MVT4000D Series

High Performance Digital Temperature Sensor

GENERAL DESCRIPTION

[Patents protected & patents pending]

MEMS Vision's temperature (T) sensors are built by combining the company's revolutionary MoSiC® technology with its extensive ASIC design experience. This combination enables high levels of performance, such as fast temperature measurements and high accuracy

The technology also offers a very robust proprietary sensor-level protection, ensuring excellent stability against aging and harsh environmental conditions such as shock and volatile chemicals.

The highly miniaturized smart sensors are fully calibrated and provide standard digital I²C outputs to enable plug-and-play integration. The output temperature resolution can be programmed for maximum flexibility and to minimize power consumption, depending on the application and operating conditions.

The micro-Watt levels of power consumption of these sensors make them the ideal choice for portable and remote applications.

MEMS Vision's temperature sensors offer the industry's most competitive performance-to-price value, for a wide range of applications and end users.

FEATURES

- **Fast RH response time**
  Down to 2 seconds time constant
- **High accuracy**
  Temperature (MVT4001D): ±0.2°C typ. (-10°C – 80°C)
  Wide operating Range: -40°C – 125°C
- **Configurable resolution**
  8, 10, 12 or 14 bits
- **Fully compliant I²C interface**
- **Extended supply voltage range of 1.71V – 3.6V**
- **Very low power consumption**
  0.18 µA avg. current at one temperature meas. per second (8-bit res., 3.3V supply)
- **Small Form Factor for use in compact systems**
  2.5 x 2.5 x 0.9 mm DFN-style LGA package

USER BENEFITS

- **Long Term Stability and Reliability:**
  Proprietary sensing structures and protection technology, robust biasing circuitry, and self-diagnosis algorithms ensure accurate and repeatable measurements.
- **Digital Output:**
  Allows for native interfacing with embedded system components such as FPGAs or off-the-shelf microcontrollers.
- **Fully Calibrated System:**
  Built-in digital sensor calibration ensures high accuracy measurements and linear behavior under varying sensing environments.

APPLICATIONS

The MVT4000D series is ideal for use in environmental sensing for consumer electronics, automotive, industrial, agricultural, and other sectors. Some application examples include:

- OEM products
- Instrumentation
- Medical equipment
- White goods
- Battery-powered systems
- Drying
- Meteorology
- Refrigeration equipment
- Smartphones and tablets
- HVAC systems
- Building automation
- Data logging

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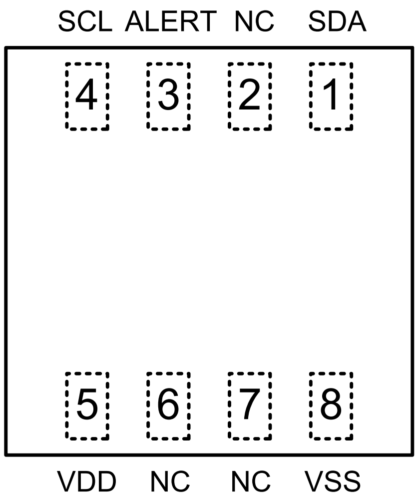

Fig. 1: Diagram of pin configuration (top view).

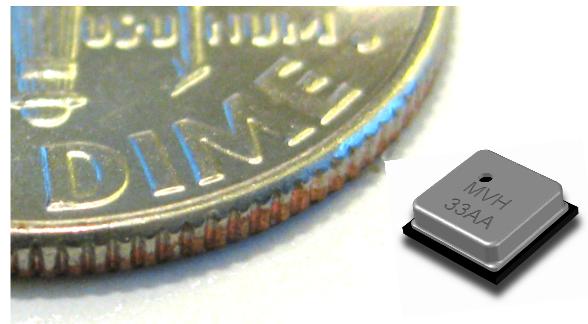

Fig. 2: DFN-style LGA package.

2 Pin Assignment and Application Circuit

Table 1: Pin Assignment.

Pin	Name	Function
1	SDA[1]	I^2C data
2	NC	No connect
3	ALERT	Digital output indicating an alarm condition. Leave floating if unused.
4	SCL[1]	I^2C clock (up to 400 kHz)
5	VDD	Positive supply
6	NC	No connect
7	NC	No connect
8	VSS	Negative supply or ground

[1]Requires a 2.2 kΩ pull-up resistor.

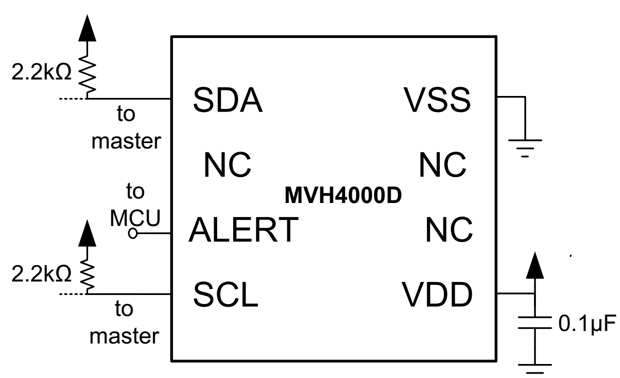

Fig. 3: Application Circuit.

3 Functional Description

The MVT4000D series sensors are highly integrated digital devices that accurately measure temperature levels.

An analog-to-digital converter (ADC) with a configurable resolution is interfaced with a highly accurate sensor in order to allow for the measurement of temperature. High precision biasing and clock generation ensures stable operation over a wide temperature range. The sensor can be used to measure the ambient temperature in real-time or be used for data-logging, and can interface with any I^2C compliant system for digital transmission of the acquired data.

Calibration data and compensation logic are integrated within the system, such that the chip does not require any user calibration, and is readily compensated for accurate operation over a wide range of temperature levels.

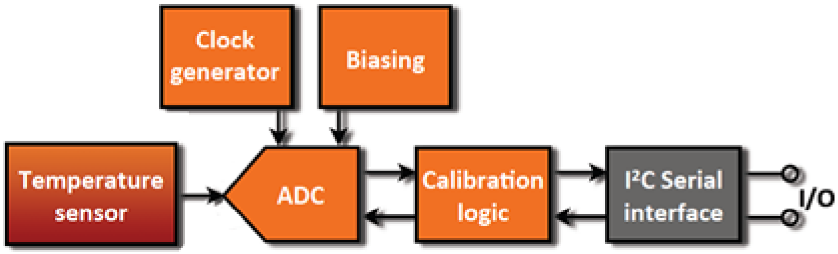

Fig. 4: MVT4000D series functional diagram.

4 Chip Performance Summary

Table 2: MVT4000D Series Specifications.

At T_A = +25°C, V_{DD} = +1.71 V to +3.6 V unless otherwise noted.

PARAMETER		CONDITION	MIN	TYP	MAX	UNITS
TEMPERATURE SENSOR						
Range			-40		125	°C
Accuracy Tolerance[2]	MVT4001D	-10°C to 80°C		±0.2	±0.3	°C
	MVT4004D	0°C to 70°C		±0.3	±0.5	
Resolution		14 bits		0.01	0.02	°C
Response Time Constant[3] (τ_T)				> 2		sec.
Long-term Stability					0.02	°C/yr
Supply Voltage Dependency				0.03	0.1	°C/V
CHIP TEMPERATURE RANGE						
Operating Range			-40		125	°C
Recommended Storage Range			0		60	°C
Storage Range			-40		125	°C
MEASUREMENT TIME						
8 bits Resolution		Temperature Measurement (Including digital compensation)		0.37		ms
10 bits Resolution				0.45		
12 bits Resolution				0.60		
14 bits Resolution				0.91		
SLEEP MODE						
Sleep Current	I_{SD}	25°C		0.010	0.025	µA
		-40°C to 125°C			2.5	µA
POWER SUPPLY						
Operating Supply Voltage	V_{DD}		1.71	3.3	3.6	V

Table 2 (cont'd): MVT4000D Series Specifications

PARAMETER		CONDITION	MIN	TYP	MAX	UNITS
SUPPLY CURRENT						
Average Current (V_{DD} = 3.3V)	I_Q	8 bits resolution one T meas./s	0.15	0.18	0.20	µA
		10 bits resolution one T meas./s	0.17	0.20	0.23	
		12 bits resolution one T meas./s	0.21	0.25	0.29	
		14 bits resolution one T meas./s	0.29	0.36	0.43	

[2]See Fig. 5 for more details.
[3]Response time depends on system thermal mass (e.g., PCB dimensions and thickness) and airflow.

5 Temperature Tolerances

5.1 Accuracy Tolerances

The typical and maximum temperature accuracy tolerances for the MVT4000D series sensors are shown in Fig. 5.

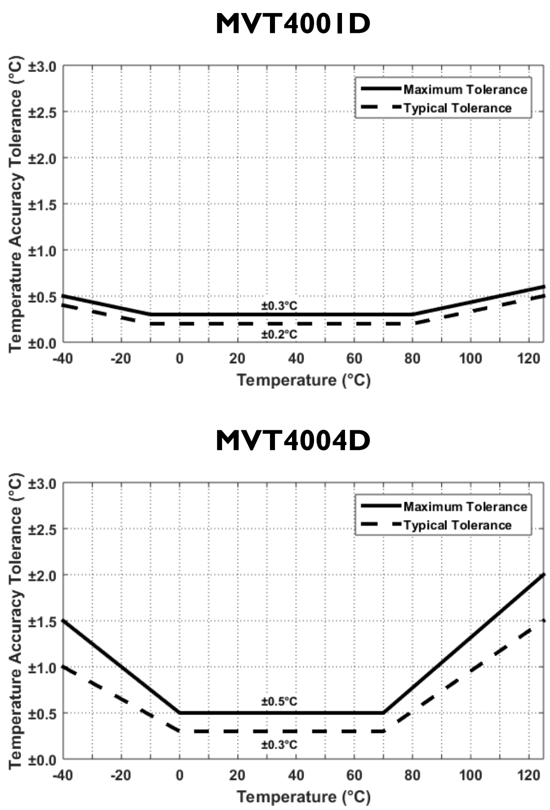

Fig. 5: Temperature tolerances.

6 User Guide

6.1 Sensor Communications

The MVT4000D series sensors communicate using the Inter-IC (I^2C) standard bus protocol. To accommodate multiple devices, the protocol uses two bi-directional open-drain lines: a Serial Data Line (SDA) and a Serial Clock Line (SCL). Because these are open-drain lines, pull-up resistors to VDD must be provided as shown in Fig. 6. Several slave devices can share the I^2C bus, but only one master device can be present on the line.

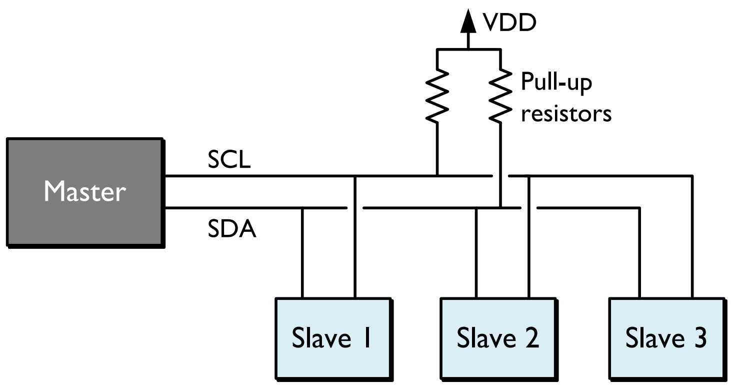

Fig. 6: Diagram of an I^2C interconnect with one master and three slave devices.

Each transmission is initiated when the master sends a '0' start bit (S), and the transmission is terminated when the master sends a '1' stop bit (P). ***These bits are exclusively transmitted while the SCL line is high.*** The waveforms corresponding to these conditions are illustrated in Fig. 7.

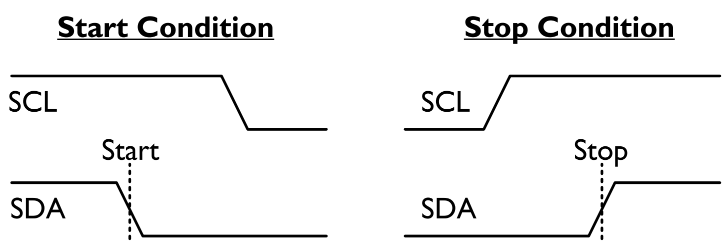

Fig. 7: I^2C bus start and stop conditions.

Once the start condition has been sent, the SCL line is toggled at the prescribed data-rate, clocking subsequent data transfers. Data on the SDA line is always sampled on the rising edge of the SCL line and must remain stable while SCL is high to prevent false Start or Stop conditions (see Fig. 7).

Following the start bit, address bits select the device targeted for communications and a read/write bit indicates the transfer direction of any subsequent data. The master sends the unique 7-bit address of the desired device and a read/write bit set to '1' to indicate a read from slave to master or to '0' to indicate a write from master to slave. All transfers consist of eight data bits and one response bit set to '0' for Acknowledge (ACK) or '1' for Not Acknowledge (NACK). After the acknowledge signal is received another data byte can be transferred, or the communication can be stopped with a stop bit.

An MVT4000D series sensor operates as a slave on the I^2C bus and supports data rates of up to 400 kHz in accordance with the I^2C protocol. The default address of the sensor is 0x54. Custom I^2C addresses can be provided upon request (please contact support@mems-vision.com for details). The sensor can be interfaced with any I^2C master such as a microcontroller, and the master is responsible for generating the SCL signal for all communications with the MVH4000D series sensor.

The official I²C-bus specification and user manual documentation can be found at:
http://www.nxp.com/documents/user_manual/UM10204.pdf.

The MVT4000D series sensors are equipped with different commands to configure the chip and to perform measurement as described in Table 3.

Table 3: Commands Code and Description.

Command Code (HEX)	Description
0xE3	Hold Temperature Measurement
0xF3	No-hold Temperature Measurement
0xA7	Read Register
0xA6	Write Register
0x30	Stop Periodic Measurements
0xD7	Read Sensor ID

The Hold and No-hold commands will be described in Section 6.2, and the read and write register commands will be described in Section 6.4. The format of the fully calibrated measurement data returned by the MVT4000D sensor is described in Table 4, and this can be converted to temperature readings by using the equations in Section 6.2.3.

Table 4: Measurement Command Modes.

Measurement Command Mode	Description	Number of data bytes sent on the I²C bus
Temperature	The chip only measures temperature and sends the 14-bit result once the measurement is complete.	2 bytes + 1 byte CRC

6.2 Performing Measurements with the MVT4000D Series Sensors

There are two types of measurement commands:

1. Hold measurement commands: The MVT4000D series sensor holds the SCL line low during the measurement and releases the SCL line when the measurement is complete. This lets the master know exactly when the measurement has finished. Using this mode will prevent the master from communicating with any other slave until the measurement is complete. Note that the minimum frequency for the SCL clock in this mode is 200 kHz.
2. No-hold measurement commands: The MVT4000D series sensor does not hold the SCL line low, and the master is free to initiate communication with other slaves while the chip is performing the measurement. To obtain the measurement data, the master must request the result from the chip after the expected conversion time which depends on the measurement resolution as summarized in Section 6.2.4. There is no minimum clock frequency when in this mode.

6.2.1 Performing a Hold Measurement

A hold measurement sequence consists of the following steps, as illustrated in Fig. 8.

1. Wake up the MVT4000D series sensor from sleep mode by sending its I²C address with a write bit, and initiate a measurement by sending the desired hold measurement command.

2. Change the direction of communication by sending a start bit, the MVT4000D I^2C address, and a read bit. The SCL line is held low by the sensor during the measurement process, which prevents the master from initiating any communications with other slaves on the bus.
3. Once the requested measurement is completed by the MVT4000D series sensor, the SCL line is released and the chip waits for the SCL clock signal to send the results. The sensor will then transmit the requested measurement data on the bus for the master to capture.

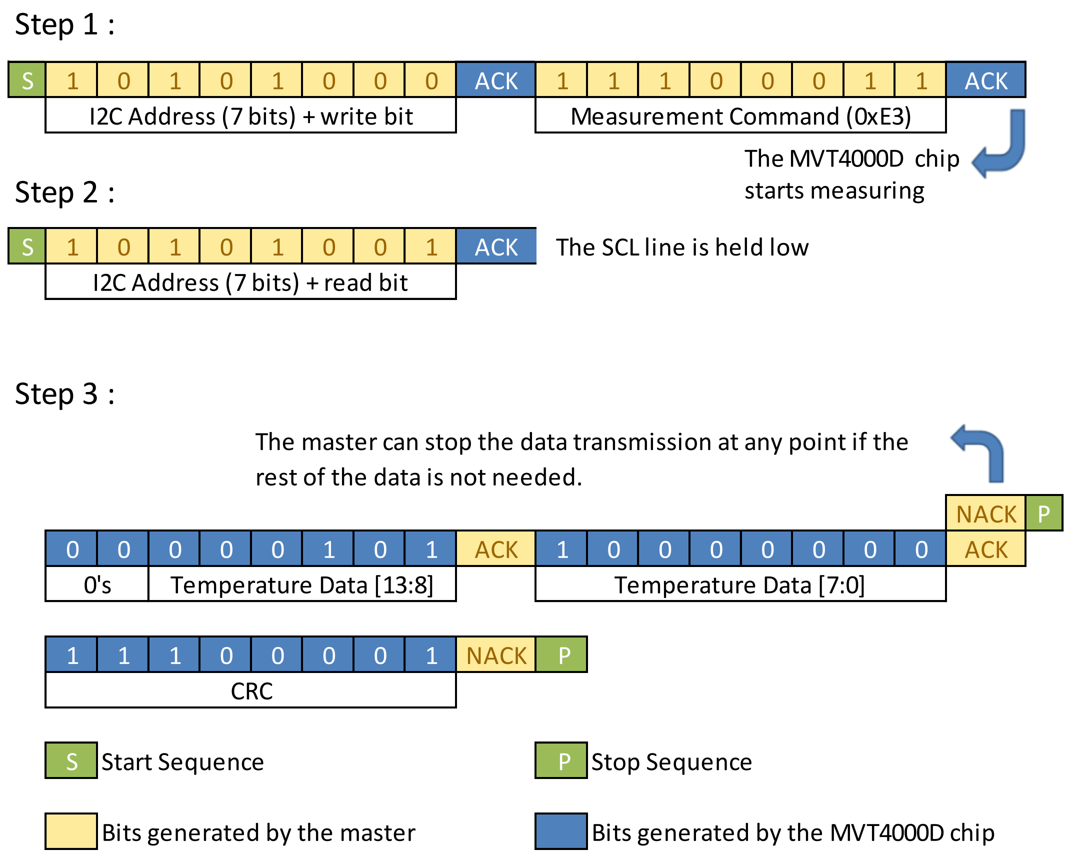

Fig. 8: Typical hold measurement sequence for a temperature command.

6.2.2 Performing a No-Hold Measurement

A no-hold measurement sequence consists of the following steps, as illustrated in Fig. 9.

1. Wake up the MVT4000D series sensor from sleep mode by sending its I^2C address with a write bit, and initiate a measurement by sending the desired no-hold measurement command.
2. To read the result from the MVT4000D series sensor, the master has to send the chip its I^2C address and a read bit. If the measurement is completed and the result is ready, the chip will send an ACK bit and starts to send the result over the bus. If the measurement is still in progress, the chip will send a NACK bit and the master will need to try to read the result again.

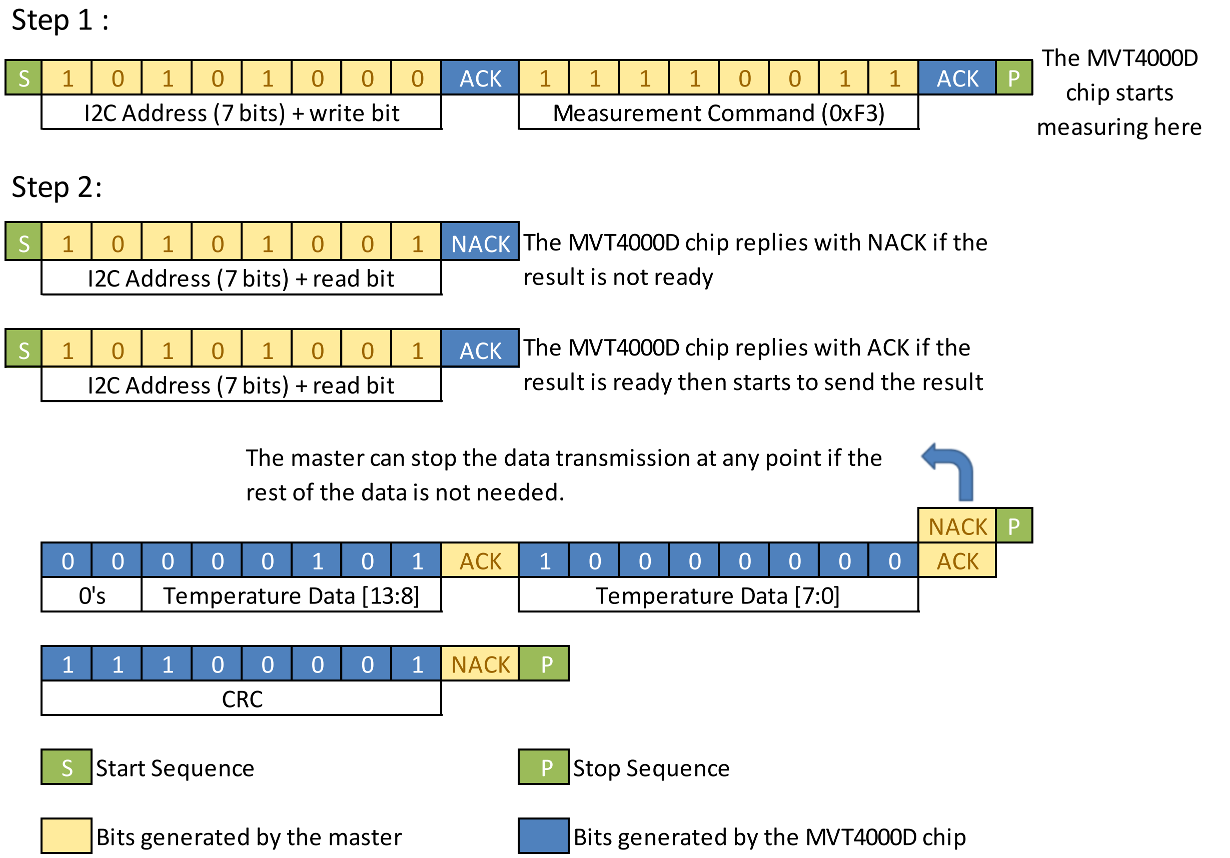

Fig. 9: Typical no-hold measurement sequence for a temperature command.

6.2.3 Interpreting the Data

As stated in Table 4, the measurement data will be two bytes long. The most significant bit of the reading is sent first followed by the least significant bits. The temperature measurement is always scaled up to a 14-bit value regardless of the selected resolution of the sensor. The temperature (in degrees Celsius) is obtained as follows:

$$Temperature\ [°C] = \frac{Temperature\ [13:0]}{2^{14} - 1} * 165 - 40$$

6.2.4 Measurement Conversion Times

The MVT4000D series sensors are designed to have relatively fast conversion times. The conversion time depends on the resolution of the measurement, and Table 5 summarizes the conversion times for different resolutions.

Table 5: Conversion Times.

Measurement	Resolution (bits)	Measurement Time (ms)
Temperature	8	0.37
	10	0.45
	12	0.60
	14	0.91

6.2.5 CRC Checksum Calculation

An 8-bit CRC checksum is transmitted after each measurement so the user can check for data corruption during communications if desired. The properties of the CRC algorithm used are summarized in Table 6, and the CRC is based on 4 bytes of data: 0x0000 followed by the 2 bytes of temperature data.

Table 6: CRC Checksum Properties.

Property	Value
Input Data Width	32 bits
CRC Width	8 bits
Polynomial	0x1D ($x^8 + x^4 + x^3 + x^2 + 1$)
Initial Value	0xFF
Final XOR Value	0x00
Reflect Input	No
Reflect Output	No
Example	CRC (0x00001280) = 0xAC

6.3 Periodic Measurement Mode

The MVT4000D sensors can also be configured to measure at regular intervals without user intervention, and the process to enable this mode is described in Section 6.5.2. In this mode, the user can read the latest temperature data by issuing a data fetch sequence, which consists of sending the MVT4000D I^{2}C address with a read bit. The sensor will then send the latest measurement result over the I^{2}C bus. The data fetch sequence is illustrated in Fig. 10.

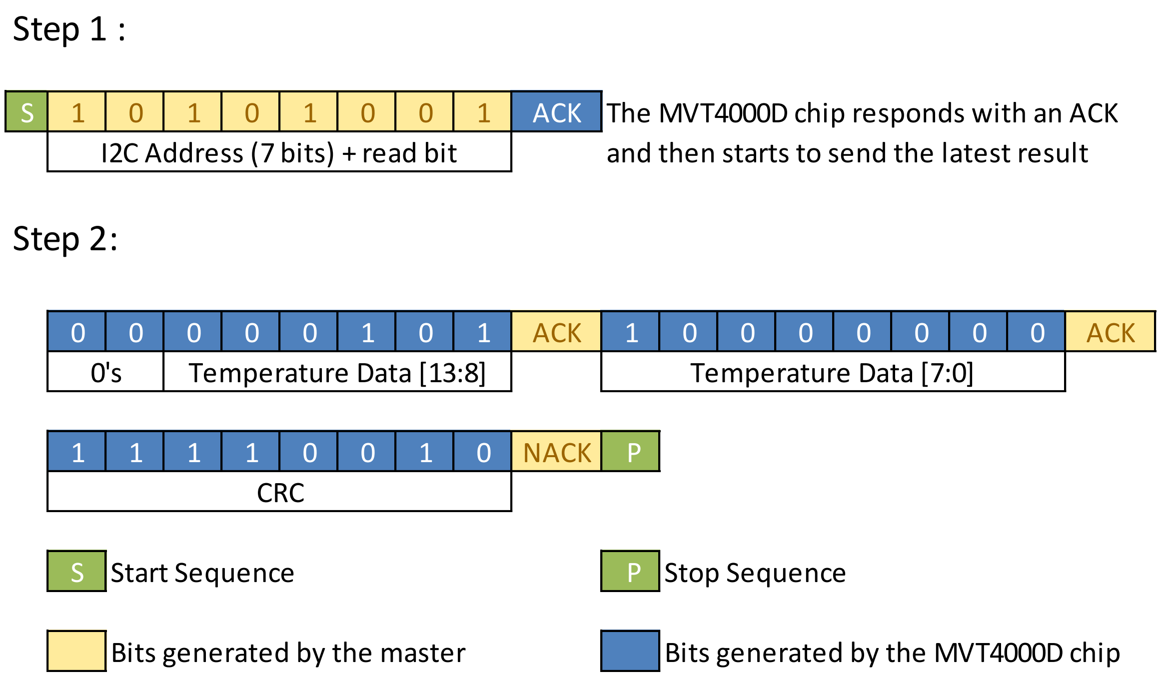

Fig. 10: Sequence to retrieve the latest results in periodic measurement mode.

The frequency of the periodic measurements can be set using the configuration registers. Section 6.4 describes how these registers are accessed, and Section 6.5.2 provides the register settings needed to configure and activate the periodic measurements.

When the periodic measurement mode is active, the only commands the chip will respond to are the data fetch command, and a command to stop the periodic measurements. The command to stop periodic measurements is issued by sending the I^{2}C address with a write bit, followed by the command 0x30, as shown in Fig. 11. Once the periodic measurements have been stopped, the chip returns to sleep and is ready to accept all valid I^{2}C commands.

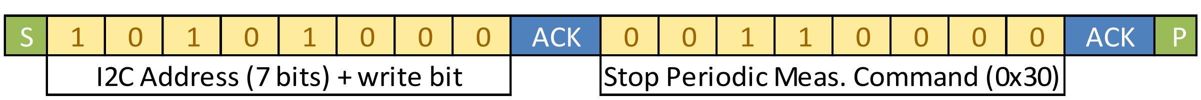

Fig. 11: Sequence to stop periodic measurements.

6.4 Accessing Configurable Sensor Registers

The MVT4000D measurement settings can be changed by accessing the appropriate configuration registers and altering their values. This can be done by issuing a Write Register command. A Read Register command is also available to read the configuration register values. These commands will be described in this section, and the configuration registers and settings will be described in Section 6.5.

While accessing specific configuration bits in any register, all the other bits in that register must be left unchanged. To write a specific bit/bits in a register, the process is as follows:

1. Read the entire configuration register using the sequence described in Section 6.4.1.
2. Mask the register such that only the required bits are changed, according to the configuration parameters in Section 6.5.
3. Write the new register back to the appropriate address using the Write Register command sequence described in Section 6.4.2.

All configuration registers will be reset to their default values if the power supply to the chip is cutoff.

6.4.1 Read Register Command

A Read Register sequence consists of the following steps, as illustrated in Fig. 12.

1. Wake up the MVT4000D series sensor from sleep mode by sending its I^{2}C address with a write bit, and initiate a Read Register command by sending the command 0xA7.
2. Send the address of the register to be read.
3. Change the direction of communication by sending the MVT4000D I^{2}C address and a read bit. The chip will send the data stored in this register, after which the master replies with a NACK and a STOP bit.

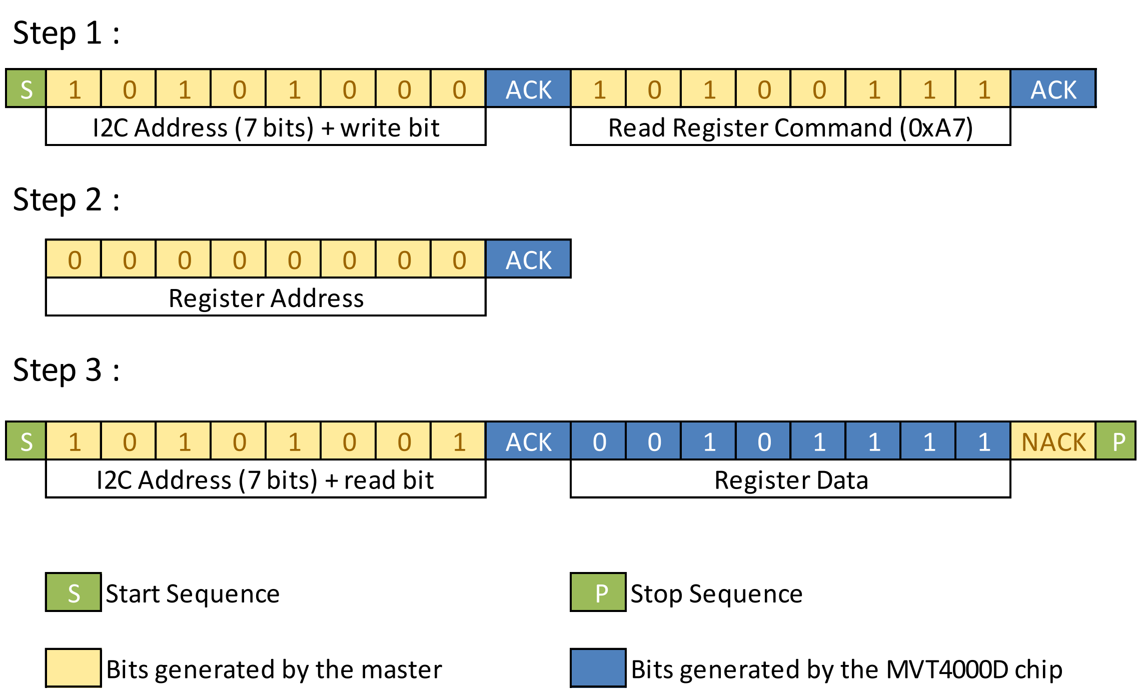

Fig. 12: Read Register command sequence.

6.4.2 Write Register Command

A Write Register sequence consists of the following steps, as illustrated in Fig. 13.

1. Wake up the MVT4000D series sensor from sleep mode by sending its I^2C address with a write bit, and initiate a Write Register command by sending the command 0xA6.
2. Send the address of the register to write.
3. Send the data to be stored in this register followed by a STOP bit.

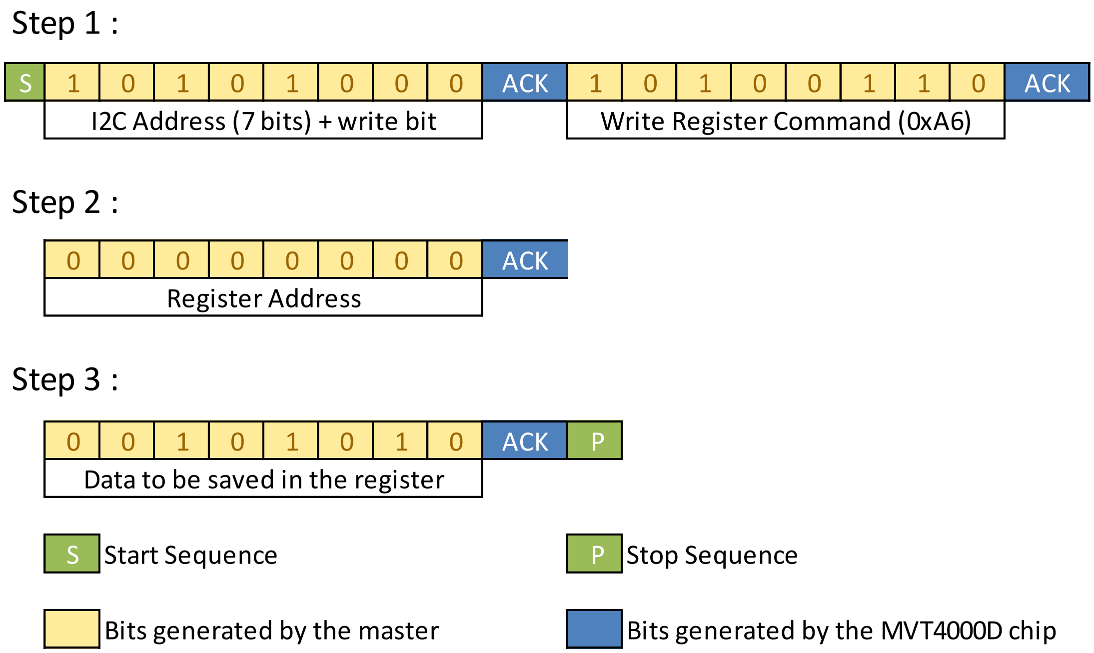

Fig. 13: Write Register command sequence.

6.5 Configuration Bits

6.5.1 Setting the Measurement Resolution

The chip can be configured to perform measurements at different temperature resolutions by using the Read and Write Register commands with the appropriate register address. There are four separate resolution settings for the temperature measurements, as summarized in Table 7.

Table 7: Temperature Measurement Resolution Settings.

Setting	Register Address (HEX)	Bits	Description
Resolution for temperature measurement	0x00	<1:0>	0b00 for 8 bits
			0b01 for 10 bits
			0b10 for 12 bits
			0b11 for 14 bits

6.5.2 Periodic Measurement Settings

The registers that are used to activate and configure the periodic measurement settings are shown in Table 8.

Table 8: Periodic Measurement Settings.

Setting	Register Address (HEX)	Bits	Description
Activate Periodic Measurements	0x02	<7>	0b0 when periodic measurements are deactivated
			0b1 to activate periodic measurements
Frequency of Periodic Measurements	0x02	<5:4>	0b00 for a measurement every 0.5 s
			0b01 for a measurement every 1 s
			0b10 for a measurement every 2.5 s

6.6 Reading the Sensor ID Number

The sensor ID is a 32-bit number that can be used to identify a given device. Each sensor has a unique ID that can be used for traceability. The sequence to read the sensor ID is as follows:

1. Wake up the MVT4000D series sensor from sleep mode by sending its I^2C address with a write bit, and initiate a Read Sensor ID command by sending the command 0xD7.
2. Change the direction of communication by sending the MVT4000D I^2C address and a read bit. The SCL line is held low by the sensor while it retrieves the ID from internal memory to prevent data corruption. The sensor takes approximately 10 µs to retrieve the ID from internal memory.
3. Once the request is completed by the MVT4000D series sensor, the SCL line is released and the chip waits for the SCL clock signal to send the results. The sensor will then transmit the 4-byte sensor ID on the bus for the master to capture, MSB first.

The command sequence to read the sensor ID is illustrated in Fig. 14.

Step 1 :

S	1	0	1	0	1	0	0	0	ACK	1	1	0	1	0	1	1	1	ACK
	I2C Address (7 bits) + write bit									Read Sensor ID Command (0xD7)								

Step 2 :

S	1	0	1	0	1	0	0	1	ACK
	I2C Address (7 bits) + read bit								

The MVT4000D chip reads the sensor ID from internal memory, and the SCL line is held low. This process takes ~10µs.

Step 3 :

0	0	0	0	0	1	0	1	ACK	1	0	0	0	0	0	0	0	ACK
Sensor ID [31:24]									Sensor ID [23:16]								

0	0	0	0	0	1	0	1	ACK	1	0	0	0	0	0	0	0	NACK	P
Sensor ID [15:8]									Sensor ID [7:0]									

S Start Sequence

P Stop Sequence

Bits generated by the master

Bits generated by the MVT4000D chip

Fig. 14: Read Sensor ID command sequence.

6.7 I²C Timing Specifications

The timing diagram for all I²C communications is shown in Fig. 15, and the minimum and maximum values for each critical timing parameter (e.g., setup times, hold times) are listed in Table 9.

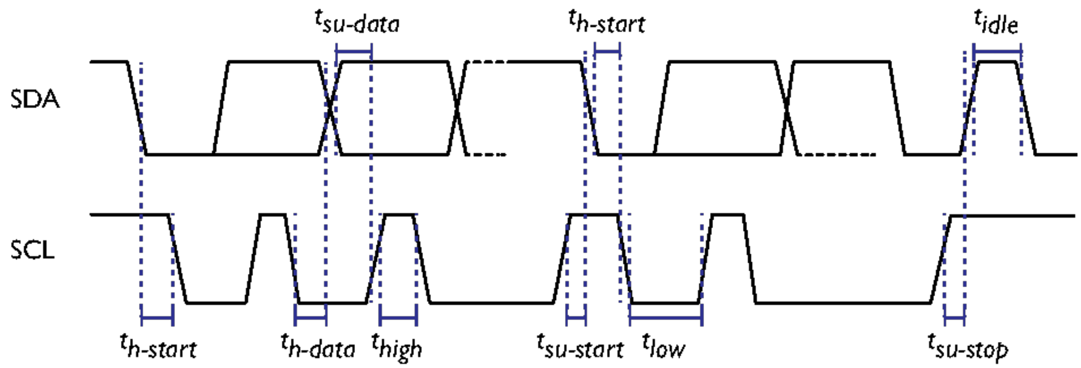

Fig. 15: I²C timing diagram.

Table 9: I²C Timing Parameters.

Parameter	Symbol	Min	Max	Units
SCL frequency	f_{SCL}	0	400	kHz
Start bit setup time	$t_{su\text{-}start}$	0.1		µs
Start bit hold time	$t_{h\text{-}start}$	0.1		µs
Minimum SCL low/high widths	t_{low} | t_{high}	0.6		µs
Data setup time	$t_{su\text{-}data}$	0.1		µs
Data hold time	$t_{h\text{-}data}$	0	0.5	µs
Stop bit setup time	$t_{su\text{-}stop}$	0.1		µs
SDA unused time between stop and start bits	t_{idle}	1		µs

7 Package and PCB Information

The MVT4000D series sensors are packaged in a 2.5 × 2.5 × 0.9 mm 8-pin dual-flat no-leads (DFN)-style LGA package.

7.1 Package Drawing

The mechanical drawing of the LGA package is shown in Fig. 16, and a suitable land pattern for soldering the sensor to a PCB is shown in Fig. 17.

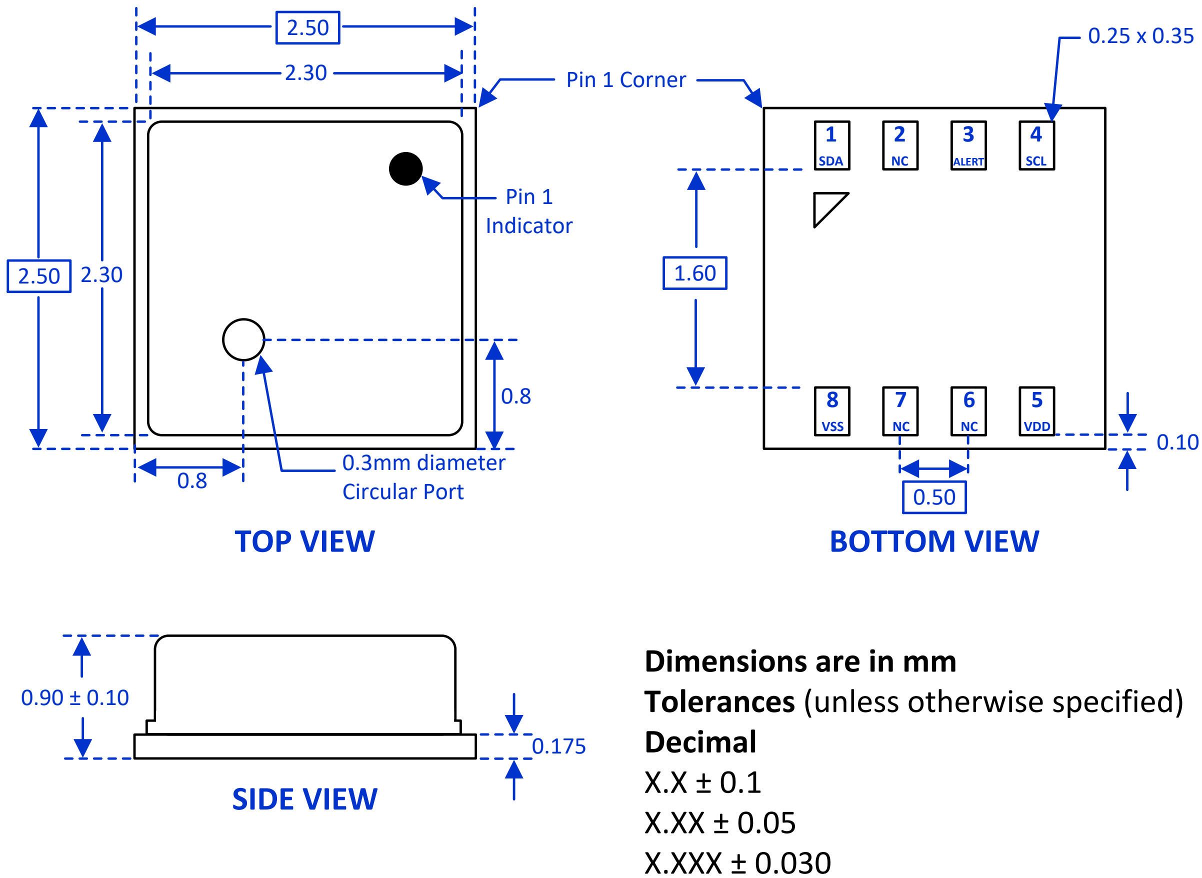

Fig. 16: LGA package drawing.

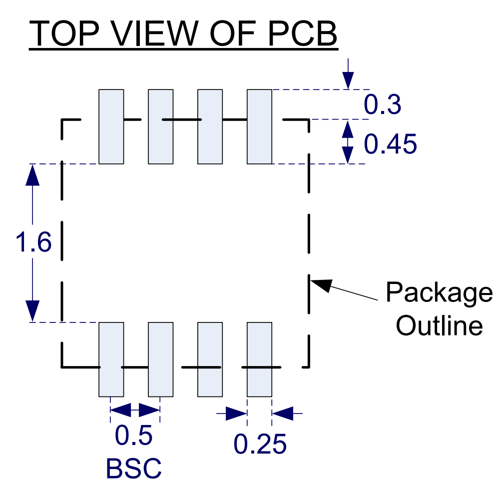

Fig. 17: LGA package land pattern (top view).

7.2 Tape and Reel Information

The MVT4000D series sensors are shipped in tape and reel packaging and enclosed in sealed anti-static bags. Standard packaging sizes are 400, 1500, and 2500 units (please contact MEMS Vision for other volumes). The tape has a 406.4mm leader (102 pockets) and a 165.1mm trailer (42 pockets). A drawing of the packaging tape is shown in Fig. 18, which also shows the sensor orientation.

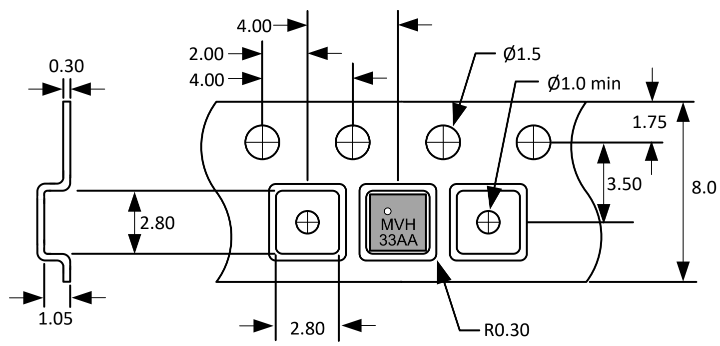

Fig. 18: Packaging tape drawing.

7.3 Soldering Information

Standard reflow ovens can be used to solder the MVT4000D series sensor to the PCB. The peak temperature (T_p) for use with the JEDEC J-STD-020D standard soldering profile is 260°C. For manual soldering, the contact time must be limited to 5 seconds at up to 350°C. In either case, if solder paste is used, it is recommended to use 'no-clean' solder paste to avoid the need to wash the PCB.

Note that reflow soldering is recommended for optimal performance. The recommended lead-free (RoHS compliant) reflow soldering profile is shown in Fig. 19.

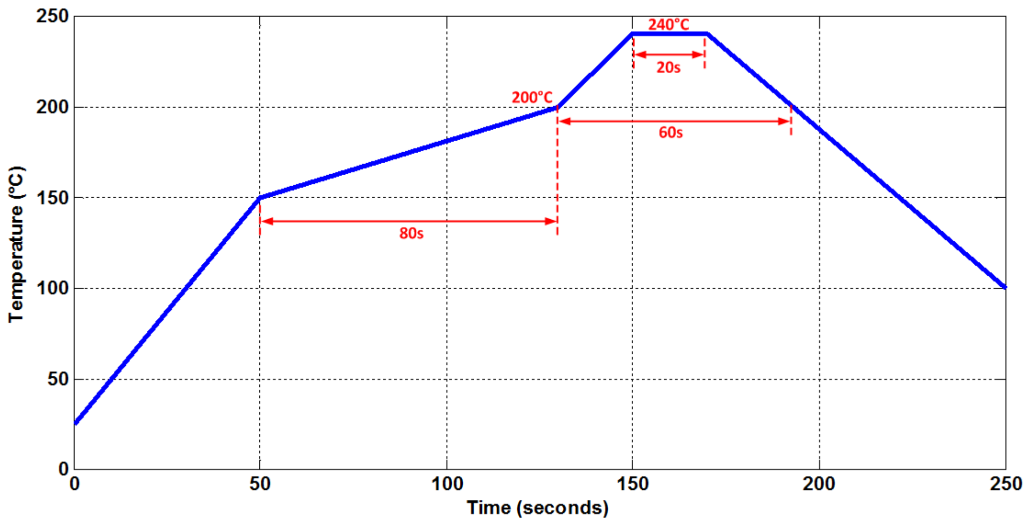

Fig. 19: Recommended lead-free soldering profile

7.4 PCB Layout Considerations

When designing the PCB, undesired heat transfer paths to the MVT4000D series chip must be minimized. Excessive heat from other components on the PCB will result in inaccurate temperature measurements. As such, ***solid metal planes for power supplies should be avoided in the vicinity of the sensor*** since these will act as thermal conductors. To further reduce the heat transfer from other components on the board, openings can be milled into the PCB as shown in Fig. 20.

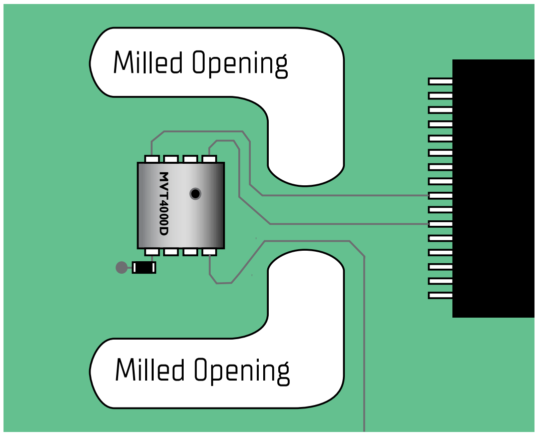

Fig. 20: Thermal isolation of sensor using milled PCB openings.

8 Storage and Handling Information

Once the sensors are removed from their original packaging, it is recommended to store them in metal-in antistatic bags. The nominal storage conditions for the MVT4000D series chip are at temperatures in the range of 10 to 50°C and at humidity levels within the range of 20% to 60% RH.