	2	1	0
0	ODR[2:0]			EN_ LPFP	LPFP_ CFG	BDU	SIM

ODR[2:0] Selection of operating mode and ODR as per table 22

ODR[2:0]	Output Data Rate [Hz]
000	Power-down mode / single-conversion mode
001	1
010	10
011	25
100	50
101	75
110	100
111	200

Table 22: Output data rate selection

EN_LPFP Enable/disable Low-pass filter. For more information refer to section 8.4.2

0: low-pass filter is disabled; 1: low-pass filter is enabled

LPFP_CFG Configure low-pass filter. For more information refer to section 8.4.2

BDU Block data update feature

0: data register updates continuously; 1: data register not updated until MSB and LSB has been read

SIM SPI interface mode selection

0: 4-wire interface; 1: 3-wire interface

BDU: Block data update feature

While reading the output data, this feature can be enabled to inhibit the values of data registers to be updated until all bytes of the pressure or temperature data registers have been read.

This feature should be enabled when the reading of the data is slower than the output data rate (ODR). By default, the BDU bit is set to '0' and data registers are updated continuously. When BDU feature is enabled, reading of the pressure or temperature values sampled at different times can be avoided.

For example, when reading of the register *DATA_P_XL* is initialized, the remaining part of the pressure data registers *DATA_P_L* and *DATA_P_H* are not updated until all three bytes (XL, L and H) have been read. In case of temperature data readout, if *DATA_T_L* is read than the value of *DATA_T_H* will not be updated until read.

It is strongly recommended to enable BDU feature. This avoids an update of the DATA_x_x registers until all the parts of the corresponding DATA_x registers have been read.

13.7 CTRL_2 (0x11)

Address: 0x11
Type: R/W
Default Value: 00010000b (0x10)

7	6	5	4	3	2	1	0
BOOT	INT_H_L	PP_OD	IF_ADD_ INC	0	SW RESET	LOW_ NOISE_ EN	ONE_ SHOT

BOOT — Reboots memory content. For details refer to section 7.3
0: normal operation; 1: reboot memory content

INT_H_L — Select interrupt: active high or active low
0: active high; 1: active low

PP_OD — Push-pull or open-drain selection on the *INT* pin
0: push-pull; 1: open-drain

IF_ADD_INC — Register address is automatically incremented during multiple byte access
0: disabled; 1: enabled
This is a multi-read/write feature that enables a repeated read/write operation during a single bus transaction by automatically incrementing the register address. This feature is enabled by default.

SWRESET — Perform a software reset. For more information, refer to section 7.4
0: Normal operation; 1: software reset

LOW_NOISE_ENABLE — Enable low-noise or low-power configuration. For more information refer to section 8.4.1
0: low-power mode; 1: low-noise mode

ONE_SHOT — Enables single data acquisition of pressure and temperature. For more information refer to section 8.2
0: normal operation; 1: a new data set is acquired

13.8 CTRL_3 (0x12)

Address: 0x12
Type: R/W
Default Value: 00000000b

7	6	5	4	3	2	1	0
0	0	INT_F_FULL	INT_F_WTM	INT_F_OVR	DRDY	INT_S[1:0]	

INT_F_FULL FIFO full status (128 unread samples) is routed to *INT* pin
0: disabled; 1: FIFO full interrupt enabled

INT_F_WTM User defined FIFO threshold full status is routed to *INT* pin
0: disabled; 1: FIFO threshold level interrupt enabled

INT_F_OVR FIFO overrun status is routed to *INT* pin
0: disabled; 1: FIFO overrun interrupt enabled

DRDY Data-ready signal routed to *INT* pin
0: disabled; 1: enabled

INT_S[1:0] Interrupt event control on *INT* pin. Refer to table 23

INT_S[1]	INT_S[0]	*INT* pin configuration
0	0	Data signal (priority order: DRDY or INT_F_WTM or INT_F_OVER or INT_F_FULL)
0	1	Pressure high event
1	0	Pressure low event
1	1	Pressure low or high event

Table 23: INT pin configuration

13.9 FIFO_CTRL (0x13)

Address: 0x13
Type: R/W
Default Value: 00000000b

7	6	5	4	3	2	1	0
0	0	0	0	STOP_ ON_ WTM	TRIG_ MODES	F_ MODE[1:0]	

STOP_ON_WTM Enables user defined FIFO threshold level (defined in register FIFO_WTM, 0x14) for FIFO buffer. when number of samples in the FIFO buffer are equal to the set threshold value then FIFO is considered as full.

0: disabled; 1: enabled

TRIG_MODES Enable triggered FIFO mode. Refer Table 24

F_MODE[1:0] Select FIFO mode. Refer Table 24

FIFO_CTRL [2:0]			FIFO Mode
TRIG_MODE	F_MODE[1]	F_MODE[0]	
x	0	0	Bypass mode
0	0	1	FIFO mode
0	1	x	Continuous mode
1	0	1	Bypass-to-FIFO mode
1	1	0	Bypass-to-Continuous mode
1	1	1	Continuous-to-FIFO mode

Table 24: Setting FIFO modes

13.10 FIFO_WTM (0x14)

Address: 0x14
Type: R/W
Default Value: 00000000b

7	6	5	4	3	2	1	0
0	WTM[6:0]						

WTM[6:0] User-defined FIFO threshold level.

13.11 REF_P_L (0x15)

Address: 0x15
Type: R
Default Value: 00000000b

7	6	5	4	3	2	1	0
REFL[7:0]							

REFL[7:0] LSB part of the reference pressure value

13.12 REF_P_H (0x16)

Address: 0x16
Type: R
Default Value: 00000000b

7	6	5	4	3	2	1	0
REFH[15:8]							

REFH[15:8] MSB part of the reference pressure value

Reference pressure is stored as 16-bits two's complement value. When AUTOZERO or AUTOREFP function for differential pressure interrupt is enabled, first instantaneous pressure measurement data is automatically stored in the *REF_P_H* and *REF_P_L* registers.

Compensated pressure data is a 24-bit value but REF_P is a 16-bit value. Only 16 most significant bits of the compensated pressure value are stored in the *REF_P_H* and *REF_P_L* registers.

13.13 OPC_L (0x18)

Address: 0x18
Type: R/W
Default Value: 00000000b

7	6	5	4	3	2	1	0
OPC[7:0]							

OPC[7:0] LSB part of the pressure offset value

13.14 OPC_H (0x19)

Address: 0x19
Type: R/W
Default Value: 00000000b

7	6	5	4	3	2	1	0
OPC[15:8]							

OPC[15:8] MSB part of the pressure offset value

Pressure offset value can be stored in OPC_L and OPC_H register as a 16-bit word expressed as two's complement.

In case a residual pressure offset is present after soldering, it can be removed by performing one-point calibration with OPC registers. The offset or calibration value can be stored in the OPC_L and OPC_H registers.

Content of OPC registers is automatically subtracted from the standard pressure data registers DATA_P (0x28-0x2A) and FIFO data registers (0x78-0x7A)

DATA_P registers = Measured pressure - OPC register value * 256

13.15 INT_SOURCE (0x24)

Address: 0x24
Type: R
Default Value: Output

7	6	5	4	3	2	1	0
BOOT_ ON	0	0	0	0	IA	PL	PH

BOOT_ON Indicates Boot process status
0: BOOT process over; 1: BOOT process running

IA Interrupt active
0: no interrupt event has been generated; 1: one or more interrupt event has been generated

PL Differential pressure low event
0: no interrupt event has been generated; 1: differential pressure low event generated

PH Differential pressure high event
0: no interrupt event has been generated; 1: differential pressure high event generated

13.16 FIFO_STATUS_1 (0x25)

Address: 0x25
Type: R
Default Value: Output

7	6	5	4	3	2	1	0
FSS[7:0]							

FSS[7:0] Indicates the FIFO fill level; Number of unread samples stored in FIFO (00000000b: FIFO empty, 10000000b: FIFO full with 128 unread samples)

13.17 FIFO_STATUS_2 (0x26)

Address: 0x26
Type: R
Default Value: Output

7	6	5	4	3	2	1	0
FIFO_ WTM_ IA	FIFO_ OVER_ IA	FIFO_ FULL_ IA	0	0	0	0	0

FIFO_WTM_IA User defined FIFO threshold level status

0: FIFO is lower than threshold level; 1: FIFO is equal to or higher than the threshold level

FIFO_OVER_IA FIFO overrun status

0: FIFO is not completely filled; 1: FIFO is full and at least one sample in the FIFO has been overwritten

FIFO_FULL_IA FIFO full status

0: FIFO is not completely filled; 1: FIFO is full and no samples in the FIFO have been overwritten

13.18 STATUS (0x27)

Address: 0x27
Type: R
Default Value: Output

7	6	5	4	3	2	1	0
0	0	T_OR	P_OR	0	0	T_DA	P_DA

T_OR Temperature data overrun

0: no overrun has occurred; 1: a new temperature sample has been overwritten

P_OR Pressure data overrun

0: no overrun has occurred; 1: a new pressure sample has been overwritten

T_DA Temperature data available

0: no new temperature sample is available; 1: a new temperature sample has been generated

P_DA — Pressure data availalble

0: no new pressure sample is available; 1: a new pressure sample has been generated

13.19 DATA_P_XL (0x28)

Address: 0x28
Type: R
Default Value: Output

7	6	5	4	3	2	1	0
DATA_P[7:0]							

DATA_P[7:0] — Low part of the pressure data.

Combine this value with *DATA_P_L* and *DATA_P_H* register values to form a 24-bit number expressed in a two's complement, that gives the pressure value.

13.20 DATA_P_L (0x29)

Address: 0x29
Type: R
Default Value: Output

7	6	5	4	3	2	1	0
DATA_P[15:8]							

DATA_P[15:8] — Middle part of the pressure data.

Combine this value with *DATA_P_XL* and *DATA_P_H* register values to form a 24-bit number expressed in a two's complement, that gives the pressure value.

13.21 DATA_P_H (0x2A)

Address: 0x2A
Type: R
Default Value: Output

7	6	5	4	3	2	1	0
DATA_P[23:16]							

DATA_P[23:16] High part of the pressure data.
Combine this value with *DATA_P_XL* and *DATA_P_L* register values to form a 24-bit number expressed in a two's complement, that gives the pressure value.

13.22 DATA_T_L (0x2B)

Address: 0x2B
Type: R
Default Value: Output

7	6	5	4	3	2	1	0
DATA_T[7:0]							

DATA_T[7:0] Low part of the temperature data.
Combine this value with *DATA_T_H* register value to form a 16-bit number expressed in a two's complement, that gives the temperature value.

13.23 DATA_T_H (0x2C)

Address: 0x2C
Type: R
Default Value: Output

7	6	5	4	3	2	1	0
DATA_T[15:8]							

DATA_T[15:8] High part of the temperature data.
Combine this value with *DATA_T_L* register value to form a 16-bit number expressed in a two's complement, that gives the temperature value.

13.24 FIFO_DATA_P_XL (0x78)

Address: 0x78
Type: R
Default Value: Output

7	6	5	4	3	2	1	0
FIFO_P[7:0]							

FIFO_P[7:0] Low part of the FIFO buffer pressure data.
Combine this value with *DATA_P_L* and *DATA_P_H* register values to form a 24-bit number expressed in a two's complement, that gives the pressure value.

13.25 FIFO_DATA_P_L (0x79)

Address: 0x79
Type: R
Default Value: Output

7	6	5	4	3	2	1	0
FIFO_P[15:8]							

FIFO_P[15:8] Middle part of the FIFO buffer pressure data.
Combine this value with *DATA_P_XL* and *DATA_P_H* register values to form a 24-bit number expressed in a two's complement, that gives the pressure value.

13.26 FIFO_DATA_P_H (0x7A)

Address: 0x7A
Type: R
Default Value: Output

7	6	5	4	3	2	1	0
FIFO_P[23:15]							

FIFO_P[23:16] High part of the FIFO buffer pressure data.
Combine this value with *DATA_P_XL* and *DATA_P_L* register values to form a 24-bit number expressed in a two's complement, that gives the pressure value.

13.27 FIFO_DATA_T_L (0x7B)

Address: 0x7B
Type: R
Default Value: Output

7	6	5	4	3	2	1	0
FIFO_T[7:0]							

FIFO_T[7:0] Low part of the FIFO buffer temperature data

Combine this value with *DATA_T_H* register value to form a 16-bit number expressed in a two's complement, that gives the temperature value.

13.28 FIFO_DATA_T_H (0x7C)

Address: 0x7C
Type: R
Default Value: Output

7	6	5	4	3	2	1	0
FIFO_T[15:8]							

FIFO_T[15:8] High part of the FIFO buffer temperature data.

Combine this value with *DATA_T_L* register value to form a 16-bit number expressed in a two's complement, that gives the temperature value.

14 Physical specifications

14.1 Sensor drawing

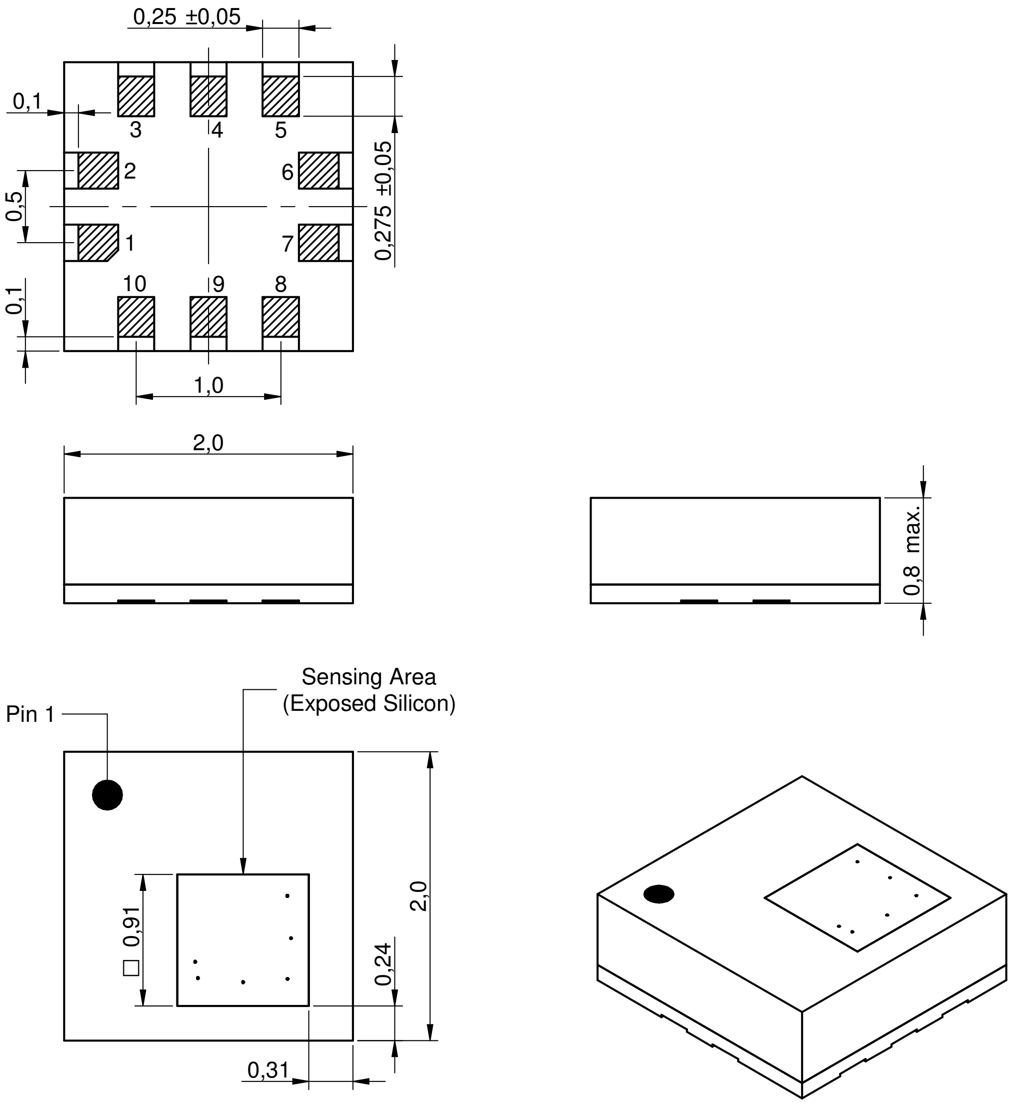


Figure 35: Sensor dimensions [mm]

14.2 Footprint

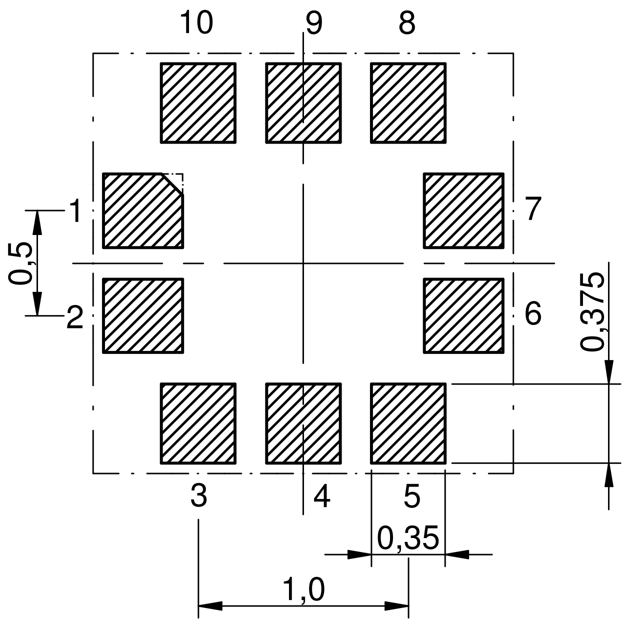


Figure 36: Recommended land pattern [mm] (top view)

15 MEMS Sensor PCB Design Guidelines

The following design guidelines for PCB, soldering, solder paste, stencil and re-flow process must be considered as a good hardware design practice for Würth Elektronik eiSos MEMS sensor products. Not following these guidelines will result in poor performance from the Würth Elektronik eiSos MEMS Sensors. e.g. offset, offset vs temperature, accuracy and accuracy vs temperature.

15.1 PCB Design rules

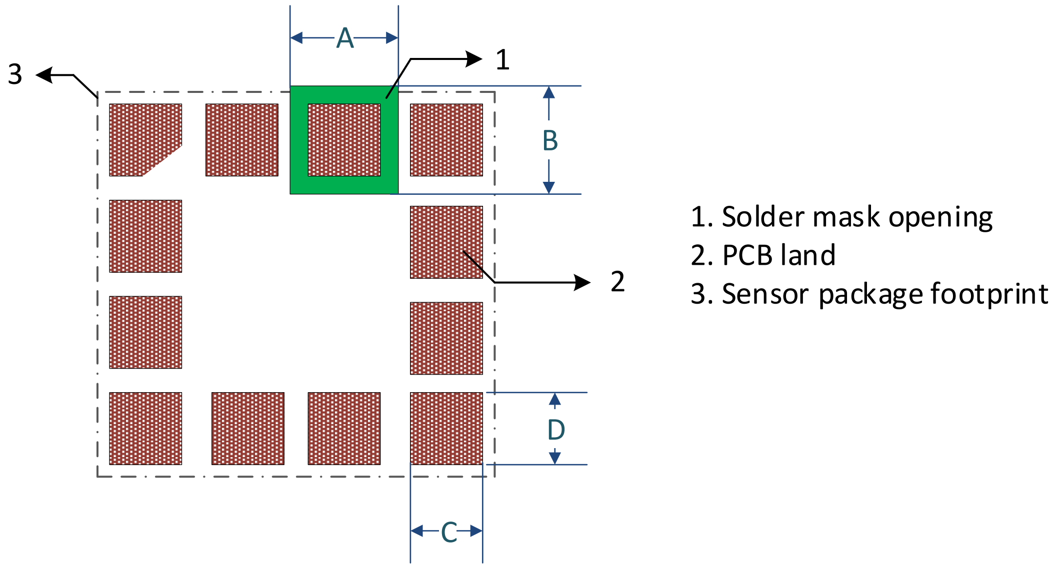


Figure 37: PCB land and solder mask recommendations for sensors with LGA package

Dimension	LGA pad spacing > 200 μm	LGA pad spacing $\leq$ 200 μm
PCB land width: C	LGA solder pad width + 0.1 mm	LGA solder pad width
PCB land length: D	LGA solder pad length + 0.1 mm	LGA solder pad length

Table 25: PCB land design dimensions

Dimension	Description
Solder mask opening width: A	PCB land length + 0.1 mm
Solder mask opening length: B (when applicable)	PCB land length + 0.1 mm

Table 26: Solder mask opening dimensions

Any structure underneath the sensor should be avoided

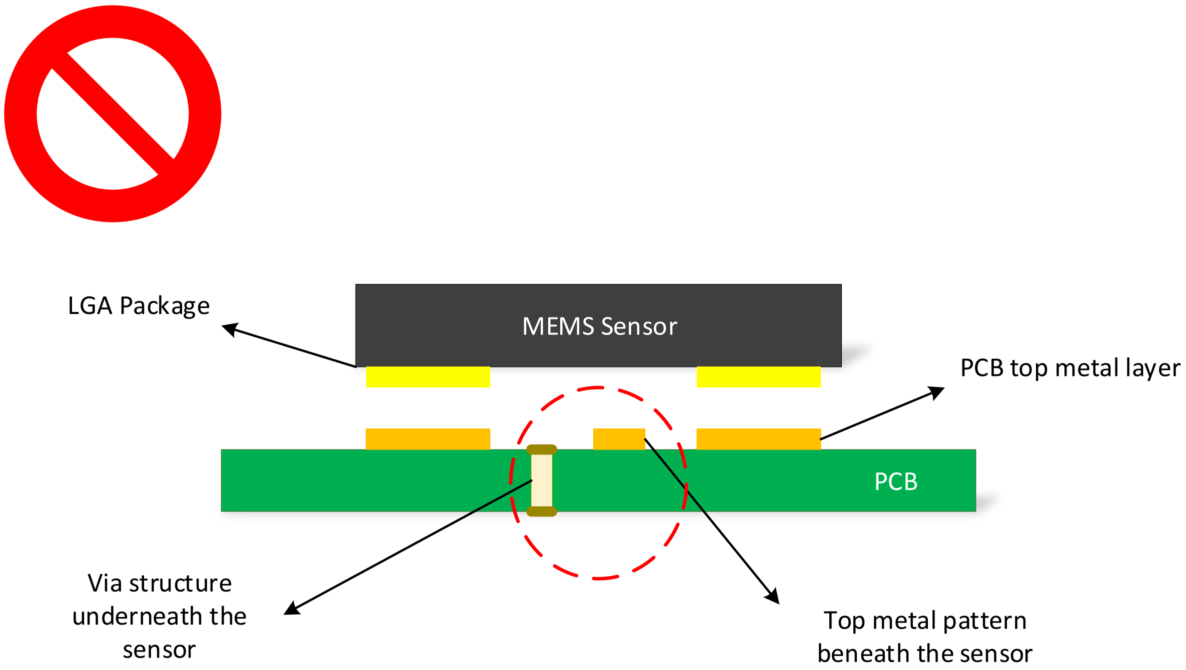


Figure 38: Incorrect PCB design

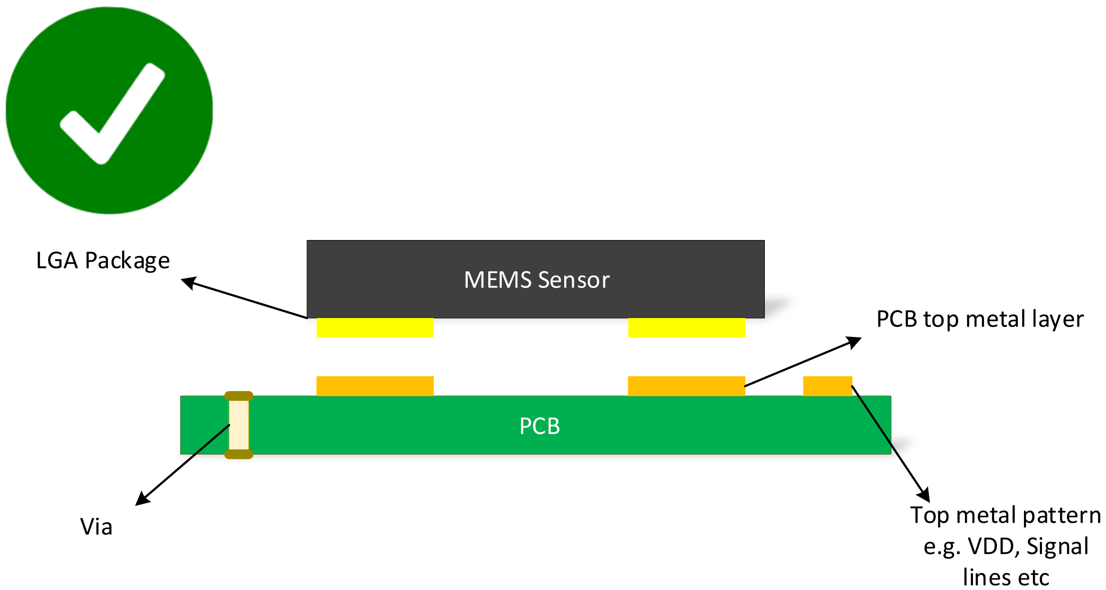


Figure 39: Correct PCB design

Screw mounting holes, vias and components at a distance greater than 2mm from the sensor is highly recommended to get optimal performance of the sensor

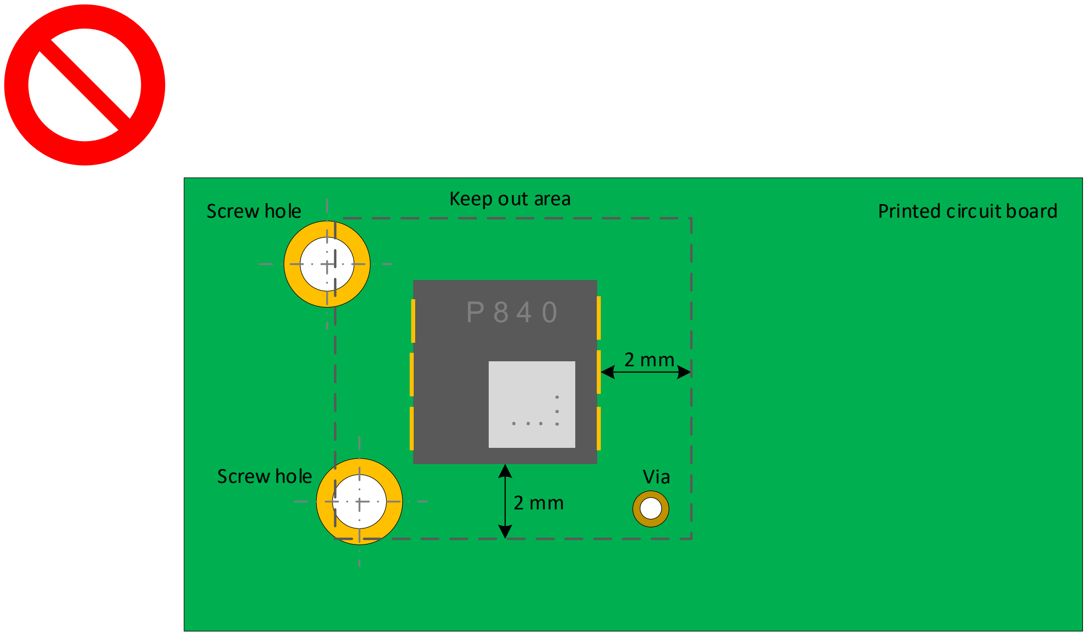


Figure 40: Components inside sensor keep out area

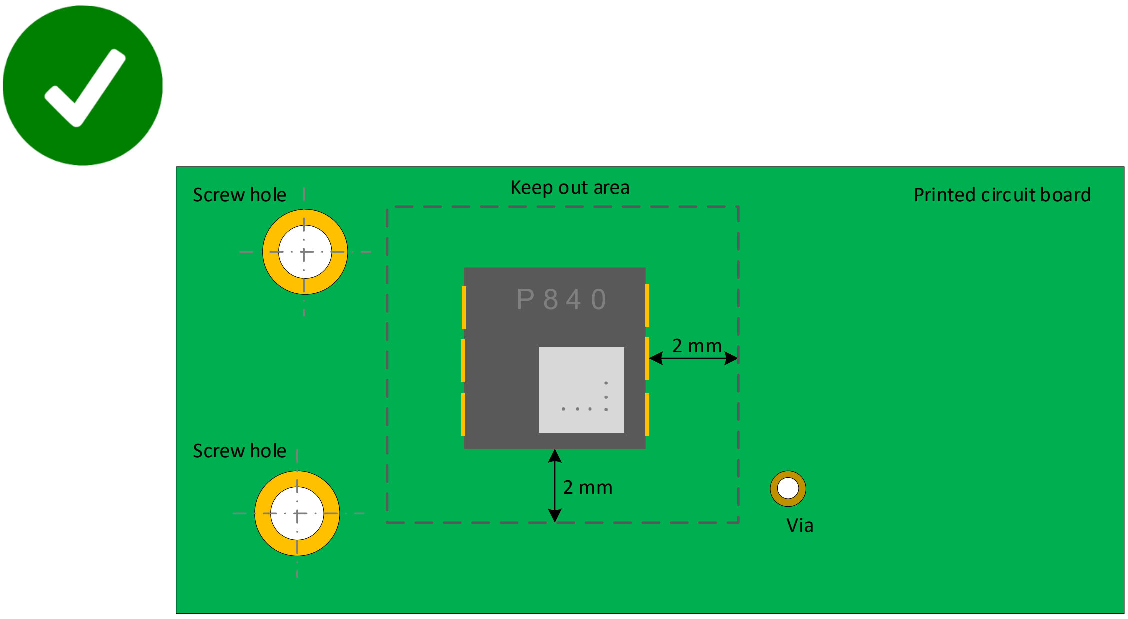


Figure 41: Components outside sensor keep out area

15.2 Guidelines for PCB Design

- The solder mask opening external to the PCB land is highly recommended. Please refer to figure 37.
- It is recommended to define a keep-out area for the sensor. Any structure underneath the sensor should be avoided.
- The traces connected to the pads should be as symmetrical as possible. Symmetry and balance to the pad connections will help the sensor self-align which leads to better control of solder paste reduction after reflow.
- Screw mounting holes at a distance greater than 2mm from the sensor is highly recommended to get optimal performance of the sensor.
- We recommend to separate digital ground from analog ground in the PCB, if enough space or layer is available. The relatively large, sharp pulses of digital current transitions might affect the precise analog signals if the two signals are not separated.

It is generelly recommended to reduce the PCB thickness (e.g. $\leq$ 1.6 mm). Intrinsic stress during PCB bending is less in thin PCBs

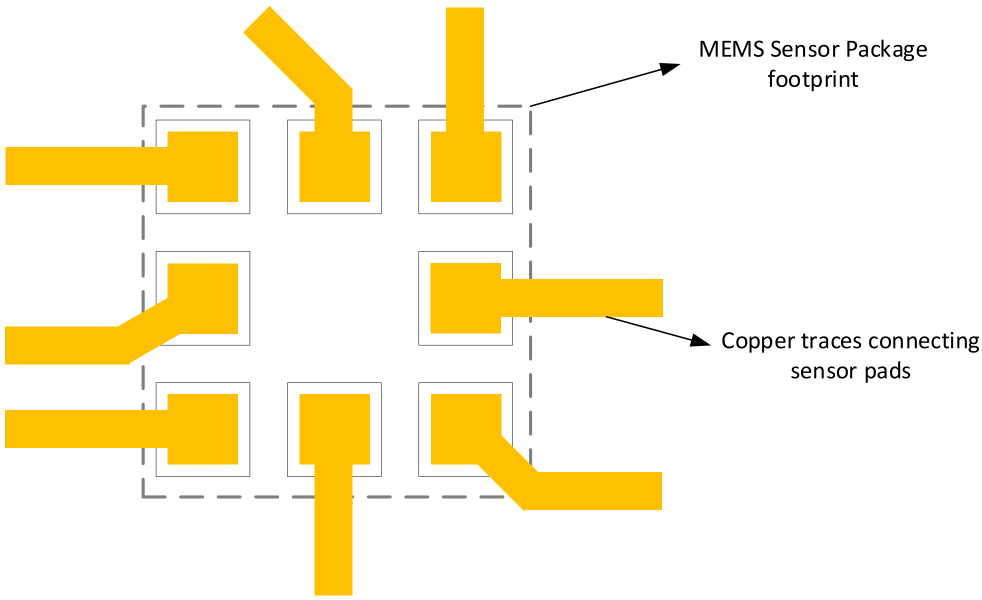


Figure 42: Asymmetrical trace and sensor pad connections

Information of the PCB design and soldering processes provided in this document is considered for use as a reference.

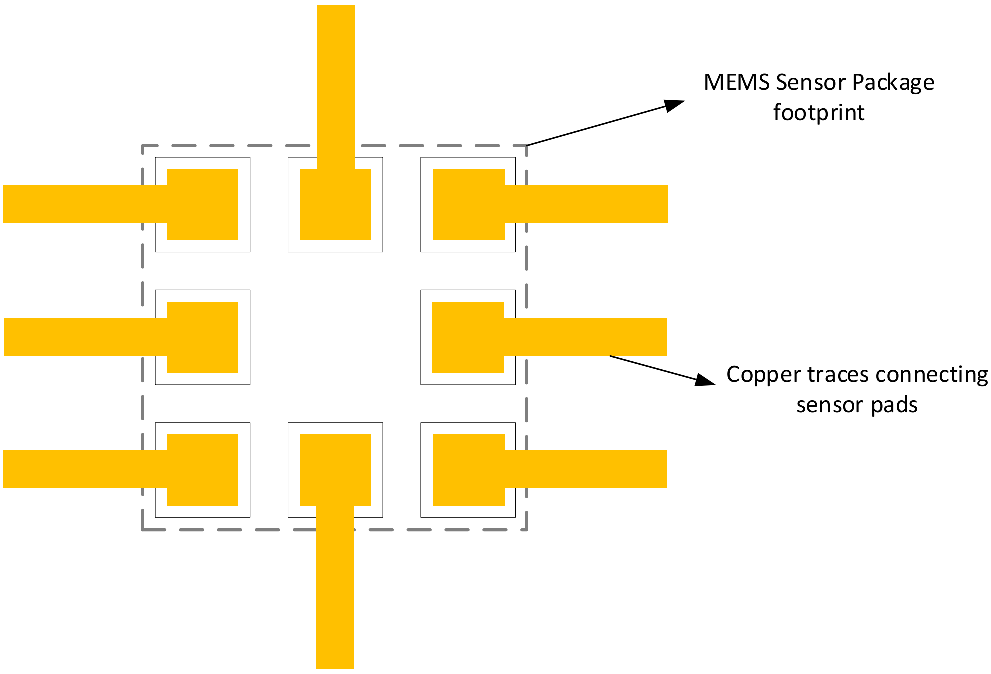


Figure 43: Symmetrical trace and sensor pad connections

PCB land design and connecting traces should be designed symmetrically

For sensor specific information please refer to corresponding data sheet of the product.

15.3 Guidelines for soldering

The following soldering guidelines should be taken into consideration for a common PCB design and industrial practices.

15.3.1 Before soldering

- Routing traces and vias below the sensor should be avoided. The active signals that are routed under may interfere with the MEMS sensor, which will affect the sensor performance.
- It is not necessary to have large traces on VDD/GND line, as the power consumption of the MEMS sensors are very low.
- For best performance of the sensor, design a ground plane under the sensor in order to reduce the PCB signal noise from the board.
- The placement of the MEMS sensor on the PCB should avoid locations in close proximity to heat sources e.g. microprocessors, batteries, graphic controllers etc.
- Push-buttons, screws and PCB anchor points can produce mechanical stress onto the PCB, hence the sensor placement close to these components should be avoided.
- PCB bending will induce mechanical stress to the sensor therewith influence the sensor performance.

15.3.2 After soldering

- In general, high-amplitude resonant vibrations of the PCB should be avoided. It could possibly damage the MEMS structure.
- The thickness of solder paster must be uniform to reduce the inconsistent stress on the sensor.
- Solder paste must be as thick as possible to reduce the decoupling stress and to avoid the PCB solder mask touching the device package.

15.4 Guidelines for stencil design and solder paste

For proper mounting process of the MEMS sensor, thickness and soldering paste pattern are very important.

- Stencil thickness of 90 - 150 μm (3.5 - 6 mils) is recommended for screen printing.
- Stainless steel stencils are recommended for solder paste application.
- The signal pad openings of the stencil should be between 70% and 90% of the PCB pad area.
- It is recommended that for better solder paste release, the aperture walls should be trapezoidal and the corners rounded.
- The stencil and printed circuit assembly should be aligned to within 25 μm (1 mil) before applying the solder paste.

15.5 Guidelines for process considerations

- To reduce the residual stress on the components, the recommended ramp-down temperature slope should not exceed -3 ℃/s.
- LGA packages show metal traces on the side of the package, hence no solder material reflow on the side of the package is allowed.
- The final volume of the solder paste applied to a single PCB land should be less than 20% of the volume of the solder paste of all pads of one device.
- It is not possible to define a specific soldering profile only for the sensors. The soldering profile depends on the number, size and placement of the components in the application board.
- Customer should use a time and temperature reflow profile based on PCB design and manufacturing knowledge.
- No-clean solder paste is recommended for assembly of the MEMS sensor to prevent further cleaning steps.
- Sensor with opening surface on top should be handled carefully. Do not pick the component with vacuum tools which make direct contact with the opening of the sensor.

It is recommended to use a standard pick and place process and equipment. Do not use the hand soldering process.

16 Manufacturing information

16.1 Moisture sensitivity level

The sensor product is categorized as JEDEC Moisture Sensitivity Level 3 (MSL3), which requires special handling.

More information regarding the MSL requirements can be found in the IPC/JEDEC J-STD-020 standard on www.jedec.org. More information about the handling, picking, shipping and the usage of moisture/re-flow and/or process sensitive products can be found in the IPC/JEDEC J-STD-033 standard on www.jedec.org.

16.2 Soldering

16.2.1 Reflow soldering

Attention must be paid on the thickness of the solder resist between the host PCB top side and the modules bottom side. Only lead-free assembly is recommended according to JEDEC J-STD020.

Profile feature		Value
Preheat temperature Min	$T_{S\ Min}$	150 ℃
Preheat temperature Max	$T_{S\ Max}$	200 ℃
Preheat time from $T_{S\ Min}$ to $T_{S\ Max}$	t_S	60 - 120 seconds
Ramp-up rate (T_L to T_P)		3 ℃ / second max.
Liquidous temperature	T_L	217 ℃
Time t_L maintained above T_L	t_L	60 - 150 seconds
Peak package body temperature	T_P	see table below
Time within 5 ℃ of actual peak temperature	t_P	20 - 30 seconds
Ramp-down Rate (T_P to T_L)*		6 ℃ / second max.
Time 20 ℃ to T_P		8 minutes max.

Table 27: Classification reflow soldering profile, Note: refer to IPC/JEDEC J-STD-020E

*** In order to reduce residual stress on the sensor component, the recommended ramp-down temperature slope should be lower than 3 ℃ /s.**

Package thickness	Volume mm^3 <350	Volume mm^3 350-2000	Volume mm^3 >2000
< 1.6mm	260 ℃	260 ℃	260 ℃
1.6mm - 2.5mm	260 ℃	250 ℃	245 ℃
> 2.5mm	250 ℃	245 ℃	245 ℃

Table 28: Package classification reflow temperature, PB-free assembly, Note: refer to IPC/-JEDEC J-STD-020E

It is recommended to solder the sensor on the last re-flow cycle of the PCB. For solder paste use a LFM-48W or Indium based SAC 305 alloy (Sn 96.5 / Ag 3.0 / Cu 0.5 / Indium 8.9HF / Type 3 / 89%) type 3 or higher.

The reflow profile must be adjusted based on the thermal mass of the entire populated PCB, heat transfer efficiency of the re-flow oven and the specific type of solder paste used. Based on the specific process and PCB layout the optimal soldering profile must be adjusted and verified. Other soldering methods (e.g. vapor phase) have not been verified and have to be validated by the customer at their own risk. Rework is not recommended.

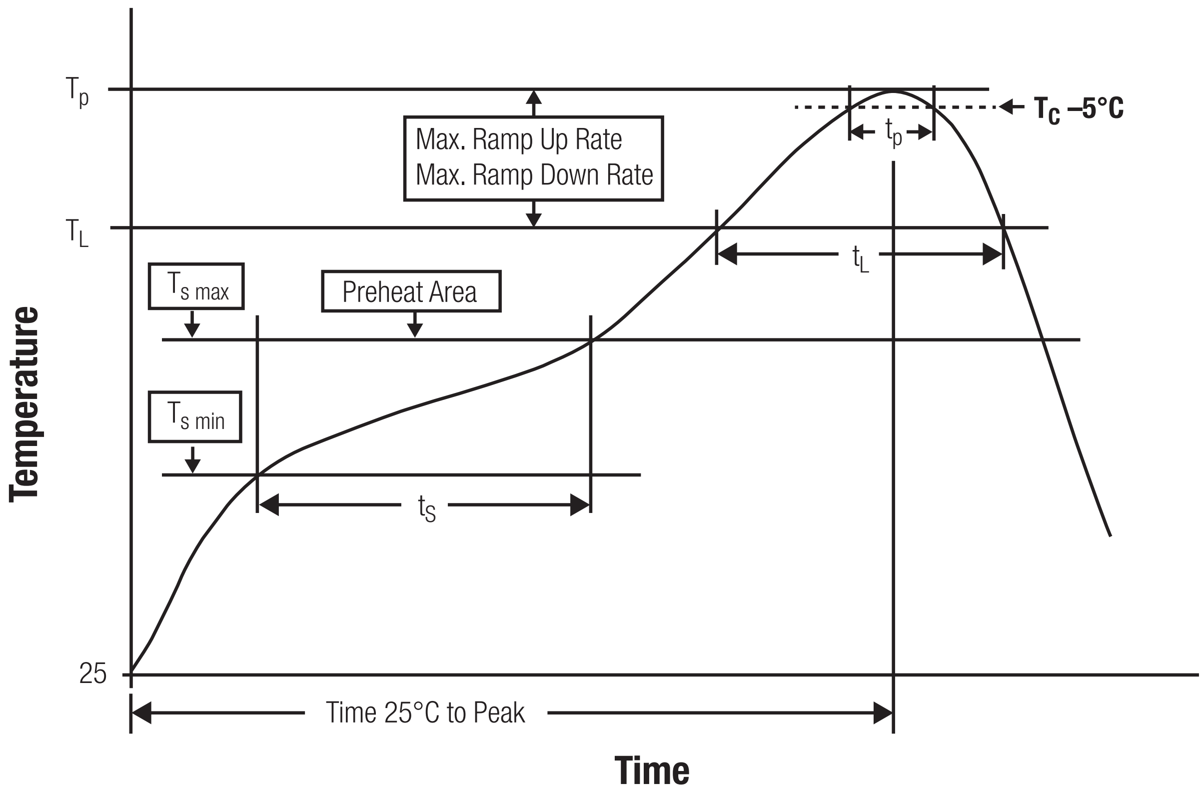


Figure 44: Reflow soldering profile

After reflow soldering, visually inspect the board to confirm proper alignment

16.2.2 Cleaning and washing

Do not clean the product. Any residue cannot be easily removed by washing. Use a "no clean" soldering paste and do not clean the board after soldering.

- Washing agents used during the production to clean the customer application might damage or change the characteristics of the component. Washing agents may have a negative effect on the long-term functionality of the product.
- Using a brush during the cleaning process may damage the component. Therefore, we do not recommend using a brush during the PCB cleaning process

16.2.3 Potting and coating

- Potting material might shrink or expand during and after hardening. This might apply mechanical stress on the components, which can influence the characteristics of the transfer function. In addition, potting material can close existing openings in the housing. This can lead to a malfunction of the component. Thus, potting is not recommended.
- Conformal coating may affect the product performance. We do not recommend coating the components.

16.2.4 Storage conditions

- A storage of Würth Elektronik eiSos products for longer than 12 months is not recommended. Within other effects, the terminals may suffer degradation, resulting in bad solderability. Therefore, all products shall be used within the period of 12 months based on the day of shipment.
- Do not expose the components to direct sunlight.
- The storage conditions in the original packaging are defined according to DIN EN 61760 - 2.
- For a moisture sensitive component, the storage condition in the original packaging is defined according to IPC/JEDEC-J-STD-033. It is also recommended to return the component to the original moisture proof bag and reseal the moisture proof bag again.

16.2.5 Handling

- Violation of the technical product specifications such as exceeding the nominal rated supply voltage, will void the warranty.
- Violation of the technical product specifications such as but not limited to exceeding the absolute maximum ratings will void the conformance to regulatory requirements.
- ESD prevention methods need to be followed for manual handling and processing by machinery.
- The edge castellation is designed and made for prototyping, i.e. hand soldering purposes only.
- The applicable country regulations and specific environmental regulations must be observed.
- Do not disassemble the product. Evidence of tampering will void the warranty.

17 Important notes

The following conditions apply to all goods within the sensors product range of Würth Elektronik eiSos GmbH & Co. KG:

17.1 General customer responsibility

Some goods within the product range of Würth Elektronik eiSos GmbH & Co. KG contain statements regarding general suitability for certain application areas. These statements about suitability are based on our knowledge and experience of typical requirements concerning the areas, serve as general guidance and cannot be estimated as binding statements about the suitability for a customer application. The responsibility for the applicability and use in a particular customer design is always solely within the authority of the customer. Due to this fact, it is up to the customer to evaluate, where appropriate to investigate and to decide whether the device with the specific product characteristics described in the product specification is valid and suitable for the respective customer application or not. Accordingly, the customer is cautioned to verify that the documentation is current before placing orders.

17.2 Customer responsibility related to specific, in particular safety-relevant applications

It has to be clearly pointed out that the possibility of a malfunction of electronic components or failure before the end of the usual lifetime cannot be completely eliminated in the current state of the art, even if the products are operated within the range of the specifications. The same statement is valid for all software and software parts contained in or used with or for products in the sensor product range of Würth Elektronik eiSos GmbH & Co. KG. In certain customer applications requiring a high level of safety and especially in customer applications in which the malfunction or failure of an electronic component could endanger human life or health, it must be ensured by most advanced technological aid of suitable design of the customer application that no injury or damage is caused to third parties in the event of malfunction or failure of an electronic component.

17.3 Best care and attention

Any product-specific data sheets, manuals, application notes, PCN's, warnings and cautions must be strictly observed in the most recent versions and matching to the products revisions. This documents can be downloaded from the product specific sections on the wireless connectivity and sensors homepage.

17.4 Customer support for product specifications

Some products within the product range may contain substances, which are subject to restrictions in certain jurisdictions in order to serve specific technical requirements. Necessary information is available on request. In this case, the field sales engineer or the internal sales person in charge should be contacted who will be happy to support in this matter.

17.5 Product improvements

Due to constant product improvement, product specifications may change from time to time. As a standard reporting procedure of the Product Change Notification (PCN) according to the JEDEC-Standard, we inform about major changes. In case of further queries regarding the PCN, the field sales engineer, the internal sales person or the technical support team in charge should be contacted. The basic responsibility of the customer as per section `17.1` and `17.2` remains unaffected.
The sensor driver software ¨Sensor SDK¨ and it's source codes are not subject to the Product Change Notification information process.

17.6 Product life cycle

Due to technical progress and economical evaluation we also reserve the right to discontinue production and delivery of products. As a standard reporting procedure of the Product Termination Notification (PTN) according to the JEDEC-Standard we will inform at an early stage about inevitable product discontinuance. According to this, we cannot ensure that all products within our product range will always be available. Therefore, it needs to be verified with the field sales engineer or the internal sales person in charge about the current product availability expectancy before or when the product for application design-in disposal is considered. The approach named above does not apply in the case of individual agreements deviating from the foregoing for customer-specific products.

17.7 Property rights

All the rights for contractual products produced by Würth Elektronik eiSos GmbH & Co. KG on the basis of ideas, development contracts as well as models or templates that are subject to copyright, patent or commercial protection supplied to the customer will remain with Würth Elektronik eiSos GmbH & Co. KG. Würth Elektronik eiSos GmbH & Co. KG does not warrant or represent that any license, either expressed or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, application, or process in which Würth Elektronik eiSos GmbH & Co. KG components or services are used.

17.8 General terms and conditions

Unless otherwise agreed in individual contracts, all orders are subject to the current version of the "General Terms and Conditions of Würth Elektronik eiSos Group", last version available at *www.we-online.com*.

18 Legal notice

18.1 Exclusion of liability

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The customer bears the responsibility for compliance of systems or units, in which Würth Elektronik eiSos GmbH & Co. KG products are integrated, with applicable legal regulations. Customer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of Würth Elektronik eiSos GmbH & Co. KG components in its applications, notwithstanding any applications-related in-formation or support that may be provided by Würth Elektronik eiSos GmbH & Co. KG. Customer represents and agrees that it has all the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences lessen the likelihood of failures that might cause harm and take appropriate remedial actions. The customer will fully indemnify Würth Elektronik eiSos GmbH & Co. KG and its representatives against any damages arising out of the use of any Würth Elektronik eiSos GmbH & Co. KG components in safety-critical applications.

18.3 Usage restriction

Würth Elektronik eiSos GmbH & Co. KG products have been designed and developed for usage in general electronic equipment only. This product is not authorized for use in equipment where a higher safety standard and reliability standard is especially required or where a failure of the product is reasonably expected to cause severe personal injury or death, unless the parties have executed an agreement specifically governing such use. Moreover, Würth Elektronik eiSos GmbH & Co. KG products are neither designed nor intended for use in areas such as military, aerospace, aviation, nuclear control, submarine, transportation (automotive control, train control, ship control), transportation signal, disaster prevention, medical, public information network etc. Würth Elektronik eiSos GmbH & Co. KG must be informed about the intent of such usage before the design-in stage. In addition, sufficient reliability evaluation checks for safety must be performed on every electronic component, which is used in electrical circuits that require high safety and reliability function or performance. By using Würth Elektronik eiSos GmbH & Co. KG products, the customer agrees to these terms and conditions.

19 License terms for Würth Elektronik eiSos GmbH & Co. KG sensor product software and source code

This License terms will take effect upon the purchase and usage of the Würth Elektronik eiSos GmbH & Co. KG sensor products. You hereby agree that this license terms are applicable to the product and the incorporated software, firmware and source codes (collectively, "Software") made available by Würth Elektronik eiSos in any form, including but not limited to binary, executable or source code form.
The software included in any Würth Elektronik eiSos sensor product is purchased to you on the condition that you accept the terms and conditions of this license terms. You agree to comply with all provisions under this license terms.

19.1 Limited license

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You are entitled to change or alter the source code for the sole purpose of creating an application embedding the Würth Elektronik eiSos sensor product. The transfer of the source code to third parties is allowed to the sole extent that the source code is used by such third parties in connection with our product or another hardware provided by Würth Elektronik eiSos under strict adherence of this license terms. Würth Elektronik eiSos will not assume any liability for the usage of the incorporated software and the source code.
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You are not allowed to reproduce, translate, reverse engineer, decompile, disassemble or create derivative works of the incorporated software and the source code in whole or in part. No more extensive rights to use and exploit the products are granted to you.

19.2 Usage and obligations

The responsibility for the applicability and use of the Würth Elektronik eiSos sensor product with the incorporated software in a particular customer design is always solely within the authority of the customer. Due to this fact, it is up to you to evaluate and investigate, where appropriate, and to decide whether the device with the specific product characteristics described in the product specification is valid and suitable for your respective application or not.
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