Data Sheet	PSD0401120

General Description

The **PSD0401120** is a high-resolution, 30kPa to 120kPa pressure sensor in a compact 10-pin LGA surface mount package. It features high accuracy and low current consumption pressure and temperature sensing. The digital output uses an I^2C interface. The **PSD0401120** combines high-linearity pressure sensor with an ultra-low-power 24-bit delta-sigma analog-to-digital converter (ΔΣADC). The pressure sensor is factory calibrated, storing the calibration coefficients in on-board memory. The calibration coefficients are used by the ΔΣADC as it processes the sensor's analog output. The **PSD0401120** also includes a temperature sensor with a nominal resolution of 0.1°C.

The I^2C interface maximizes compatibility with the communication interfaces on a wide range of popular micro-controllers and system-on-chip (SOC) devices.

Features

- Pressure range: 30kPa to 120kPa
- Temperature resolution: 0.1°k/LSB
- 24-bit ΔΣADC
- I^2C serial interface
- 3.3V_{DC} nominal power supply voltage
- 3.55mm x 3.55mm x 1.40mm surface-mount 10-pin LGA package
- Water resistant to 100m

Applications

- Barometers
- Mobile altimeters
- Indoor navigation systems
- Floor detection in buildings
- Outdoor navigation systems
- Industrial pressure and temperature sensing systems
- Pressure and temperature logging systems
- Adventure and sports watches
- Weather stations

Electrical Characteristics

Absolute Maximum Ratings (T_A = 25°C, specificized voltages are referenced to ground (GND), unless otherwise specified.) Note 1

Parameter	Conditions	Minimum	Typical	Maximum	Unit
V_{DD}				4.0	V
V_{DDIO}				4.0	V
IO Pin		-0.3		V_{DD}+0.3	V
| V_{DD} - V_{DDIO} |				0.3	V
Pressure				1000	kPa
ESD Class	Human Body Model (JESD22-A114)	-2000		2000	V
Storage Temperature		-40		125	°C

Performance Characteristics (V_{DD} = VDDIO = 1.8V, T_A = 25°C, unless otherwise specified.) Note 1

Parameters	Conditions		Minimum	Typical	Maximum	Unit
V_{DD}			1.8		3.6	V
V_{DDIO}			1.8		3.6	V
Peak Current				0.3		mA
Standby Current				50	250	nA
ΔΣADC Conversion I_{DD}	1Hz conversion rate	Low Precision		3		µA
		Standard Precision		11		
		High Precision		40		
ΔΣADC Conversion I_{DD}	OSR = 128			80		µA
	OSR = 64			42		
	OSR = 32			23		
	OSR = 16			13		
	OSR = 8			8		
	OSR = 4			6		
	OSR = 2			4		
Single Conversion Time	Temperature OSR = 1024x	OSR = 128		203		ms
		OSR = 64		105		
		OSR = 32		56		
		OSR = 16		31		
		OSR = 8		19		
		OSR = 4		13		
		OSR = 2		10		
ΔΣADC Conversion Frequency	2x ≤ Over-sampling-rate ≤ 128x		20		1350	Hz
Single Conversion Frequency	Temperature OSR = 1024x	OSR = 128		4.9		Hz
		OSR = 64		9.5		
		OSR = 32		17.9		
		OSR = 16		32.3		
		OSR = 8		52.6		
		OSR = 4		76.9		
		OSR = 2		100		
Start Time	t_{ST1} V_{DD} rising edge to communication start				1	ms
	t_{ST2} V_{DD} rising edge to measurement start				2.5	
Wake Time	T_{WU1} Sleep state to communication start				0.5	ms
	T_{WU2} Sleep state to measurement start				2	

On-Device Oscillator Frequency		3.6	4	4.4	NHz
ADC Resolution	Pressure Sensor	20	21		Bits
	Temperature Sensor	16	20		
Input Signal Center	Set input signal center based on applied bridge to match ADC	1/16		8/16	______
Integral Non-Linearity Error		-4		4	LSB
Differential Non-Linearity Error		-1		1	LSB
Power Supply Rejection	f = 217Hz squarewave, V_{MAG} = 100mV$_{p-p}$ Measurement BW = 20Hz ≤ f ≤ 20kHz	0.063			Pa_{RMS}
Measurement Frequency	Digital compensation included	5		100	Hz
Overall Non-Linearity				0.01	%FS
Operating Temperature		-20		85	°C
Storage Temperature		-40		125	°C
Overall System Non-Linearity				0.01	%FS
Pressure Sensor Performance					
Pressure Range		30		120	kPa
Pressure Resolution				0.06	Pa_{RMS}
Absolute Pressure Accuracy	30kPa ≤ Pressure ≤ 120kPa 0°C ≤ T_A ≤ 65°C		100		Pa
Relative Pressure Accuracy	Relative to absolute pressure accuracy		10		Pa
Pressure Precision	Low power		5.0		Pa_{RMS}
	Standard power		1.2		
	High precision		0.6		
Temperature Measurement Rate		1		128	Hz
Pressure Measurement Time	Low power		5		ms
	Standard power		28		
	High precision		105		
Overload Pressure				300	kPa
Pressure Compensation Temperature Range		-40		85	°C
Pressure Temperature Drift Coefficient	Pressure = 100kPa 25°C ≤ T_A ≤ 40°C		0.5		Pa/°K
Temperature Sensor Performance					
Temperature Resolution			0.003		K/LSB
Temperature Data Resolution				0.1	°C
Temperature Accuracy	-40°C ≤ T_A ≤ 50°C		±1.0		°C
Temperature Measurement Rate		1		128	Hz
Temperature Measurement Range		-40		125	°C

Note 1: *Absolute Maximum Ratings* indicate limits beyond which damage to the device may occur. *Performance Characteristics* indicate conditions for which the device is functional, but do not ensure specific performance limits. *Performance Characteristics* state DC and AC electrical specifications under specific test conditions that ensure specific

performance limits, and this assumes that the device is within the *Performance Characteristics*. Specifications are not ensured for parameters where no limit is given. The typical value, however, is a good indication of device performance.

I²C Interface Characteristics (T_A = 25°C, unless otherwise specified.)

Symbol	Parameters	Conditions	Minimum	Typical	Maximum	Unit
f_{SCL}	Serial Bus Frequency	Standard Mode	0		100	kHz
$t_{r(SDA)}$	Data Rise Time				300	ns
$t_{f(SDA)}$	Data Fall TIme				300	ns
$t_{SU(SDA)}$	SDA Setup Time		250			ns
$t_{h(SDA)}$	SDA Hold Time		0.09		3.45	µs
$t_{w(SCLL)}$	Clock-Low Time		4.7			µs
$t_{w(SCLH)}$	Clock-High Time		4.0			µs
$t_{r(SCL)}$	Clock Rise Time				1000	ns
$t_{f(SCK)}$	Clock Fall Time				1000	ns
$T_{h(ST)}$	Hold Time (Note2)		4.0			µs
$t_{su(STA)}$	Repeated START Set-Up TIme		4.7			µs
$t_{su(STOP)}$	STOP Set-up Time		4.0			µs
t_{BUF}	Bus Free Time Between Stop and Start Conditions		4.7			µs
Symbol	**Parameters**	**Conditions**	**Minimum**	**Typical**	**Maximum**	**Unit**
f_{SCL}	Serial Bus Frequency	Fast Mode	0		400	kHz
$t_{r(SDA)}$	Data Rise Time		20		300	ns
$t_{f(SDA)}$	Data Fall TIme		20*(V_{DD}/5.5)		300	ns
$t_{SU(SDA)}$	SDA Setup Time		100			ns
$t_{h(SDA)}$	SDA Hold Time		0.02		0.9	µs
$t_{w(SCLL)}$	Clock-Low Time		1.3			µs
$t_{w(SCLH)}$	Clock-High Time		0.6			µs
$t_{r(SCL)}$	Clock Rise Time		20		300	ns
$t_{f(SCK)}$	Clock Fall Time		20*(V_{DD}/5.5)		300	ns
$T_{h(ST)}$	Hold Time (Note2)		0.6			µs
$t_{su(STA)}$	Repeated START Set-Up TIme		0.6			µs
$t_{su(STOP)}$	STOP Set-up Time		0.6			µs
t_{BUF}	Bus Free Time Between Stop and Start Conditions		1.3			µs
Symbol	**Parameters**	**Conditions**	**Minimum**	**Typical**	**Maximum**	**Unit**
f_{SCL}	Serial Bus Frequency	Fast Mode+	0		1000	kHz
$t_{r(SDA)}$	Data Rise Time				120	ns
$t_{f(SDA)}$	Data Fall TIme		20*(V_{DD}/5.5)		120	ns
$t_{su(SDA)}$	SDA Setup Time		50			ns
$t_{h(SDA)}$	SDA Hold Time		0.02		0.9	µs
$t_{w(SCLL)}$	Clock-Low Time		0.5			µs
$t_{w(SCLH)}$	Clock-High Time		0.26			µs
$t_{r(SCL)}$	Clock Rise Time				120	ns
$t_{f(SCK)}$	Clock Fall Time		20*(V_{DD}/5.5)		120	ns

$T_{h(ST)}$	Hold Time (Note2)		0.26			µs
$t_{SU(STA)}$	Repeated START Set-Up TIme		0.26			µs
$t_{SU(STOP)}$	STOP Set-up Time		0.26			µs
t_{BUF}	Bus Free Time Between Stop and Start Conditions		0.5			µs

Note 2: First clock pulse is generated after this interval.

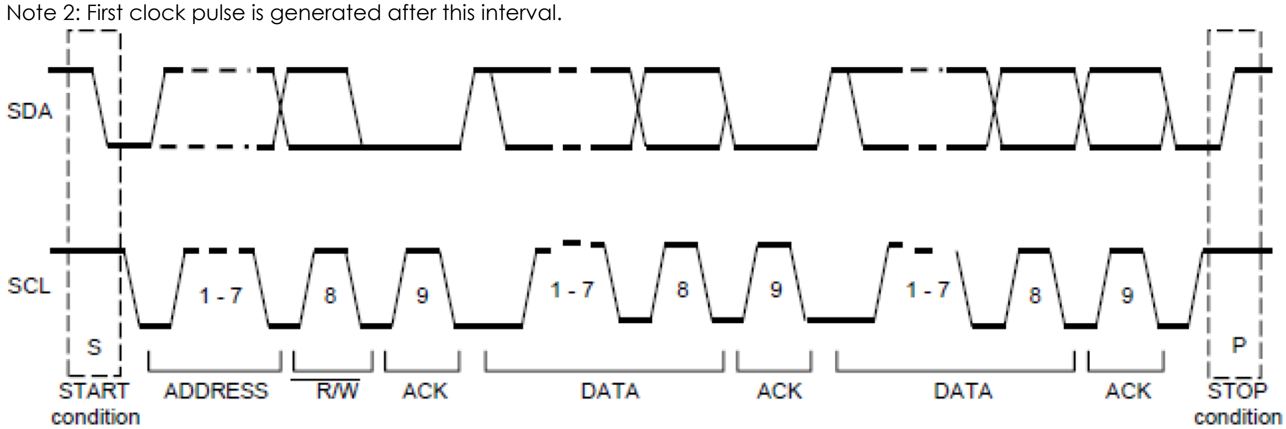


Figure 1. I2C Serial Clock and Data Diagram

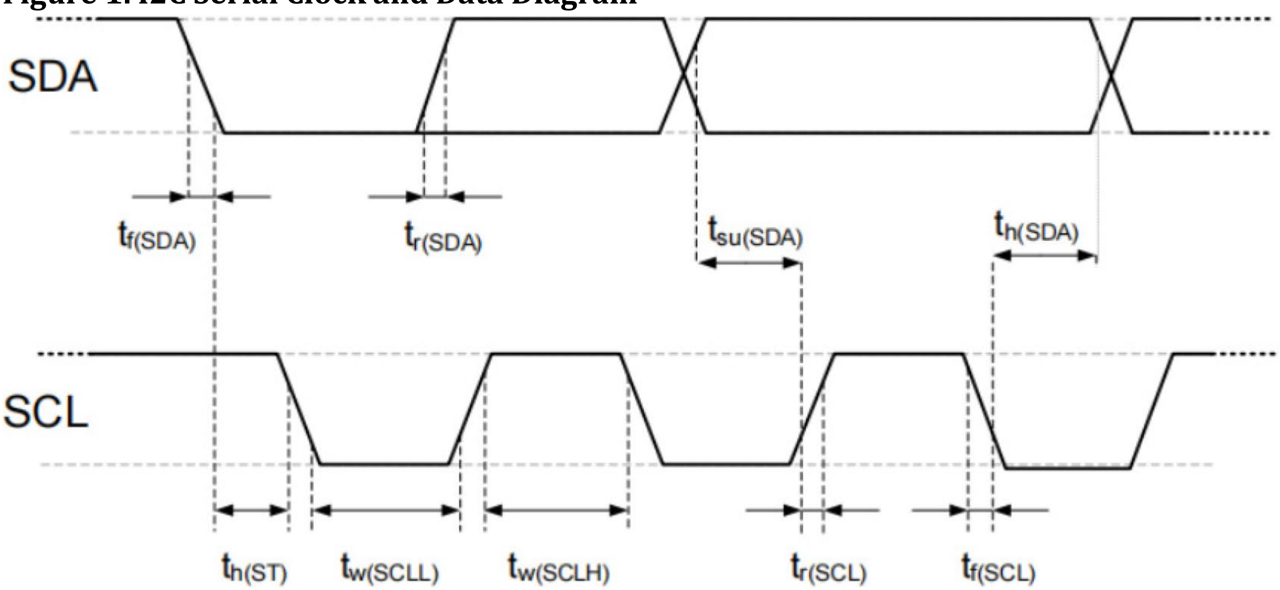
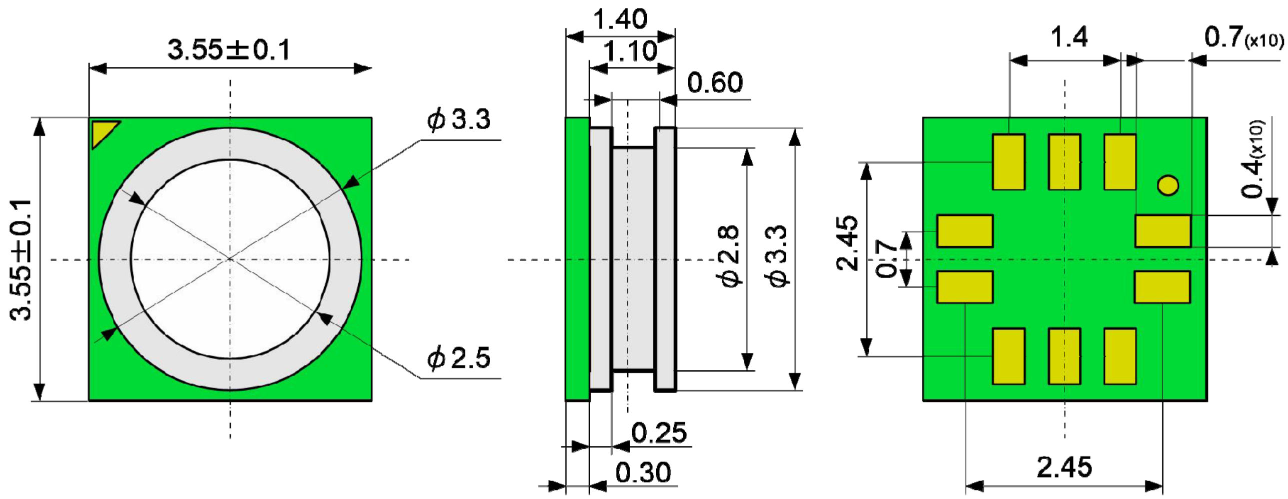
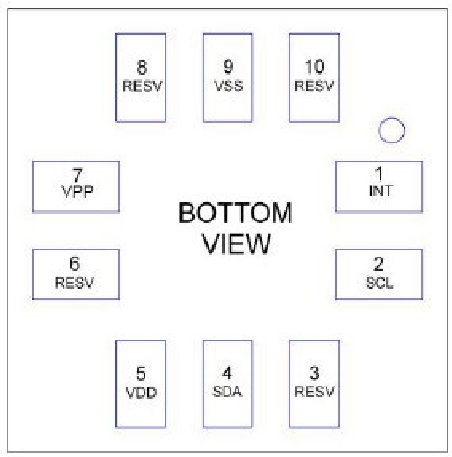


Figure 2. I2C Timing Diagram

Dimensions and Pin Definitions (Tolerance: ±0.05mm, unless otherwise specified.)





Pin	Symbol	Description
1	INT	I²C interrupt
2	SCL	Serial clock IO
3	RESV	Reserved
4	SDA	Serial data IO
5	VDDB	Sensor bridge power supply voltage input
6	RESV	Reserved
7	VPP	One-time-programming power supply voltage input
8	RESV	Reserved
9	VSS	Ground
10	RESV	Reserved

Applications Information

Functional Description

The PSD0401120 uses a MEMS piezoresistive absolute pressure sensor as a pressure detecting element. The digital output is a serial data bit stream, containing data that is proportional to the local ambient atmospheric pressure. The pressure sensor's analog output is amplified by a two-state programmable-gain preamplifier (PGA). The preamplifier features very low noise magnitude in the low-frequency signal bandwidth. Its input offset voltage is minimized through chopper-stabilization and auto-zeroing techniques.

The preamplifier drives the 24-bit delta-sigma analog to digital converter (ΔΣADC), whose output is processed by a digital filter and DSP (state-machine) that together filters noise and applies temperature and linearity compensation. The DSP is configured using programmable bits. Once conversion, linearization, and compensation are complete, the final digital value is made available as an I²C serial bit stream.

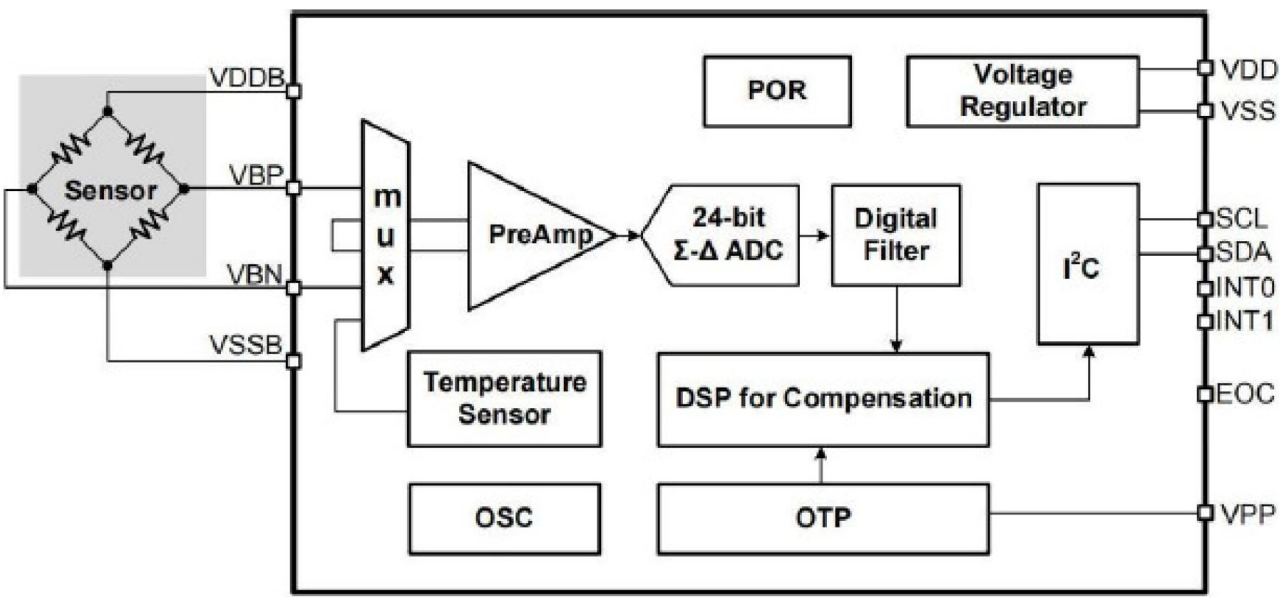


Figure 2. PSD0401120 block diagram.

Preamplifier

The first stage gain is adjustable in four major steps: 12, 20, 30, and 40. The second stage's gain, which allows fine-tuning, is adjustable in eight steps: 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, and 1.8. The preamplifier's polarity can be set to either -1 or 1. The 1-bit polarity control setting is shown in Table 1-3.

This is followed by a buffer that is designed to drive the ΔΣADC's input capacitance with the necessary current and slew rate to ensure accurate analog to digital conversion. The 24-bit ΔΣADC performs the conversion from the sensor's analog signal to a corresponding digital value and simultaneously applies temperature and linearity compensation. The PSD0401120's block diagram is shown in Figure 3.

Gain_Stage1 (bit 1)	Gain_Stage1 (bit 0)	First Stage Gain Level
0	0	12
0	1	20
1	0	30
1	1	40

Table 1-1. Preamplifier first-stage 2-bit gain level selection.

Gain_Stage2 (bit 4)	Gain_Stage2 (bit 3)	Gain_Stage2 (bit 2)	Second Stage Gain Level
0	0	0	1.1
0	0	1	1.2
0	1	0	1.3
0	1	1	1.4
1	0	0	1.5
1	0	1	1.6
1	1	0	1.7
1	1	1	1.8

Table 1-2. Preamplifier second-stage 3-bit gain level selection.

Gain_Polarity	Gain Polarity
0	**-1**
1	**1**

Table 1-3. Preamplifier 1-bit polarity selection

When using the Normal mode (NOR), adjust the preamplifier's gain and polarity using the OTP byte (address 0x14: Gain_Stage1, bits 0, 1; Gain_Stage2, bits 2, 3, 4; Gain_Polarity) (see Tables 1-1, 1-2, and 1-3). In Command mode (CMD) and processing the pressure sensors output signal, the gain is adjustable through commands A0 – A7 (Get_raw command) sent via I^2C serial communication. This is possible even if the OPT registers have previously received programming values.

Selecting the proper gain is based on the following:

1. Capture the pressure sensor's output signal.
   a. Capture the signals for different temperature/pressure combinations.
   b. Use the combinations to define two parameters
      i. Minimum differential output voltage: V_{MIN}
      ii. Maximum differential output voltage: V_{MAX}
      iii. If $V_{MIN} > V_{MAX}$, change the gain polarity (Table 1-3).
2. Configure ΔΣADC offset function to ensure that V_{MAX} and V_{MIN} have the same sign.
   a. For example, if V_{MAX} is positive and V_{MIN} is negative.
   b. The offset ratio calculation
      i. $R_{OFFSET} = |V_{MIN}| / (V_{MAX} - V_{MIN})$.
3. Compare R_{OFFSET} and $A2D_{OFFSET}$ in Table 2.
   a. If $R_{OFFSET} \leq A2D_{OFFSET}$, optimize the gain.
      i. $GAIN_{OPT} = (1 - A2D_{OFFSET}) * (V_{REG}/V_{MAX})$
   b. If $R_{OFFSET} > A2D_{OFFSET}$, optimize the gain.
      i. $GAIN_{OPT} = A2D_{OFFSET} * (V_{REG}/V_{MAX})$
4. Consult Tables 1-1 and 1-2 to set the gain to a value that is closest to $GAIN_{OPT}$.

$A2D_{OFFSET}$ (Bits 10:8) Binary	**ΔΣADC Input Range**	**A2D Offset**	**Offset_B (Prior to Compensation)**
000	-1/16 to 15/16	1/16	-7340032
001	-2/16 to 14/16	2/16	-6291456
010	-3/16 to 13/16	3/16	-5242880
011	-4/16 to 12/16	4/16	-4194340
100	-5/16 to 11/16	5/16	-3145728
101	-6/16 to 10/16	6/16	-2097152
110	-7/16 to 9/16	7/16	- 1048576
111	-8/16 to 8/16	8/16	0

Table 2. ΔΣADC offset signal selection.

ΔΣADC

The 24-bit ΔΣADC converts the preamplifier's analog output signal. An offset circuit, shown in Figure 3, generates a compensating voltage that optimizes the ΔΣADC's input range. This offset combines with the amplified sensor signal, the goal of which is to span the ΔΣADC's $-V_{REF}/2$ to $V_{REF}/2$ full range. The configurable offset voltage is set through the OTP address 0x14, A2D_Offset [10:8].

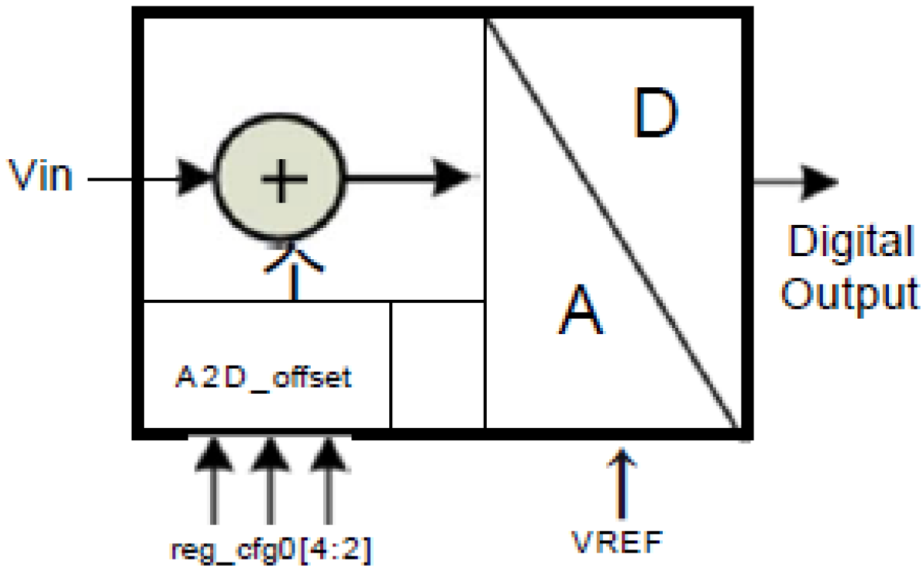


Figure 3. ΔΣADC function diagram

ΔΣADC Sampling Frequency

The ΔΣADC's sampling clock frequency is adjustable using the Clock_Div bits on the OTP address, 0x14. The different sampling clock frequency dividers and the two-bit values that set them are shown in Table 3.

Clock_Div [7:6]	ΔΣADC Sampling Clock Frequency Multiplier
00	5.3
01	4
10	2
11	1

Table 3. ΔΣADC Oscillator Frequency

Pressure Sensor Over-Sample-Rate (OSR_P)

The pressure sensor's OSR is adjustable from doubling the sample rate to increasing it by a factor of 128. It is controlled by the 3-bit [13:11] OSR_Pressure digital value in OTP address, 0x14. As the OSR increases, the sampling frequency decreases. Table 4 captures the OSR multipliers (OSR_P) that are selected by bits 11 through 13.

OSR_Pressure [13:11]	OSR_P Multipilier
000	128
001	64
010	32
011	16
100	8
101	4
110	2
111	1

Table 4. Over-Sample-Rate for Pressure Measurements

Internal Temperature Measurement Over Sample Rate (OSR_T)

PSD0401120's internal temperature measurement sample rate is adjustable. The OSR_T has a range that allows adjustment from increasing the sample rate by eight times to increasing it by a factor of 128. It is controlled by the 2-bit [15:14] OSR_Temperature digital value in OTP address, 0x14. As the OSR increases, the sampling frequency decreases. Table 5 captures the OSR multipliers (OSR_T) that are selected by bits 14 through 15.

OSR_Temperature [15:14]	OSR_T Multipilier
00	8
01	16
10	32
11	64

Table 5. Over-Sample-Rate for Internal Temperature Measurements

Bandgap Reference

The PSD0401120 incorporates a bandgap voltage reference, producing a stable 1.2V full-scale ΔΣADC reference. Though trimmed during production to compensate for integrated circuit process fabrication variations, the PSD0401120 includes user-selectable trims for the reference bandgap. These trims are accessed through OTP address 0x15. The trim values and their corresponding digital values are shown in Table 4.

V_{REF_TRIM} [2:0]	1.2V Reference Voltage Trim Adjustment (mV)
000	-28
001	-21
010	-14
011	-7
100	0
101	7
110	14
111	21

Table 4. Bandgap reference voltage trim values.

Temperature Sensor

Internal temperature measurements are made through an on-die sensor. The temperature measurements have adjustable sensitivity, offset, and non-linearity through the state-machine's compensation algorithms. Compensated temperature measurements are read through the I^2C serial interface. Compensated temperature measurements are also available to temperature compensate pressure measurements. The voltage that represents temperature is highly linear, has a 1.01mV/V/°C transfer function, a $-40°C \leq T_A \leq 40°C$ measurement range, and a 0.003°C resolution.

Uncompensated temperature does not affect pressure sensor compensation. Its compensation does not require absolute temperature accuracy, only accurate temperature differences. The temperature difference is guaranteed by the temperature sensor linearity only, not absolute temperature accuracy. Compensating the pressure and temperature sensors is independent of each other. Temperature measurement compensation is only necessary when absolute temperature accuracy is needed.

Oscillator

The PSD0401120 includes an oscillator the generates a nominally 4MHz clock signal. This signal drives the ΔΣADC's conversion process.

The nominal clock frequency is subject to typical process variations, resulting in an oscillation frequency that can vary from device to device. Though this variation can cause variations in sampling frequency, it does not compromise the conversion accuracy. To ensure that power supply variations have minimum affect of the oscillator's frequency, an on-die voltage regulator supplies the oscillator's power supply voltage.

The oscillator's frequency is trimmable through a three-bit [15:13] value (Osc_Trim) in the OTP register. Table 5 details the changes that can be made to the oscillator's output frequency.

Osc_Trim [15:13]	Oscillator Frequency Change (%)
011	10
010	7
001	3
000	0 (4MHz, nominal)
111	-4
110	-7
101	-1.3
100	-1.6

Table 5. Oscillator nominal frequency trim

On-Die Regulators

Using the on-die bandgap voltage reference, two on-die regulators are used to generate a regulated power supply voltage, one, for the analog front-end and, two, for the digital core. These two regulators are fully self-contained and do not require any additional external components. The nominal internal power supply voltage generated by the regulators is 1.67V.

Power-On Reset

The PSD0401120's Power-On Reset (POR) subcircuit generates a signal that forces a reset to all circuitry when the power supply voltage is applied. This reset signal cancels when the power supply voltage raises to the 0.5V to 0.7V range above the voltage potential on the GND pins. Once cancelled, all internal circuitry is operational.

Power-On Initialization

The sensor's state-machine, which controls all operations of the various digital sub-circuits, is reset, and initialized through a POR event, the steps of which are shown in Figure 4. The state-machine can receive commands after a power supply voltage is applied to the V_{DD} pin and the T_{ST1} interval has occurred. The state-machine can execute the first measurement conversion after a power supply voltage is applied to the V_{DD} pin and the T_{ST2} interval has occurred.

The state-machine enters its sleep mode after initialization while it waits for a command. It wakes from sleep mode when receiving a command and executes that command after the T_{WU1} interval.

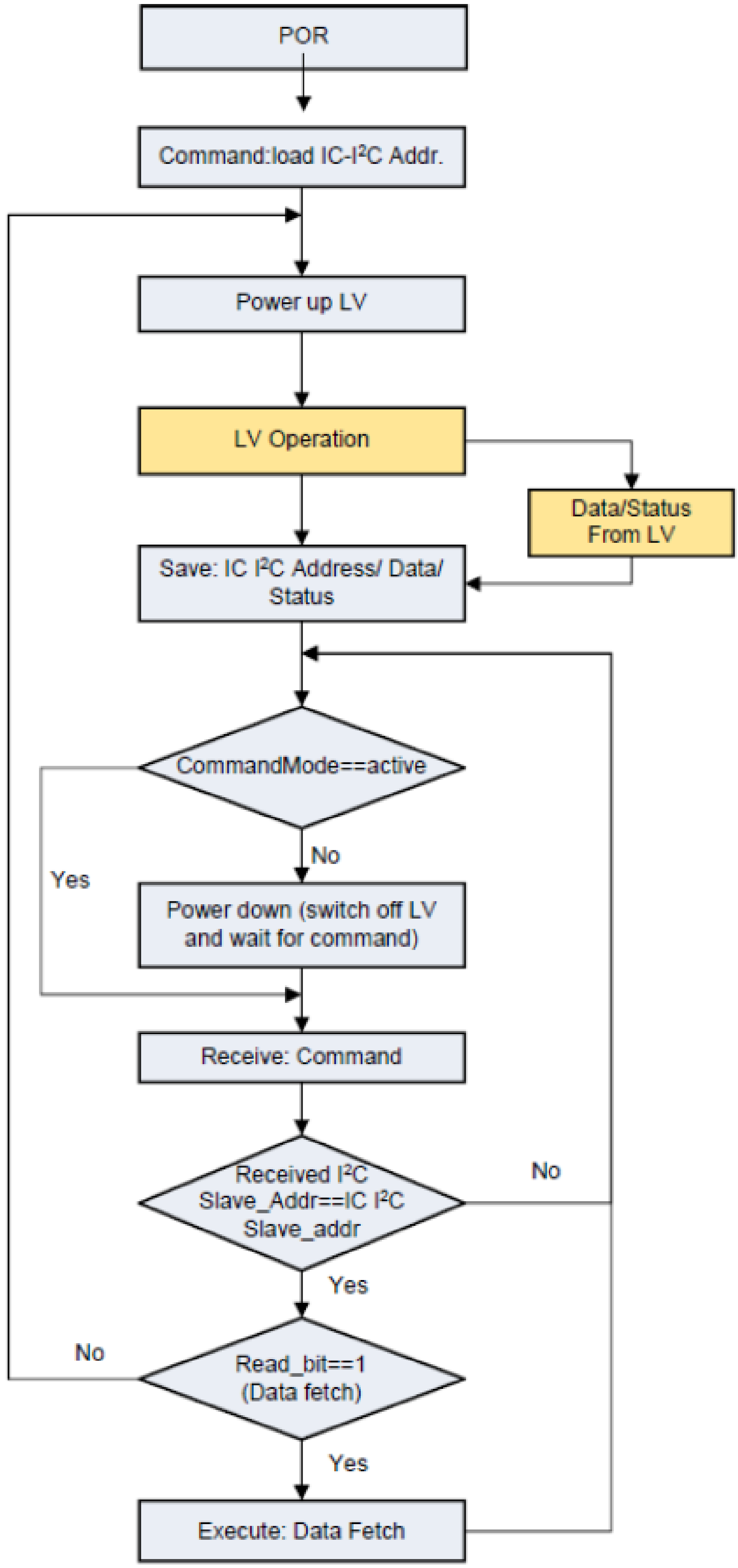


Figure 4. State-Machine's Logical Flow

Working Modes

The PSD0401120 features two operational modes: NOR (Normal) and CMD. These modes are chosen through commands sent via the I²C interface.

The NOR mode is the default mode after the power supply voltage is applied and all state-machine initialization is complete. A single pressure and temperature measurement is performed when the measurement command is sent through the I²C interface. Upon concluding the measurement, the PSD0401120 enter sleep mode, when all internal circuitry powers down, expect the I²C interface, saving power. Nominal current consumption during this sleep mode is 0.1μA.

The CMD mode is used for both measurements and compensation. All on-die subcircuits are active and operational. CMD mode is selected though internal registers accessed through the I2C interface without changing OTP values.

The I²C serial interface is powered by the external power supply voltage ($1.8 \leq V_{DD} \leq 3.6V$). The internal circuits such as the analog front-end, OTP register, and digital compensation are powered from the internal 1.67V regulator.

The 1.67V regulator starts automatically when a power supply voltage is applied to the V_{DD} pin. In turn, all circuits that operate on the 1.67V regulator begin working and the NOR mode is set. The state-machine reads the OTP register, performs a measurement, then enters sleep mode. Even in sleep mode, the I2C interface remains operational. If the CMD is used, the state-machine remains in that mode for each subsequent measurement until a mode change is implemented through the OTP register.

I²C Serial Communication

The PSD0401120 features an I²C serial communication interface and protocols. Its I²C bus uses the SCL and SDA signal pins. All communications begin with the MSB. The default 7-bit device address is 0x78 and operates as a slave. The data formats shown in Figure 5 through Figure 9.

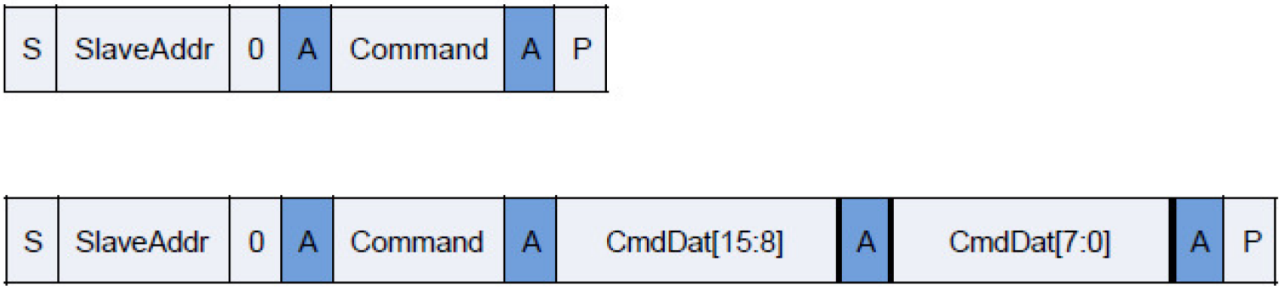


Figure 5. I2C Input Request Command

Figure 6. I2C Register Read

Figure 7. I2C Read 16-Bit OTP Data

Figure 8. I2C Read 3-Byte Original Uncompensated Pressure or Temperature Data

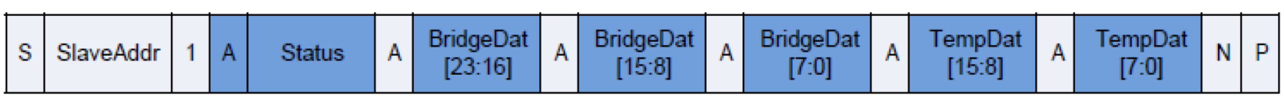


Figure 9. I2C Read 5-Byte Compensated Pressure Data and Temperature Data

The PSD0401120 responses begin at the status byte, followed by the data byte. The returned data is decided by the former command. When repeating an I2C read command, the same data is read.

Apply V_{DD} through a pull-up resistor (4.7kΩ, nominal) as shown in Figure 10. This ensures that the pins are held at logic high when communication is suspended.

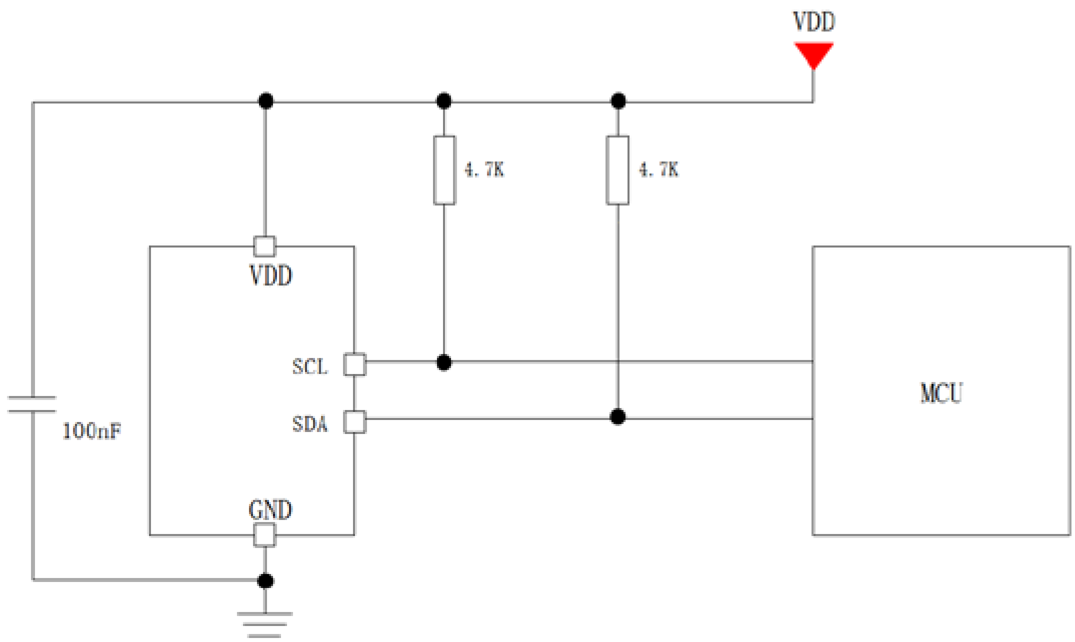


Figure 10. I²C typical application block diagram.

Bit	Name	Description
7	Reserved	0
6	Power	1 = Power on, 0 = Power off
5	Busy	1 = Busy (Pressure and temperature measurement in progress – results not ready. New commands not processed.) 0 = Idle (Last command execution complete, data ready for read.)
4	Reserved	0
3	Mode	0 = NOR mode, 1 = CMD mode
2	Memory integrity/error flag	1 = Integrity check (CRC) has failed – data has errors. 0= Integrity check (CRC) has passed – data is valid.
1	Reserved	0
0	Reserved	0

Table 6. Status bits definitions

The EOC pin's logic level further status; its logic level is high when measurements and calculations are complete.

I2C Commands

Command Byte	Return	Description	NOR Mode	CMD Mode
0x00 ~ 0x1F	16-bit data	Read data in the OTP register	Supported	Supported
0x45 ~ 0x5F		Write data to OTP register (Address is Command value subtracting 0x40 [Address is 0x00 ~ 0x1F]	Supported	Supported
0xA0 ~ 0xA7	24-bit raw data	Get_Raw (Conduct one measurement and write ADC data to registers [See Table for further interpretation]	Supported	Supported
0xA8		Start_NOM (Quite CMD mode, start NOR mode]	Not supported	Supported
0xA9		Start_CM [Quite NOR mode, start CMD mode]	Supported	Not Supported
0xAA		Write_ChecksumC [If CRC values are not written to OTP, the command checks the OTP data and wirtes CRC values to OTP]	Supported	Supported
0xAC	24-bit compensated pressure data and 15-bit compensated temperature data	Get_Cal [Measurement based on OTP settings (AZBM, BM, AZTM, and TM), write compensated pressure and temperature data to I²C interface]	Supported	Supported
0xB0 ~ 0xBF	24-bit compensated pressure data and 15-bit compensated temperature data	Get_Cal_S [Get_Cal_S and Get_Cal differ by Get_Cal is based on OTP-defined OSR, Get_Cal_S is based on command-defined OSR]	Supported	Supported

Table 7. I2C commands

Command 0xAX (HEX)	Measurement	AFE Configuration Register
0xA0, 0x0000	PM – Pressure measurement	AFE pre-programmed, set in 0x14
0xA1, 0xssss	PM – Pressure measurement	AFE ssss configured, set in 0x14
0xA2, 0x0000	PM – AZPM – Pressure measurement with AFE auto-zero	AFE pre-programmed, set in 0x14
0xA3, 0xssss	PM – AZPM – Pressure measurement with AFE auto-zero	AFE ssss configured, set in 0x14
0xA4, 0x0000	TM – Temperature measurement	AFE pre-programmed, set in 0x14
0xA5, 0xssss	TM – Temperature measurement	AFE ssss configured, set in 0x14
0xA6, 0x0000	TM – AZTM – Pressure measurement with AFE auto-zero	AFE pre-programmed, set in 0x14
0xA7, 0xssss	TM – AZTM – Pressure measurement with AFE auto-zero	AFE ssss configured, set in 0x14

Table 8. Get_Raw commands

Get-Cal_S (0xB0 – 0xBF) and Get-Cal (0xAC) differ with Get_Cal measurements are based on OPT-defined OSR, whereas Get_Cal-S measurements are based on user-defined OSR. The Get_Cal-S command allows users to choose proper OSR to generate high, middle, or low accuracy measurements with compensation.

Command 0xBX (HEX)	Function	Details
X [3] bit	OSR_T, DSADC OSR temperature measurement	0: 4x OSR 1: 8x OSR
X [2:0] bit	OSR_P, DSADC OSR pressure measurement	000: 128x OSR 001: 64x OSR 010: 32x OSR 011: 16x OSR 100: 8x OSR 101: 4x OSR 110: 2x OSR 111: 1x OSR

Table 9. Get_Cal_S Command

I²C Start Condition

The SDA logic state changes from its idle high level to a low level when SCL remains a high level. This can be repeated during the data transmission start condition, which indicates that the transaction will start again without an intermediate start bit.

Address Bits

During the first byte data transfer, the first seven bits provide a defined device address. The default address value is 0x78 (see Table . Devices with this address will respond to this transmitted address. The I^2C device address can be changed by storing a different address in the OTP register location 0x02 (Slave_Addr).

A7	A6	A5	A4	A3	A2	A1	W/R
1	1	1	1	0	0	0	0/1

Table 10. I2C address map.

Read/Write Bit Direction

During the first byte data transfer, the last bit indicates the communication direction. A "0" indicates that the Master device writes the data, whereas a "1" indicates that the Master device reads the data.

Data Byte

All bytes transferred on the SDA line except the address bits and the read/write bit are recognized as data bytes.

Acknowledge or Not-Acknowledge Bit

The Acknowledge bit (ACK) informs the sending device that the bytes have been received. The receiving device sends an ACK bit with the reception of each data or address byte. Once the ACK bit is sent, the data sending device stops driving the SDA line. SDA is pulled to a logic high. The receiving device does not need to send an ACK bit is required. When required, the receiving device must pull SDA to a logic low. If the Master does not send an ACK bit, it needs to generate a stop bit to end the transmission.

Start and Stop Condition

For both Start and Stop actions, the following occurs while the SCL's logic level is high. A Start condition is created by transitioning the SDA logic level from a logic high to a logic low. A Stop condition is created by transitioning the SDA logic level from a logic low to a logic high. This ends the I^2C communication. See Figure 11.

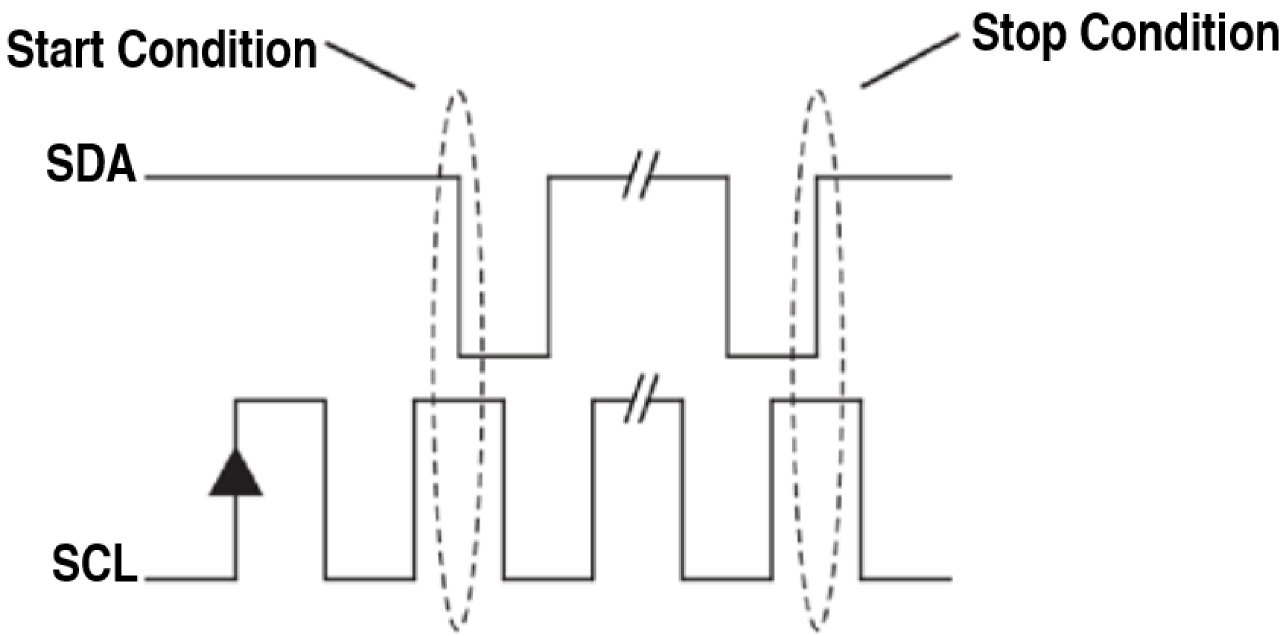


Figure 11. Start and Stop Transition Conditions

When SCL is logic-high, a Start condition is created by the SDA's **falling** edge. This initiates data transmission. Conversely, a Stop condition, which occurs at the end of a data transfer, is created by the SDA's **rising** edge when the SCL signal is a logic high. Both conditions are generated by the Master device. When the Stop command is given, all Slave devices enter an idle state, release the SDA line, and cease data transfer on the bus. In all other conditions, the SDA signal only changes state when the SCL signal is a logic low.

Following a Start command, a Slave device will respond when it recognizes the address byte by issuing an acknowledgement bit by pulling SDA to a logic-low on the ninth CLK cycle. Until the Master issues a stop bit, the data transfer continues.

Acknowledge and Not Acknowledge Bits (ACK/NACK)

After every byte transmission, feedback is created by the receiving device using an Acknowledge or Not Acknowledge bit. Holding the SDA line low during a HIGH SCL period creates an Acknowledge bit, whereas a Not Acknowledge bit is generated when the receiver leaves the SDA line passively pulled HIGH and does not respond. This characteristic makes it clear that in response to an address byte, all Slaves with a non-matching address send a Not Acknowledge bit by not responding.

An ACK bit denotes that a byte (address or data) was transmitted and received successfully, and that the transmission can either continue to the next byte transfer or a stop condition or a repeated start can be issued (Figure 6).

The receiver can use a NACK to indicate the presence of an error somewhere in the data transmission. The NACK signals the transmitting device to terminate the transmission immediately or to make another attempt by sending a repeated start.

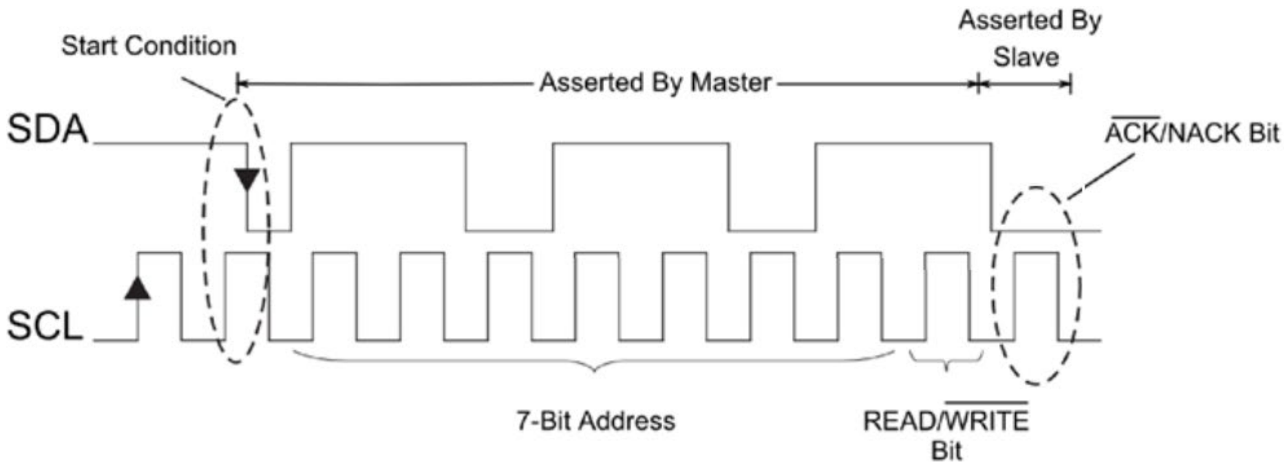


Figure 6. A Signal Diagram Showing a Start Condition, 7-bit Address of 0x6D and a Read Command. The Slave Device Responds with a (logic-low) Acknowledgment.

Data Bits

The transmission data is encoded as data bits and transmitted in an 8-bit format, MSB first. Each bit is synchronized with the SCL signal, as shown in Figure 7. The data on the SDA line must remain stable during the SCL's logic-high period. Data can only transition between logic states when the SCL signal is a logic low. The receiver reads a data bit while the SCL state is logic high. The transmitter asserts each bit only while SCL is a logic low. There are no limits to the number of bytes in a transmission. An Acknowledge bit, generated by the recipient, must follow each byte.

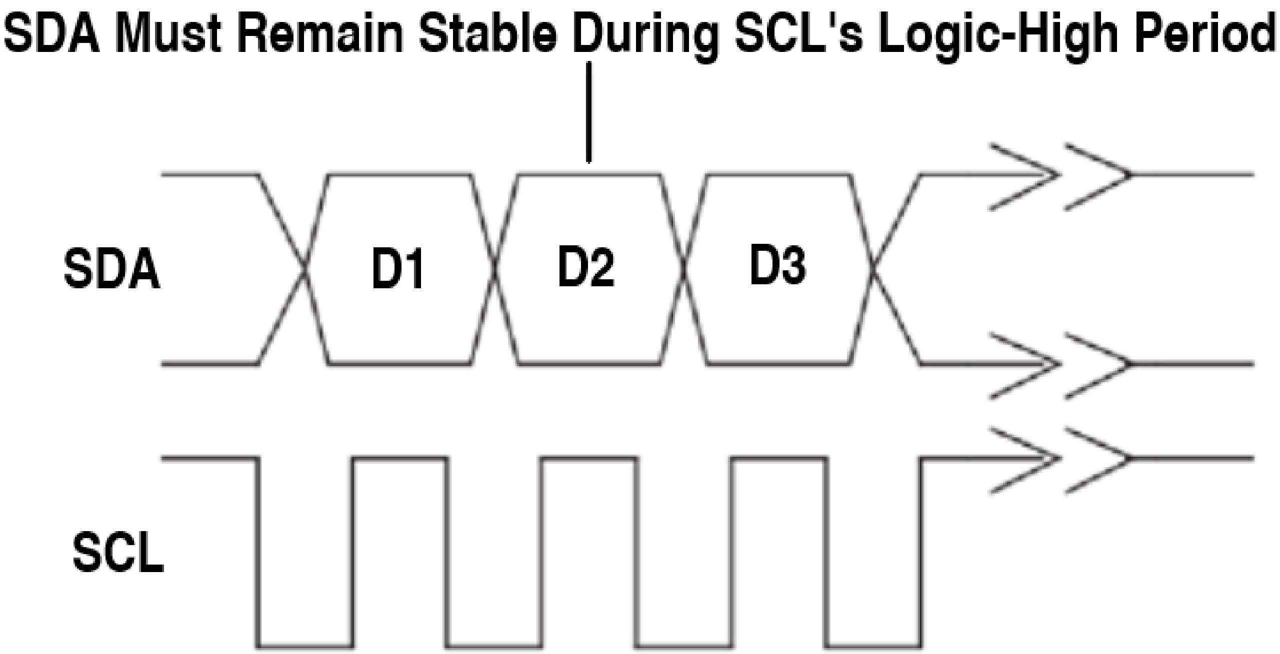


Figure 7. Bit Transition for Valid Data Bits.

Register Description (See Notes 1 and 2 below.)

Address	Bit Address	Register Name	Default Value	Description
0x30	7 – 4	Sleep time <3:0>	4'b0000	0000b: 62.5ms 0001b:125ms .... 1111b:1s[1]
	3	SCO	1'b0	1[2]
	2 - 0	Measurement CTRL <2:0>	3'b000	000b: single temperature acquisition mode 001b: single pressure acquisition mode 010b: combines a pressure acquisition followed immediately by a temperature acquisition 011b: sleep mode[3]

Note 1: Address 0x30, bit 2 – bit 0 represents collection mode.
Note 2: After sending the conversion instruction to address 0x30, interrogate address 0x20, bit 0. A logic 1 in bit 0 signifies that the conversion is completed and automatically resets to 0 after the read. A logic o in bit 0 signifies that a conversion is in progress and data is not ready to read.
[1] Only valid in sleep mode.
[2] Set to 1 as data collection begins. Automatically resets to 0 when collection ends.
[3] While sleep mode is active, a combined acquisition occurs at intervals determined by Sleep time.

Pressure Data Register Description (See Notes 1, 2, and 3 below.)

Address	Bit Address	Register Name	Default Value
0x06	7 – 0	PDATA <23:16>	0x00
0x07	7 – 0	PDATA <15:8>	0x00
0x08	7 – 0	PDATA <7:0>	0x00

Note 1: Signed two's-complement number.
Note 2: When RAW_P is a logic high, the raw data of the pressure/temperature channel is stored.
Note 3: When RAW_P is a logic low, the pressure calibration data is stored.

The ADC's digital output has 24-bit resolution. Its MSB is the sign bit, designating a positive or negative value.

Pressure Data Decimal Conversion

Given the hexadecimal values found in addresses 0x06, 0x07, and 0x08 converting them to decimal is accomplished using Equation 1.

$$\text{Decimal Value} = \text{Dec}(0x06)(2^{16}) + \text{Dec}(0x07)(2^{8}) + \text{Dec}(0x08)(1) \qquad (1)$$

The values generated by Equation 1 can be **normalized** according to the following rules:
If Equation 1's result is greater than 2^{23}, then the normalized value is:
$(\text{Decimal Value} - 2^{24})/(2^{23})$
If Equation 1's result is less than or equal to 2^{23}, then the normalized value is:
$(\text{Decimal Value})/(2^{23})$

The resultant pressure value P is determined by:
$P = (P_H - P_L)/A*(\text{ADC}$ **normalized** $\text{value} - B) + P_L$

Where
P = Calculated pressure value
P_H = Air pressure range, upper limit: 18.86psi
P_L = Air pressure range, lower limit: 4.35psi
A = Transfer function coefficient: 0.8
B = Transfer function coefficient: 0.1

A Pressure Calculation Example

Pressure Range		Output Voltage		Transfer Function Coefficient	
P_L	P_H	Zero Count	Full-Scale Count	A	B
30kPa	200kPa	$0.1*V_{DD}$	$0.9*V_{DD}$	0.8	0.1

The following is assumed that the following relation applies after sensor calibration.

Correspondence Calibration	Zero Code	Full-Scale Code
Apply Pressure Value	4.35psi	18.86psi
Expected Value	0.1	0.9
Corresponding Decimal Value	2^{20}*0.1 =104858	2^{20}*0.9 = 943718

Temperature Data Register Description (See notes 4, 5, and 6 below.)

Address	Bit Address	Register Name	Default Value
0x09	7 – 0	PDATA <23:16>	0x00
0x0A	7 – 0	PDATA <15:8>	0x00

Note 4: Signed two's-complement number.
Note 5: When RAW_T is a logic high, it is undefined.
Note 3: When RAW_T is a logic low, the temperature calibration data is stored.

The ADC's digital output has 16-bit resolution. Its MSB is the sign bit, designating a positive or negative value.

Temperature Data Decimal Conversion

Given the hexadecimal values found in addresses 0x09 and 0x0A converting them to decimal is accomplished using Equation 2.

$$\text{Decimal Value} = \text{Dec}(0x07)(2^8) + \text{Dec}(0x08)(1) \qquad (2)$$

The values generated by Equation 2 can be **normalized**, which produces the actual temperature value, according to the following rules:
If Equation 2's result is greater than 2^{15}, then the normalized value is:
(Decimal Value – 2^{16})/(2^8)
If Equation 2's result is less than or equal to 2^{15}, then the **normalized** value is:
(Decimal Value)/(2^8)

Master Device Writing Data to Slave Device

A Master device addressing and writing data received by a Slave device is shown in the Figure 8 signal diagram. Initiating communication, the START bit is the first bit sent. This is followed by the address byte. During this transmission, all Slave devices are monitoring the first seven bits of the address byte, looking to see if it matches their unique address. The Slave device that finds an address match listens for the last bit to determine if a read from, or write to, the Slave will occur. All remining Slave devices, since their addresses do not match that sent by the Master, ignore further communication, and send a NACK.

The Slave device that recognizes the address and write command responds with an ACK (acknowledge) bit. This informs the Master that the Slave device is active on the bus and waiting for further communication. The Master proceeds by sending byte-format data. The Master can write to a specific Slave device register by writing the command byte before sending the data. After a byte transfer, the Slave issues an ACK bit. When data transfer ends, the Master terminates the transfer by issuing a STOP condition (both SDA and SCL are set to a logic high).

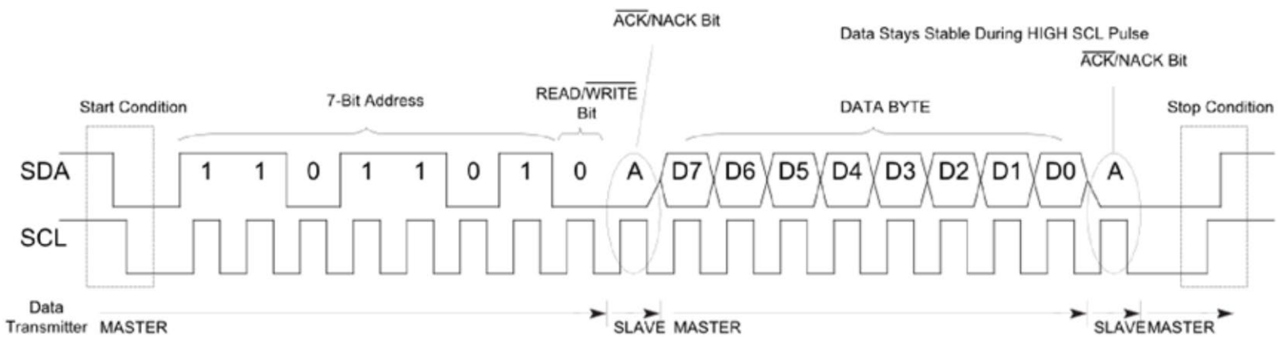


Figure 8. I²C Write Sequence Transmission

Master Device Reading Data from Slave Device

A Master device addressing and reading data sent by a Slave device is shown in the Figure 9 signal diagram. Initiating communication, the START bit is the first bit sent. This is followed by the address byte. During this transmission, all Slave devices are monitoring the first seven bits of the address byte, looking to see if it matches their unique address. The Slave device that finds an address match listens for the last bit to determine if a read from, or write to, the Slave will occur. All remining Slave devices, since their addresses do not match that sent by the Master, ignore further communication, and send a NACK.

The Slave device that recognizes the address and read command responds with an ACK (acknowledge) bit. This informs the Master that the Slave device is active on the bus, The Slave transmits byte-format data. The Master sends an ACK bit at the end of each byte. When the Master receives all necessary and requested data, it responds with a NACK bit. The Master then resumes bus control. The Master then terminates the transfer by issuing a STOP condition (both SDA and SCL are set to a logic high).

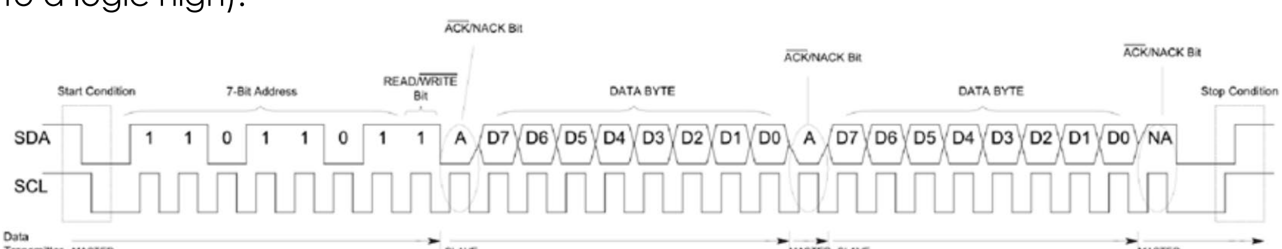


Figure 9. I²C Read Sequence Transmission

Whereas control of the SDA line is passed between the Master and the various Slaves, the SCL line is always controlled by the Master; it always clocks the data, whether going to a Slave or coming from the Slave to the Master.

Pressure and Temperature Sensor Compensation

The pressure sensor and on-die temperature sensor are calibrated by the state-machine. The details are as follows.

Effects of Digital Compensation

The PSD0401120's pressure sensor uses a Wheatstone bridge configuration. This sensor type inherently has offset, sensitivity, and non-linearity errors as well as temperature drift. The on-die digital calibration minimizes the aforementioned errors and compensates for the linearity errors producing an output that is proportional to the input pressure over the operating temperature range. The typical performance before calibration and after calibration is shown in Figure XX.

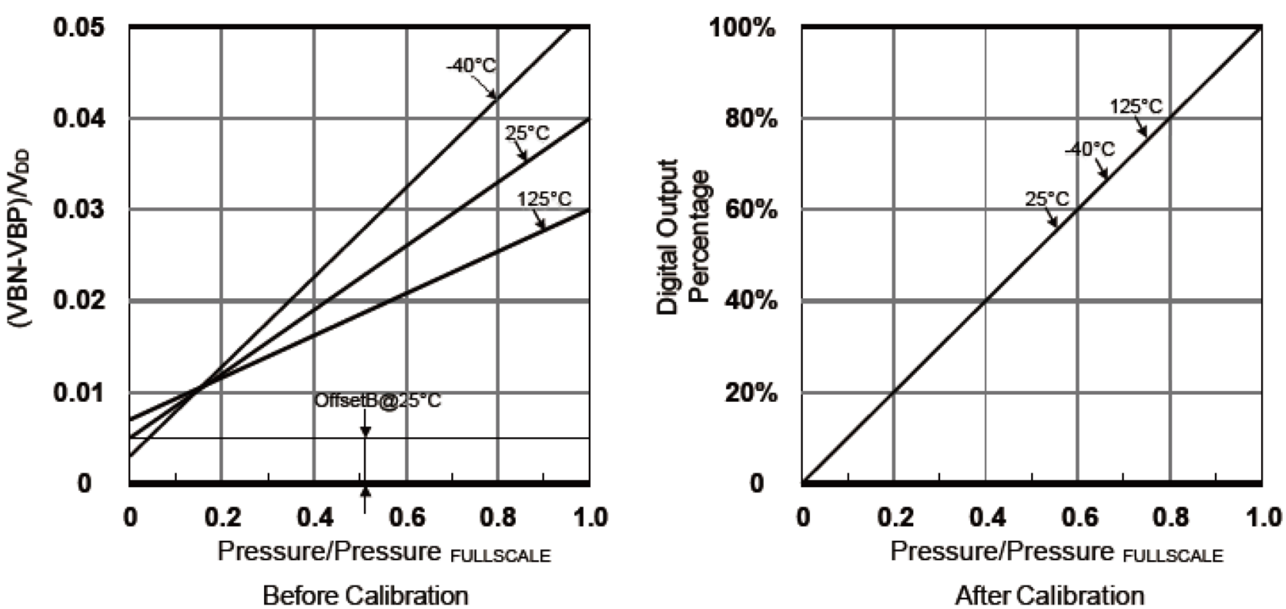


Figure XX. Example of Typical Error Calibration.

Digital Compensation

The correction coefficients used by the compensation algorithms are listed in Table 11. These values can be stored in the OTP register. They are copied and stored in a mirror register when power is applied algorithmic calculations.

Parameter	**Description**
B_{raw}	Pressure sensor ΔΣADC output data
B	Conditioned pressure sensor data
B_{tmp}	Intermediate pressure sensor result
B_{shift}	Pressure sensor shift for post-compensation/post-assembly offset compensation
$Gain_{PS}$	Pressure sensor gain
$Gain_{T}$	Temperature gain coefficient
$Offset_{PS}$	Pressure sensor offset
$Offset_{T}$	Temperature offset coefficient
SOT_{tcg}	TC_{gain} second order term
SOT_{tco}	TC_{offset} second order term
SOT_{B}	Braw second order term
TC_{gain}	Pressure sensor gain temperature coefficient
TC_{offset}	Pressure sensor offset temperature coefficient
T_{shift}	Temperature shift for post-compensation
T_{base}	Base temperature raw data
T_{raw}	Base temperature ΔΣADC raw data
T_{tmp}	Temperature intermediate result
T	Conditioned temperature data

Table 11. Compensation Coefficient Definitions

The $Gain_{B}$, $Offset_{B}$, TC_{gain}, TC_{offset}, SOT, $Gain_{T}$, $Offset_{T}$, T_{base} values can be written to the OPT register. These values are read and stored in registers when power is applied and used for the compensation algorithm calculations.

Pressure Sensor Digital Compensation

The device has two pressure sensor compensation algorithms, a parabolic curve, and an S curve. Select either by setting the SOT_curve bit in the OTP register.

The formula for the seven-point **parabolic** compensation curve is:

$$B = Gain((1 + TC)(\Delta T + SOT)(\Delta T^2)(B - Offset + TC(\Delta T + SOT)\Delta T^2) + 1 \quad (1)$$

$$B = (B_{tmp}(1 + B_{tmp}(SOT_B)) + B_{shift} \quad (2)$$

The seven-point pressure sensor **S-curve** compensation is:

$$B_{tmp} = Gain_B(1 + TC_{gain}(\Delta T + SOT_{tcg})\Delta T^2)(B_{raw} - Offset_B + TC_{offset}((\Delta T + SOT_{tco})\Delta T^2) \quad (3)$$

$$B = \left(B_{tmp}(1 + |B_{tmp}|)(SOT_B) + 1\right) + B_{shift} \quad (4)$$

When the PSD0401120 generates its digital output (I2C 0xAC command), output B[23:0] is three bytes long. Equation 5 calculates the output ratio.

$$Pressure\_Sensor\_Output[\%] = \frac{B[23:0]}{2^{24}}(100\%) \quad (5)$$

Simple compensation is also available. This compensation needs less pressure and temperature data. For example, there are choses of 6-point, 5-point, 4-point, 3-point, 2-point, 1-point. See Table xx for further information.

Temperature Sensor Digital Compensation

The PSD0402230's temperature sensor output is 16-bits and is compensated through a DSP algorithm using equations (6) and (7).

$$T_{tmp} = Gain_T(T_{raw} + Offset_T) + 1 \quad (6)$$

$$T = \left(T_{tmp}\left(1 + T_{tmp}(SOT_T)\right)\right) + T_{shift} \quad (7)$$

When reading five-byte data using the 0xAC I²C command, the 16-bit temperature data are the last two bytes.

$$Temperature\ [C°] = \frac{T[15:0]}{2^{16}}(190 - 40) \quad (8)$$

Sequence

1 – Data Collection

The relationship between the compensation coefficients and minimum test points are captured in Table 12.

Coefficients Compensated	**Temperature T1**			**Temperature T2**			**Temperature T3**		
	Minimum Points			Minimum Points			Minimum Points		
$Gain_B$, $Offset_B$	P1	P2	-	-	-	-	-	-	-
$Gain_B$, $Offset_B$, SOT_B	P1	P2	P3	-	-	-	-	-	-
$Gain_B$, $Offset_B$, TC_{offset}, TC_{gain}	P1	P2	-	P1	P2	-	-	-	-
$Gain_B$, $Offset_B$, TC_{offset}, SOT_B, SOT_{offset}	-	P2	-	P1	P2	P3	-	P2	-
$Gain_B$, $Offset_B$, TC_{offset}, TC_{gain}, SOT_{offset}, SOT_{gain}	P1	P2	-	P1	P2	-	P1	P2	-
$Gain_B$, $Offset_B$, TC_{offset}, TC_{gain} SOT_{offset}, SOT_{gain}, SOT_B	P1	-	P3	P1	P2	P3	P1	-	P3
P1, P2, P3 are three different pressure conditions: P1 < P2 < P3									

Table 12. Compensation Coefficients and Test Points

Before retrieving conversion data, the PSD0402230 mode to CMD and register values so that the raw pressure and temperature can read. Store the collected pressure sensor and temperature data under set pressure and temperature conditions.

2 – Coefficient calculation

Based on the collected data, calculate the coefficients and write them to the OTP register.

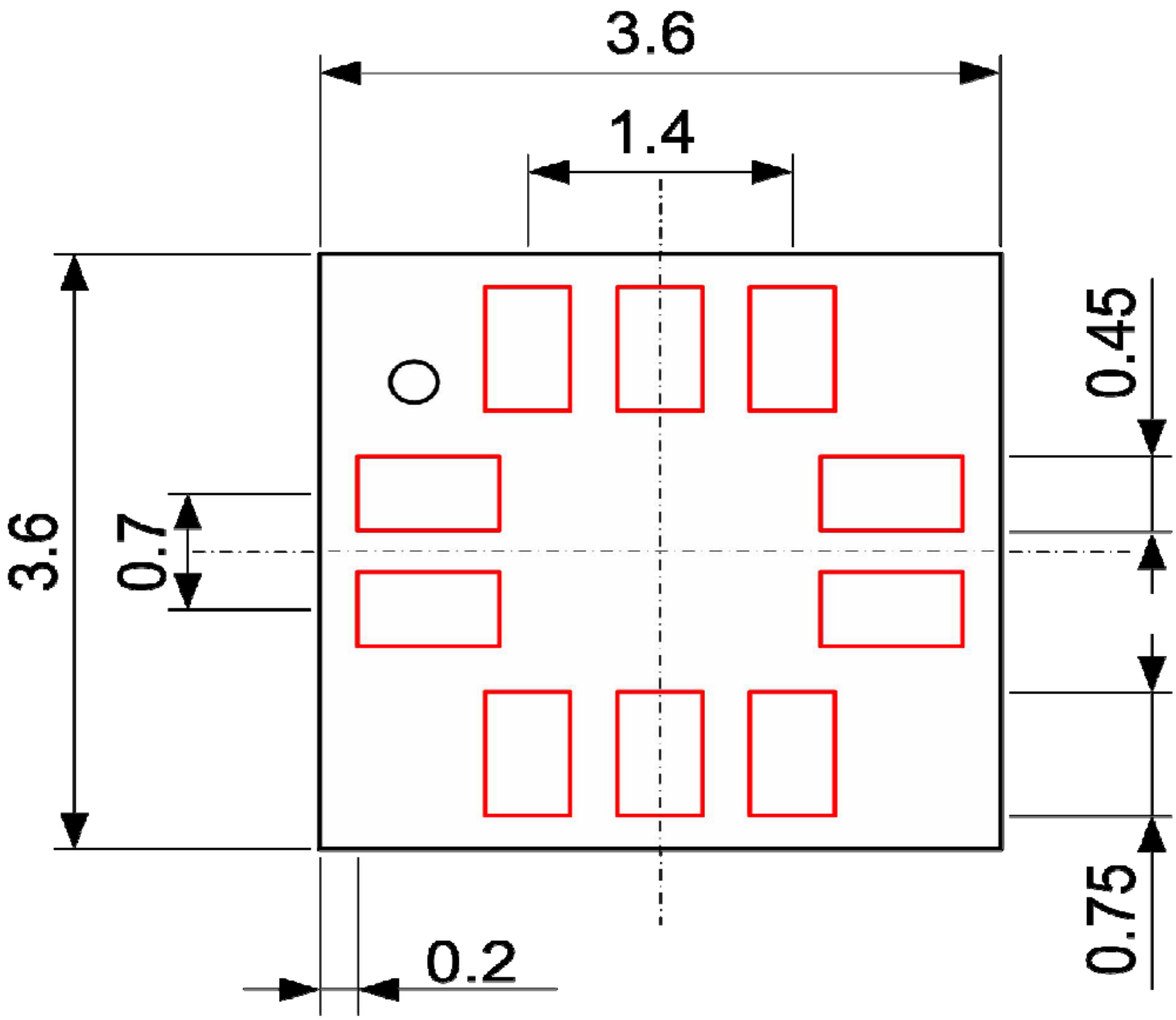
Temperature Coefficient Source

The temperature coefficient source is found in register address 28H. The source is controlled by the value of Bit 7. Setting Bit 7 to 1 selects the temperature sensor co-located with the pressure sensor. Setting Bit 8 to 0 selects the temperature sensor within the state machine.

Interrupt

The INT signals the End-Of-Conversion. INT automatically generates an interrupt when a command is sent through the I²C interface when the measurement is completed, and the data is ready for a read. INT automatically reset after a data read. The conversion status is available by monitoring the corresponding register.

Recommended PCB Landing Pad Layout and Dimensions



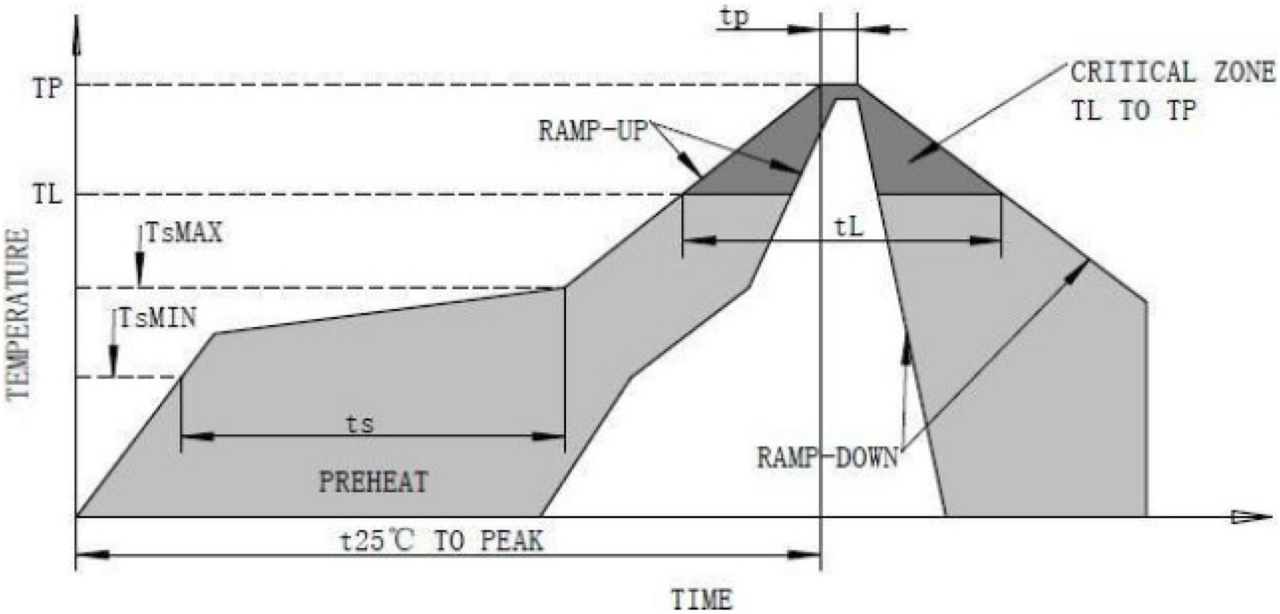
Assembly Recommendations

Soldering and Assembly

The PSD0401120 has a small physical structure, which means that its thermal capacity is limited. Therefore, during the reflow process use only the heat necessary to complete PCB assembly. Excess heat beyond that necessary for proper reflow may cause thermal deformation that can alter and degrade the sensor's performance characteristics. Additionally, ensure that flux or other debris is not allowed to invade the device's interior.

SMT Soldering

The reflow heat profile shown in Figure 13 is recommended.



Profile Feature		Pb-free Assembly	
Average Ramp-up Rate (T_SMAX to TP)		3	°C/second (max)
Preheat	Minimum Temperature (T_SMIN)	150	°C
	Maximum Temperature (T_SMAX)	200	°C
	Time (TSMIN to T_SMAX) (TS)	60 < tS < 80	seconds
Time maintained above	Tempeature (TL)	217	°C
	Time (tL)	60 < tL < 150	seconds
Peak Temperature (TP)		260	°C
Peak Temperature Time (0.95TP)		60 < tp < 150	seconds
Ramp-down Rate		4	°C/second (max)
Room-to-peak Temperature Time		8	Minutes (max)

Figure 13. Recommended Solder Reflow Temperature Profile and Timing.

Cleanout

During manufacturing, the PSD0401120 is assembled in a dust-free environment. It is recommended that the PCB assembly process is also performed in a dust-free environment (Class 7, ISO14644-1 is suggested). If not possible, use a temporary cover over the sensor during assembly that prevents dust or particles entrance into the device's interior. Since post reflow cleaning increases the risk of damage to the sensor, the use of "no-cleaning" solder paste is recommended.

Sensor Port

The sensor is located internally below the device's port. Any foreign object that enters the port can cause damage, rendering the device damaged and leading to errant data or completely inoperable. Therefore, using an acoustically transparent protective membrane is encouraged.

Environment

To avoid the sensitivity and output value changes, avoid exposing the sensor to light sources.

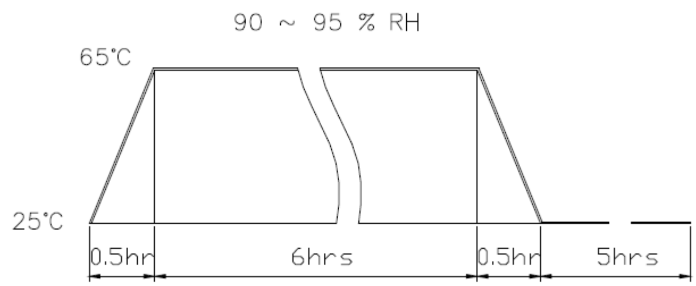
Pressure Range

Ensure that the range of pressure that will be measured is within the range of the sensor. Pressures outside this range can damage the sensor.

ESD Protection

Ensure that when stored prior to assembly onto a PCB that the PSD0401120 is stored in an ESD protective container. Please practice proper ESD protocols to prevent ESD damage while handling the device.

Reliability Testing

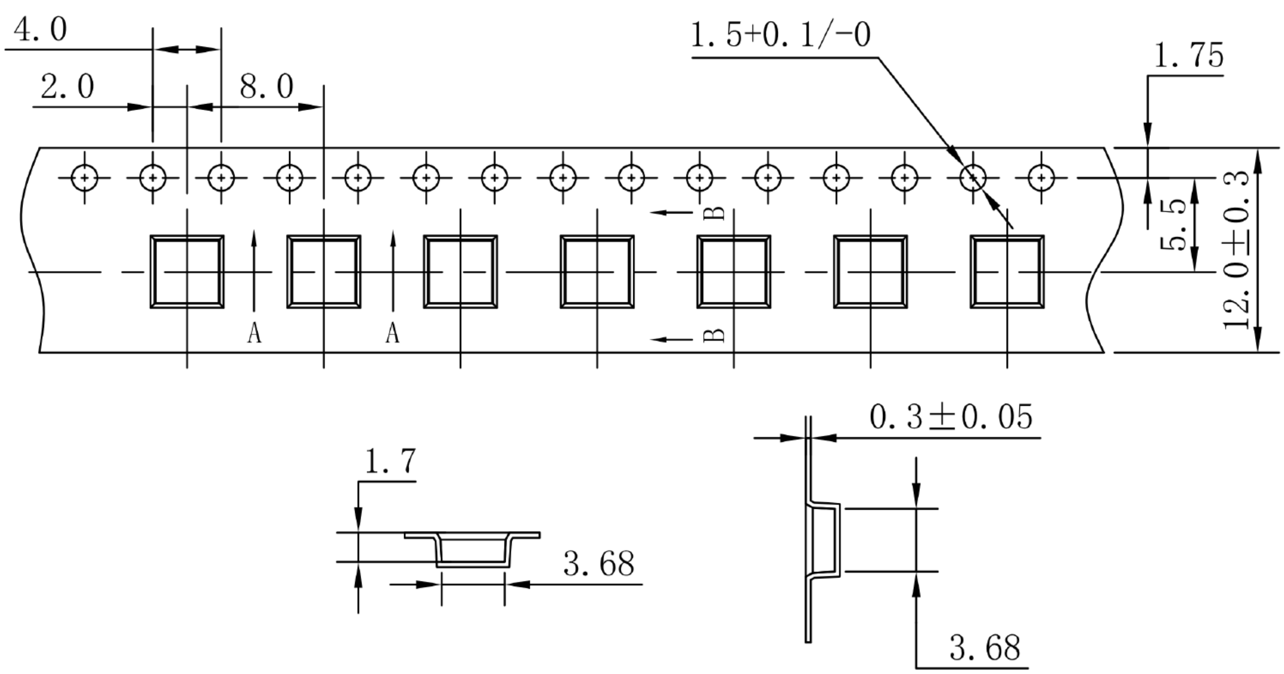
Type of Test	**Test Specifications**
High Temperature Test	96 hours at 70±3°C
Low Temperature Test	96 hours at -30±3°C
Humidity Test	96 hours at 30±3°C with relative humidity at 92~95%
Temperature Cycle Testing	Run for 5 cycles with each cycle consisting of: 
Vibration Test	Frequency: 10~55~10Hz Oct/min Amplitude: 1.5mm Duration: 2 hours each of 3 perpendicular directions
Drop Test	Drop the speaker contained in normal box onto the surface of 40mm thick board 10 times from the height of 75cm.
Load Test	Must perform normal with program White-Noise source at Rated Power for 96 Hours

After each test let rest for 6 hours in standard room temperature, the part shall be within ±3dB.

Packaging

Reel Specifications

Carrier Tape Information [Unit: mm]



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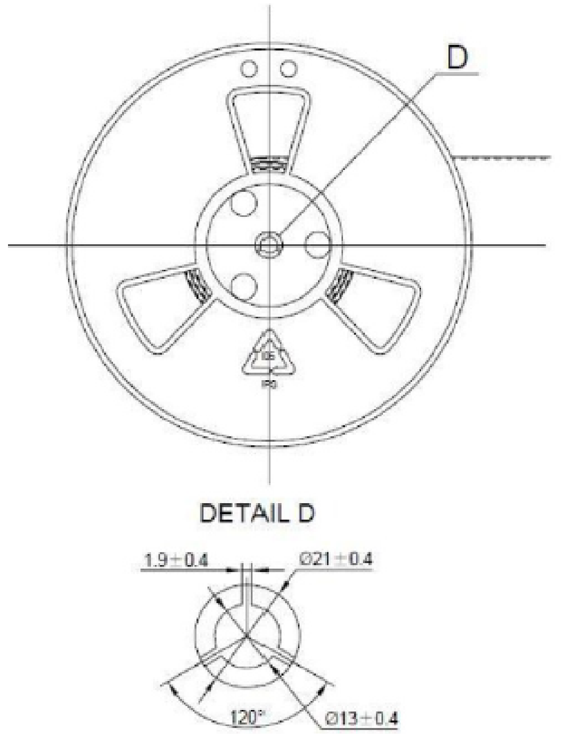
<tr><td>
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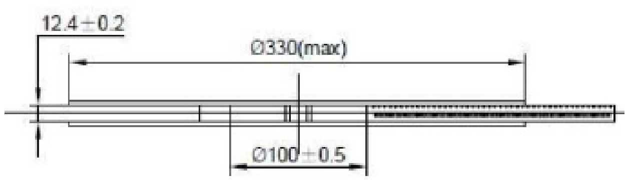
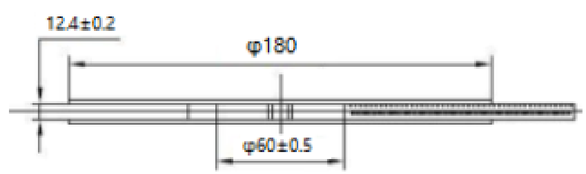
<tr><td>
</td><td>
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Specifications Revisions

Revision	Description	Date	Approval
A	Datasheet from Engineering	07/24/2024	KH

Note:

1. Unless otherwise specified:
   A. All dimensions are in millimeters.
   B. Default tolerances are ±0.5mm and angles are ±3°.
2. Specifications subject to change or withdrawal without notice.