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BMP388

Digital pressure sensor

BMP388 – Datasheet

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BMP388

Digital pressure sensor

The BMP388 is a digital sensor with pressure and temperature measurement based on proven sensing principles. The sensor module is housed in an extremely compact 10-pin metal-lid LGA package with a footprint of only 2.0 × 2.0 mm² and max 0.8 mm package height. Its small dimensions and its low power consumption of 3.4 µA @1Hz allow the implementation in battery driven devices such as mobile phones, GPS modules or watches.

Typical applications

- Vertical velocity indication (e.g. rise/sink speed)
- Internet of things
- Enhancement of GPS navigation
  (e.g. time-to-first-fix improvement, dead-reckoning, slope detection)
- Indoor navigation & localization (floor detection, elevator detection)
- Outdoor navigation, leisure and sports applications
- Weather forecast
- Health care applications (e.g. spirometry)
- Fitness applications like enhancement of calorie detection
- AR & VR applications
- Context awareness

Target Devices

- Flying toys
- Drones
- Handsets such as mobile phones, tablet PCs, GPS devices
- Navigation systems
- Portable health care devices
- Home weather stations
- Watches
- White goods

Key features

Table 1: Key Features of BMP388

Package	2.0 mm x 2.0 mm x 0.75 mm metal lid LGA
Digital interface	I²C (up to 3.4 MHz) and SPI (3 and 4 wire, up to 10 MHz)
Supply voltage	V_{DD} main supply voltage range: 1.65 V to 3.6 V V_{DDIO} interface voltage range: 1.2 V to 3.6 V
Relative accuracy	typ. ± 8 Pa, equiv. to ± 0.66 m (700 ... 900 hPa, 25 . . . 40 °C)
Absolute accuracy	typ. ± 50 Pa (300 ...1100 hPa, -20 ...+65 °C)
Temperature coefficient offset	typ. ± 0.75 Pa/K (0 ... 55°C @700 -1100 hPa)
Current consumption	3.4 µA at 1 Hz pressure and temperature 2.0 µA in sleep mode
Operating range	-40 – +85 °C, 300–1250 hPa
The product is RoHS compliant, halogen-free, MSL1	

BMP388 enables accurate altitude tracking and is specifically suited for drone applications. The best-in-class TCO between -20-65°C for accurate altitude measurement over a wide temperature range of the BMP388 greatly enhance the drone flying experience by making accurate steering easier. It is compatible for use with other Bosch sensors, including the new BMI088 for better performance, robustness and stability. The new BMP388 sensor offers outstanding design flexibility, providing a single package solution that can also be easily integrated into other existing and upcoming devices such as smart homes, industrial products and wearables.

The sensor is more accurate than its predecessor BMP280, covering a wide measurement range from 300 hPa to 1250 hPa.

This new barometric pressure sensor exhibits an attractive price-performance ratio coupled with low power consumption.

It is available in a compact 10-in 2.0 x 2.0 x 0.75 mm³ LGA package with metal lid

Due to the built-in hardware synchronization of the pressure sensor data and its ability to synchronize data from external devices such as acceleration sensors, the BMP388 is ideally suited for fitness and navigation applications which require highly accurate, low power and low latency sensor data fusion.

The new interrupt functionality provides simple access to data and storage. Examples of interrupts than can be used in a power efficient manner without using software algorithms include: Data ready interrupt, watermark interrupt (on byte level) or FIFO full interrupt.

BMP388 also includes a new FIFO functionality. This greatly improves ease of use while helping to reduce power consumption of the overall device system during full operation. The integrated 512 byte FIFO buffer supports low power applications and prevents data loss in non-real-time systems.

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1. Specification

If not stated otherwise,

- All values are valid over the full voltage range
- All minimum/maximum values are given for the full accuracy temperature range
- Minimum/maximum values of drifts, offsets and temperature coefficients are ±3σ values over lifetime
- Typical values of currents and state machine timings are determined at 25 °C
- Typical values of currents and state machine timings are determined at 25°C. minimum/maximum values of currents are determined at -40°C/85°C.
- Minimum/maximum values of state machine timings are determined using corner lots over 0…+65 °C temperature range.

Table 2: General electrical parameter specifications

OPERATING CONDITIONS BMP388						
Parameter	**Symbol**	**Condition**	**Min**	**Typ**	**Max**	**Unit**
Operating temperature range	T_A	operational	-40	25	+85	°C
		full accuracy	0		+65	
Operating pressure range	P	full accuracy	300		1250	hPa
Sensor supply voltage	V_{DD}	ripple max. 50mVpp	1.65	1.8	3.6	V
Interface supply voltage	V_{DDIO}		1.2	1.8	3.6	V
Sleep current	$I_{DD,sleep}$	V_{DD} = V_{DDIO} 1.8-3.6 V		2		µA
Peak current	I_{peak}	during pressure measurement		700	800	µA
Current at temperature measurement	I_{DDT}			300	400	µA
Relative accuracy pressure	A_{rel}	900 ... 1100 hPa 25 . . . 40 °C		±0.08[1]		hPa
				±66		cm
Offset temperature coefficient	TCO	700-1100 hPa 0 . . . 55 °C		±0.75		Pa/K
		700-1100 hPa -20 . . .0 °C		±1.0		Pa/K
Absolute accuracy pressure	A^P_{full}	300. . 1100 hPa -20 . . . 65 °C		±0.50		hPa
	A^P_{ext}	900. . 1100 hPa 25 . . . 40 °C		±0.40		hPa
	A^P	1100 . . 1250 hPa 0 . . 65 °C		±0.50		hPa

[1] Mean value

Resolution of output data in highest resolution mode at lowest bandwidth	R^P	Pressure		0.016		Pa
Noise in pressure	$V_{p,full}$	Full bandwidth, highest resolution See chapter 3.4.4		1.2		Pa
	$V_{p,filtered}$	Lowest bandwidth, highest resolution See chapter 3.4.4		0.03		Pa
Absolute accuracy temperature[3]	A^T	@ 25 °C		±0.3		°C
		0 . . . +65 °C		±0.50		°C
Long term stability[4]	ΔP_{stab}	12 months		±0.33		hPa
Solder drifts		Minimum solder height 50 µm		< ±1.0		hPa
Start-up time	$t_{startup}$	Time to first communication after both V_{DD} > 1.58V and V_{DDIO} > 0.65V			2	ms
Possible sampling rate	f_{sample}	*osrs_t* = *osrs_p* = 1; See chapter 3.9			200	Hz
ODR accuracy	$\Delta t_{standby}$	25°C		2	+/- 12[5]	%

[3] Temperature measured by the internal temperature sensor. This temperature value depends on the PCB temperature, sensor element self-heating and ambient temperature and is typically above ambient temperature.

[4] Long term stability is specified in the full accuracy operating pressure range 0 ... 65°C

[5] From -40 to 85°C

2. Absolute maximum ratings

The absolute maximum ratings are provided in Table 3 .

Table 3: Absolute maximum ratings

Parameter	Symbol	Condition	Min	Max	Unit
Voltage at any supply pin		V_{DD} and V_{DDIO} Pin	-0.3	3.8	V
Voltage at any interface pin			Vss -0.3	V_{DDIO} + 0.3	V
Storage temperature		≤ 65% rel. H.	-45	+85	°C
Overpressure survivability	P_{OVER}			2 000 000	Pa
Mechanical shock	M_S	MIL-STD-883H 2002.5		12000	g
Maximum allowable dust particle inside package	$Dust_{MAX}$	ISO 12103-1 A2		300[6]	µm
ESD		Charge device model (CDM)	Class C2a: 500V to <750V		
		Human body model (HBM)	Class 2: 2 kV		

Note: Stresses above these listed maximum ratings may cause permanent damage to the device. Exposure beyond specified electrical characteristics (Table 2) may affect device reliability or cause malfunction.

3. Functional description

The BMP388 consists of a Piezo-resistive pressure sensing element and a mixed-signal ASIC. The ASIC performs A/D conversions and provides the conversion results and sensor specific compensation data through a digital interface.

BMP388 provides highest flexibility to the designer and can be adapted to the requirements regarding accuracy, measurement time and power consumption by selecting from a high number of possible combinations of the sensor settings.

BMP388 can be operated in three power modes (see section 3.3):

sleep mode | normal mode | forced mode

In sleep mode, no measurements are performed. Normal mode comprises an automated perpetual cycling between an active measurement period and an inactive standby period. In forced mode, a single measurement is performed. When the measurement is finished, the sensor returns to sleep mode.

[6] Defined by hole size

A set of oversampling settings is available ranging from ultra-low power to highest resolution setting in order to adapt the sensor to the target application. The settings are predefined combinations of pressure measurement oversampling and temperature measurement oversampling. Pressure and temperature measurement oversampling can be selected independently from 0 to 32 times oversampling (see sections 3.4.1 and 3.4.2):

- Temperature measurement
- Ultra low power
- Low power
- Standard resolution
- High resolution
- Ultra high resolution
- Highest resolution

BMP388 is equipped with a built-in IIR filter in order to minimize short-term disturbances in the output data caused by the slamming of a door or window. The filter coefficient ranges from 0 (off) to 127.

3.1. Block diagram

Figure 1 shows a simplified block diagram of the BMP388:

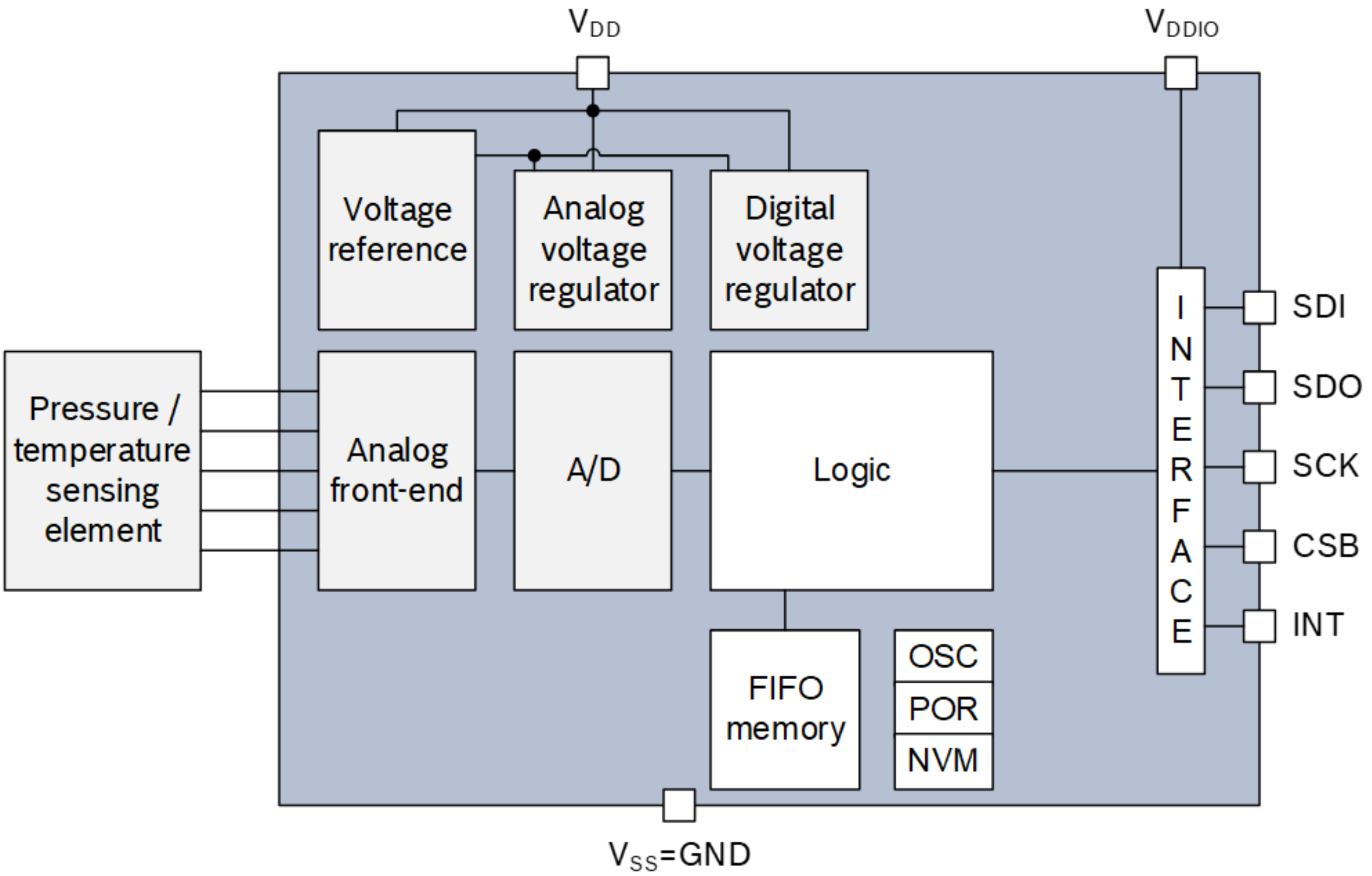

Figure 1: Block Diagram BMP388

3.2. Power management

The BMP388 has two separate power supply pins

- V_{DD} is the main power supply for all internal analog and digital regulator blocks.
- V_{DDIO} is a separate power supply pin, used for the supply of the digital interface.

V_{DD} and V_{DDIO} pins can be energized in any order.

A power-on reset generator is built in which resets the logic circuitry and the register values after the power-on sequence. The slope for ramp up time must not be less than 10µms. After powering up, the sensor settles in sleep mode (see section 3.3).

Completion of the power-on-reset or soft reset is indicated by the bit *por_detected[0].* The bit is cleared after reading.

Holding any interface pin (SDI, SDO, SCK or CSB) at a logical high level when V_{DDIO} is switched off can permanently damage the device due caused by excessive current flow through the ESD protection diodes.

3.3. Power modes

The BMP388 offers three power modes: sleep mode, forced mode and normal mode. These can be selected using the mode[1:0] bits in control register *"pwr_ctrl"*.

Table 4: mode settings

***mode*[1:0]**	**Mode**
00	Sleep mode
01 and 10	Forced mode
11	Normal mode

3.3.1. Sleep mode

Sleep mode is set by default after power on reset. In sleep mode, no measurements are performed and power consumption (I_{DDSL}) is at a minimum. All registers are accessible; Chip-ID and compensation coefficients can be read.

3.3.2. Forced mode

In forced mode, a single measurement is performed according to selected measurement and filter options. When the measurement is finished, the sensor returns to sleep mode and the measurement results can be obtained from the data registers. For a next measurement, forced mode needs to be selected again. Forced mode is recommended for applications which require low sampling rate or host-based synchronization.

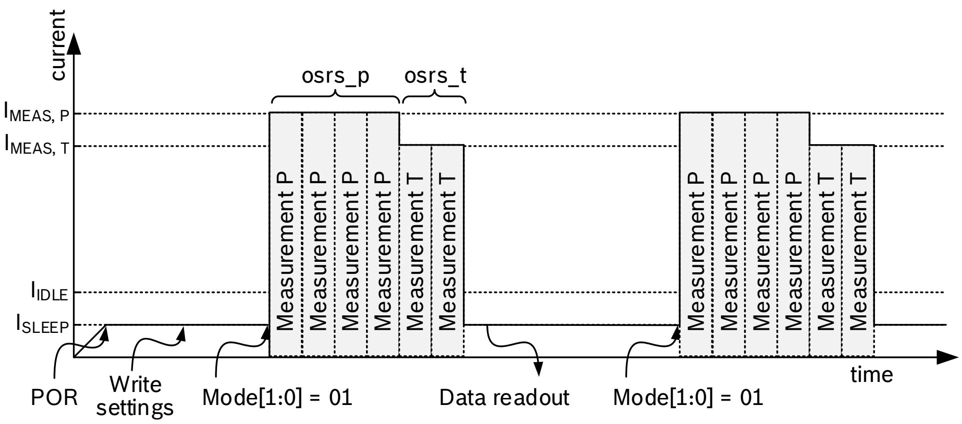

Figure 2: Force mode timing diagram

3.3.3. Normal mode

Normal mode continuously cycles between an (active) measurement period and an (inactive) standby period. The measurement rate is set in the *odr_sel* register (see 4.3.18), where various prescaler for sample frequencies $f_{sampling}$=200Hz can be selected. The sampling period τ calculated by

$$\tau_{sampling} = prescaler/f_{sampling}.$$

After setting the mode, measurement and filter options, the last measurement results can be obtained from the data registers without the need of further write accesses. Normal mode is recommended when using the IIR filter, and useful for applications in which short-term disturbances (e.g. blowing into the sensor) should be filtered.

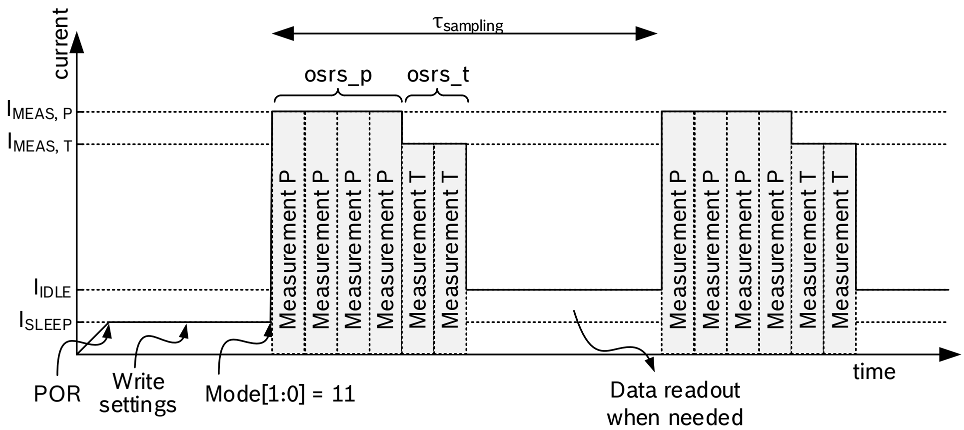

Figure 3: Normal mode timing diagram

3.3.4. Mode transition diagram

The supported mode transitions are displayed below. If the device is currently performing a measurement, execution of mode switching commands is delayed until the end of the currently running measurement period. Further mode change commands are ignored until the last mode change command is executed. Also, mode change commands that are not legal are ignored.

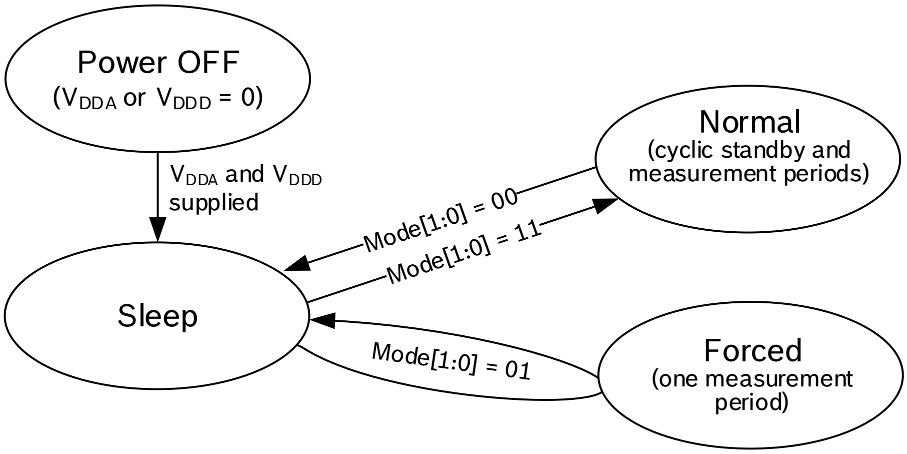

Figure 4: Mode transition diagram

3.4. Measurement flow

The BMP388 measurement period consists of a temperature and pressure measurement with selectable oversampling. After the measurement period, the data are passed through an optional IIR filter, which removes short-term fluctuations in pressure (e.g. caused by slamming a door). The flow is depicted in the diagram below.

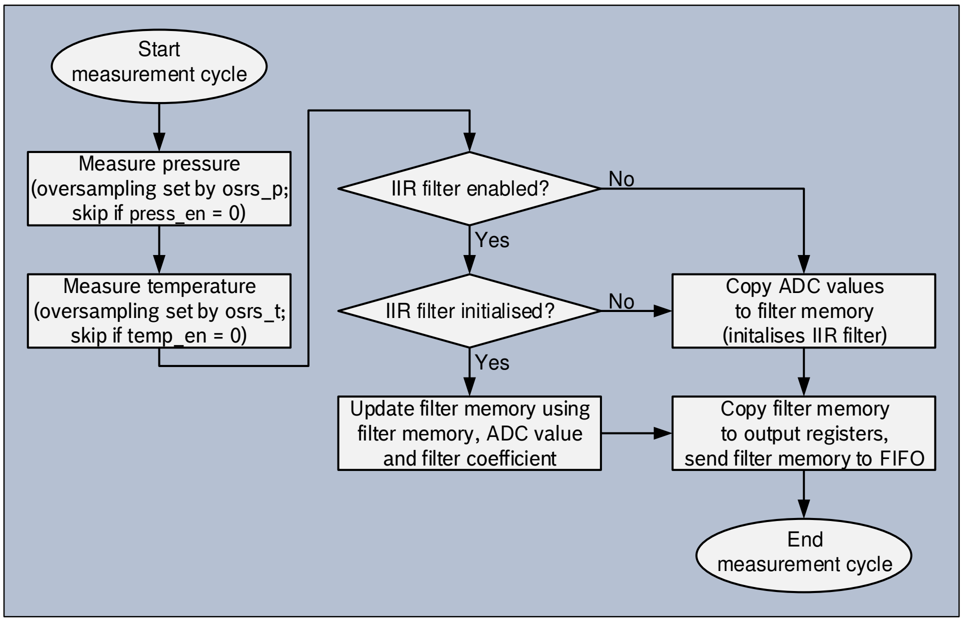

Figure 5: BMP388 measurement cycle

The individual blocks of the diagram above will be detailed in the following subsections.

3.4.1. Pressure measurement

Pressure measurement can be enabled or skipped. Skipping the measurement could be useful if BMP388 is used as temperature sensor. When enabled, several oversampling options exist. Each oversampling step reduces noise and increases the output resolution by one bit, which is stored in the XLSB data register.

Enabling the measurement is selected by press_en bit in *“PW_CTRL[0]”* register (see 4.3.16). The oversampling setting *osr_p* can be configured in *“OSR[2:0]”* register (see 4.3.17).

Table 5: *osr_p* settings

Oversampling setting	*osr_p*	Pressure oversampling	Typical pressure resolution	Recommended temperature oversampling
Ultra low power	000	×1	16 bit / 2.64 Pa	×1
Low power	001	×2	17 bit / 1.32 Pa	×1
Standard resolution	010	×4	18 bit / 0.66 Pa	×1
High resolution	011	×8	19 bit / 0.33 Pa	×1
Ultra high resolution	100	×16	20 bit / 0.17 Pa	×2
Highest resolution	101	×32	21 bit / 0.085 Pa	×2

3.4.2. Temperature measurement

Temperature measurement can be enabled or skipped. Skipping the measurement could be useful to measure pressure extremely rapidly. When enabled, several oversampling options exist. Each oversampling step reduces noise and increases the output resolution by one bit, which is stored in the XLSB data register. Noise and increases the output resolution by one bit, which is stored in the XLSB data register.

Enabling the measurement is selected by temp_en bit in *“PW_CTRL[1]”* register (see 4.3.16). The oversampling setting *osr_t* can be configured in *“OSR[5:3]”* register (see 4.3.17).

Table 6: *osrs_t* settings

osr_t	Temperature oversampling	Typical temperature resolution
000	×1	16 bit / 0.0050 °C
001	×2	17 bit / 0.0025 °C
010	×4	18 bit / 0.0012 °C
011	×8	19 bit / 0.0006 °C
100	×16	20 bit / 0.0003 °C
101	×32	21 bit / 0.00015 °C

It is recommended to base the value of *osr_t* on the selected value of *osrs_p* as per Table 5. Temperature oversampling above ×2 is possible, but will not significantly improve the accuracy of the pressure output any further. The reason for this is that the noise of the compensated pressure value depends more on the raw pressure than on the raw temperature noise. Following the recommended setting will result in an optimal noise-to-power ratio.

3.4.3. IIR filter

The environmental pressure is subject to many short-term changes, caused e.g. by slamming of a door or window, or wind blowing into the sensor. To suppress these disturbances in the output data without causing additional interface traffic and processor work load, the BMP388 features an internal IIR filter. It effectively reduces the bandwidth of the output signals[7]. The output of a next measurement step is filter using the following formula:

$$data_{filtered} = \frac{data_{filtered\_old} * filter\_coefficient + data_{ADC}}{filter\_coefficient + 1}$$

where data_filtered_old is the data coming from the previous acquisition, and data_ADC is the data coming from the ADC before IIR filtering.

The IIR filter can be configured using setting *iir_filter* in *"CONFIG"* register (see 4.3.20).

When writing to the register *filter*, the filter is reset. The next value will pass through the filter and be the initial memory value for the filter. IIR filter is reset if the temperature or pressure measurement is disabled (*temp_en* or *press_en* registers changed from '1' to '0') or when a transition from sleep mode to normal mode occurs. After enabling of pressure or temperature measurement, the filtering will start, thus the next incoming value will pass unfiltered and be the initial value of the IIR filter.

The step response (e.g. response to in sudden change in height) of different filter settings is displayed in Figure 6.

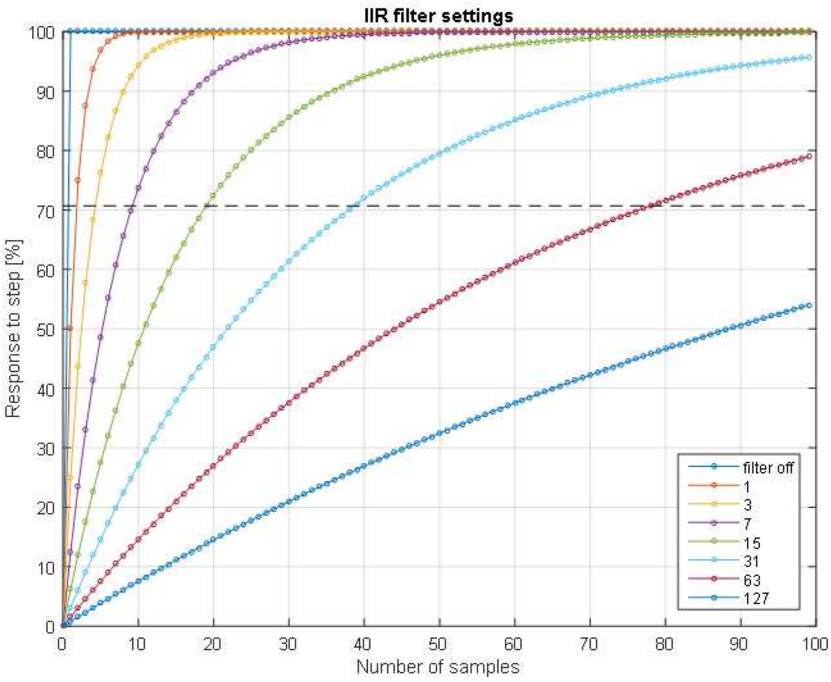

Figure 6: Step response at different IIR filter settings

3.4.4. Oversampling

Noise depends on the oversampling and filter settings selected. The stated values were determined in a controlled pressure environment and are based on the average standard deviation of 32 consecutive measurement points taken at highest sampling rate (for details please refer to Table 21). This is required to exclude long term drifts from the noise measurement.

[7] Since most pressure sensors do not sample continuously, filtering can suffer from signals with a frequency higher than the sampling rate of the sensor. E.g. environmental fluctuations caused by windows being opened and closed might have a frequency <5 Hz. Consequently, a sampling rate of ODR = 10 Hz is sufficient to obey the Nyquist theorem.

Table 7: Noise in pressure

Typical RMS noise in pressure [Pa]								
Oversampling setting	**IIR filter coefficient**							
	off	**2**	**4**	**8**	**16**	**32**	**64**	**128**
Ultra low power	6.6	3.8	2.5	1.7	1.2	0.8	0.6	0.4
Low power	4.3	2.5	1.6	1.1	0.8	0.5	0.4	0.3
Standard resolution	3.2	1.8	1.2	0.8	0.6	0.4	0.3	0.2
High resolution	2.3	1.3	0.9	0.6	0.4	0.3	0.2	0.1
Ultra high resolution	1.6	0.9	0.6	0.4	0.2	0.2	0.1	0.1
Highest resolution	1.2	0.7	0.4	0.3	0.3	0.1	0.1	<0.1

Table 8: Noise in temperature

Typical RMS noise in temperature [°C]	
Temperature oversampling	**IIR filter off**
Ultra low power	0.005
Low power	0.005
Standard resolution	0.005
High resolution	0.005
Ultra high resolution	0.004
Highest resolution	0.003

3.5. Filter selection

In order to select optimal settings, the following use cases are suggested:

Table 9: Recommended filter settings based on use cases

Use case	Mode	Over-sampling setting	osrs_p	osrs_t	IIR filter coeff. (see 4.3.20)	I_{DD} [µA] (see 3.8)	ODR [Hz] (see 3.4.1)	RMS Noise [cm] (see 3.4.4)
handheld device low-power (e.g. Android)	Normal	High resolution	x8	×1	2	145	12.5	11
handheld device dynamic (e.g. Android)	Normal	Standard resolution	×4	×1	4	310	50	10
Weather monitoring (lowest power),	Forced	Ultra low power	×1	×1	Off	4	1/60	55
Drop detection	Normal	Low power	×2	×1	Off	358	100	36
Indoor navigation	Normal	Ultra high resolution	×16	×2	4	560	25	5
Drone	Normal	Standard Resolution	x8	x1	2	570	50	11

3.6. FIFO Description

The BMP388 contains a 512 Bytes FIFO (first-in-first-out) data buffer. To enable data collecting in the FIFO, *fifo_mode* is set at '1' and data to be collected are defined through *fifo_press_en* and *fifo_temp_en*. The FIFO mode is disabled, when no writing is defined which according to the following two cases:

- *fifo_mode*='0'
- *fifo_mode*='1' and *fifo_press_en*='0' and *fifo_temp_en*='0'

If the FIFO is disabled when FIFO byte count is greater than 0, no new frame is written to the FIFO, but FIFO is operational:

- Frames already written in the FIFO remain stored and can be read out
- FIFO interrupts and their corresponding statuses are still evaluated
- after all bytes are read out, Sensortime (if enabled) and Empty frames are generated
- FIFO can be flushed

3.6.1. FIFO input data

Storing of pressure and/or temperature measurement results is enabled by setting fifo_press_en='1' and fifo_temp_en='1' respectively. Storing of data can be enabled or disabled on a per-channel basis in any combination. Filtered or unfiltered data are stored to the FIFO; if data_select="01", filtered data are stored, otherwise unfiltered data are stored to the FIFO. The Number of bytes available in FIFO is readable through fifo_length_1<0> (MSBs) and fifo_length_0<7:0> (LSBs) registers.

The FIFO byte count registers fifo_length_0 and fifo_length_1 are updated only when a full frame has been written to FIFO and is available for read-out. FIFO byte count registers are also updated after each full-frame read from the FIFO.

FIFO byte count registers increment or decrement is equal to frame length; intermediate increments (corresponding to a partial frame) are not readable.

3.6.2. FIFO data sampling selection

The FIFO input data rate is reduced by selecting a down-sampling factor in register fifo_subsampling. Down-sampling factor ranges from 1 to 128 and is equal to $2^{fifo\_subsampling}$. Down-sampling is applied in the normal mode only and is aligned to the measurement timing grid. Down-sampling counter is reset and data saved to the FIFO at the end of the first measurement when a transition from sleep mode to normal mode occurs.

3.6.3. FIFO read out

FIFO is read out via fifo_data register. FIFO reads are never blocked, however an ongoing read from the FIFO does not block writing to the FIFO.

During burst read, the address counter stops incrementing when fifo_data address is reached; this allows a complete reading of the FIFO content within one burst read transaction.

3.6.4. FIFO overflow behavior

A FIFO overflow occurs if the FIFO is full and a new data is written to the FIFO. FIFO full means free space is less than maximum frame length (9 bytes). In case of overflow the FIFO can either stop recording data or overwrite the oldest data. The behavior is controlled by register fifo_stop_on_full.

- Streaming mode, fifo_stop_on_full='0':
  if the new frame does not fit inside the remaining free space in the FIFO RAM, FIFO will repeatedly delete the oldest frame until it creates enough space for the new one.
- FIFO stop-on-full mode, fifo_stop_on_full='1':
  The newest frame is discarded. Normal operation resumes if the FIFO full condition no longer persists.

3.6.5. FIFO Frames

One data frame is composed of a header and a set of data organize as described in table below.

Table 10: Data frame composition

Bit	7		6	5	4	3	2	1	0
Header		fh_mode[1:0]		fh_param[3:0]				0	0
Data		Data bytes							

The number of data bytes is defined by the header.

3.6.5.1. Header Format

Table 11: Header format

fh_mode[1:0]	Definition	fh_param[3:0]
10	Sensor frame	Sensor enable bits
01	Control frame: configuration error	0001
01	Control frame: FIFO input configuration change	0010

3.6.5.2. Sensor Frame Format

A sensor frame consists of a header and data bytes

Table 12: Sensor frame format

Bit	7	6	5	4	3	2	1	0
Header	1	0	s	t	0	p	0	0
Data	data bytes							

Sensor data in frame is defined by s (time), t (temperature) and p (pressure) sensor enable bits:

- If s='1', the frame corresponds to the sensor-time frame, in that case, t=p='0'
- If t='1' or/and p='1', the frame corresponds to a normal pressure or/and a temperature frame
- If s=t=p='0', the frame corresponds to an empty frame

Table 13: Sensor-time frame

Bit	7	6	5	4	3	2	1	0
Header	1	0	1	0	0	0	0	0
Sensor-time	time_xlsb[7:0]							
	time_lsb[7:0]							
	time_msb[7:0]							

The data for the sensor-time frame consists of register sensor_time content at the time the sensortime frame transmission has started. A sensor-time frame is not stored in the FIFO, but append to every FIFO burst read operation after all data has been transmitted if fifo_time_en='1'.

Table 14: Normal pressure and temperature frame

Bit	7	6	5	4	3	2	1	0
Header	1	0	0	1	0	1	0	0
Temp	temp_xlsb[7:0]							
	temp_lsb[7:0]							
	temp_msb[7:0]							
Press	press_xlsb[7:0]							
	press_lsb[7:0]							
	press_msb[7:0]							

If one of t and p is '0', the corresponding data is not part of the frame; the frame is therefore reduced to 4 bytes.

A FIFO empty frame is a sensor frame with no sensor enabled. This frame is returned if the last frames was read-out or if FIFO is empty.

Table 15: FIFO empty frame format

Bit	7	6	5	4	3	2	1	0
Header	1	0	0	0	0	0	0	0
Data	0	0	0	0	0	0	0	0

When a configuration error is detected, a configuration error frame is stored into the FIFO

Table 16: Control frame: configuration error

Bit	7	6	5	4	3	2	1	0
Header	0	1	0	0	0	1	0	0
Opcode	0	0	0	0	0	0	0	1

If FIFO is enabled and a change in registers "FIFO_CONF_2" or "OSR" or "ODR" or "CONFIG" or press_en or temp_en occurs, a control frame is inserted just before the first sensor frame with new configuration is stored to the FIFO. If multiple configuration change becomes active at the same time, only one control frame is inserted. Configuration changes are tracked when the device is in normal mode.

3.6.6. **Corner cases**

3.6.6.1. Under-read

In case the FIFO is under-read (not all frames were taken from the FIFO, but the last frame read was read entirely), the next readout will continue at the frame that was just about to be sent.

3.6.6.2. Partial frame read

In case the FIFO is under-read and a partial data frame read occurred (not all frames were taken from the FIFO, and the last frame read was not read entirely), the entire last data frame is repeated upon the next read access.

When fifo_stop_on_full='0', the oldest frames are overwritten when new frames are available and the FIFO is full. When this happens, the partially read data frame is not repeated but the oldest frame available in the RAM is sent instead.

Sensortime frame is not repeated when read only partially, its payload always contains current sensortime counter value.

If the read of the frame is interrupted after two or more bits of the frame's last byte were already read, then frame is discarded even though not all bits were read and the frame was read only partially.

3.6.6.3. Over-read

If the burst read continues after all frames have been read out, a sensortime frame is sent after the FIFO becomes empty during a burst read operation if fifo_time_en='1'. After that or when FIFO was completely read, the empty frame is returned as long as the burst read is

active.

3.6.7. FIFO flush conditions

The FIFO can be flushed by issuing either *fifo_flush* or a *softreset* in the command register "CMD" (see 4.3.22):

Table 17: fifo_fluch and softreset commands

	Value
fifo_flush	0xB0
softreset	0xB6

3.7. Interrupts

The BMP388 provides an interrupt pin (INT), which allows to signal certain events to the host processor. Different events can be mapped to the interrupt pin, which all are processed with a logical OR.

The available interrupts are listed below and can be read in the "INT_STATUS" register (see 4.3.8):

- FIFO watermark interrupt
- FIFO full interrupt
- Data ready interrupt

3.7.1. Interrupt default mode

After a power-on or soft reset has completed, the interrupt pin is in push-pull and active high mode.

3.7.2. Interrupt pin latching

The chip can be operated in non-latched or latched mode:

- Non-latched mode: Interrupts' conditions are selected as a contributors to the INT pad. INT pad is de-asserted as soon as the conditions of all the interrupts propagated to the INT pad are not valid.
  For data ready, interrupt contribution is de-asserted by reading *int_status* or after 2.5ms after assertion of the interrupt.
  For FIFO interrupts, INT pad contributions are not affected by fifo_data readings, only by the interrupt conditions
- Latched mode: Interrupt statuses are selected as contributors of the INT pad.

The minimum interrupt pulse width is T_{int} = 1µs

3.7.3. Monitoring

The status of interrupt bits is always visible in the "INT_STATUS" register. (see 4.3.8) for details.

3.7.4. Interrupt Pin Configuration

The interrupt pin / pad is configured by the Bits in the "INT_CTRL" register (see 4.3.14). However, the status bits are not influenced thereby.

The output mode of the INT pad is controlled by *int_od* bit:

Table 18: int_od

int_od='0'	**Push-pull**
int_od='1'	Open-drain

The level of the interrupt pad can be configured and switched by *int_level* between active low and active high:

Table 19: int_level

int_level='0'	**active_low**
int_level='1'	active_high

The latching of interrupts for INT pad and INT_STATUS register can be enabled by *int_latch='1'* or disabled by *int_latch='0'*.

FIFO interrupts are mapped to the INT pad by enabling the respective functions. For mapping FIFO watermark reached interrupt to the pad, the *fwtm_en* bit shall be written to '1' (disabling by '0'). The FIFO full interrupt can be mapped by writing *ffull_en* with '1').

3.7.5. Interrupt functions

3.7.5.1. FIFO watermark interrupt

The FIFO watermark interrupt is used to signal, that fill level of the FIFO has reached a pre-set limit.

Fifo_length_1 & fifo_length_0 ≥ *fifo_wtm_1 & fifo_wtm_0*

The watermark level can be set and adjusted by the user by writing the registers and 0x15 "FIFO_WTM_0" and 0x16 "FIFO_WTM_1" (see 4.3.11) in a single burst transaction. If the FIFO watermark level is set to zero, the interrupt condition will never be satisfied.

The status of the watermark interrupt can be read back through the *fwm_int* bit. The interrupt condition is also updated after the end of a serial interface transaction which wrote into the registers fifo_wtm_0 or fifo_wtm_1.

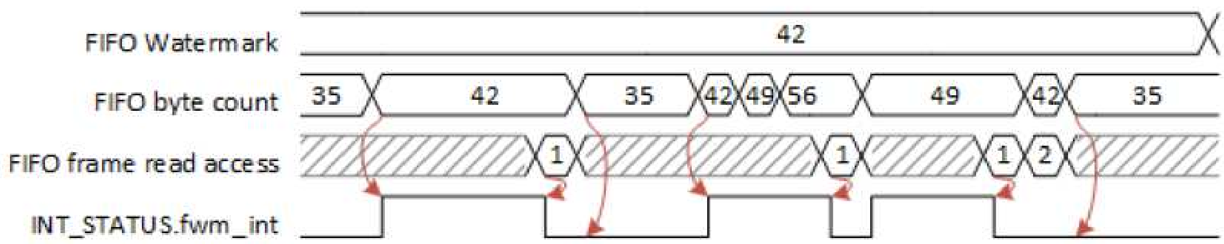

Figure 7: FIFO watermark interrupt, non-latched with reads from FIFO

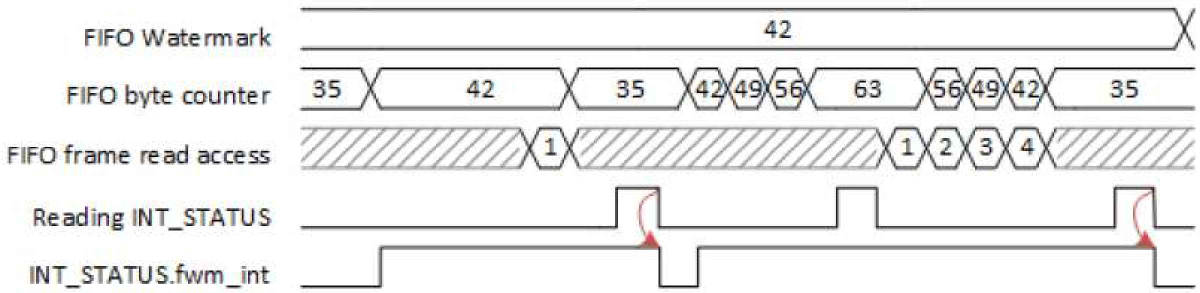

Figure 8: FIFO watermark interrupt, latched, with reads from FIFO

3.7.5.2. FIFO full interrupt

FIFO Full interrupt status is asserted when the full interrupt condition is satisfied, when the filling level of the FIFO

number of unread bytes in the FIFO = *fifo_length_1 & fifo_length_0* is equal or higher than 504.

The status of the FIFO full interrupt can be read back through the ffull_int bit. Interrupt status is cleared by reading the ffull_int bit high '1' when the FIFO filling level is lower than 504.

The FIFO full interrupt is propagated to INT pad only when it is enabled by setting bit ffull_en='1'. Latching mode configuration bit int_latch selects whether the interrupt status or condition is propagated to the INT pad.

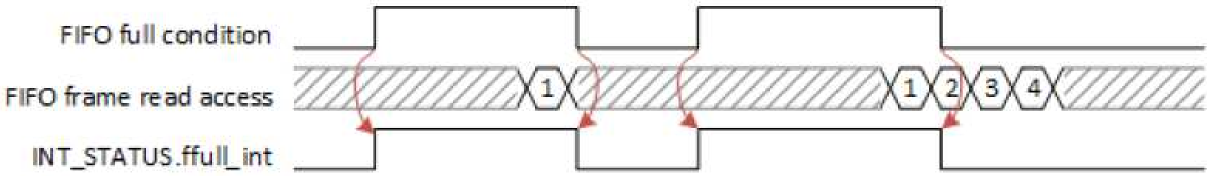

Figure 9:FIFO full interrupt, non-latched, with reads from FIFO

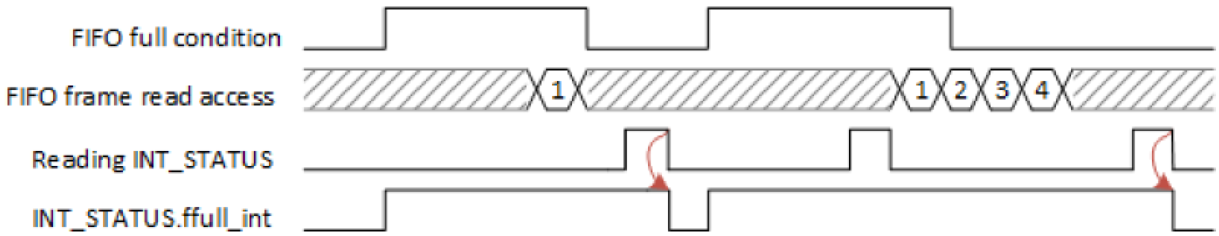

Figure 10: FIFO full interrupt, latched, with reads from FIFO

3.7.5.3. Data ready

Data ready interrupt status *int_status.drdy* is asserted after a pressure and temperature measurement ends and conversion results are stored to the data registers and to the FIFO. The status of the interrupt can be read back through the *drdy* bit. The data ready interrupt is propagated to INT pad when it is enabled by setting *drdy_en*='1'. Interrupt status is cleared by reading *drdy* bit high '1'. Data ready INT pad contribution is cleared automatically 2.5 ms after the interrupt assertion in the non-latched mode (int_latch='0').

Corner cases:

- If data ready interrupt is changed from latched to non-latched mode (int_latched changed from '1' to '0') after the interrupt was already asserted;
  timer is not running and it is not starting during the ongoing measurement, self-clearing does not happen. Timer is starting when next data ready comes.
- If data ready is changed to be propagated to INT pad (*drdy_int* changed from '0' to '1') after the interrupt was already asserted;
  data ready INT pad contribution remains '0' until next data ready interrupt assertion.

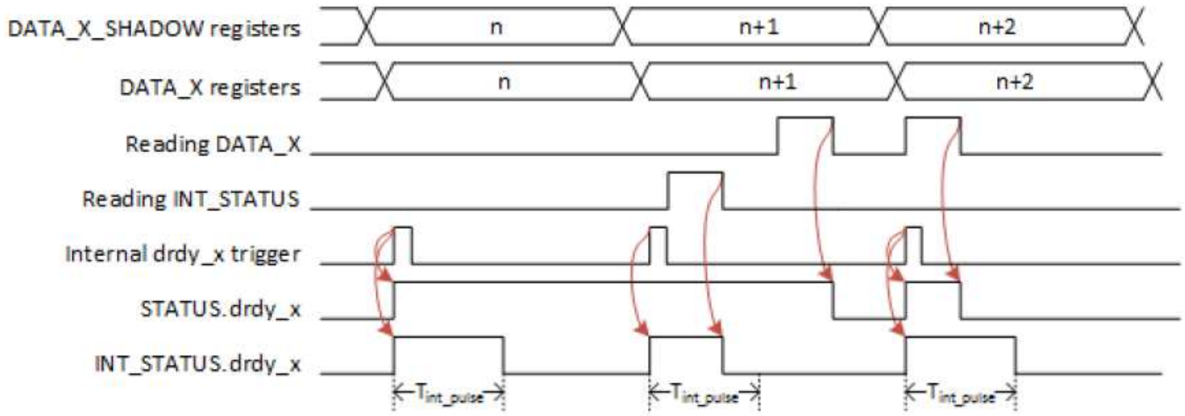

Figure 11: Data ready interrupt, non-latched mode, with read of data registers

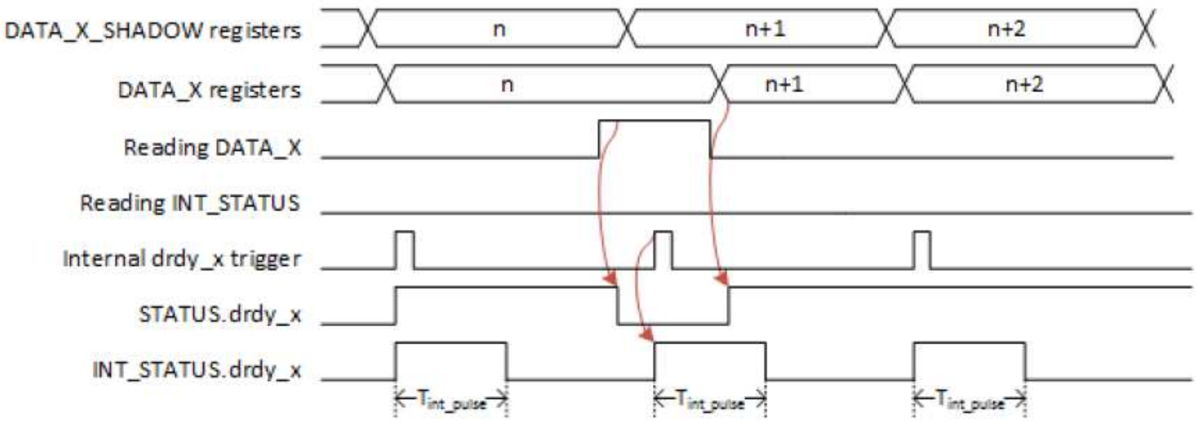

Figure 12: Data ready interrupt, non-latched mode, with read of data registers during register update

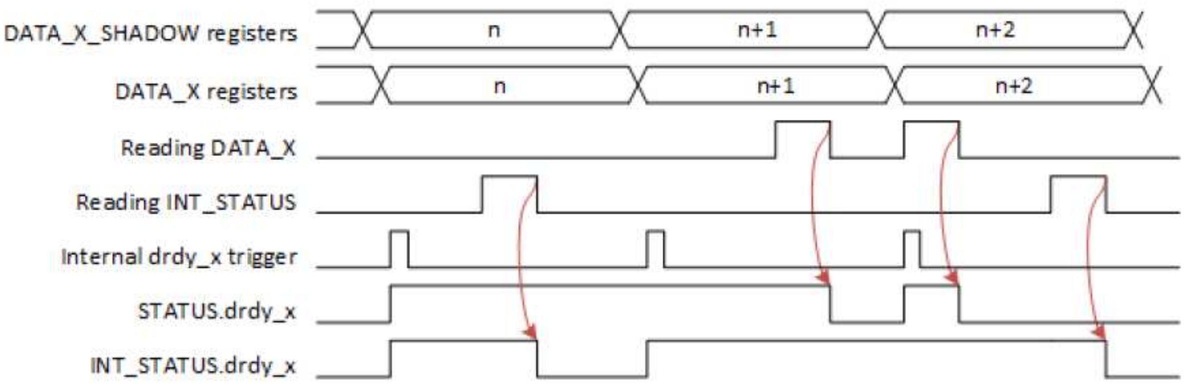

Figure 13: Data ready interrupt, latched mode, with read of data registers

3.8. Current consumption

The current consumption depends on ODR and oversampling setting. The values given below are normalized to an ODR of 1 Hz. The actual consumption at a given ODR can be calculated by multiplying the consumption in Table 20 with the ODR used. The actual ODR is defined either by the frequency at which the user sets forced measurements or by oversampling and sampling period settings in normal mode in Table 23.

Table 20: Current consumption

Oversampling setting	Pressure oversampling	Temperature oversampling		I_{DD} [µA] @ 1 Hz forced mode	
			Typ	Calculated Forced Mode	Max
Ultra low power	×1	×1	3.4	4.3	7.4
Low power	×2	×1	4.8	5.6	9.3
Standard resolution	×4	×1	7.8	8.2	12.8
High resolution	×8	×1	13.8	13.3	19.5
Ultra high resolution	×16	×2	26.2	24.3	33.5
highest resolution	×32	×2	46.4	45.0	59.2

3.9. Measurement timings

The rate at which measurements can be performed in forced mode depends on the oversampling settings *osr_t* and *osr_p*. Thus in normal mode, the measurement rate is determined by the sampling frequency fsample.

3.9.1. Measurement time

The following table explains the typical and maximum measurement time based on selected oversampling setting. The minimum achievable frequency is determined by the maximum measurement time.

Table 21: measurement time

Oversampling setting	Pressure oversampling	Temperature oversampling	Measurement time [ms]			Measurement rate [Hz]		
			Typ	Max	calculated min time in forced mode	Typ	Min	calculated max rate in forced mode
Ultra low power	×1	×1	5.5	5.7	4.9	181.8	155.6	202
Low power	×2	×1	7.5	8.7	6.9	133.3	114.6	144.1
Standard resolution	×4	×1	11.5	13.3	10.9	87.0	75.0	91.4
High resolution	×8	×1	19.5	22.5	18.9	51.3	44.4	52.8
Ultra high resolution	×16	×2	37.5	43.2	36.9	26.7	23.1	27.1
highest resolution	×32	×2			68.9			14.5