

Atmospheric Pressure Measurements

Technical Note

INTRODUCTION

Atmospheric pressure - The term atmospheric pressure refers to the pressure generated by the weight of the air surrounding the earth. The pressure as a function of altitude is not a linear function due to the compressibility of air; the atmosphere is denser at lower altitudes. The atmosphere is also not uniform, there are mounds and valleys that create high and low pressure areas. The atmosphere is in constant motion like the oceans, wind blows from high pressure areas to low pressure areas as well as rises and falls as it is heated and cooled by land and water areas. A barometric reading used by meteorologists measures the atmospheric pressure and is typically normalized to sea level. An absolute pressure transducer will measure the combined altitude and barometric pressure at that location. This application note will discuss atmospheric pressure measurements, not normalized barometric reading. The following circuits could be used to measure the absolute atmospheric pressure or the output could be converted to altitude readings between -1000 feet and 12,000 feet.

TRANSDUCER DESIGN

A transducer to measure atmospheric pressure over the altitude range of -1000 ft. to 12000 ft. will be designed with the following specifications:

Table with 2 columns: Specification and Value. Rows include Pressure Range (absolute), Linearity, Full Scale (span), Output Voltage Swing, Sensitivity, Offset Voltage, Full Scale, and Excitation voltage.

The pressure range is determined by the minimum and maximum altitude the system will be expected to operate over. The standard atmospheric pressure at -1000 ft is 31.0185 in Hg and the standard atmospheric pressure at 12,000 ft is 19.029 in Hg. The standard atmospheric pressure at sea level is 29.9213 in Hg.

The transducer output voltage swing is designed to interface to an analog-to-digital converter with a 0 volt to 5 volt input voltage range. A 12 bit A/D converter will have a resolution of 0.0032 in Hg or 1.22 mV per LSB.

At -1,000 ft., 1 LSB is equal to 2.9 ft, and at 12,000 ft 1 LSB is equal to 4.3 feet.

The sensor to be used in this application is the Honeywell SCX15AN, the sensor specifications are:

Table with 2 columns: Specification and Value. Rows include Operating Pressure Range, Sensitivity, Zero Pressure Offset, Combined linearity and Hysteresis, and Long Term Stability (offset & span).

Reference conditions: TA = 25 °C, excitation voltage 12 volts, and pressure applied to port A.

Figure 1 shows the circuit that will be used. Amplifier A1 and zener Z1 generate the 5.0 volt reference voltage for the circuit. Potentiometer R3 adjusts the voltage at TP1 to precisely 5.00 volts. The sensor is ratiometric to the supply voltage, operated at 5.0 volts the sensor specifications are:

Sensitivity at 5.0 V = (5 / 12) x 6.0 mV/psi = 2.5 mV/psi ± 1 % (1)
= (2.5 mV) / 2.036 = 1.228 mV/in Hg. ± 1 %

Amplifier A2 is used to generate an offset voltage which sets the input voltage to amplifier A3 and A4 to 0 volts at 19 in Hg. Amplifier A2 has the following gain equation:

Av = 1 + (R6 / R5) = 1.00909 (2)

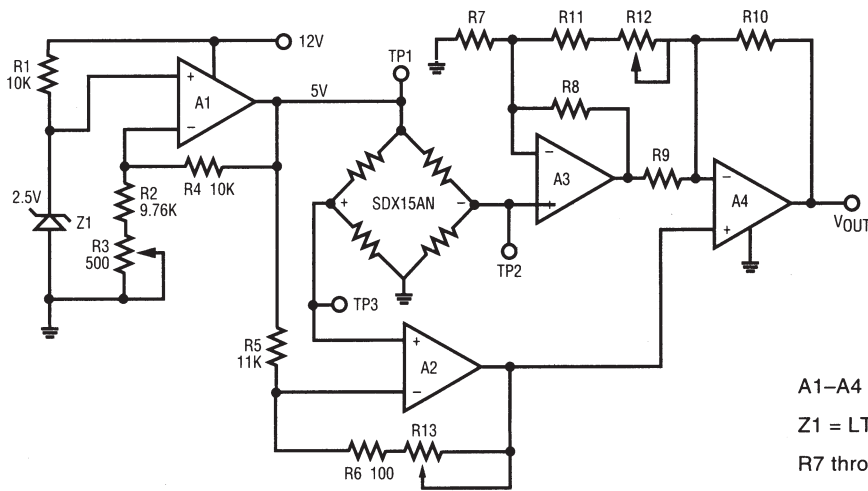
This gain will increase the sensor output to 1.23906 mV / in Hg from 1.228 mV/Hg.

Amplifier A2 also has a common mode gain which shifts the offset by as much as ±0.8 mV. The common mode shift is due to the sensor output not being at exactly half the excitation voltage, the specification is 6.0 volts (0.2 at 12 volt excitation)

Com. Mode = .2 x (5 / 12) x (100 / 11,000) = 0.80 mv (3)

This is the largest offset error in the system.

FIGURE 1



A1–A4 = LT1014C
 Z1 = LT1009 – 2.5V
 R7 through R10 = 100K
 All resistors PN55 1%

The amplifier gain is determined as follows: With 5.0 volt excitation, the sensor has a sensitivity of 1.239 mV/in Hg. at the output of A2. A span of 12 in Hg. equals 14.8687 mV to the instrumentation amplifier. The instrumentation amplifier gain is calculated by dividing the output swing of 4.596 volts by the sensor output of 14.8687 mV, this equals a gain of 309.11. Amplifier A3 and A4 make up the instrumentation amplifier, the gain is set by adjusting the values of R11 and R12. Let the combined value of R11 and R12 = Rg, the Gain equations are:

$$A_v = \frac{V_o}{V_{in}} = 2 \left(1 + \frac{r_f}{12} \right) \quad (4)$$

$$R_g = \frac{200 \text{ k}}{A-2} \quad (R_f = 100 \text{ k}) \quad (5)$$

Solving equation 2 for a gain of 309.11 gives Rg = 651.24 Ohm. In circuits that do not have adjustable amplifier gains, a fixed standard 1 % value can be selected for R11 and R12 where R11 = 634 Ohm and R12 = 17.4 Ohm. In circuits that are adjustable R11 would be 634 Ohm and R12 would be a 50 Ohm pot.

CALIBRATION OPTIONS

We can now do an error analysis on three possible calibration variations of the circuit.

1. Circuit with no adjustments.
2. Circuit with single point adjustment.
3. Circuit with offset and span adjustment.

In applications that do not require precision, the circuit can be used with no adjustments. The RMS error for the circuit would be ±0.09 in Hg.

1. NO ADJUSTMENT

In the non-adjustable circuit, all potentiometers are removed, R2 is 10 k ±1 % and R3, R12 and R13 are shorted. The error budget at 25 °C is:

Offsets

SCX15AN	= ±0.125 mV
VosA2	= ±0.180 mV
VosA3	= ±0.180 mV
VosA4	= ±0.180 mV
Common Mode A2	= ±0.80 mV

The Offset RMS error is:

$$\text{Offset RMS} = \sqrt{0.125 \text{ mV}^2 + 0.18 \text{ mV}^2 + 0.18 \text{ mV}^2 + 0.18 \text{ mV}^2 + 0.8 \text{ mV}^2}$$

$$\text{Offset RMS} = 0.868 \text{ mV} = 0.74 \text{ in Hg} \quad (6)$$

SPAN

SCX15AN	= ±1 %
Input Resistors	= ±1 %
Feedback Resistors	= ±1 %

$$\text{SPAN RMS} = \sqrt{1 \%^2 + 1 \%^2 + 1 \%^2} \quad (7)$$

$$\text{SPAN RMS} = 1.73 \% = 0.433 \text{ in Hg}$$

Total RMS Error =

$$\sqrt{0.74 \text{ in Hg}^2 + 0.433 \text{ in Hg}^2} = 0.89 \text{ in Hg} \quad (8)$$

With no adjustments the total RMS error is 0.89 in Hg or 7.4 % of Span. (822 ft at sea level) This circuit may be adequate for someone just interested in pressure changes and wants no calibration.

2. SINGLE POINT ADJUSTMENT

The second calibration option is a single point calibration. A reference barometer is used to measure the local atmospheric pressure, and using this data the circuit can be adjusted with one calculation and two simple adjustments.

1. The sensor output is calibrated by adjusting the 5.0 volt reference voltage. The procedure is:
 - a. Read the output of the reference barometer. (calib. in inches of mercury)
 - b. Multiply the reading by 1.228×10^{-3}

1.228×10^{-3} is the sensor sensitivity from Eq. 1. Multiplying the barometer reading by the sensitivity gives the ideal sensor output for the local atmospheric pressure. To make the first adjustment – measure the differential voltage between test points TP-2 and TP-3, then adjust R3 until the voltage agrees with the calculated voltage. This adjustment compensates:

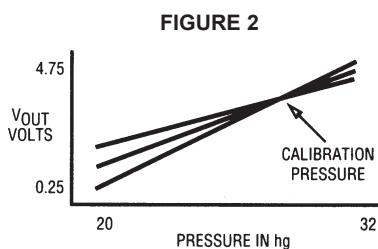
1. Reference voltage tolerances
2. SCX15AN offset and span tolerance

The second step in the calibration procedure compensates for the error introduced by A2 common mode error and the output amplifier errors. The output is forced to agree with the reference by adjusting R13. This adjustment compensates offset errors due to:

1. A2 Common mode Error
2. A3 & A4 offset error
3. R7 through R12 tolerances

This calibration technique forces the error to be zero at the reference pressure and have maximum error at the lowest pressure (highest altitude) due to the gain or slope error as shown in figure 2:

The worst case error at 12,000 ft would be 0.433 in Hg or 585 ft at 12,000 feet.



3. TWO POINT COMPENSATION

The third calibration option is to do a conventional two point calibration applying two known pressures to the transducer and adjusting the slope and offset for the desired output. Unfortunately the barometer is not calibrated at 0 psia which means there will be some interaction between offset and span adjustments. The circuit changes are R2 = 10 k and R3 shorted.

The sensitivity is adjusted first (slope).

- a. Set the pressure applied to the transducer to 28 in Hg (The output should read 3.625 V (0.80 V)
- b. Record the output, then decrease the pressure to 22 in Hg (The output should change by approximately 2.298 V)
- c. Adjust R12 until a change of 6 in Hg results in a change in the output voltage of 2.298 V.

After the sensitivity has been set the offset can be calibrated.

- a. Set the pressure to 25 in Hg and adjust the offset pot R13 for 2.548 V at the output.
- b. Check the output at the pressure extremes. (19 in Hg = 0.250 V and 31 in Hg = 4.846 V).

After the circuit has been calibrated, the remaining error will be due to the linearity error of the sensor and will be maximum at half scale or 5,500 feet. The SCX15AN is specified to have a maximum linearity error of $\pm 0.5\%$ of span. The two point calibration forces the error to be zero at 19 in Hg and at 31 in. Hg. The span in this case is 12 in Hg and the error at 5,500 ft is 0.060 in Hg or 67 ft maximum.

DIGITIZING

After the calibration technique has been decided the next consideration is how much resolution is required in the Analog to Digital converter. The most common A/D converters are 8,10 and 12 bit:

8 Bit = $5 \text{ V}/256 = 19.5 \text{ mV/Bit} = .051 \text{ in Hg /Bit} = 47 \text{ ft at sea level}$

10 Bit = $5 \text{ V}/1024 = 4.88 \text{ mV/Bit} = .013 \text{ in Hg/Bit} = 12 \text{ ft at sea level}$

12 Bit = $5 \text{ V}/4096 = 1.22 \text{ mV/Bit} = .003 \text{ in Hg/Bit} = 4 \text{ ft at sea level}$

CONCLUSION

By selecting pressure sensors and operational amplifiers with low offsets and reasonably tight specs, a circuit to measure atmospheric pressure can be designed that requires minimum calibration. The same circuit can be used to measure both atmospheric pressure and altitude. Since the conversion from pressure to altitude is not linear, the atmospheric pressure reading will have to be converted to altitude by use of a controller or PC. To summarize, the RMS errors of the three calibration techniques are:

- No Calibration ± 0.89 in Hg or 822 ft
@ sea level; $\pm 1,203$ ft @ 12 k ft
- Single Point ± 0.433 in. Hg or 0 ft
@ cal altitude; ± 585 ft @ 12 k ft
- Two Point ± 0.060 in Hg or 0 ft @ sea level - 67 ft
@ 5.5 k ft - 0 @ 12 k ft

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INTERNET

www.honeywell.com/sensing

info.sc@honeywell.com

Honeywell

Sensing and Control

www.honeywell.com/sensing

Honeywell

11 West Spring Street

Freeport, Illinois 61032

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