

# Ultra-Low Pressure Digital Sensor

SM9541 Series



## Features

- Fully digital, pressure calibrated and temperature compensated output
- I<sup>2</sup>C Digital Interface
- Compensated temperature range: -5 to 65°C
- Compound gage and differential pressure configurations
- Insensitive to mounting orientation
- Robust JEDEC SOIC-16 package for automated assembly
- Manufactured according to ISO9001 and ISO/TS 16949 standards
- RoHS & REACH compliant
- Pressure ranges from 10 cm\*H<sub>2</sub>O to 140 cm\*H<sub>2</sub>O (0.14 to 2 PSI)

## Description

The SM9541 Series is a digital, low pressure MEMS sensor family offering state-of-the-art pressure transducer technology and CMOS mixed signal processing technology to produce a digital, fully conditioned, multi-order pressure and temperature compensated sensor in JEDEC standard SOIC-16 package with a dual vertical porting option. It is available in both compound gage or differential pressure configurations. With the dual porting, a vacuum-gage measurement is possible to minimize altitude errors due to changes in ambient pressure.

Combining the pressure sensor with a signal-conditioning ASIC in a single package simplifies the use of advanced silicon micro-machined pressure sensors. The pressure sensor can be mounted directly on a standard printed circuit board and a high level, calibrated pressure signal can be acquired from the digital interface. This eliminates the need for additional circuitry, such as a compensation network or microcontroller containing a custom correction algorithm.

The SM9541 is shipped in sticks or tape & reel.

## Potential Applications

| Medical                         | Industrial               | Consumer         |
|---------------------------------|--------------------------|------------------|
| Sleep Apnea                     | Airflow Measurement      | Sports Equipment |
| CPAP                            | Pneumatic Gages          | Appliances       |
| Ventilators                     | Pressure Switches        |                  |
| Oxygenators                     | Safety Cabinets          |                  |
| Negative Pressure Wound Therapy | Life Sciences            |                  |
| Air Flow Monitors               | Gas Flow Instrumentation |                  |
| Gas Flow Instrumentation        | Liquid Level Measurement |                  |

## Absolute Maximum Ratings

All parameters are specified at V<sub>DD</sub> = 3.3 V supply voltage at 25°C, unless otherwise noted.

| No. | Characteristic            | Symbol           | Minimum | Typical | Maximum | Units |
|-----|---------------------------|------------------|---------|---------|---------|-------|
| 1   | Supply Voltage            | V <sub>DD</sub>  | 0.0     |         | 6.0     | V     |
| 2   | Supply Current            | I <sub>DD</sub>  | 0.0     | 2.0     | 4.0     | mA    |
| 3   | Update Period             |                  |         |         | 2       | ms    |
| 4   | Operating Temperature (a) | T <sub>OP</sub>  | -5      | 32      | +65     | °C    |
| 5   | Storage Temperature (a)   | T <sub>STG</sub> | -40     | -       | +125    | °C    |
| 6   | Media Compatibility (a,b) |                  |         |         |         |       |

### Notes:

a. Tested on a sample basis.

b. Clean, dry gas compatible with wetted materials. Wetted materials include Pyrex glass, silicon, alumina ceramic, epoxy, RTV, gold, aluminum, and nickel.

| No. | Product Number      | Operating Pressure             | Proof Pressure (P <sub>PROOF</sub> ) <sup>(a)</sup> | Burst Pressure (P <sub>BURST</sub> ) <sup>(a)</sup> |
|-----|---------------------|--------------------------------|---|---|
| 7   | SM9541-010C-S-C-3-S | -0.5 to 10 cmH <sub>2</sub> O  | ±1.5 PSI  | ±3.0 PSI  |
| 8   | SM9541-010C-D-C-3-S | -10 to 10 cmH <sub>2</sub> O   |   |   |
| 9   | SM9541-020C-S-C-3-S | -1 to 20 cmH <sub>2</sub> O    | ±4.8 PSI  | ±6.0 PSI  |
| 10  | SM9541-020C-D-C-3-S | -20 to 20 cmH <sub>2</sub> O   |   |   |
| 11  | SM9541-040C-S-C-3-S | -5 to 40 cmH <sub>2</sub> O    |   |   |
| 12  | SM9541-040C-D-C-3-S | -40 to 40 cmH <sub>2</sub> O   |   |   |
| 13  | SM9541-100C-S-C-3-S | -5 to 100 cmH <sub>2</sub> O   | ±12 PSI   | ±15 PSI   |
| 14  | SM9541-100C-D-C-3-S | -100 to 100 cmH <sub>2</sub> O |   |   |
| 15  | SM9541-140C-S-C-3-S | -20 to 140 cmH <sub>2</sub> O  |   |   |

## Operating Characteristics - Specifications

All parameters are specified at V<sub>DD</sub> = 3.3 V DC supply voltage at 25°C, unless otherwise noted.

| Compound Gage |  |                    |         |         |         |        |
|---------------|--|--------------------|---------|---------|---------|--------|
| No.           | Characteristic                                   | Symbol             | Minimum | Typical | Maximum | Units  |
| 16            | Supply Voltage                                   | V <sub>DD</sub>    | 3.0     | 3.3     | 3.6     | V      |
| 17            | Pressure Output @ P <sub>MIN</sub>               | Out <sub>MIN</sub> |         | 1,638   |         | Counts |
| 18            | Pressure Output @ P <sub>MAX</sub>               | Out <sub>MAX</sub> |         | 14,745  |         | Counts |
| 19            | Full Scale (-0.5 to 10 cmH <sub>2</sub> O) Span  | FSP                |         | 13,107  |         | Counts |
| 20            | Full Scale (-1 to 20 cmH <sub>2</sub> O) Span    |                    |         |         |         |        |
| 21            | Full Scale (-5 to 40 cmH <sub>2</sub> O) Span    |                    |         |         |         |        |
| 22            | Full Scale (-5 to 100 cmH <sub>2</sub> O) Span   |                    |         |         |         |        |
| 23            | Full Scale (-20 to +140 cmH <sub>2</sub> O) Span |                    |         |         |         |        |
| 24            | Resolution                                       |                    |         | 14      |         | Bits   |
| 25            | Accuracy (c,d)                                   | ACC                | -1      |         | +1      | %FS    |
| 26            | Compensated Temperature Range                    | T <sub>COMP</sub>  | -5      |         | +65     | °C     |

### Notes:

c. The accuracy specification applies over all operating conditions. This specification includes the combination of linearity, repeatability, and hysteresis errors over pressure, temperature, and voltage.

d. Maximum 10-year zero pressure offset shift < ±2%FS based on 1000 hours of HTOL testing.

## Operating Characteristics - Specifications

All parameters are specified at  $V_{SUPPLY} = 3.3$  V DC supply voltage at 25°C, unless otherwise noted.

| Differential |  |             |         |         |         |        |
|--------------|--|-------------|---------|---------|---------|--------|
| No.          | Characteristic                                   | Symbol      | Minimum | Typical | Maximum | Units  |
| 27           | Supply Voltage                                   | $V_{DD}$    | 3.0     | 3.3     | 3.6     | V      |
| 28           | Pressure Output @ $P_{MIN}$                      | $OUT_{MIN}$ |         | 1,638   |         | Counts |
| 29           | Pressure Output @ $P_{MAX}$                      | $OUT_{MAX}$ |         | 14,745  |         | Counts |
| 30           | Full Scale (-10 to 10 cmH <sub>2</sub> O) Span   | FSP         |         | 13,107  |         | Counts |
| 31           | Full Scale (-20 to 20 cmH <sub>2</sub> O) Span   |             |         |         |         |        |
| 32           | Full Scale (-40 to 40 cmH <sub>2</sub> O) Span   |             |         |         |         |        |
| 33           | Full Scale (-100 to 100 cmH <sub>2</sub> O) Span |             |         |         |         |        |
| 34           | Resolution                                       |             |         | 14      |         | Bits   |
| 35           | Accuracy <sup>(d,e)</sup>                        | ACC         | -1      |         | +1      | %FS    |
| 36           | Compensated Temperature Range                    | $T_{COMP}$  | -5      |         | +65     | °C     |

### Notes:

d. Maximum 10-year zero pressure offset shift < ±2%FS based on 1000 hours of HTOL testing.

e. The accuracy specification applies over all operating conditions. This specification includes the combination of linearity, repeatability, and hysteresis errors over pressure, temperature, and voltage.

## Qualification Standards

- REACH Compliant
- RoHS Compliant
- PFOS/PFOA Compliant
- For qualification specifications, please contact Sales at [sales@si-micro.com](mailto:sales@si-micro.com)



## SM9541 – I<sup>2</sup>C Communication

### 1. SCL Clock frequency:

100kHz to 400kHz

### 2. Slave Address

- The factory setting for the I<sup>2</sup>C slave address is 28HEX. The part will only respond to the set address.

### 3. Read Operations

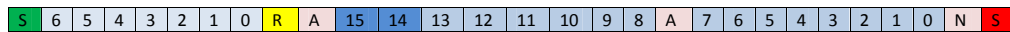
- For read operations, the I<sup>2</sup>C master command starts with the 7-bit slave address with the 8th bit = 1 (READ). The SM9541 as the slave sends an acknowledge (ACK) indicating success.
- The SM9541 has four I<sup>2</sup>C read commands: Read\_DF2, Read\_DF3, and Read\_DF4. The following figures show the structure of the measurement packet for three of the four I<sup>2</sup>C read commands, which are further explained below.

#### 3.1 I<sup>2</sup>C Read\_DF (Data Fetch):

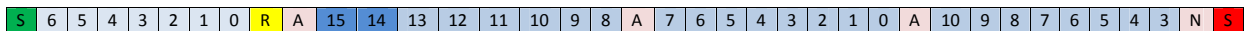
- For the Data Fetch commands, the number of data bytes returned by the SM9541 is determined by when the master sends the NACK and stop condition.

- For the Read\_DF3 data fetch command (Data Fetch 3 Bytes), the SM9541 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 Read\_DF2 command is used if corrected temperature is not required. The master terminates the READ operation after the two bytes of bridge data.

- I2C Read\_DF2 – Data Fetch 2 Bytes:
  - Slave returns only pressure data to the master in 2 bytes.
  - Start Condition – Device Slave Address [6:0] – Read/Write Bit (Read = 1) – Wait for Slave ACK – 2 status bits – 6 pressure bits [13:8] – Master ACK – 8 pressure bits [7:0] – Master NACK – Stop Condition

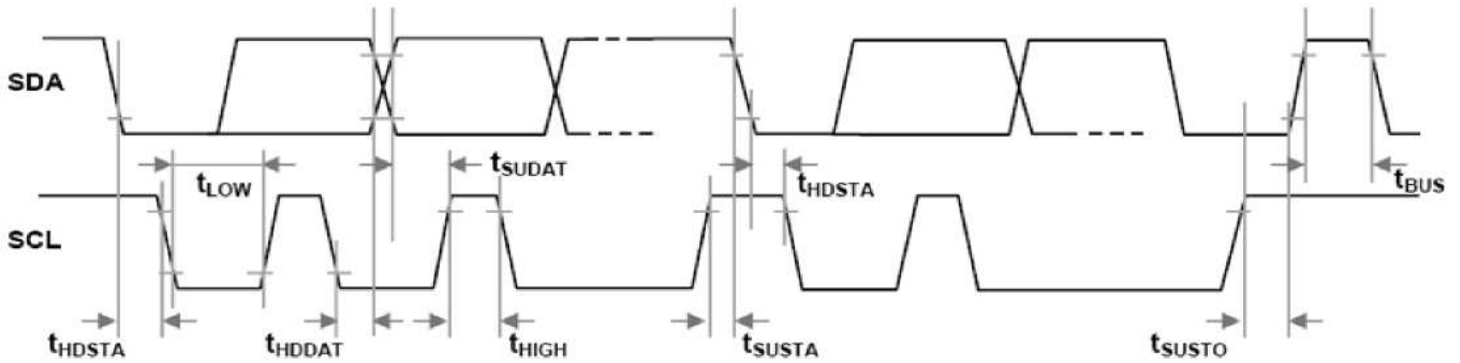


- I2C Read\_DF3 – Data Fetch 3 Bytes:
  - Slave returns 2 pressure data bytes and temperature high byte [10:3] to the master.
  - Start Condition – Device Slave Address [6:0] – Read/Write Bit (Read = 1) – Wait for Slave ACK – 2 status bits – 6 pressure bits [13:8] – Master ACK – 8 pressure bits [7:0] – Master ACK – 8 temperature bits [10:3] – Master NACK – Stop Condition



- I2C Read\_DF4 – Data Fetch 4 Bytes:
  - Slave returns 2 pressure data bytes and and 2 temperature bytes ([10:3] and [2:0]xxxxx) to the master.
  - Start Condition – Device Slave Address [6:0] – Read/Write Bit (Read = 1) – Wait for Slave ACK – 2 status bits – 6 pressure bits [13:8] – Master ACK – 8 pressure bits [7:0] – Master ACK – 8 temperature bits [10:3] – Master ACK – 3 temperature bits [2:0] – Master NACK – Stop Condition



I<sup>2</sup>C Timing


| 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 |     |     | $\mu$ s |
| Minimum SCL Clock Low Width <sup>1</sup>                 | $t_{LOW}$   | 0.6 |     |     | $\mu$ s |
| Minimum SCL Clock High Width <sup>1</sup>                | $t_{HIGH}$  | 0.6 |     |     | $\mu$ s |
| Start Condition Hold Time Relative to SCL Edge           | $t_{SUSTA}$ | 0.1 |     |     | $\mu$ s |
| Data Hold Time on SDA Relative to SCL Edge               | $t_{HDDAT}$ | 0.0 |     |     | $\mu$ s |
| Data Setup Time on SDA Relative to SCL Edge              | $t_{SUDAT}$ | 0.1 |     |     | $\mu$ s |
| Stop Condition Setup Time on SCL                         | $t_{SUSTO}$ | 0.1 |     |     | $\mu$ s |
| Bus Free Time Between Stop Condition and Start Condition | $t_{BUS}$   | 2.0 |     |     | $\mu$ s |

### 5. Differences SM9541 I<sup>2</sup>C Protocol vs. Original I<sup>2</sup>C protocol

- **Note: There are three differences in the SM9541 protocol compared with the original I<sup>2</sup>C protocol**
- Sending a start-stop condition without any transitions on the CLK line (no clock pulses in between) created 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 failing SDA edge is not allowed between the start condition and the first rising SCL edge. If using an I<sup>2</sup>C address with the first bit 0, SDA must be held low from the start condition through the first bit.

### 6. Diagnostic Features – Status Bits

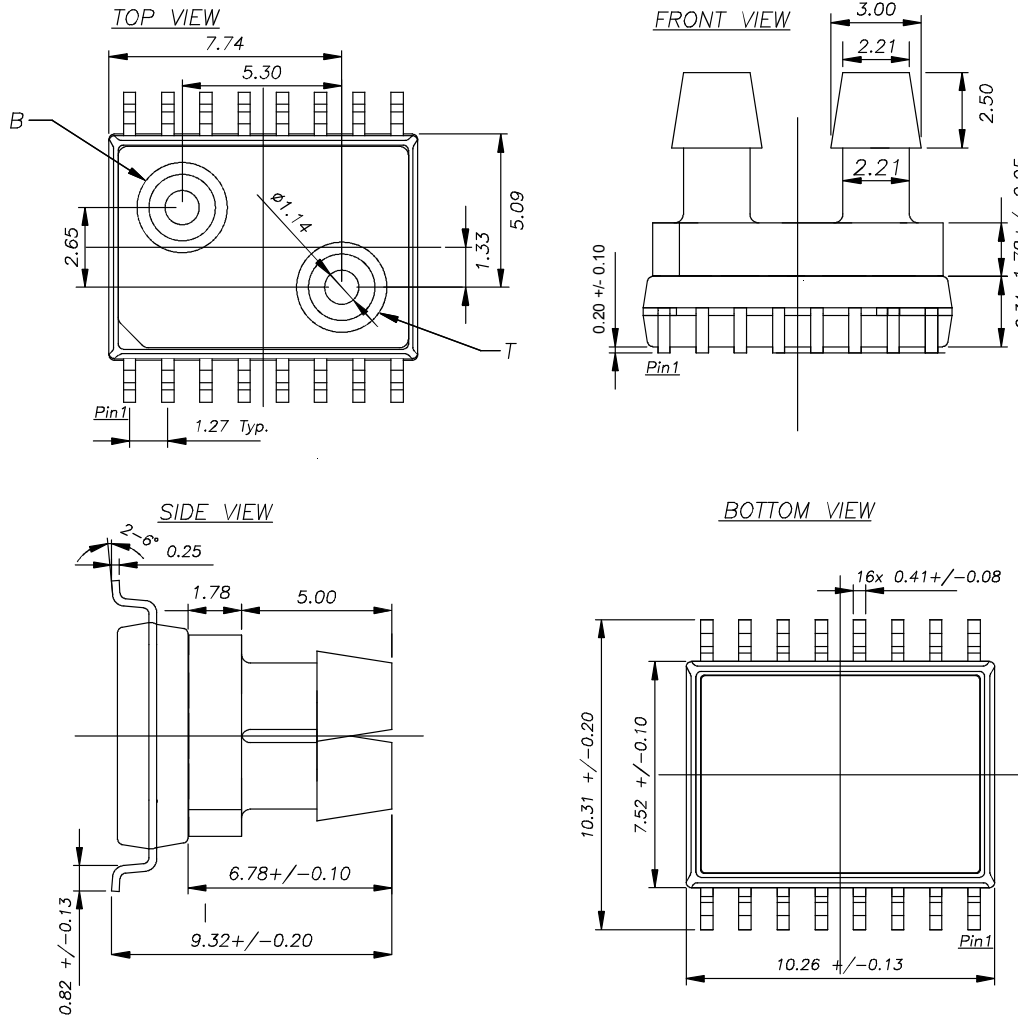
- The SM9541 offers diagnostic features to ensure robust system operation. The diagnostic states are indicated by a transmission of the status of the 2 MSBs of the pressure high byte data.

| Status Bits (2 MSBs of Output Packet) | Symbol  |
|---------------------------------------|---|
| 00                                    | Normal operation, good data packet (not applicable)                             |
| 01                                    | Device in Command Mode (not applicable for normal operation)                    |
| 10 <sup>(1)</sup>                     | Stale data: Data that has already been fetched since the last measurement cycle |
| 11                                    | Diagnostic condition exists   |

Note<sup>(1)</sup>: If a data fetch is performed before or during the first measurement after power-on reset, then “stale” will be returned, but this data is actually invalid because the first measurement has not been completed.

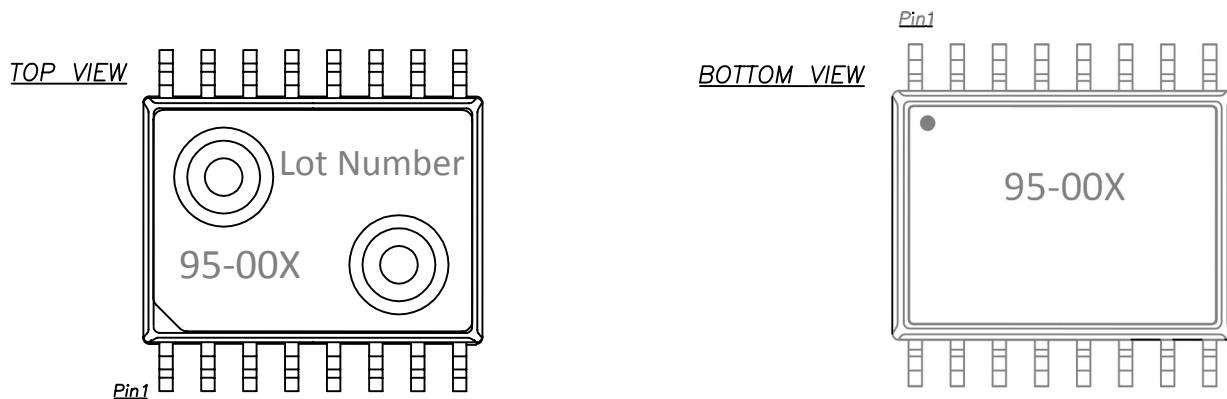
- When the two MSBs are 11, one of the following faults listed below is indicated:
  - Invalid EEPROM signature
  - Loss of bridge positive or negative
  - Bridge input short
  - Loss of bridge source
- All diagnostics are detected in the next measurement cycle and reported in the subsequent data fetch. Once a diagnostic is reported, the diagnostic status bits will not change unless both the cause of the diagnostic is fixed and a power-on-reset is performed.

## SOIC-16 Package Dimensions



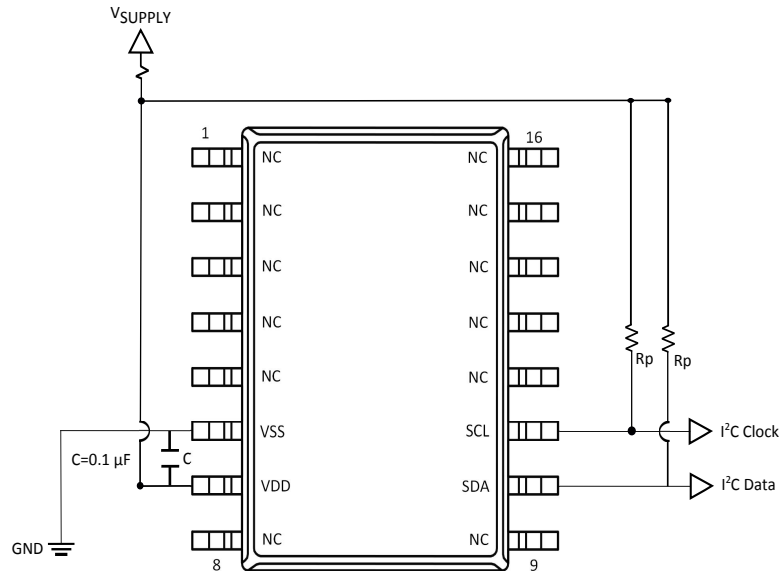
- All dimensions in units of [mm]
- Moisture Sensitivity Level (MSL): Level 3
- Wetted materials: Silicon, glass, copper, silicone, epoxy, mold compound.
- Tolerance on all dimensions  $\pm 0.13$  mm unless otherwise specified.
- [B] is tube connected to bottom side of sensor die.
- [T] is tube connected to top side of sensor die. Topside pressure is positive pressure. An increase in topside pressure will result in an increase in sensor output

## Part & Lot Number Identification





SM9541 + Family Applications Circuit



"C" needs to be in close proximity of the device

$R_p$  = Pull-up Resistors  
 For Example: 4.7 k $\Omega$  Resistors

Package Labeling

| Pin Number | Pin Function    |
|------------|-----------------|
| 1          | NC (No Connect) |
| 2          | NC              |
| 3          | NC              |
| 4          | NC              |
| 5          | NC              |
| 6          | VSS             |
| 7          | VDD             |
| 8          | NC              |
| 9          | NC              |
| 10         | SDA             |
| 11         | SCL             |
| 12         | NC              |
| 13         | NC              |
| 14         | NC              |
| 15         | NC              |
| 16         | NC              |

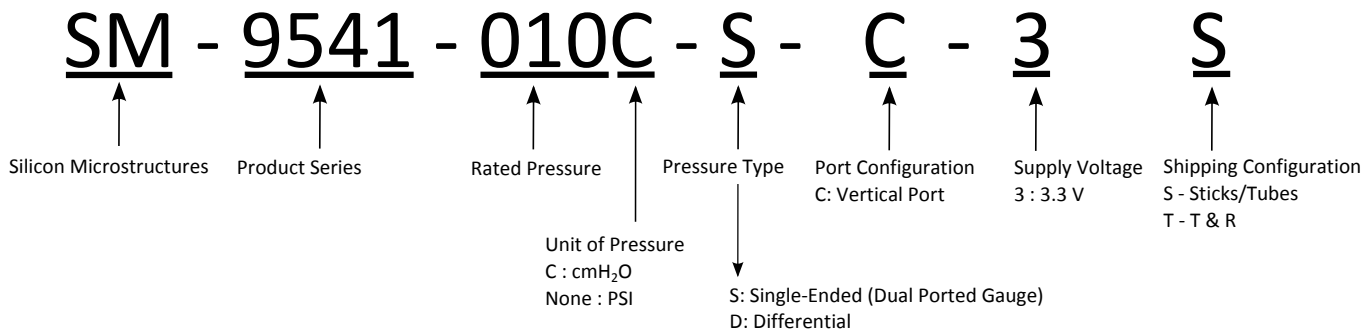
NOTES:

- Do not make electrical connections to NC pins as this can adversely affect the output of the sensor

## Ordering Information

| Order Code          | Part Marking | Negative Pressure Range | Positive Pressure Range | Pressure Type  | Tube Configuration | Shipping Method      |
|---------------------|--------------|-------------------------|-------------------------|----------------|--------------------|----------------------|
| SM9541-010C-S-C-3-S | 95 - 001     | -0.5 cmH <sub>2</sub> O | 10 cmH <sub>2</sub> O   | Compound Gauge | Dual Vertical      | 45 Units (per stick) |
| SM9541-010C-D-C-3-S | 95 - 001     | -10 cmH <sub>2</sub> O  | 10 cmH <sub>2</sub> O   | Differential   |                    |                      |
| SM9541-020C-S-C-3-S | 95 - 002     | -1 cmH <sub>2</sub> O   | 20 cmH <sub>2</sub> O   | Compound Gauge |                    |                      |
| SM9541-020C-D-C-3-S | 95 - 002     | -20 cmH <sub>2</sub> O  | 20 cmH <sub>2</sub> O   | Differential   |                    |                      |
| SM9541-040C-S-C-3-S | 95 - 002     | -5 cmH <sub>2</sub> O   | 40 cmH <sub>2</sub> O   | Compound Gauge |                    |                      |
| SM9541-040C-D-C-3-S | 95 - 002     | -40 cmH <sub>2</sub> O  | 40 cmH <sub>2</sub> O   | Differential   |                    |                      |
| SM9541-100C-S-C-3-S | 95 - 003     | -5 cmH <sub>2</sub> O   | 100 cmH <sub>2</sub> O  | Compound Gauge |                    |                      |
| SM9541-100C-D-C-3-S | 95 - 003     | -100 cmH <sub>2</sub> O | 100 cmH <sub>2</sub> O  | Differential   |                    |                      |
| SM9541-140C-S-C-3-S | 95 - 003     | -20 cmH <sub>2</sub> O  | 140 cmH <sub>2</sub> O  | Compound Gauge |                    |                      |

## Part Number Legend:



## Pressure Conversion Chart

| Unit                | 10 cmH <sub>2</sub> O | 20 cmH <sub>2</sub> O | 40 cmH <sub>2</sub> O | 100 cmH <sub>2</sub> O | 140 cmH <sub>2</sub> O |
|---------------------|-----------------------|-----------------------|-----------------------|------------------------|------------------------|
| PSI                 | 0.14                  | 0.3                   | 0.6                   | 1.4                    | 2.0                    |
| kPa                 | 1                     | 2                     | 4                     | 10                     | 14                     |
| mbar                | 10                    | 20                    | 39                    | 98                     | 137                    |
| bar                 | 0.01                  | 0.02                  | 0.04                  | 0.10                   | 0.14                   |
| in*H <sub>2</sub> O | 4                     | 8                     | 16                    | 39                     | 55                     |
| mm*Hg               | 7.4                   | 15                    | 29                    | 74                     | 103                    |
| hPa                 | 10                    | 20                    | 39                    | 98                     | 137                    |
| in*Hg               | 0.29                  | 0.58                  | 1.16                  | 2.9                    | 4.0                    |
| Pa                  | 981                   | 1,961                 | 3,923                 | 9,807                  | 13,729                 |

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