Understanding Absolute Pressure Sensors

Technical Note

INTRODUCTION

Most people are typically accustomed to dealing in gage pressure, that is, pressure relative to the normal atmospheric pressure which surrounds us. As such, "absolute" pressure and absolute pressure sensors which measure pressure relative to a perfect vacuum can be somewhat confusing. Also, because zero absolute pressure (a perfect vacuum) is impossible to achieve, it is much harder to measure and calibrate absolute pressure sensors. This application note will discuss what absolute pressure is, how it is best measured and how to calibrate absolute pressure sensors.

DIFFERENTIAL (GAGE) PRESSURE

It is often easier to understand absolute pressure if we have a clear understanding of differential and gage pressure which we are generally more familiar with.

Differential pressure is the pressure difference measured between two pressure sources. This is usually expressed in pounds per square inch differential (psid). When one source is the ambient pressure, this is then called gage or relative pressure and is typically expressed in pounds per square inch gage (psig). Therefore, gage pressure is simply a special case of differential pressure with pressures measured differentially but always relative to the local ambient pressure. In the same respect, absolute pressure can also be considered a differential pressure where the measured pressure is compared to a perfect vacuum.

ABSOLUTE PRESSURE

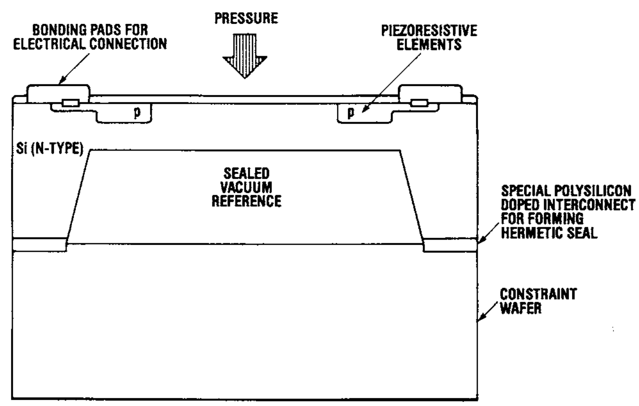
Absolute pressure sensors are most commonly used to measure changes in barometric pressure or as altimeters. These applications require reference to a fixed pressure as they cannot be simply referenced to the surrounding ambient pressure.

Absolute pressure is defined as the pressure measured relative to a perfect vacuum. For example, 10 pounds per square inch absolute (psia) would be 10 psi above a perfect vacuum. This is roughly 4.7 psi below the standard atmospheric pressure at sea level of 14.7 psia. 0 psia is then the pressure of a perfect vacuum.*

Honeywell's absolute pressure sensors are made by hermetically sealing a vacuum reference chamber on one side of the integrated circuit sensing element. (See Figure 1) Pressures to be measured are then measured relative to this vacuum reference. The actual "vacuum" which is sealed into the sensor is approximately 0.0005 psia (25 millitorr). Using this near vacuum as a reference eliminates any potential thermal errors which would occur if any gas was trapped in the reference chamber as it would exert a pressure during expansion and contraction with temperature in accordance with Boyles law. One of the advantages of integrated circuit sensors is the small volume of trapped vacuum reference which, in conjunction with a reliable silicon-to-silicon hermetric seal, makes these devices time and temperature stable.

FIGURE 1

Cross Sectional View of an Intergrated Circuit Sensor Element



CALIBRATING ABSOLUTE SENSORS

To use any sensor in an absolute application, we must be able to accurately calibrate the device for offset and span. This requires understanding offset and span in terms of absolute pressure.

OFFSET VOLTAGE

The Offset voltage is defined as the sensor's output at *zero differential pressure*. For gage sensors, this is the output with ambient pressure (0 psig) applied to the sensor. As such, offset voltages are relatively easy to measure for gage sensors. However, for an absolute device, the offset voltage is the output voltage of the sensor with a perfect vacuum (0 psia) applied to the sensor. This means that with normal atmospheric pressure applied to the absolute sensor, there will be an output voltage which corresponds to approximately 14.7 psia at sea level.

*Footnote: For illustration purposes in this note, pounds per square inch (psi) is used as the unit of pressure measure. This unit can obviously be converted to other common pressure units such as mmHg, kPa, bar, etc.. (See the attached chart for individual conversion factors.)

Because a perfect vacuum is impossible or at least impractical to obtain, measuring the actual offset voltage for absolute sensors is not possible. At Honeywell, we draw a vacuum to 1 psia and then in combination with the output at full scale, use a straight line approximation to calculate the 0 psia output or offset voltage. This same technique can be applied using any two pressure points provided the sensor is perfectly linear. The non-linearity induced errors will vary depending on the pressure points used but can easily be limited to less than ±0.1 % if the 10 % full scale output (FSO) and 90 % FSO reference points are used for the straight line approximation of 0psia.

SPAN

Span is defined as the full scale output (FSO) voltage minus the offset voltage. For example, if at 15 psia an output of 101 mV was obtained and at 0 psia the offset voltage was 1 mV, the span would be 100 mV (101 mV (FSO) – 1 mV (offset) = 100 mV full scale span). It is important to note that for an absolute sensor, span is also defined relative to a perfect vacuum.

Measuring the span of absolute sensors has similar problems associated with it as those of measuring the offset voltage and ideally would require a calibrated perfect vacuum source as a reference. When calibrating the span or offset, the absolute pressure reference point most often used is atmospheric pres-sure. An accurate reading of atmospheric pressure can be obtained by calling your local airport. Any other available pressure reference within the sensors range can then be used as the second pressure point to allow accurate calibration of span and offset.

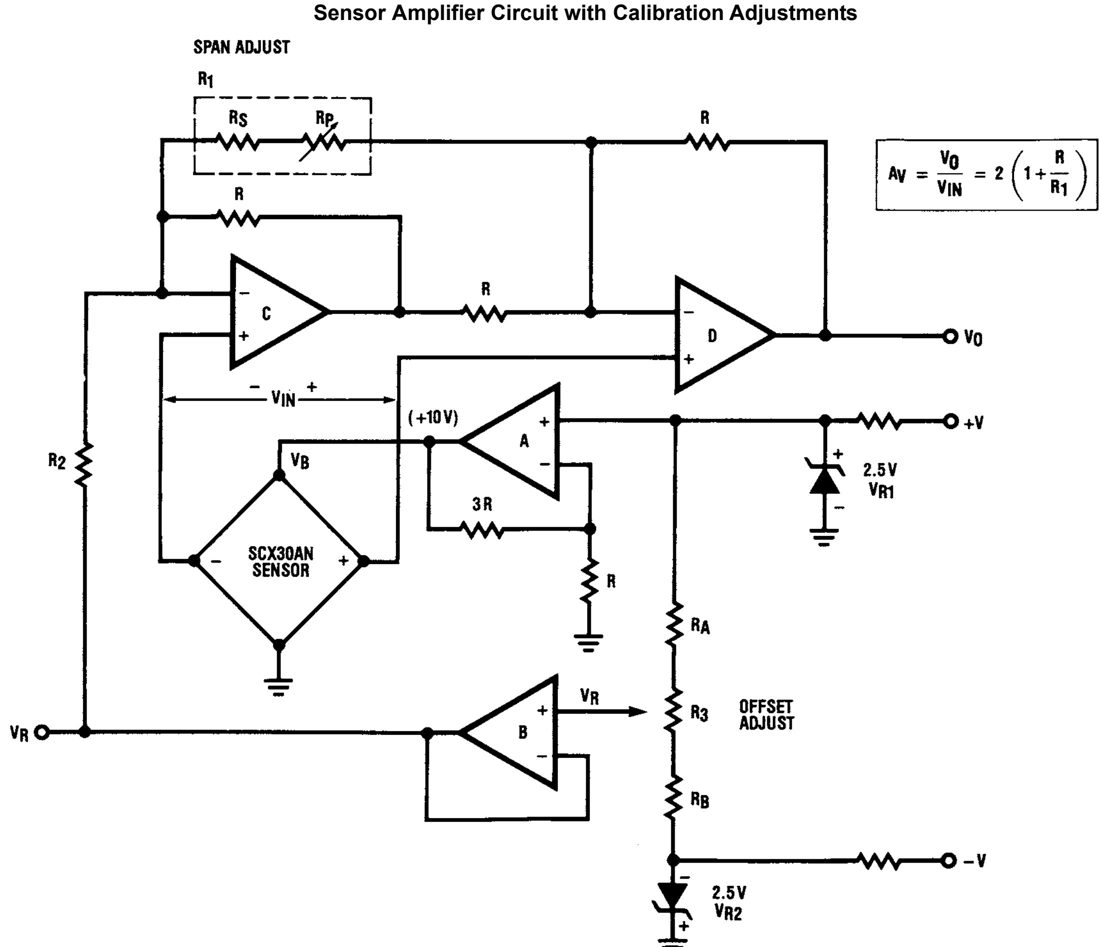
EXAMPLE #1—Adjusting Offset and Span for an Absolute Sensor

For this example we will assume the following:

1) We need to calibrate a circuit to give a 0 Vdc-5 Vdc output for 0 psia-30 psia input. The circuitconsists of an SCX30AN sensor and amplifier circuitry with adjustments for offset and span (sensitivity). (See Figure 2).
2) The only available pressure source/standard is a 15.000 psig gage reference pressure. Therefore, the local airport must be relied upon for the absolute barometric reference point. We will assume that they give a reading of 755 mmHg for the current barometric pressure.

FIGURE2

Sensor Amplifier Circuit with Calibration Adjustments



$$A_V = \frac{V_O}{V_{IN}} = 2\left(1+\frac{R}{R_1}\right)$$

(This is equal to14.60 psi, as 755 mmHg x 0.019337 psi/mmHg=14.60 psi.) Mathematically, it can easily be shown that using these two refer ence pressure points (barometric pressure and a gage reference), one can properly adjust for offset and span.

The basic output equation at a given voltage for this sensor is given by:

$$V_{OUT} = (S \times P) + V_{OS}$$

where: V_{OUT} Is the output voltage in volts
S is the sensitivity of the sensor in volts/LC
P is the applied pressure, and
V_{OS} is the offset error of the sensor.

Determining sensitivity using these two pressure points gives us two equations as follows:

At atmospheric pressure,

$$V_{01} = [S \times (P_{atmos})] + V_{OS}$$

And at 15psig,

$$V_{02} = [S \times (P_{atmos} + 15 \text{ psig})] + V_{OS}$$

Assuming S is constant then:

$$V_{02} - V_{01} = S \times (15 \text{ psig}) \text{ or,}$$

$$S = \frac{V_{02} - V_{01}}{15} \text{ volts/PSI} \qquad (1)$$

To solve for sensitivity since we have one equation, we need to know both V_{02} and V_{01}.

Once sensitivity is known offset can also be determined as:

$$V_{OS} = V_{01} - S \cdot P_{atmos} \qquad (2)$$

where: V_{OS} = Offset error of the sensor
V_{01} = Measured output at P_{atmos}
S = Calculated sensitivity for each sensor
P_{atmos} = Barometric pressure which is given

An example of a calibration procedure for our sensor circuit Is given below:

1) Apply power and allow the circuit to warm-up. Measure the output of the circuit with ambient (barometric) pressure applied. Let's as sume that the output of the circuit is 2.458 volts. We can calculate that the "ideal" reading at 14.60 psia (ambient barometric pressure) is 2.433 volts (14.60 psi/30.00 psi x 5.00 volts = 2.433 volts). However, given only this one measurement point, we cannot determine how much of this error is due to zero pressure (offset) error and how much is due to ambient pressure (sensitivity) error.

2) Next, apply the in-house 15.00 psig reference pressure and measure the output. For this example, we'll assume an output reading of 4.972 volts. Using Equation (1), we can now determine the actual sensitivity of our sensor as follows:

$$S = \frac{V_{02} - V_{01}}{15} = \frac{4.972 \text{ V} - 2.458 \text{ V}}{15 \text{ psi}} = 0.168 \text{ V/psi}$$

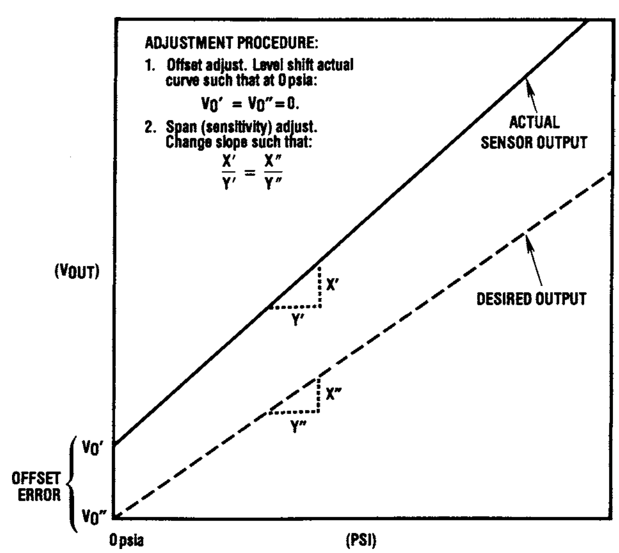
Then, using Equation (2), the offset error is calcu- lated to be:

$$V_{OS} = V_{01} - S \cdot P_{atmos} = 2.458 \text{ V} - [0.168 \text{ V/psi } (14.60 \text{ psia})] = 0.011 \text{ volts}$$

3) We can now adjust the offset and span as follows: Since the circuit shown in Figure 2 has the advantage of virtually independent trims, we can adjust offset and then span in this example. For circuits with more interactive effects it may be better to first adjust span, then offset, (i.e. Rotate the curve, then level shift. See Figure 3 for a simple graphic depiction of the adjust procedure.) In either case, one should go back and check the first adjustment after completing the second.

For best results, offset should be set at the lowest reference pressure. In this example, offset is then set at barometric pressure (14.60 psia). The offset adjust should be adjusted such that the output at barometric pressure (V_{01}) is 2.447 volts. This is the original reading of 2.458 volts minus the calculated offset error of 0.011 volts.

FIGURE 3
Basic Calibration Process for Offset and Span



Once the offset is adjusted, span is set using either the highest reference pressure available or where maximum accuracy is required. The 15 psig reference point is used here as an example. Span adjustment should be made to set the output at 15 psig (V_{02}) to 4.933 volts. This is 29.60 psi times the ideal sensitivity of 0.1667 volts per psi (5.00 volts/30 psi = 0.1667 V/psi).

To complete the calibration process, we can now check and fine tune, if necessary, the offset reading.

CONCLUSION

Although absolute pressure sensors are perhaps not as well understood or easily calibrated as gage pressure devices, by using barometric pressure as a reference in conjunction with any other reference point, gage or absolute, absolute pressure devices can be accurately calibrated.

PRESSURE UNIT CONVERSION CONSTANTS
(Most Commonly Used – Per International Conventions)

	PSI(1)	In. H_2O(2)	In. Hg(3)	kPa	millibar	cm H_2O(4)	mm Hg(5)
PSI(1)	1.000	27.680	2.036	6.8947	68.947	70.308	51.715
In. H_2O(2)	3.6127×10^{-2}	1.000	7.3554×10^{-2}	0.2491	2.491	2.5400	1.8683
In. Hg(3)	0.4912	13.596	1.000	3.3864	33.864	34.532	25.400
kPa	0.14504	4.0147	0.2953	1.000	20.000	20.2973	7.5006
millibar	0.01450	0.40147	0.02953	0.100	1.000	1.01973	0.75006
cm H_2O(4)	1.4223×10^{-2}	0.3937	2.8958×10^{-2}	0.09806	0.9806	1.000	0.7355
mm Hg(5)	1.9337×10^{-2}	0.53525	3.9370×10^{-2}	0.13332	1.3332	1.3595	1.000

Notes: 1. PSI — pounds per square inch 2. at 4 °C [39 °F] 3. at 0 °C [32 °F] 4. at 4 °C [39 °F] 5. at 0 °C [32 °F] 6. 1 Torr=1 mmHg

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