Sensata Technologies

8MPP2 SENSOR

with I²C OPERATION

INTERFACE MANUAL

1 GENERAL INFORMATION

1.1 Overview

Brief Description

The 8MPP2, is a piezo resistive MEMS bridge sensor that outputs corrected pressure values via the I²C bus. The device features digital compensation of sensor offset, sensitivity, and temperature drift. A piezo resistive MEMS sense element and CMOS integrated circuit are mated digitally to produce fast and precise measurements in a pre-configured, compact, and robust package.

Features

- Update rates from 0.5ms to 125ms depending on resolution and power settings
- Fast power-up to data output response: 3ms
- Standard Mode (100 kHz) and Fast Mode (400 kHz) I²C bit rates
- 2nd order nonlinearity pressure compensation
- 2nd order temperature compensation
- Internal temperature compensation reference
- Accuracy ±2% Full Scale over life including Linearity, Repeatability, and Hysteresis over the entire temperature range. ±1% out of the box.

Benefits

- Excellent for low-power battery applications
- Improved accuracy over corrected analog signal output devices
- Incorporated error handling and diagnostics

Physical Characteristics

- Supply voltage: 2.7V to 5.5V
- Current consumption as low as 70µA depending on programmed sample rate
- Typical current consumption in Sleep Mode < 2µA at 25°C
- Operation temperature: -35°C to 85°C
- Full-scale pressure range: configurable 0-1 up to 0-5 psig

Applications

- Residential and commercial gas meters
- Battery powered applications
- Natural gas pressure sensing

8MPP2 Application Example

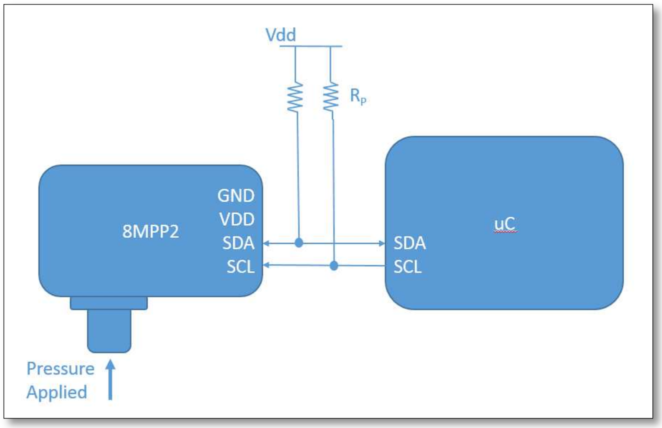


Figure 1-1: Digital I2C pressure sensor connected to a microcontroller

Ordering Example

8MPP2-01-0x28-U-0

- 01 = 1 psig Full Scale
- 0x28 = I²C Device Address
- U = Continuous Update Mode
- 0 = 0 ms power down time

- See section 5-- 'Ordering Information' for all configurations’

Contents

2 SENSOR CHARACTERISTICS

2.1 Absolute Maximum Ratings

Table 2.1: 8MPP2 Maximum Ratings

PARAMETER	SYMBOL	MIN	TYP	MAX	UNITS
Supply Voltage	V_{DD}	-0.3		6.0	V
I/O Pins	$V_{I/O}$	-0.3		V_{DD}+0.3	V
Storage Temperature	T_{STOR}	-50		150	°C

2.2 Operation Conditions

Table 2.2: 8MPP2 Operating Conditions

PARAMETER	SYMBOL	MIN	TYP	MAX	UNIT
Supply Voltage[1]	V_{SUPPLY}	2.7		5.5	V
Ambient Temperature Range[2]	T_{AMB}	-35		85	°C
I²C Pull-Up Resistance	R_P	1	2.2		kΩ
External Capacitance on Supply Voltage	C_{VDD}	100	220	470	nF

1. Accuracy specification is not guaranteed if operated outside of *ordered* voltage range.
2. Contact factory for extended temperature ranges.

2.3 Electrical Parameters

Table 2.3: 8MPP2 Electrical Parameters

PARAMETER	SYMBOL	MIN	TYP	MAX	UNITS
Supply					
Active Supply Current	I_{DD}		2000	2500	uA
Sleep Mode Supply Current	I_{stndby}		0.5	5	uA
Power-On-Reset Level	V_{POR}	1.8		2.5	V
DIGITAL I/O					
Input Low Level	V_{IL}	0		0.2	V_{SUPPLY}
Input High Level	V_{IH}	0.8		1	V_{SUPPLY}
Output Sourcing Current @V_{OH}=V_{DD}-0.2V	I_{OH_SDA}	-1.9	-3.1	-4.8	mA
	I_{OH_EOC}	-0.63	-1.2	-1.9	mA
Output Sink Current @V_{OL}=0.2V	I_{OL_SDA}	2.3	3.9	6.2	mA
	I_{OL_EOC}	0.85	1.7	3.0	mA
SDA Load Capacitance @400kHz	C_{SDA}			200	pF
Input Capacitance (each Pin)	C_{I2C_IN}			10	pF
Total System					
Start-Up Time (Power up to data ready)	t_{STA}		2.8	3.2	ms
Response Time (Time to data ready)	f_{meas}		0.5		ms
Accuracy - TEB[1,2]	$Error_{out}$		0.75	1	%FS
Accuracy Over - Life[1,2]	$Error_{out}$			2	%FS

1. Accuracy specification includes the total error band over the entire temperature range from -35°C to 85°C.
2. Total Error Band includes errors from nonlinearity, hysteresis, and repeatability.

2.4 I²C Timing Characteristics

Table 2.4: I²C Parameters

PARAMETER	SYMBOL	MIN	TYP	MAX	UNITS
SCL clock frequency	f_{SCL}	100		400	kHz
Start condition hold time relative to SCL edge	t_{HDSTA}	0.1			µs
Minimum SCL clock low width[1)]	t_{LOW}	0.6			µs
Minimum SCL clock high width[1)]	t_{HIGH}	0.6			µs
Start condition setup time relative to SCL edge	t_{SUSTA}	0.1			µs
Data hold time on SDA relative to SCL edge	t_{HDDAT}	0			µs
Data setup time on SDA relative to SCL edge	t_{SUDAT}	0.1			µs
Stop Condition setup time on SCL	t_{SUSTO}	0.1			µs
Bus free time between stop condition and start condition	t_{BUS}	2			µs

1) Combined low and high widths must equal or exceed minimum SCLK period.

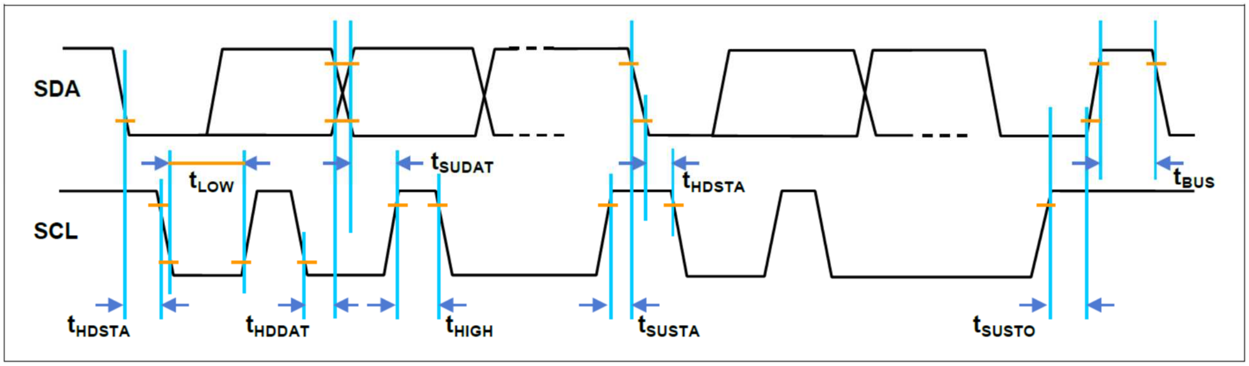


Figure 2-1: I²C Timing Diagram

Note: There are three differences in the 8MPP2 protocol compared with the original I²C protocol:

- Sending a start-stop condition without any transitions on the CLK line (no clock pulses in between) creates a communication error for the next communication, even if the next start condition is correct and the clock pulse is applied. An additional start condition must be sent, which results in restoration of proper communication.
- The restart condition—a falling SDA edge during data transmission when the CLK clock line is still high— creates the same situation. The next communication fails, and an additional start condition must be sent for correct communication.
- A falling SDA edge is not allowed between the start condition and the first rising SCL edge. If using an I²C address with the first bit 0, SDA must be held low from the start condition through the first bit.

3 FUNCTIONAL DESCRIPTION

3.1 Modes of Operation

The 8MPP2 can be configured to operate in either Sleep Mode or Update Mode.

Update Mode: Measurements are taken at a fixed, selectable rate.
(See section 3.1.1)

Sleep Mode: Measurements are only taken upon request by master
(See section 3.1.2)

Some users' will power down the sensor between measurements to conserve power. In this case it is recommended that the user requests update mode.

Figure 3-1 below gives a general overview of the 8MPP2 operation. Details of operation, including the power-up sequence, measurement modes and diagnostics are given in the subsequent sections.

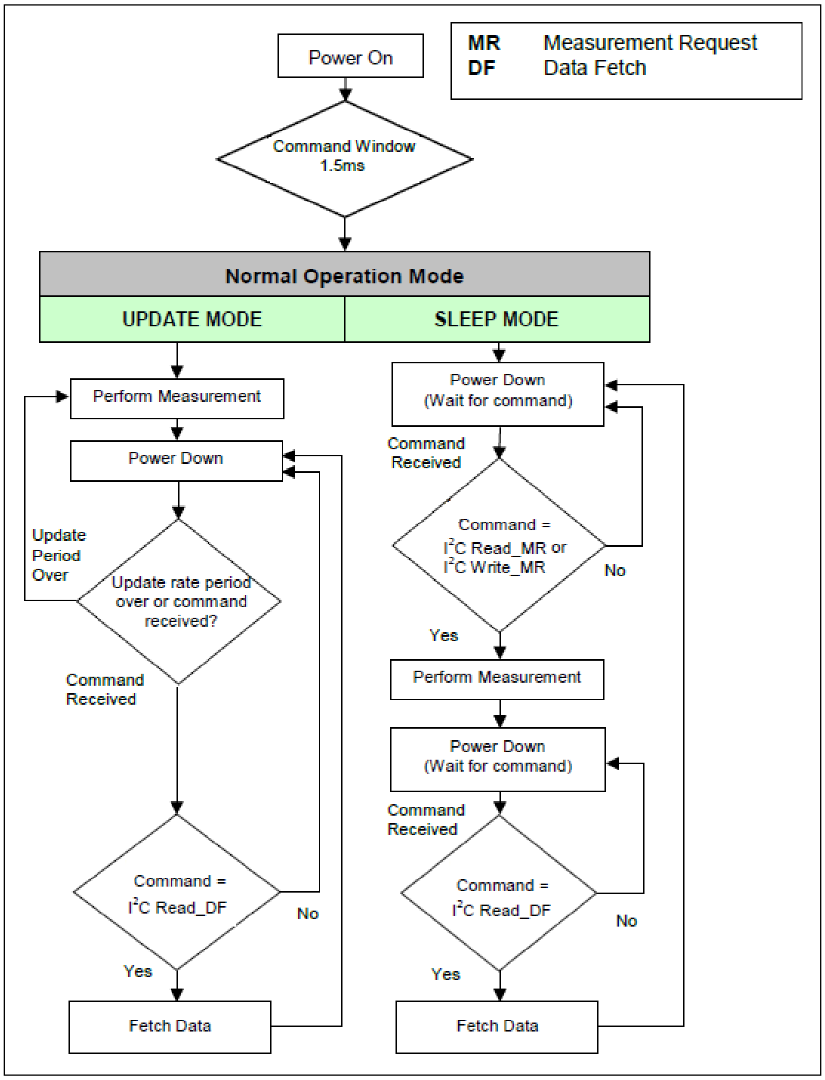


Figure 3-1: General Operation of 8MPP2

On system power-on reset (POR), the 8MPP2 wakes up and initializes itself. After the 1.5 ms initialization window the device will immediately start performing the required A2D conversions (Temp, AZ, Bridge). When Update Mode has been selected, the first corrected data will be written to the digital interface within 2.8 ms of power-on.

Operation after the power-on sequence depends on whether the part is programmed in Sleep Mode or in Update Mode. In Sleep Mode, the part waits for commands from the master before taking measurements. In Update Mode, data is taken at a fixed, selectable rate. More detail is given about Update Mode and Sleep Mode in sections 3.1.1 and 3.1.2 respectively.

3.1.1 Update Mode

In Update Mode, the digital core will perform measurements and correction calculations at a selectable update rate and update the I^2C output register. The power-on measurement sequence for the Update Mode is shown in Figure 3-2.

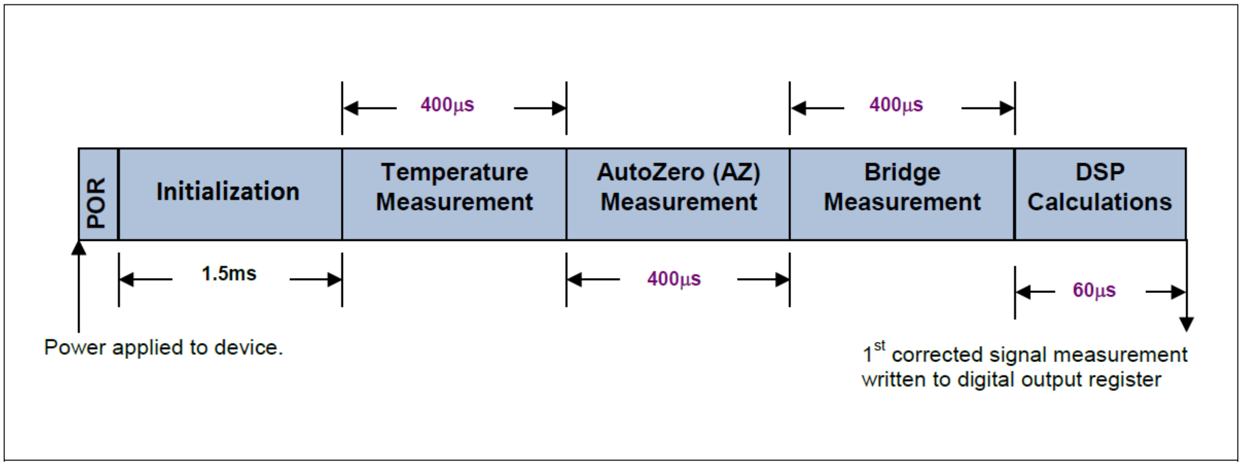


Figure 3-2: Update Mode Timing Diagram

If the sensor is programmed for the fastest update rate, conversions will continue to happen after the power-up sequence. If the 8MPP2 is not in the fastest update rate, the sensor will power down internally after writing to the digital output register. The duration of the power-down period is determined by the Update_Rate selection. See Table 3.1 for the update rates. After the power-down period has expired, the 8MPP2 will power up; take another pressure reading followed by calculations; write to the digital output register; and power down. Temperature and Auto-Zero (AZ) are slower moving quantities but must be updated periodically. When the sensor is configured in Update Mode, these two quantities are measured periodically (referred to as special measurements).

As illustrated in Figure 3-3, valid data output to the digital register occurs after the measurement and the DSP calculations are complete. At this point the controller can fetch the data in I^2C with a Read_DF command. Specifics of the Read_DF command are given in section 3.1.3. After a valid output has been read by the controller, the status bits are set to "stale," indicating that the measurement has not been updated since the last Read_DF. This mode allows the application to simply read the digital output at any time and be assured the data is no older than the selected update period. See Table 3.3 for more information on the status bits. The sensor should be polled at a frequency slower than 20% more of the update rate period listed in Table 1.

Table 3.1: Update Mode update rates

Update Rate	Update Period	Measurement Cycles between Special Measurements
0	0.5 ms	255
1	1.5 ms	127
2	6.5 ms	31
3	32.0 ms	15

1) All time values shown are typical, multiply by 1.5 for worst case
2) There is no power down period with update rate 0

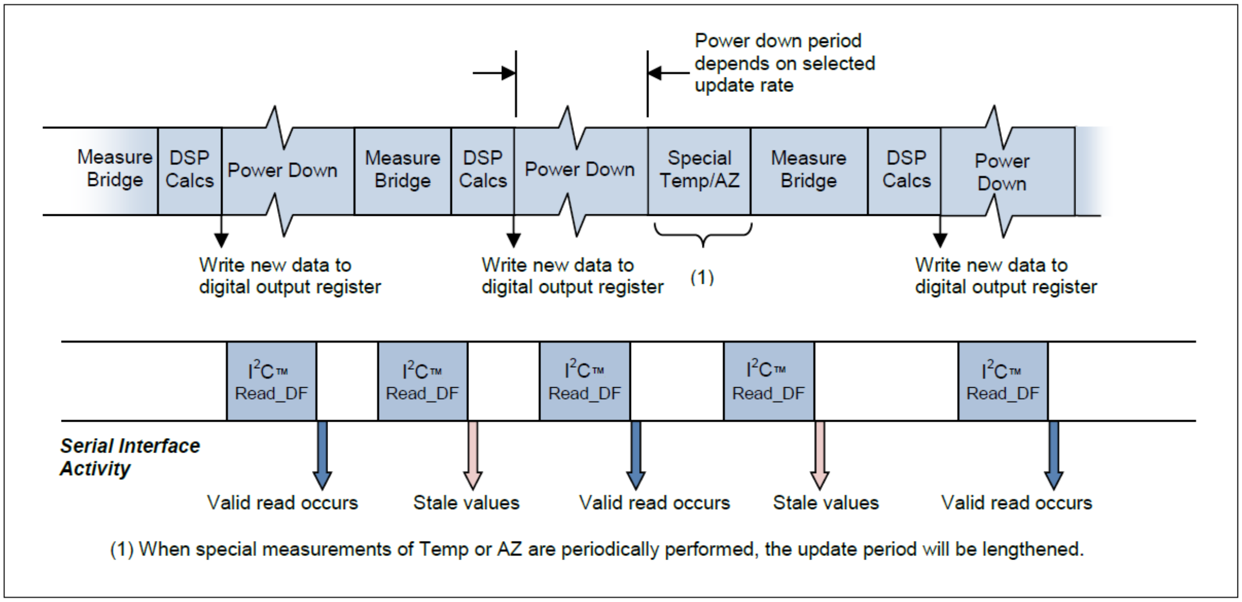


Figure 3-3: Update Mode Data Fetch Timing Diagram

The benefit of slower update rates is power savings. If the update period is increased, the device will be powered down for longer periods of time, so power consumption will be reduced. When a special measurement occurs, a BP/BN (bridge) measurement will occur directly afterward. The update period during this special measurement will be increased by one conversion time over the standard measurement period.

3.1.2 Sleep Mode

In Sleep Mode, after initialization, the 8MPP2 will power down until the controller sends a Read_MR or a Write_MR command. Specifics on the Read_MR and Write_MR commands are given in section 3.1.3. A Read_MR or Write_MR wakes the ZSC31014 and starts a measurement cycle. If the command is Read_MR, the part performs temperature, auto-zero (AZ), and a pressure measurement followed by the DSP correction calculations (see Figure 3-4 If the command is Write_MR, the part measures only the pressure and performs the correction calculations using previously measured temperature and auto-zero data (see Figure 3-5). Valid values are then written to the digital output register, and the 8MPP2 powers down again.

Following a measurement sequence and before the next measurement can be performed, the controller must send a Read_DF command, which will fetch the data as 2, 3 or 4 bytes (see section 3.1.3), without waking the 8MPP2. When a Read_DF is performed, the data packet returned will be the last measurement made with the status bits set to “valid.” See Table 3.3 for more information on the status bits. After the Read_DF is completed, the status bits will be set to “stale.” The next Read_MR or Write_MR will wake the part again and start a new measurement cycle. If a Read_DF is sent while the measurement cycle is still in progress, then the status bits of the packet will read as “stale.” The sensor should be polled at a frequency slower than 20% more than the Sleep Mode response times listed in Table 3.2.

Note: Data is considered invalid from system power-on reset (POR) until the first measured data is written to the digital register. Sending an I^{2}C Write_MR as the first command after power-on delivers invalid data; even though the status bits report it as “valid”. This is due to the correction calculations being performed with an uninitialized temperature and Auto-Zero value.

Table 3.2: Sleep Mode response times

Measurement Request	Response
Read MR	1.5 ms
Write MR	0.5 ms
1) All time values shown are typical, multiply by 1.5 for worst case	

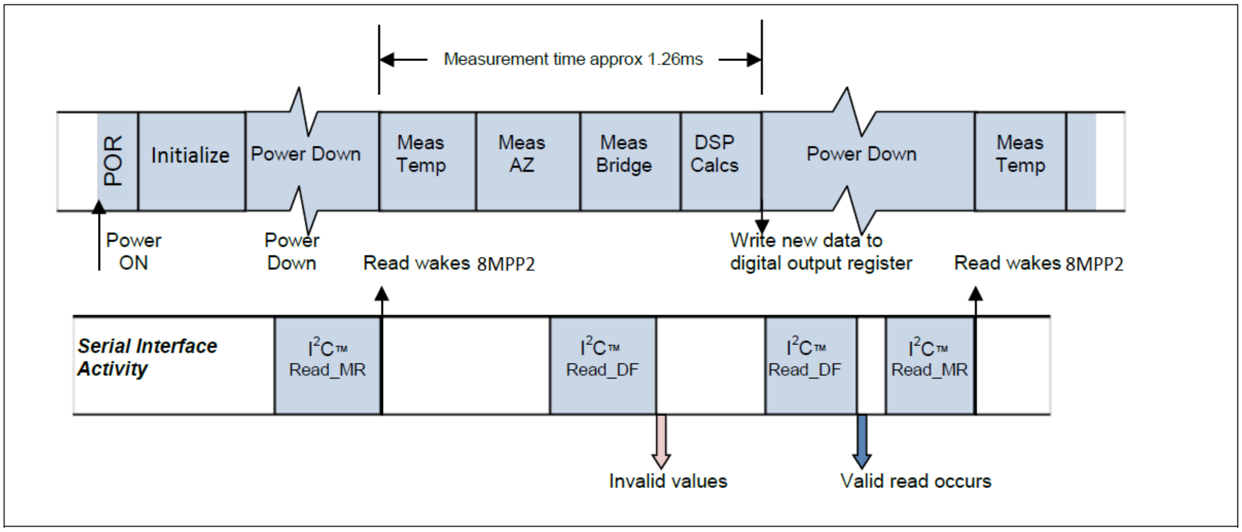


Figure 3-4: Sleep Mode Timing Diagram

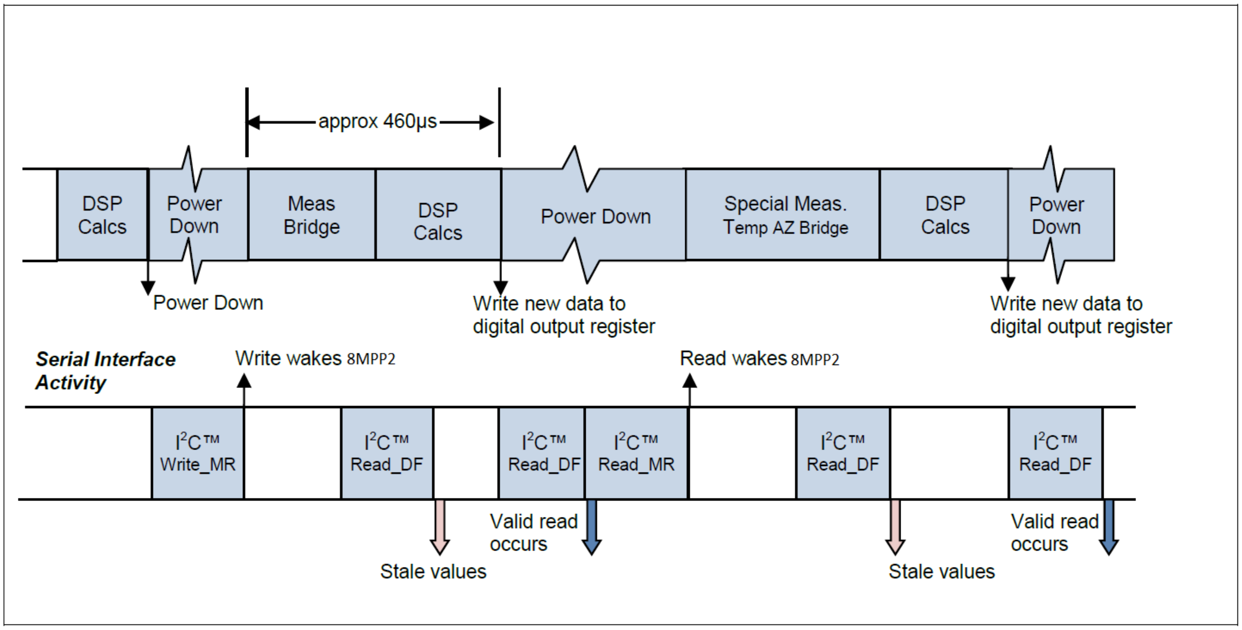


Figure 3-5: Sleep Mode Data Fetch Timing Diagram

3.1.3 I²C Communications

For read operations, the I²C controller command starts with the 7bit slave address with the 8th bit =1 (READ). The sensor as the device sends an acknowledge (ACK) indicating success. The 8MPP2 has four I²C read commands: Read_MR, Read_DF2, Read_DF3, and Read_DF4. These commands are described below.

For write operations, the I²C controller command starts with the 7-bit slave address with the 8th bit =0 (WRITE). The sensor as the device sends an acknowledge (ACK) indicating success. The 8MPP2 has one general I²C write command format: I²C Write_MR. These commands are described below.

Measurement Request

The Read_MR (see example 1 in Figure 3-7) communication contains only the slave address and the READ bit (1) sent by the master. After the ZSC31014 responds with the slave ACK, the master must create a stop condition. This is only used in Sleep Mode (see section 3.1.2) to wake up the device and start a complete measurement cycle (including the special measurements) followed by the DSP calculations and writing the results to the digital output register. The I²C Read_MR function can also be accomplished using the I²C Read_DF2 or Read_DF3 command and ignoring the “stale” data that will be returned.

Write_MR is a special I²C write operation, which only includes the 7-bit slave address and the WRITE bit (0). This command can only be sent in Sleep Mode (see section 3.1.2). It wakes up the part and starts a measurement cycle for the bridge values **only** (no special measurement) and a DSP calculation based on former AZ and Temperature values. After finishing the calculation with valid results written to the digital register, the ZSC31014 powers down again and a Read_DF (see section 3.1.3) is required to read the valid values. See Figure 3-6 for an illustration of Write_MR. The I²C Write_MR function can also be accomplished using the I²C WRITE command with “don’t care” data in Sleep Mode.

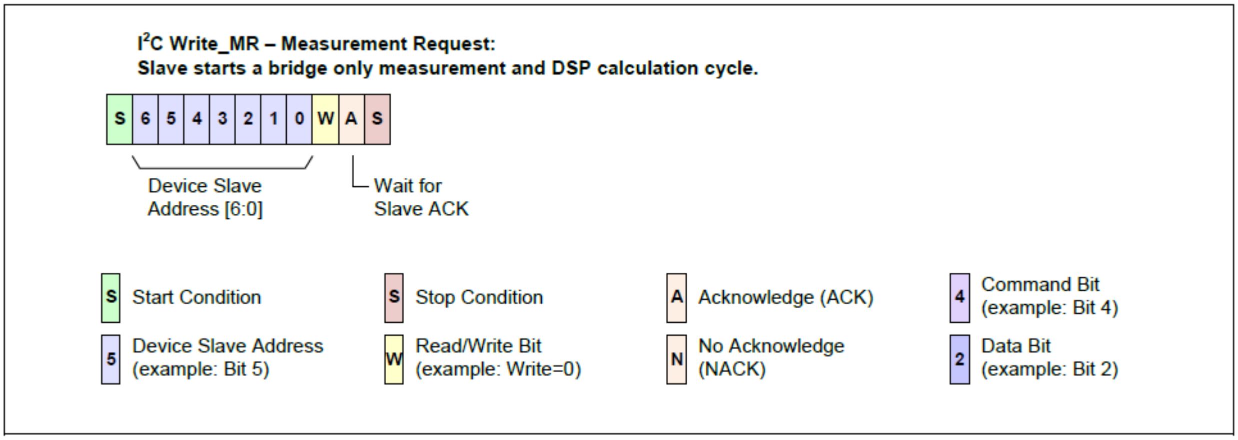


Figure 3-6: Write Measurement Request Bitmap

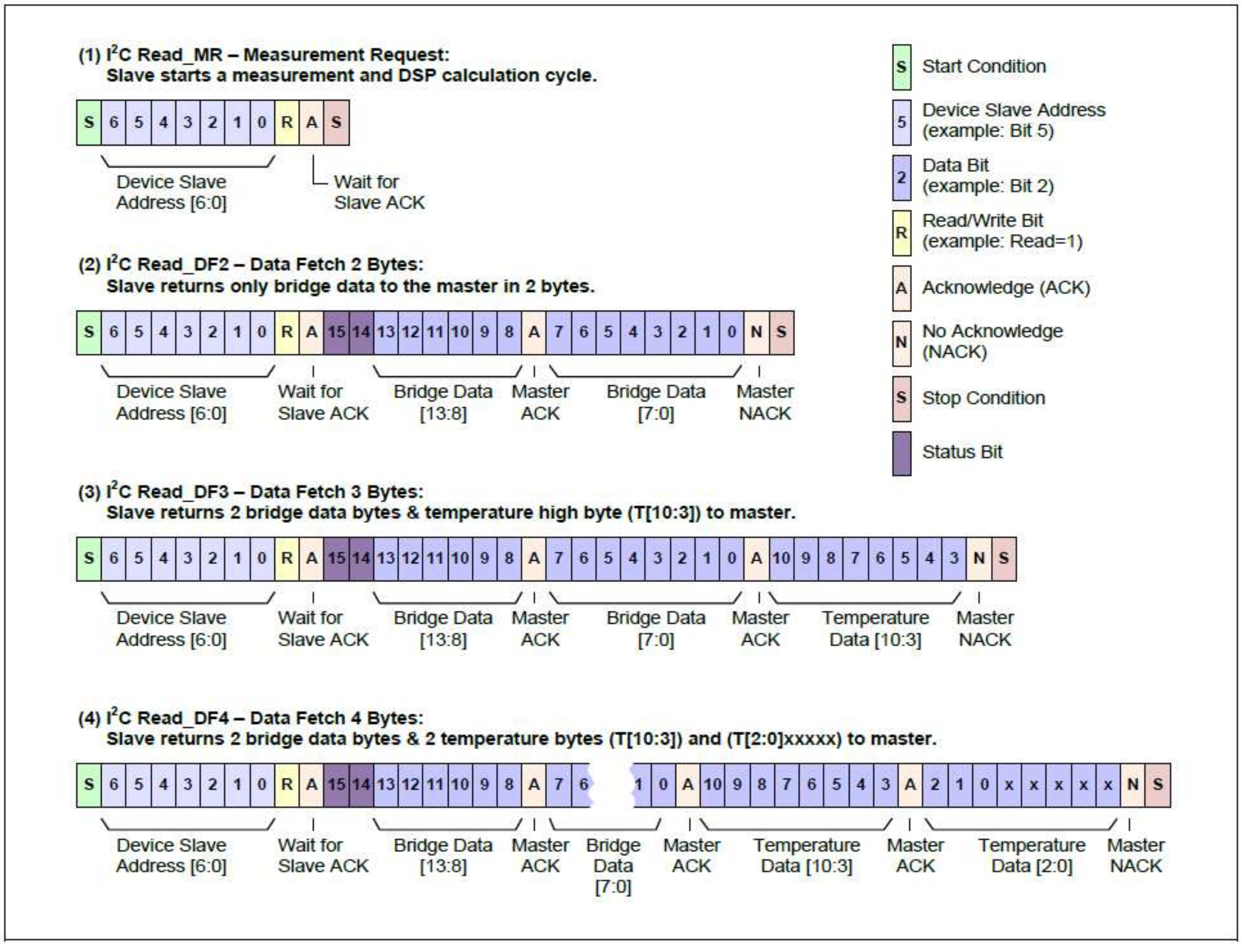


Figure 3-7: Read Measurement Request Bitmap

Data Fetch

For Data Fetch commands, the number of data bytes returned by the sensor is determined by when the master sends the NACK and stop condition. For the Read_DF3 data fetch command (Data Fetch 3 Bytes; see example 3 in Figure 3-7), the 8MPP2 returns three bytes in response to the master sending the slave address and the READ bit (1): two bytes of bridge data with the two status bits as the MSBs and then 1 byte of temperature data (8-bit accuracy). After

receiving the required number of data bytes, the master sends the NACK and stop condition to terminate the read operation.
For the Read_DF4 command, the master delays sending the NACK and continues reading an additional final byte to acquire the full corrected 11-bit temperature measurement. In this case, the last 5 bits of the final byte of the packet are undetermined and should be masked off in the application. The temperature measurement is taken inside the sensor and does not necessarily represent the temperature of the sensed media.

The Read_DF2 command is used if corrected temperature is not required. The master terminates the READ operation after the two bytes of bridge data (see example 2 in Figure 3-7).

Interpreting Data

To convert the fetched pressure data into pounds per square inch (psi), Equation 3-1 is used:

$$P = \left(\frac{P_{High} - P_{Low}}{13107}\right)(X - 1638) + P_{Low}$$

Equation 3-1

Where

P is the measured pressure in psi
P_{High} is the maximum pressure to be measured (High side of the Full-Scale Range)
P_{low} is the minimum pressure to be measured (Low side of the Full-Scale Range)
X is the pressure data [13:0] converted to decimal

Alternatively, the fetched pressure data can be converted into a percent of the full-scale pressure range (%FS) using Equation 3-2:

$$\%FS = \frac{X}{2^{14}} * 100$$

Equation 3-2

Where

%FS is the percent of the full-scale pressure range
X is the pressure data [13:0] converted to decimal

To convert the fetched temperature data into degrees Celsius (°C), Equation 3-3 is used:

$$T = \frac{T_{Byte\,1}[7:0] * 64 - T_{Byte\,2}[7:2]}{2^{14}} * 165 - 40$$

Equation 3-3

Every Data Fetch Measurement Packet contains two status bits in the MSBs of the first byte, *see* Figure 3-7. These bits are used to determine the status of the data being fetched.

Table 3.3: Data Status Bits

Status Bits	Definition
00	Fresh Data/Normal Operation: First Data Fetch since the last measurement cycle

01	Device in invalid state, reset power
10	Stale Data: A Data Fetch has already been performed since the last measurement cycle. **Note:** If a Data Fetch is performed before or during the first measurement after power-on-reset (POR), then “Stale Data” status bits will be returned. This data is still invalid because the first measurement has not been completed.
11	Diagnostic condition exists, check sensor

Note: If codes 01 and 11 continue after several power cycles replace sensor and contact Sensata.

4 APPLICATIONS INFORMATION

4.1 Data Fetch Example

Figure 4.1 shows a successful 4-Byte Data Fetch, where Channel 1 (yellow) is the Serial Data Line (SDA) and Channel 2 (blue) is the Serial Clock Line. The Measurement Packet read can be interpreted from left to right:

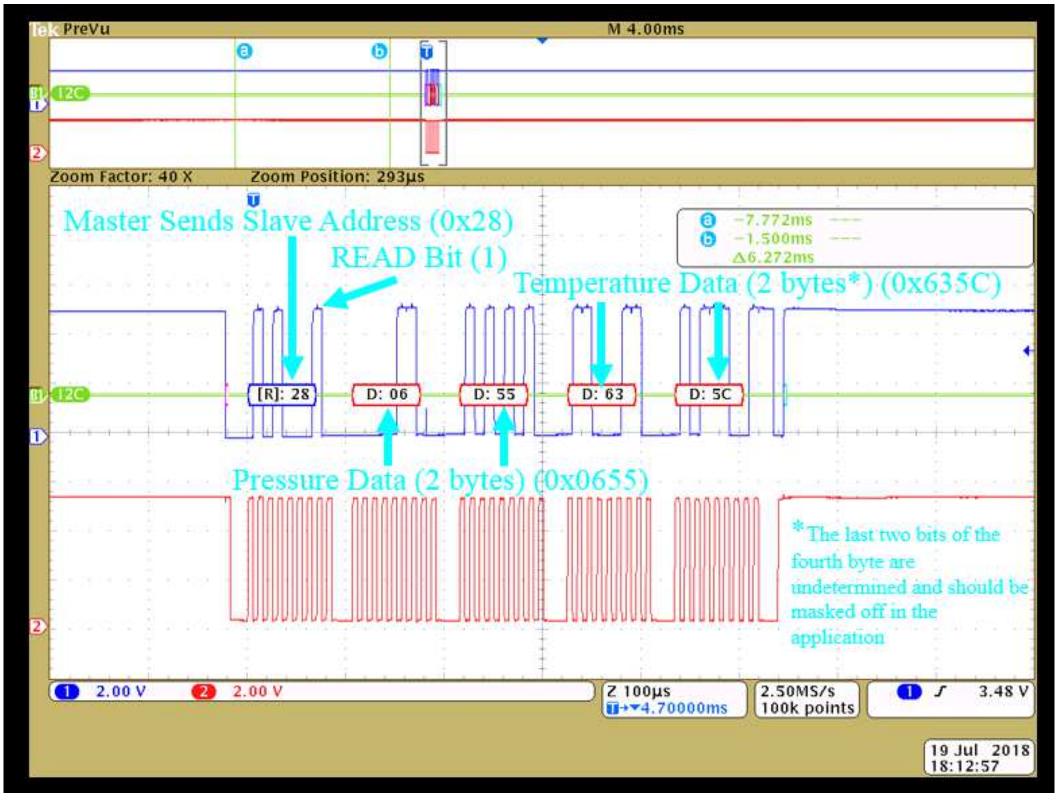


Figure 4-1: 4-Byte Data Fetch Example

Start Condition → Slave Address (0x28) → READ bit (1) → ACK (0) → Fresh Data Status Bits (00) (see 3.5.1) → Pressure Data 1 → ACK (0) → Pressure Data 2 → ACK (0) → Temperature Data 1 → ACK (0) → Temperature Data 2 → Don’t Care Data → NACK (1) → Stop Condition.

Interpretation a 4-Byte Data Fetch. SDA (yellow) and SCL (blue)

4.2 Power Consumption

In general, power consumption decreases with decreasing resolution, decreasing supply voltage, decreasing operating temperature and increasing power-down periods. This section will explain the phases of power consumption and provide user's with equations for estimating power consumption. Section 4.2.4 shows the calculations required to determine the power consumption. These include a "Break Even" calculation that takes into account the sample rate which helps determine the optimum operating mode. The "Break Even" calculation should be performed for every application. This will determine the mode in which the least amount of power consumption is used.

4.2.1 Update Mode

The following graph shows the current consumption timing while operating in updated mode with 6 ms power down selected. Time = 0 indicates when power is applied to the sensor. The sensor immediately starts to draw its active current of 2000 uA. It does this for around 2.8 ms. During this time the sensor is initializing, performing a temperature measurement, performing a pressure measurement, performing an auto-zero, and calculating the fully compensated output value. The sensor then goes to sleep which draws around 0.5 uA for 6 ms. This sleep time depends on what the user selects when ordering and can be 0 ms, 1 ms, 6, ms, and 32 ms. This example is with 5 ms power down time selected. The sensor then performs 255 pressure only measurements repeating the pressure measurement and power down cycle. The 256^{th} measurement includes a temperature measurement and an auto zero correction which takes 1.5 ms. This cycle repeats until power to the sensor is turned off.

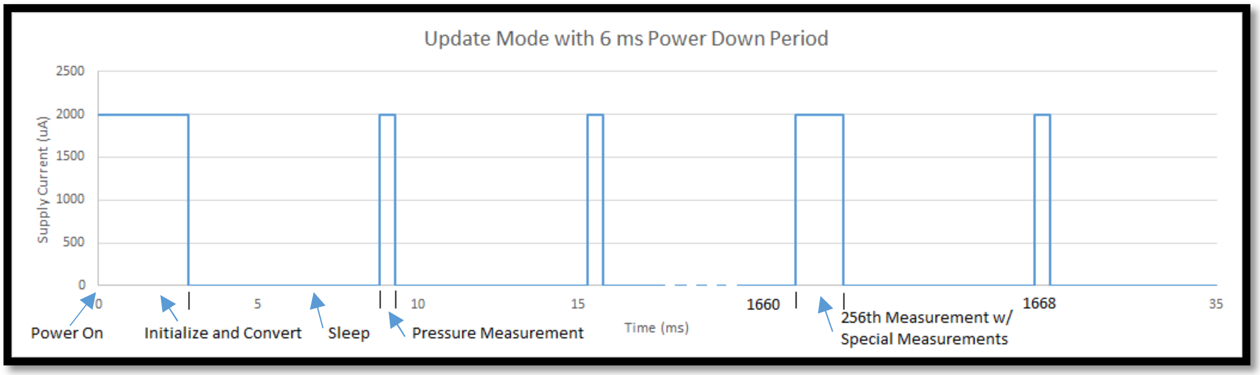


Figure 4-2: Power Diagram for Update Mode with 6 ms Power Down Period

Example Measured Supply Current

The following table shows measured supply current at different supply voltages.

- The measurements were taken at room temperature.
- The current was measured using a differential oscilloscope probe across a 46.9Ω resistor.
- The values in the table were reported by the oscilloscope's calculated rms measurement function over approximately 10 measurement cycles.

Table 4.1: Average current by Update Rate and supply voltage

Update Rate (ms)	uArms @ 2.7V	uArms @ 3.3V	uArms @ 5V
0.5	1850.6	2179.3	2870.9
1.5	1056.6	1248.7	1649.9
6.5	488.1	632.2	770.5
32	227.1	276.0	387.4

4.2.2 Sleep Mode

The following graph shows the current consumption timing while operating in sleep mode. Time = 0 indicates when power is applied to the sensor. The sensor immediately starts to draw its active current of 2000 uA. It does this for around 1.8 ms. During this time the sensor is initializing. The sensor then goes to sleep which draws around 0.5 uA. The sensor stays asleep until it receives a measurement request. There are two types of measurement requests. READ_MR initiates a temperature measurement, a pressure measurement, an auto-zero, and calculates the fully compensated output value. WRITE_MR initiates a pressure only measurement. This is explained in section 3.1.3. The time between measurement requests is application specific.

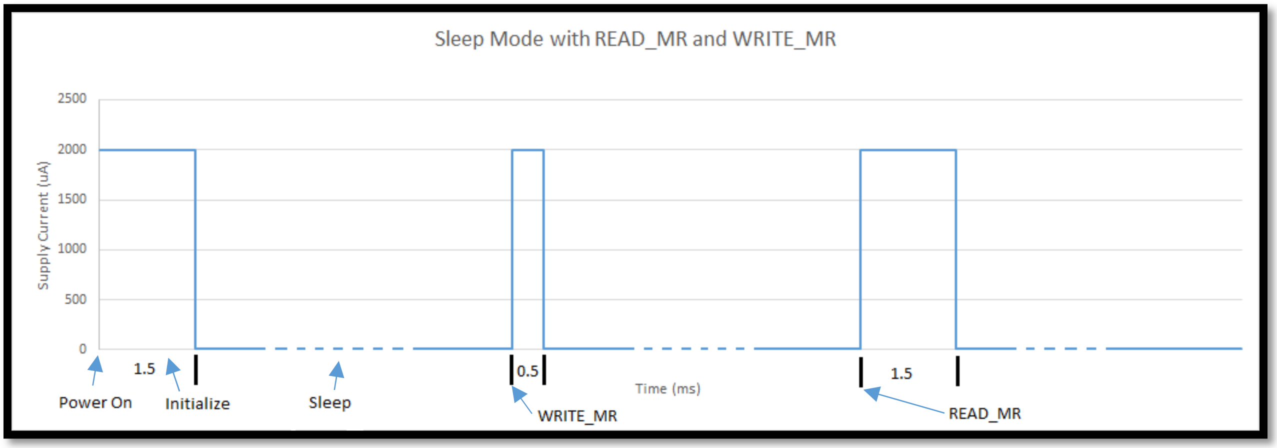


Figure 4-3: Power Diagram for Sleep Mode

4.2.3 Power Down Between Measurements

The following graph is an example of the current consumption timing when the user powers down the sensor between measurements. The selected operating mode is updated mode with 5 ms or greater power down selected. Time = 0 indicates when power is applied to the sensor. The sensor immediately starts to draw its active current of 2000 uA. It does this for around 2.8 ms. During this time the sensor is initializing, performing a temperature measurement, performing a pressure measurement, performing an auto-zero, and calculating the fully compensated output value. The sensor then goes to sleep which draws around 0.5 uA until the sensor is powered down.

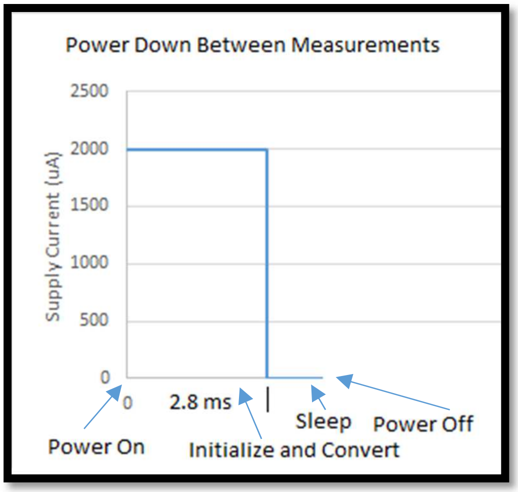


Figure 4-4: Power Diagram for Powering Down Device Between Measurements

4.2.4 Calculation Example

If the application is battery powered or if power consumption is a concern this calculation can be used to determine which mode to order.

Charge Break-even time (T_{be}) calculation between Sleep Mode and power down between measurements.

$$T_{be} = \frac{I_{active} * (T_{init} - T_{WRITE_{MR}})}{I_{sleep}}$$

Equation 4-1

Where:

I_{active} = Active current consumption during conversion
T_{init} = Time between power on/initialization and first conversion complete
T_{WRITE_MR} = Time for pressure only conversion
I_{sleep} = Current consumption during sleep

Example for 8MPP2 sensor

$$(2\ mA) * (2.3\ ms) = (0.5\ uA) * T_{be}$$

Equation 4-2

$$T_{be} = 9.2\ seconds$$

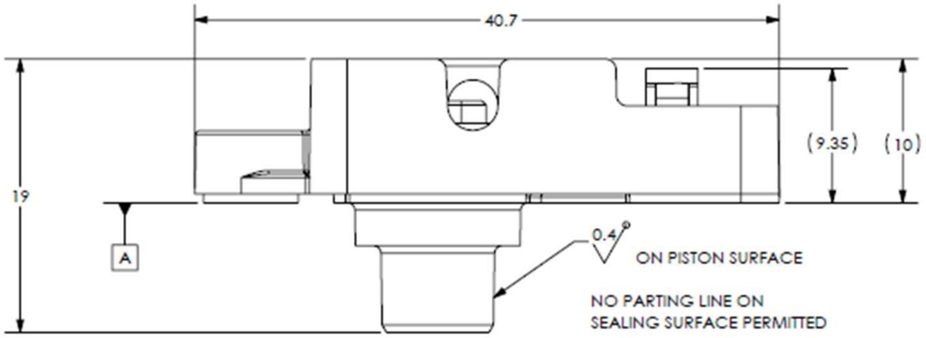
So, if the pressure measurement interval is shorter than 9.2 seconds, Sleep Mode uses less battery charge.

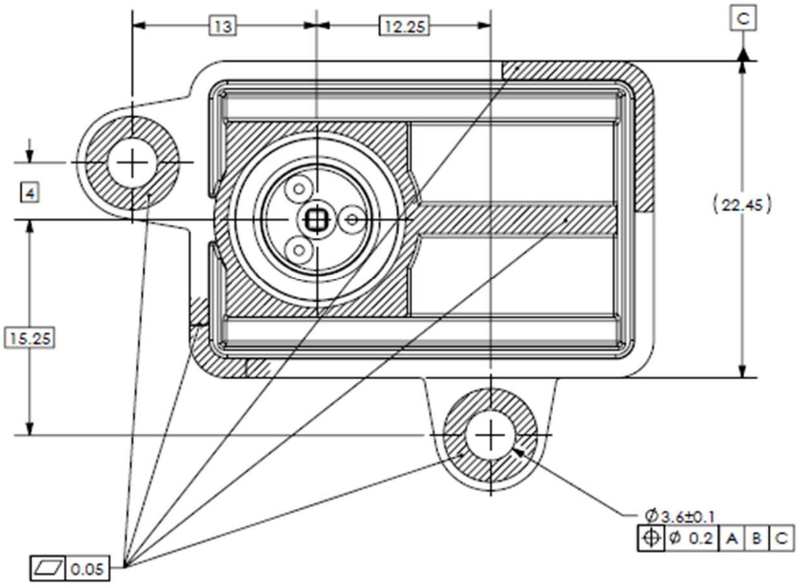
4.3 I²C Bus

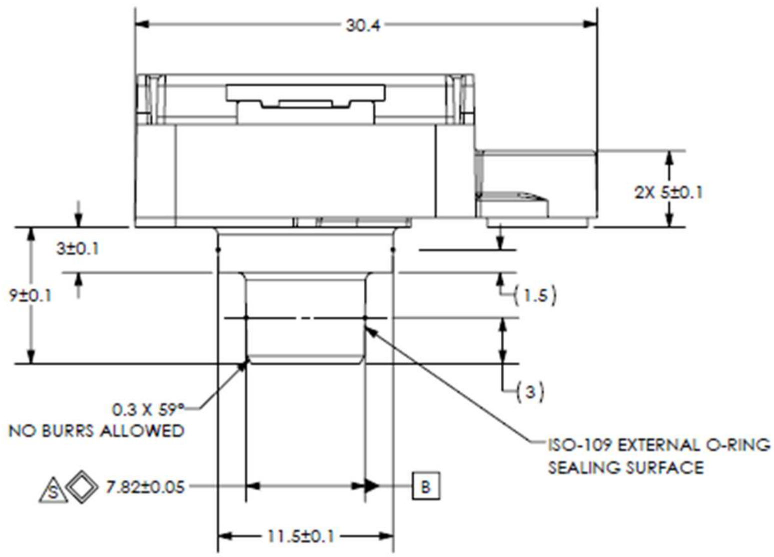
Refer to the following application report for determining I²C bus design:
http://www.ti.com/lit/an/slva689/slva689.pdf

4.4 Mechanical Interface Details

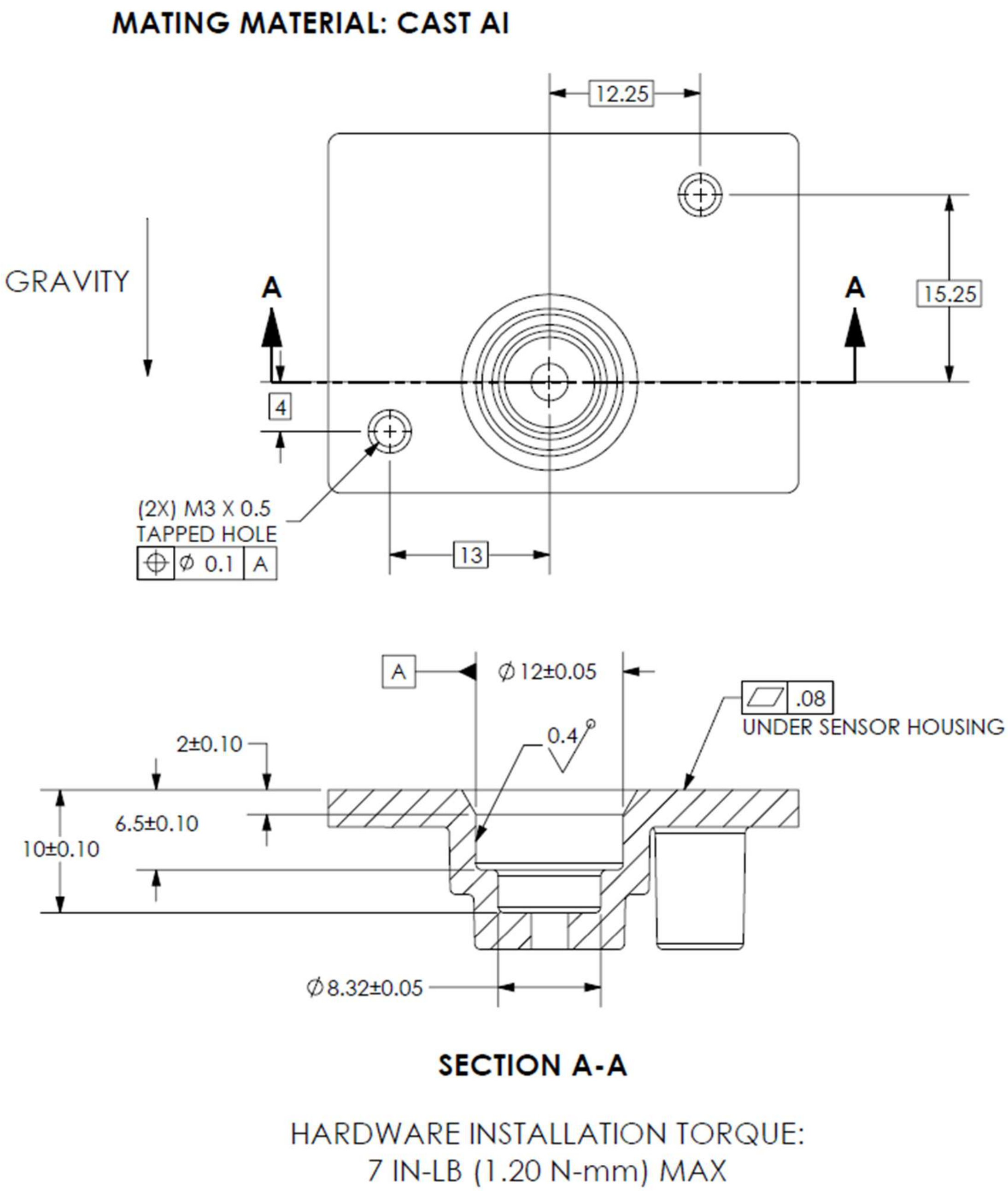
Sensor geometry (all dimensions in millimeters):







Recommended Manifold Mating Geometry (all dimensions in millimeters):



5 ORDERING INFORMATION

***Refer to 8MPP2 Technical Datasheet for up to date ordering information details**

EXAMPLE:

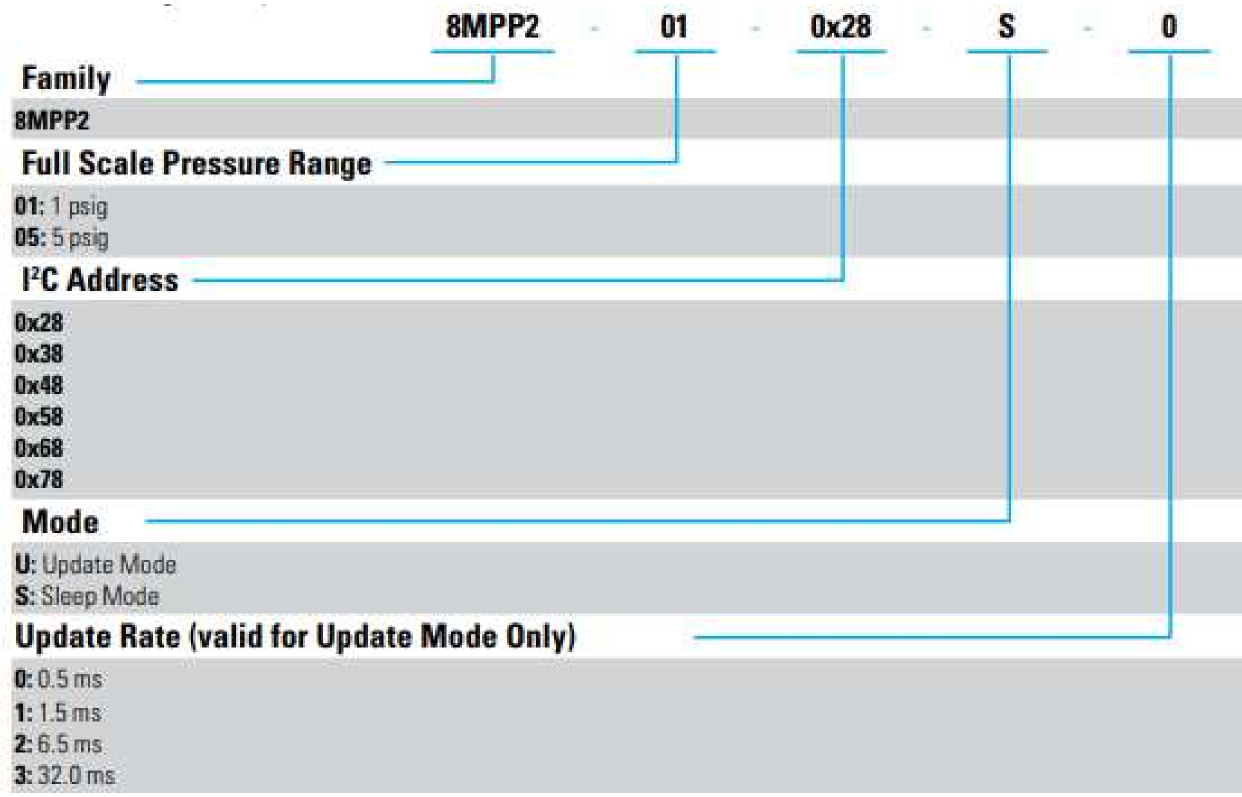


Figure 5-1: Ordering Information Breakdown Diagram

6 ACRONYMS AND ABBREVIATIONS

DF – Data Fetch
I²C – Inter-integrated Circuit, I-Squared-C
MR – Measurement Request
SCL – Serial Clock
SDA – Serial Data

7 TABLE OF FIGURES

8 TABLE OF TABLES

9 REVISION HISTORY

Table 9.1: Document Revision History

Release No.	Date	Revision Description
---	4/22/2019	First Release; JLP

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