

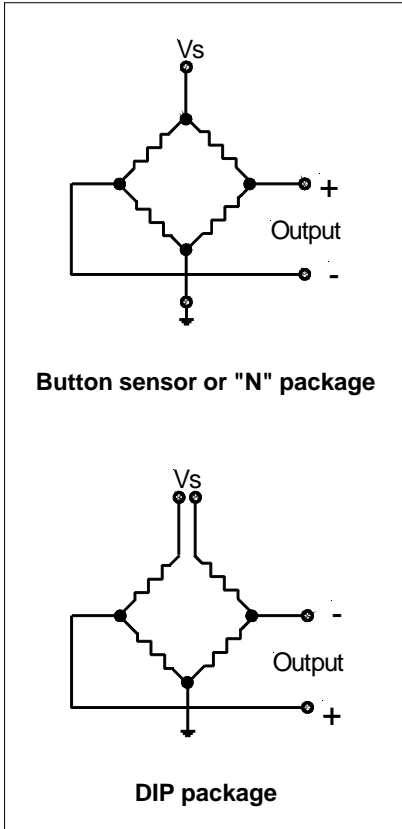
## FEATURES

- 0...1 to 0...150 psi
- Absolute, differential and gage devices
- High impedance bridge
- Low power consumption for battery operation

## APPLICATIONS

- Industrial controls
- Pneumatic controls
- Medical instrumentation
- Barometry

## EQUIVALENT CIRCUIT

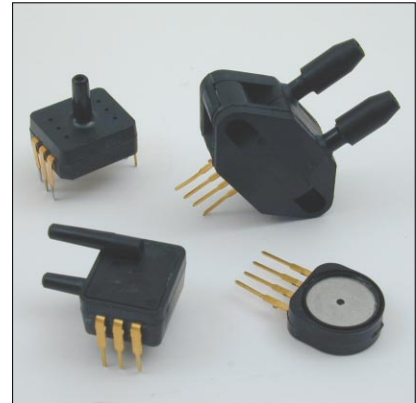


## GENERAL DESCRIPTION

The SX series of pressure sensors provides the most cost effective method of measuring pressures up to 150 psi. These sensors were specifically designed to be used with non-corrosive and non-ionic media, such as air and dry gases. Convenient pressure ranges are available to measure differential, gage and absolute pressures from 0 to 1 psi up to 0 to 150 psi.

The absolute (A) devices have an internal vacuum reference and an output voltage proportional to absolute pressure. The differential (D) devices allow application of pressure to either side of the diaphragm and can be used for gage or differential pressure measurements.

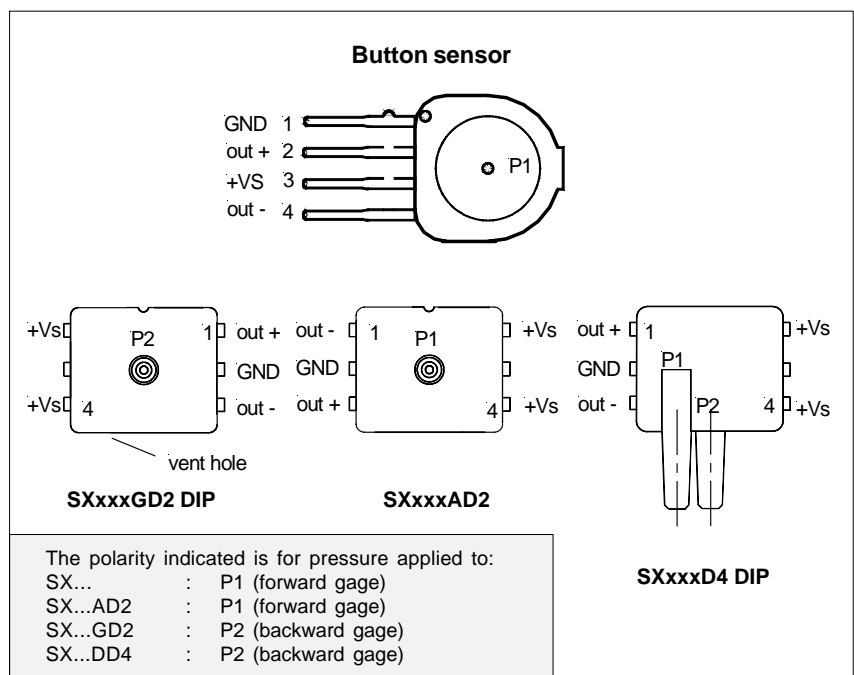
This product is packaged either in SenSym's standard low cost chip carrier "button" package, a plastic ported "N" package or a dual inline package (DIP). All packages are designed for applications where the sensing element is to be integral to the OEM equipment. These packages



can be o-ring sealed, epoxied, and/or clamped onto a pressure fitting. A closed bridge 4-pin SIP configuration is provided for electrical connection to the button or "N" package.

Because of its high-impedance bridge, the SX series is ideal for portable and low power or battery operated systems. Due to its low noise, the SX is an excellent choice for medical and low pressure measurements.

## ELECTRICAL CONNECTION



**PRESSURE SENSOR CHARACTERISTICS**

( $V_s = 5.0 \pm 0.01$  V,  $t_{amb} = 25$  °C, common-mode pressure = 0 psig, pressure applied to **P1** for Button, N and A2 housings, pressure applied to **P2** for G2 and D4 housings)

**Maximum ratings**

Supply voltage, $V_s$	+12 $V_{DC}$	Maximum pressure at any port <sup>11</sup>	150 psig
Temperature ranges		Lead temperature (soldering 4 sec.)	250 °C
Operating	-40°C to +85°C		
Storage	-55°C to +125°C		

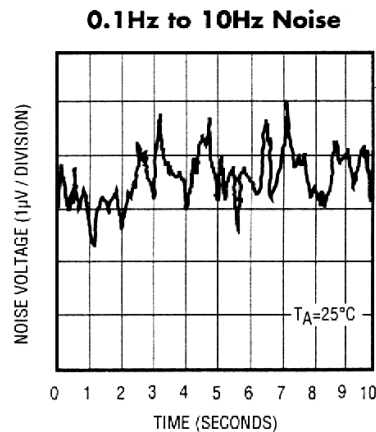
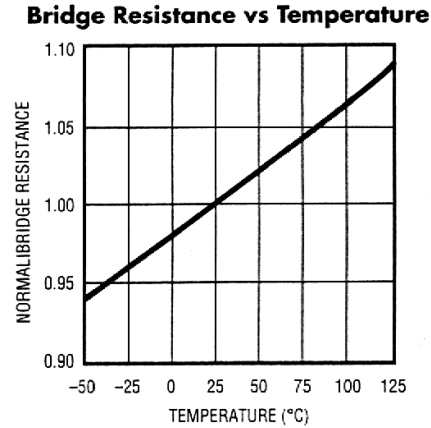
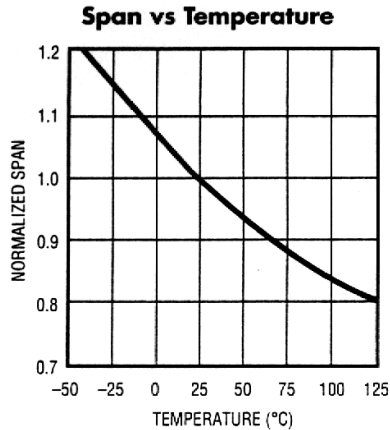
Part number	Operating pressure	Proof pressure <sup>8</sup>	Full-scale span <sup>1</sup>		
			Min.	Typ.	Max.
SX01...	0...1 psi	20 psi	15 mV	20 mV	25 mV
SX05...	0...5 psi	20 psi	50 mV	75 mV	100 mV
SX15...	0...15 psi	30 psi	75 mV	110 mV	150 mV
SX30...	0...30 psi	60 psi	75 mV	110 mV	150 mV
SX100...	0...100 psi	150 psi	100 mV	150 mV	200 mV
SX150...	0...150 psi	200 psi	75 mV	110 mV	150 mV

**PERFORMANCE CHARACTERISTICS**

( $V_s = 5.0 \pm 0.01$  V,  $t_{amb} = 25$  °C, common-mode pressure = 0 psig, pressure applied to **P1** for Button, N and A2 housings, pressure applied to **P2** for G2 and D4 housings)

Characteristics	Min.	Typ.	Max.	Unit	
Zero pressure offset <sup>9</sup>	-35	-20	0	mV	
Temperature effects (0 to 70 °C) <sup>4,7</sup>	Offset	±4		µV/V/°C	
	Span	-2550	-2150	-1900	ppm/°C
	Bridge impedance	+690	+750	+810	
Combined linearity and hysteresis <sup>2</sup>		±0.2	±0.5	%FSS	
Repeatability <sup>3</sup>		±0.5			
Long term stability of offset and span <sup>6</sup>		±0.1		mV	
Input impedance		4.1		kΩ	
Output impedance		4.1			
Response time <sup>5</sup>		0.1		ms	

## TYPICAL PERFORMANCE CHARACTERISTICS



### Specification notes:

- Span is the algebraic difference between the output voltage at full-scale pressure and the output at zero pressure.
- Hysteresis is the maximum output difference at any point within the operating pressure range for increasing and decreasing pressure. Linearity is the maximum deviation of measure output at constant temperature (25°C) from "Best Straight Line" determined by three points, offset, full scale pressure and half full scale pressure.
- Maximum difference in output at any pressure with the operating pressure range and temperature within 0°C to +70°C after:
  - 100 temperature cycles, 0°C to +70°C
  - 1.0 million pressure cycles, 0 psi to full scale span
- Slope of the best straight line from 0°C and 70°C. For operation outside this temperature, contact Sensortronics for more specific applications information.
- Response time for a 0 to full-scale span pressure step change.
- Long term stability over a one year period .
- This parameter is not 100 % tested. It is guaranteed by process design and tested on a sample basis only.
- If the proof pressure is exceeded, even momentarily, the package may leak or burst, or the pressure sensing die may fracture.  
Note: The proof pressure for the forward gage of all devices in the D4-package is the specified value or 100 psi, whatever is less.
- The zero pressure offset is 0 mV Min, 20 mV Typ and 35 mV Max for part nos. SX...G2 and SX...D4.

### MECHANICAL AND MOUNTING CONSIDERATIONS

#### Button sensor element

The button sensor element was designed to allow easy interface with additional cases and housings which then allow pressure connection. The device can be mounted with an o-ring, gasket, or RTV seals on one or both sides of the device. The device can then be glued or clamped into a variety of fixtures and the leads can be bent as necessary to allow for ease of electrical connection. However, caution is advised as repeated bending of the leads will cause eventual breakage.

For most gage applications, pressure should be applied to the top side of the device (see Physical Construction Drawing). For differential applications, the top side of the device (P1) should be used as the high pressure port and the bottom (P2) as the low pressure port.

The button SX package has a very small internal volume of 0.06 cubic centimeters for P1 and 0.001 cubic centimeters for P2.

#### "N" packaged sensor

The "N" packaged sensor is designed for convenient pressure connection and easy PC board mounting. To mount the device horizontally to a PC board, the leads can be bent downward and the package attached to the board using either tie wraps or mounting screws. For pressure attachment, tygon or silicon tubing is recommended.

The "N" package version of the sensor has two (2) tubes available for pressure connection. For gage devices, pressure should be applied to port P1. For differential pressure applications, port P1 should be used as the high pressure port and P2 should be used as the low pressure port.

#### GENERAL DISCUSSION

##### Output characteristics

The SX series devices give a voltage output which is directly proportional to applied pressure. The devices will give an increase in positive going output when increasing pressure is applied to pressure port P1 of the device. If the devices are operated in the backward gage mode, the output will increase with decreases in pressure. The devices are ratiometric to the supply voltage. Changes in supply voltage will cause proportional changes in the offset voltage and full-scale span.

##### User calibration

SX series devices feature the button IC pressure sensor element. This will keep overall system costs down by allowing the user to select calibration and temperature compensation circuits which specifically match individual application needs. In most cases, the primary signal conditioning elements to be added to the SX by the user are: offset and span calibration and temperature compensation.

Some typical circuits are shown in the application section.

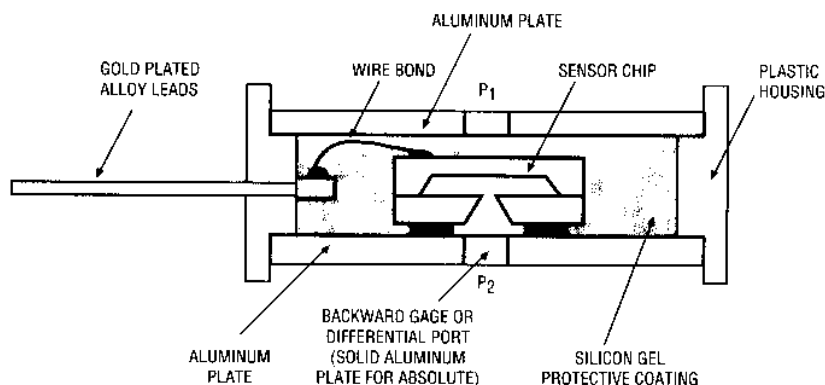
#### Vacuum reference (absolute devices)

Absolute sensors have a hermetically sealed vacuum reference chamber. The offset voltage on these units is therefore measured at vacuum, 0 psia. Since all pressure is measured relative to a vacuum reference, all changes in barometric pressure or changes in altitude will cause changes in the device output.

#### Media compatibility

SX devices are compatible with most non-corrosive gases. Because the circuitry is coated with a protective silicon gel, some otherwise corrosive environments can be compatible with the sensors. As shown in the physical construction diagram below for the button sensor element and "N" package, fluids must generally be compatible with silicon gel, RTV, plastic, and aluminum for forward gage use and RTV, silicon, glass and aluminum for backward gage or differential applications. For questions concerning media compatibility, contact the factory.

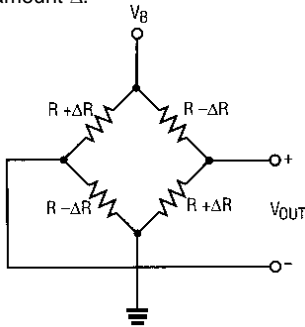
### PHYSICAL CONSTRUCTION



**APPLICATION INFORMATION**

**General**

The SX family of pressure sensors functions as a Wheatstone bridge. When pressure is applied to the device (see Figure I) the resistors in the arms of the bridge change by an amount  $\Delta$ .



**Figure I. Button sensor bridge schematic**

The resulting differential output voltage  $V_O$  is easily shown to be  $V_O = V_B \times \Delta$ . Since the change in resistance is directly proportional to pressure,  $V_O$  can be written as:

$$V_O = S \times P \times V_B \pm V_{OS} \quad (1)$$

Where:  $V_O$  is the output voltage in mV  
 $S$  is the sensitivity in mV/V per psi  
 $P$  is the pressure in psi  
 $V_B$  is the bridge voltage in volts.

$V_{OS}$  is the offset error (the differential output voltage when the applied pressure is zero). The offset voltage presents little problem in most applications, since it can easily be corrected for in the amplifier circuitry, or corrected digitally if a microprocessor is used in the system.

**Temperature effects**

In this discussion, for simplicity of notation, the change of a variable with temperature will be designated with a dot (•) over the variable. For example,

$$\dot{S} = \frac{\text{change in sensitivity}}{\text{change in temperature}} = \frac{\delta S}{\delta T}$$

From equation (1), and ignoring the  $V_{OS}$  term, it is seen that for a given constant pressure, the output voltage change, as a function of temperature\*, is:

$$\dot{V}_O = \dot{S} P V_B \quad (2)$$

Thus, in order for output voltage to be independent of temperature, the voltage across the bridge,  $V_B$ , must change with temperature in the "opposite direction" from the sensitivity change with temperature. From the typical curves for the temperature dependence of span (span =  $S \times P \times V_B$ ),

it can be seen that the sensitivity change with temperature is slightly non-linear and can be correlated very well with an equation of the form:

$$S = S_0[(1 - \beta T_D) + \rho T_D^2] \quad (3)$$

where  $T_D$  is the temperature difference between 25°C and the temperature of interest,  $S_0$  is the sensitivity at 25°C, and beta ( $\beta$ ) and rho ( $\rho$ ) are correlation constants. Fortunately, between 0°C and 70°C the change in sensitivity with temperature is quite linear, and excellent results can be obtained over this temperature range by ignoring the second-order temperature dependent term. Operating outside the 0°C and 70°C temperature range will require a more rigorous mathematical approach and the use of non-linear compensating circuitry, if accuracy of better than  $\pm 1\%$  is required. Because the majority of SX applications fall within the 0°C to 70°C operating temperature range, the discussion and circuit designs given here will ignore the non-linear effects.

Thus:

$$S = S_0 (1 - \beta T_D) \quad (4)$$

Substituting equation (4) into equation (1) and ignoring  $V_{OS}$ , it can be shown that the necessary bridge voltage,  $V_B$ , will be of the form:

$$V_B = \frac{V_{BO}}{(1 - \beta T_D)} = V_{BO} [(1 - \beta T_D + (\beta T_D)^2 + \dots)]$$

where  $V_{BO}$  is the bridge voltage at 25°C. This equation is again non-linear. However, for the temperature range of interest, and since  $\beta$  is small (0.215%/°C from the electrical tables), the above expression can be approximated by:

$$V_B = V_{BO} [1 + \beta T_D]$$

with less than 1% error. Thus to compensate for a negative 2150 ppm/°C sensitivity change with temperature, the bridge voltage should increase with temperature at a rate of +2150 ppm/°C.

The above value of bridge voltage change will be used in the circuit discussions that follow. That is to say, the required change in terms of ppm/°C is:

$$\left(\frac{\dot{V}_B}{V_B}\right) = +2050 \text{ ppm/}^\circ\text{C}$$

The bridge input resistance\*,  $R_B$  also changes with temperature and is quite linear in the temperature range of interest. The bridge resistance has a temperature coefficient of typically:

$$\left(\frac{\dot{R}_B}{R_B}\right) = +750 \text{ ppm/}^\circ\text{C}$$

This term enters into several compensation circuit equations, particularly when the bridge excitation is from a constant current source.

To summarize, the following list indicates how the sensor variables can be accommodated

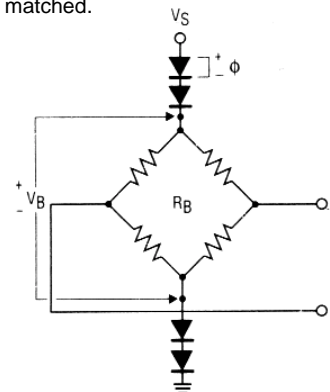
- Full-scale span from device to device. Make the gain adjustment in the op amp circuitry
- Temperature coefficient of span:
  - 1) temperature compensate the bridge or
  - 2) temperature compensate the op amp gain
- Offset voltage: Adjustment in op amp circuitry
- Offset voltage temperature coefficient: Usually can be ignored. For more precise design requirements, contact the factory for information on how to compensate for this term.

**Bridge compensation circuits**

Although thermistors can be used to temperature compensate the bridge (and in fact will be required for extended temperature operation), they are inherently non-linear, difficult to use in volume production, and more expensive than the circuit approaches shown here, which use inexpensive semiconductor devices. The circuits shown have been designed to incorporate a minimum number of adjustments and allow interchangeability of devices with little variation from device to device. In general, equations for the bridge voltage and its change with temperature are given to enable the user to modify or adjust the circuitry as required.

**1. Diode string (Figure II)**

For systems using 6 V supplies, this method of compensating for the effects of span over temperature is the lowest cost solution. The diodes are small signal silicon diodes, such as 1N914 or 1N4148, and do not have to be matched.



**Figure II. Diode String Span Compensation**

**APPLICATION INFORMATION (cont.)**

a)  $V_B = V_S - 4\phi$

b)  $\left(\frac{V_B}{V_S}\right) = \frac{\left(\frac{\phi}{\phi}\right)}{\left(\frac{V_S}{\phi} - 4\right)}$

c)  $\left(\frac{\phi}{\phi}\right) = -2500 \text{ ppm}/^\circ\text{C}$  for silicon diodes

**Figure II. Equations**

For example, solving equation (b) for  $V_B/V_S$  when

$V_S = 6.0 \text{ V}$

$\phi = 0.7 \text{ V}$

Yields:

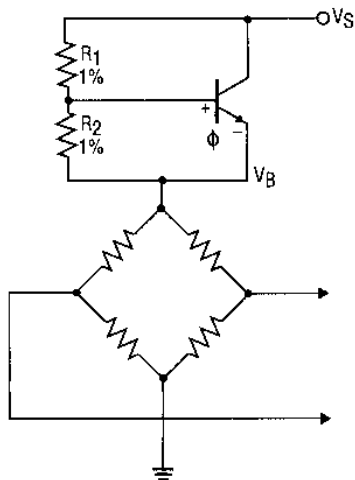
$\frac{V_B}{V_S} = 2188 \text{ ppm}/^\circ\text{C}$

Since the sensor's span changes with temperature at  $-2150 \text{ ppm}/^\circ\text{C}$ , this technique will typically result in an overall negative TC of  $38 \text{ ppm}/^\circ\text{C}$ . This error is acceptable in most applications.

For operation with  $V_S$  above 6V, it is recommended to use the transistor or constant current compensation technique.

**2. Transistor compensation network**

Figure III uses a single transistor to simulate a diode string, with the equations as shown. The values shown in Table I were found to give excellent results over  $0^\circ\text{C}$  to  $70^\circ\text{C}$ . Again, if precision temperature compensation is required for each device, the fixed value resistors shown for  $R_1$  in Table I can be replaced by a 3.24k resistor in series with a 1k pot. Then, each device's temperature compensation can be individually adjusted.



**Figure III. Transistor/Resistor span TC compensation**

a)  $V_B = V_S - \alpha \phi$

b)  $\left(\frac{V_B}{V_S}\right) = - \left(\frac{\phi}{\phi}\right) \times \left(\frac{1 - \alpha}{\frac{V_S}{\phi} - \alpha}\right)$

c)  $\alpha = 1 + \frac{R_1}{R_2}$

d)  $\left(\frac{\phi}{\phi}\right) = -2500 \text{ ppm}/^\circ\text{C}$

**Table I. Selected R values vs VS for figure III**

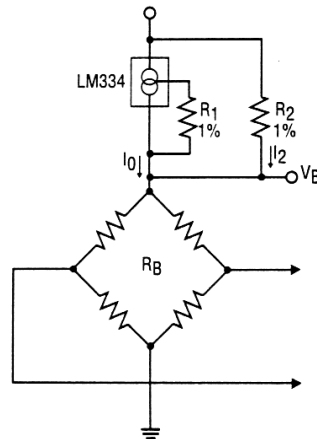
$V_S$	$R_1 (\Omega)$	$R_2 (\Omega)$
5V	3.32k	1.43k
9V	4.02k	806
12V	4.22k	604

**3. Constant current excitation**

(Figure IV)

The circuits shown in Figures II and III, although simple and inexpensive, have one drawback in that the voltage across the bridge is determined by the compensation network. That is, the compensation network is determined and what voltage is "leftover" is across the bridge. The circuit of Figure IV solves this problem and allows the bridge voltage to be independently selected. In Figure IV, the bridge is driven from a constant current source, the LM334, which has a very well known and repeatable temperature coefficient of  $+3300 \text{ ppm}/^\circ\text{C}$ . This temperature coefficient (TC), in conjunction with the TC of the bridge resistance, is too high to compensate the sensitivity TC, hence resistor  $R_2$  is added to reduce the total circuit TC.

The basic design steps for this method of temperature compensation are shown below. However, please refer to SenSym's Application Note SSAN-16 for details on the temperature compensation technique.



**Figure IV. Constant current span TC Compensation**

a)  $V_B = \alpha (V_S + I_O R_2)$

b)  $\left(\frac{V_B}{V_S}\right) = \left(\frac{R_B}{R_B}\right) (1 - \alpha) + \left(\frac{I_O}{I_O}\right) \left[1 - \alpha \left(\frac{V_S}{V_B}\right)\right]$

c)  $\alpha = \frac{R_B}{R_2 + R_B}$

d)  $\left(\frac{I_O}{I_O}\right) = 3360 \text{ ppm}/^\circ\text{C}$ ,  $\left(\frac{R_B}{R_B}\right) = +750 \text{ ppm}/^\circ\text{C}$

e)  $I_O = \frac{67.7 \text{ mV}}{R_1}$

The design steps are straight forward:

- 1) Knowing  $V_S$  and the desired bridge voltage  $V_B$ , solve equation (b) for  $\alpha$ .
- 2) Now, solve equation (c) for  $R_2$ , letting  $R_B = 4650\Omega$ .
- 3) Solve equation (a) for  $I_O$ .
- 4) Find  $R_1$  or its nearest 1% tolerance value from equation (e).

Table II gives specific 1% resistor values in ohms, for several popular system voltages. For best results, the resistors should be 1% metal film with a low temperature coefficient.

**Table II. Selected R values vs VS for figure IV**

$V_S$	$V_B$	$R_1(\Omega)$	$R_2(\Omega)$
5V	3V	147	11.0k
6V	4V	105	9.53k
9V	6V	68.1	9.53k
12V	9V	43.2	8.25k
15V	10V	41.2	9.53k

**Amplifier design**

There are hundreds of instrumentation amplifier designs, and the intent here will be to briefly describe one circuit which:

- does not load the bridge
- involves minimal components
- provides excellent performance

**Amplifier adjustment procedure**

1. Without pressure applied,
  - (a) Short points A and B together as shown in Figure V. Adjust the 1 k common-mode rejection (CMRR) pot until the voltage at test point ( $T_p$ )  $V_x$  is equal to the voltage at test point ( $T_p$ )  $V_R$ .

This is easily accomplished by placing a digital voltmeter between these test points and adjusting for 0.000.

**APPLICATION INFORMATION (cont.)**

- (b) Remove the short and adjust the 500 Ω offset adjust pot until  $V_x$  is again equal to  $V_R$ .
  - (c) Adjust the 2k reference ( $V_R$ ) adjust pot to get an output voltage ( $V_O$ ) equal to 1.00V.
2. Apply the full-scale pressure and adjust the span adjust pot,  $R_5$ , to get the output voltage that is desired to represent full-scale.

The choice of the operational amplifiers to use is based on individual cost/performance trade-offs. The accuracy will be primarily limited by the amplifier's common-mode rejection, offset voltage drift with temperature and noise performance. Low cost, low performance devices, such as the LM324 can be used if the temperature ranges limited to 25°C +15°C and an accuracy of +2% is adequate.

For more precise applications amplifiers such as the LT1014 and LT1002 have been found to be excellent.

An amplifier that uses a single supply is shown in Figure V. Table III gives resistor values for various supply and full-scale output combinations.

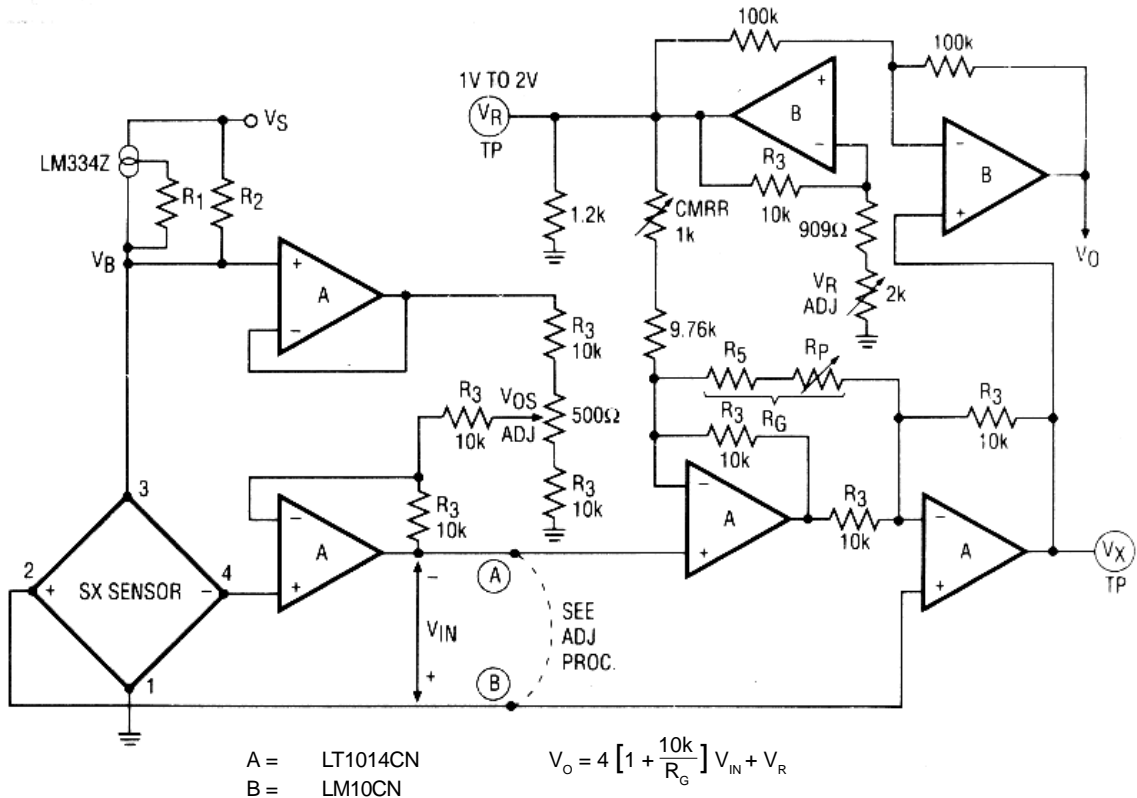
**Factory compensated devices**

This application note provides the necessary information for temperature compensating and calibrating the SX sensors. In some case, the customer may find that SX devices which have been factory adjusted for temperature compensation and span are more economical for a particular application. SenSym does offer devices with this feature. For more information on these factory calibrated and compensated devices, the SCX series and SDX series, please contact Sensortechonics.

**Table III. For 0 to 70°C operation**

$V_S$	$V_B$	$R_2$	$R_1$	SPAN		
				FS	$R_5$	$R_p$
5V	3.5V	9.09k	118Ω	3V	604Ω	2k
6V	4.5V	8.45k	86.6Ω	4V	604Ω	2k
9V	7V	7.87k	54.9Ω	5V	1k	2k
12V	10V	7.15k	36.5Ω	5V	1.82k	5k
12V	10V	7.15k	36.5Ω	10V	511Ω	2k
15V	12V	7.68k	31.6Ω	5V	1.4k	5k
15V	12V	8.87k	31.6Ω	10V	604Ω	2k

**Note:** Application information shown here is based on the closed bridge configuration.

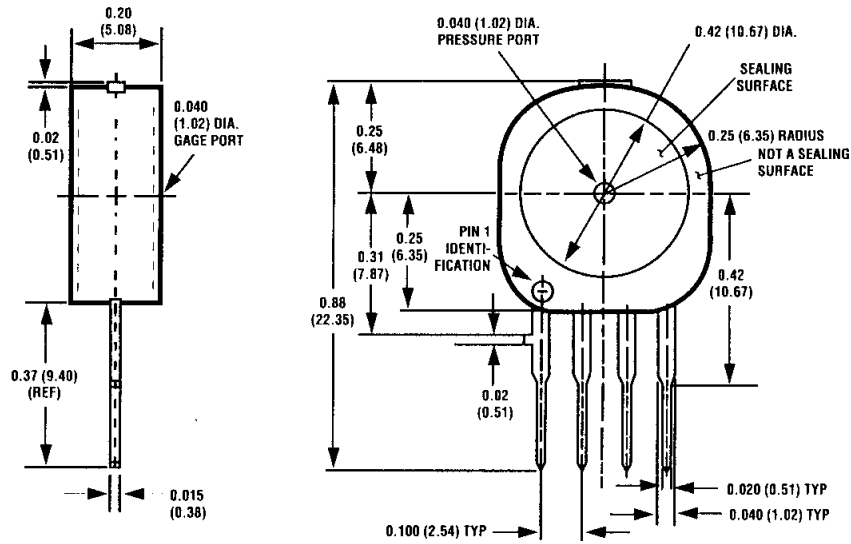


Resistors labeled  $R_3$  are 5-Element Resistor Arrays 10 kΩ. Two required

**Figure V: Button Sensor Amplifier Circuit**

**PHYSICAL DIMENSIONS**

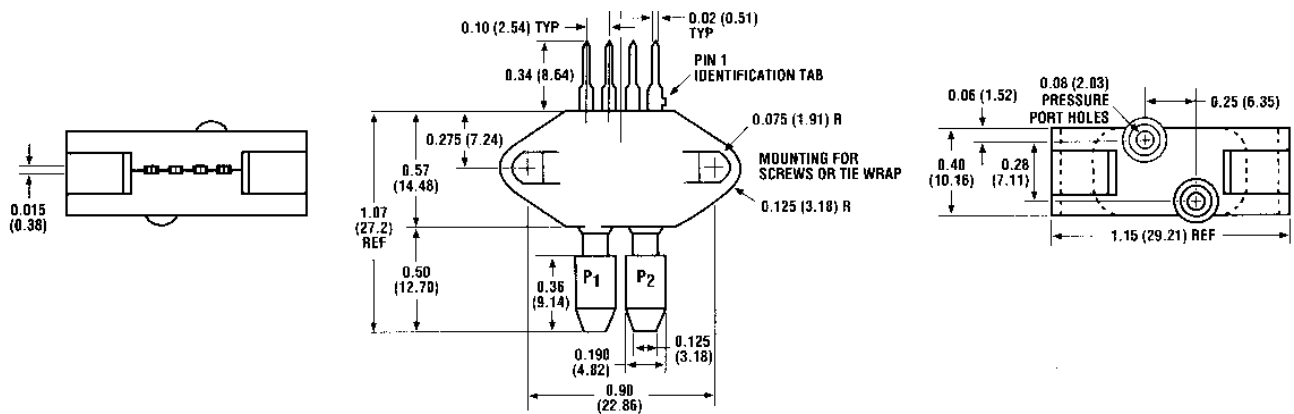
**Button package**



mass: 1 g

dimensions in inches (mm)

**N package**



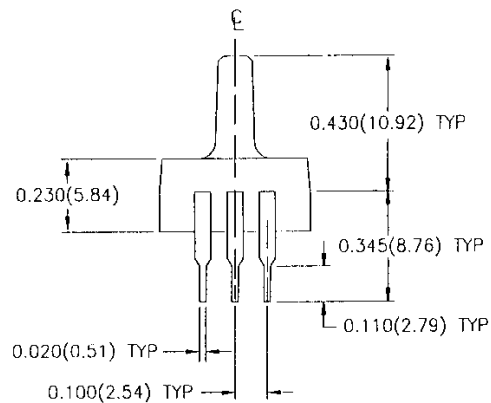
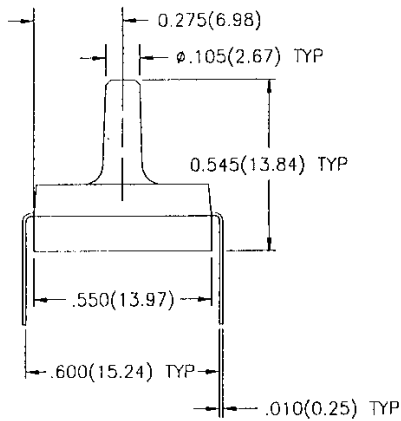
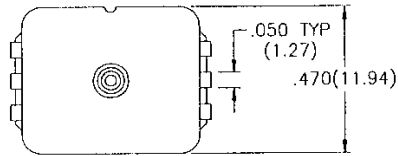
mass: 5 g

dimensions in inches (mm)



## PHYSICAL DIMENSIONS

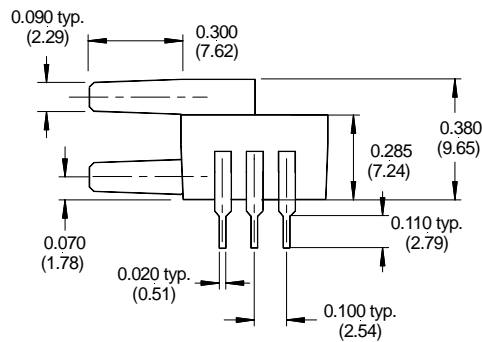
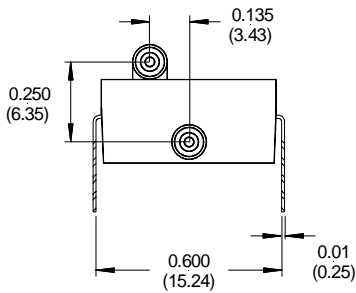
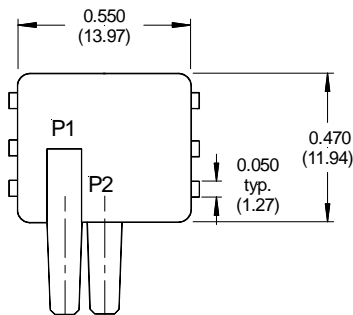
### Basic sensor DIP "D2" package



mass: 1 g

dimensions in inches (mm)

### Basic sensor DIP "D4" package



mass: 1 g

dimensions in inches (mm)

**ORDERING INFORMATION**

Pressure range		Order part no.			
		Button package	"N" package	DIP "D2" package (single ported)	DIP "D4" package (dual ported)
<b>Absolute pressure</b>	0 - 15 psi	SX15A	SX15AN	SX15AD2	---
	0 - 30 psi	SX30A	SX30AN	SX30AD2	---
	0 - 100 psi	SX100A	SX100AN	SX100AD2	---
	0 - 150 psi	SX150A	---	---	---
<b>Gage pressure</b>	0 - 1 psi	use differential devices	use differential devices	SX01GD2	---
	0 - 5 psi			SX05GD2	---
	0 - 15 psi			SX15GD2	---
	0 - 30 psi			SX30GD2	---
	0 - 100 psi			SX100GD2	---
	0 - 150 psi			---	---
<b>Differential pressure</b>	0 - 1 psi	SX01D	SX01DN	---	SX01DD4
	0 - 5 psi	SX05D	SX05DN	---	SX05DD4
	0 - 15 psi	SX15D	SX15DN	---	SX15DD4
	0 - 30 psi	SX30D	SX30DN	---	SX30DD4
	0 - 100 psi	SX100D	SX100DN	---	SX100DD4
	0 - 150 psi	SX150D	SX150DN	---	---

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