

# Pressure Sensors

## Pressure Sensor Auto-Referencing – Note #10

### INTRODUCTION

Pressure sensors are not “ideal” devices. Laser trimming on MICRO SWITCH high level amplified sensors reduces null and full scale errors to approximately 1% to 2% of span, but does not completely eliminate them. Additional corrective circuitry is sometimes necessary for applications with extremely tight tolerances. Figure 1 illustrates the “ideal” pressure sensor. Output drift with time, trimming tolerances, and changes in ambient temperature all contribute to a constant offset error (common-mode error), designated by  $\Delta V_o$ . Changes in ambient temperature also add another deviation, known as sensitivity shift, which changes the slope of the pressure versus voltage curve.

A family of techniques known as auto-referencing provides a powerful tool to compensate for these errors. System design engineers find the method attractive since implementation costs are minor in comparison with ultra-stable pressure sensors. Also, device accuracy is substantially increased. Either analog or digital auto-referencing is possible. This application note covers the digital method, as it is the most cost-effective and easiest to use.

### COMMON-MODE AUTO REFERENCING

Common-mode errors are those present at some reference pressure and contribute the constant offset voltage in Figure 1. These errors are generally larger than the sensitivity shift, especially at pressures close to the reference pressure. Therefore, they allow the greatest accuracy improvement when auto-referenced.

Common-mode errors are easily corrected. Sample the output voltage at reference pressure and compare it to the desired reference voltage. Generate an error correction voltage and subtract it from the output signal at any “measure” pressure. See Figure 2.

Common-mode auto-referencing is expressed by the formula:

$$V_{corr} = V_{out} - \Delta V_o$$

$V_{out}$  is any measured output signal,  $\Delta V_o$  is the common-mode error, and  $V_{corr}$  is the corrected output signal. Note that no slope correction is provided for sensitivity shift error, and the actual output signal will appear as shown in Figure 3.

The basic functions required to implement common-mode auto-referencing are shown in the block diagram of Figure 4. They include analog switches, a sample-and-hold, summers, and synchronizing logic for switching between the read and reference cycles on the input and output sides of the pressure sensor.

To maintain optimum system accuracy, auto-referencing should be used as often as possible in order to eliminate errors due to power supply fluctuations and output drift with time. To assure that the pressure measurements will be the most accurate, they should immediately follow the auto-reference command.

Certain types of measurement cycles are inherently suited to auto-zeroing (reference pressure is actually zero). Ideally, there is a series of short cycles which can have a quick referencing inserted prior to each cycle. A short measurement cycle preceded by a reference point, followed by a lengthy period of no activity, is also well suited. Many applications are in one of these categories. Many that are not can be converted to the short repeated cycle format, with a little design creativity.

Examples of “ideal” applications are: weighing scale; toilet tanks; washing machines; and pressure reservoirs such as tire pressure, oil pressure, and LP gas tank pressure. The reference condition is applied before the measurement. Other categories are flow measurement and control applications, such as electronic fuel injection systems, sphygmomanometers, and forced air heating systems. Flow rate is zero at some point, usually at system power-up.

Although common-mode auto-referencing is almost a universal technique, there are situations where it would be of little value; systems with short measurement cycles where the reference point is read or manually adjusted before cycle start-up, or where the sensor is AC coupled and the DC response is ignored.

### COMMANDING AUTO-REFERENCING

The key to an auto-reference circuit is applying the trigger signal to command the reference to take place at the appropriate time. There are three levels of sophistication.

Figure 1. Sensor Errors

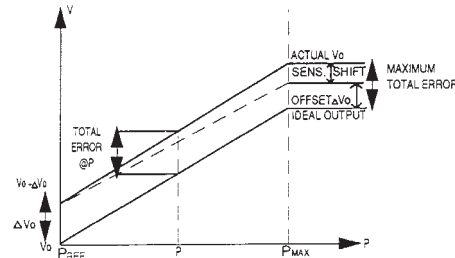


Figure 3. Auto-Referenced Signal

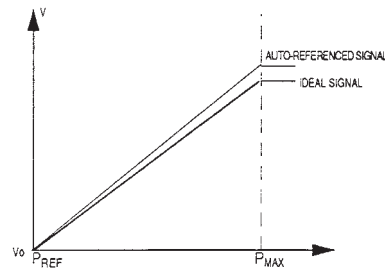


Figure 2. Common-mode Errors

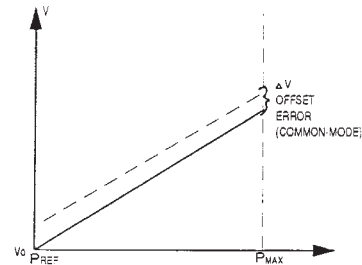
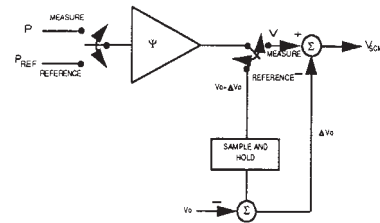


Figure 4. Basic Common-mode Auto-Referencing



# Pressure Sensors

## Pressure Sensor Auto-Referencing – Note #10

### Manual Command

The simplest auto-referencing method is the manual command. A momentary contact switch initiates the auto-zeroing sequence. This is the most restrictive method, as it requires the user to be present while the system is running in order to periodically reference the sensor. However, it could be done as part of a routine calibration procedure.

### Semi-automatic Command

The user initiates the action. After it is triggered, the system sequences through multiple functions controlled by timers or shift registers. This could include solenoid actuation to switch from measurement to reference pressure, followed by the auto-reference function, then a return to the measurement mode. Figure 4 illustrates a basic semi-automatic circuit.

### Automatic Command

The system steps through multiple functions similar to the semi-automatic command. However, on returning to the measurement mode, additional timing circuitry triggers and after a set measurement time the sequence is restarted. Depending upon the degree of complexity desired, a small microprocessor-based system and its related software could consolidate the auto-reference circuitry, timing and control logic all into one unit.

### ESTABLISHING A SYSTEM REFERENCE POINT

Batch processing and continuous processing are the two main categories of measurement cycle. In a batch process, a reference condition exists at some time, usually at system power-up. For example, a toilet tank has a high water level prior to flushing, corresponding to some reference pressure. When the flushing cycle is complete, the tank is filled to the previous level. The obvious point for auto-referencing is just prior to flushing when the water is at a known level. In a continuous process, there is no easily accessed reference condition. For example, the volume of fluid in a water tower is being monitored. This is a function of the depth of the water and can be sensed with a pressure sensor. Unlike the toilet, without actually taking a pressure measurement, there is no point in time at which the depth will be known.

The sensor/auto-reference/enable system can be used for a simple case when a known reference exists periodically. Also, a reference condition actuator such as a solenoid valve can be used. It can switch the sensor input from the measured pressure to some other reference pressure. The solenoid can be activated by the user, some condition such as power-up, or a timer activated circuit (see Figure 5). The valve must be activated long enough for the pressure to have a chance to stabilize so a valid reading may be taken. For instance, consider the water tower. A gage pressure sensor near the bottom senses the water depth. A vent tube to the surface serves as a pressure reference. A 3-way solenoid valve is the actuator, connecting the water and the vent to the sensor input port. A timer circuit is the enabler (see Figure 6).

Next, suppose the water exits through a single pipe of constant diameter. The velocity can be measured with a differential pressure sensor. A 2-way solenoid connected between the two inlet ports serves as the reference actuator as shown in Figure 7.

### CIRCUIT EXAMPLE

The simplest auto-reference case is where the enable command is given manually and the reference condition occurs naturally. Figure 7 is the block diagram, and Figure 8 shows the actual circuit. An 8-bit A/D converter performs the sample-and-hold function, and there are several op-amp summer configurations. No actuator, such as a solenoid valve, is necessary because the reference condition occurs naturally, and the user knows when it occurs. The manual enable is a simple pushbutton momentary contact switch.

This auto-zero circuit is designed for use with a high level sensor with a null output of 1V, such as MICRO SWITCH amplified pressure sensor products. The null specification is  $1V \pm 50mV$ . To guarantee the ability to auto-zero under virtually all conditions, the null range used in this design is  $1V \pm 100mV$ .

The sensor is at null output, the only time auto-zeroing is allowed. Null output ( $V_{null}$ ) ranges from 0.9 to 1.1V. At these levels, auto-zeroing requires voltage to be added in some cases and subtracted in others. To circumvent this, op-amp #1 is used as a level shifter and summer.

Figure 5. Auto-Reference with Reference Condition Actuators

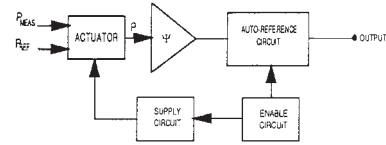


Figure 6. Timer Actuated Circuit, Single Port Sensor

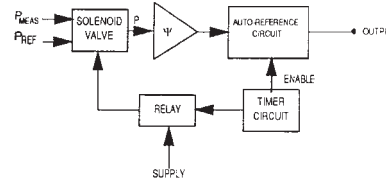
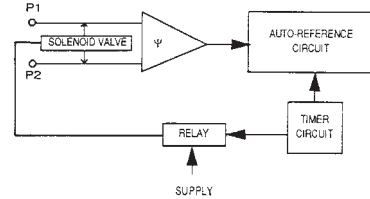


Figure 7. Timer Activated Circuit, Dual Port Sensor



100mV is added to the sensor output to shift the null range to 1.0 - 1.2V. Now, voltage need only be subtracted to provide auto-zeroing. The summer portion of op-amp #1 subtracts the auto-zero correction voltage ( $V_{corr}$ ) from this shifted null range and the auto-zeroed signal appears at  $V_{out}$ .

The output of op-amp #2 is  $V_{out} + V_{corr}$ . Since  $V_{out} = V_{null} + 100mV - V_{corr}$ , a simple substitution shows that the output is actually the shifted sensor null output,  $V_{null} + 100mV$ . Consequently, the input to the  $V_{in}$  pin on the A/D converter varies from 1 to 1.2V. The conversion range is properly scaled to 1 - 1.2V, to provide maximum possible resolution. With this scaling, a 1V input corresponds to a digital output of all zeros, and a 1.2V input provides all ones at the output. Each output bit is connected to a voltage follower to prevent exceeding the current drive capabilities of the A/D converter, which would pull down the voltage at the outputs. Each of the 8 bits is connected in an inverting summing amplifier configuration using op-amp #3. The negative feedback resistor has been selected such that the maximum digital output (all bits logic "1") provides an analog voltage of

# Pressure Sensors

## Pressure Sensor Auto-Referencing – Note #10

–200mV, and the minimum digital output (all bits logic “0”) provides an analog voltage of 0mV. This voltage is fed into op-amp #4 (a unity gain inverting amplifier), whose output is the offset correction voltage  $V_{corr}$ . It ranges from 0mV to 200mV when the shifted null output is 1V to 1.2V.  $V_{corr}$  is then subtracted from the shifted null output, resulting in the auto-zeroed value of 1.0V at  $V_{out}$ .

The A/D converter ADC0801 allows a great deal of flexibility in setting the dynamic voltage range of the analog input voltage.  $V_{in}^{(+)}$  varies from 1 to 1.2V. The 200mV span is set by applying a 100mV signal at  $V_{ref}/2$ . The 100mV signal is a temperature-stable voltage reference consisting of an LM336 voltage-reference and an LM124 op-amp circuit. The 1V offset is absorbed by applying a 1V signal to the  $V_{in}^{(-)}$  differential input pin, which can be made temperature stable in a similar fashion if so desired.

Commanding auto-zeroing is relatively simple. The WR pin on the ADC0801 should normally be at a high level. A pushbutton switch brings it to a low level, conversion begins and auto-zeroing occurs. When it is brought back to a high level, the digital outputs latch and remain at that level until auto-zeroing is again commanded.

This circuit is designed to auto-zero a signal of 1V = 100mV. Adjusting this range to suit your needs is simple. First, set the reference voltage at the output of op-amp #5 by adjusting the 50 ohm potentiometer value to set the span for the A/D converter. This provides the appropriate level shifting for the sensor null. Next, change the feedback resistor connected to op-amp #3 to provide the new correction voltage span. Then, if null offset is not 1V, change the  $V_{in}^{(-)}$  input to the new offset value. When the auto-zero range is changed, keep in mind that there is a trade-off. As the span increases, resolution of the correction decreases. The designer determines the allowable resolution for a given auto-zero application. If a greater resolution is necessary, either decrease the auto-zero range or switch to a larger bit A/D converter. Each additional bit will increase resolution by a factor of two.

### ACCURACY

Auto-referencing replaces common-mode error sources. The accuracy limits of the auto-reference circuit replace them. Accuracy is related to the resolution of the A/D converter and the reference drift over temperature is now only a function of the stability of the reference voltage applied to the A/D converter. With an 8-bit converter, the common-mode error can be reduced by as much as 250 times, leaving only the sensitivity shift (normal-mode) error. This is a significant improvement for the added cost involved. In any application where maximizing sensor accuracy is of value, consider an auto-referencing circuit.

Figure 8. Auto-Zero Circuit

