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Implementing Auto Zero for Integrated Pressure Sensors

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INTRODUCTION

This application note describes how to implement an auto–zero function when using a Motorola integrated pressure sensor with a microcontroller and an analog to digital converter (MCU and an A/D). Auto–zero is a compensation technique based on sampling the offset of the sensor at reference pressure (atmospheric pressure is a zero reference for a gauge measurement) in order to correct the sensor output for long–term offset drift or variation.

Sources of offset errors are due to device to device offset variation (trim errors), mechanical stresses (mounting stresses), shifts due to temperature and aging. Performing auto–zero will greatly reduce these errors. The amount of error correction is limited by the resolution of the A/D.

In pressure sensing applications where a zero–pressure reference condition can exist, auto–zero can be implemented easily when an integrated pressure sensor is interfaced to an MCU.

EFFECTS OF OFFSET ERRORS

Figure 1 illustrates the transfer function of an integrated pressure sensor. It is expressed by the linear function:

$$V_{OUT} = V_{OFF} + [(V_{FSO} - V_{OFF})/(P_{MAX} - P_{REF})]*P$$
$$= V_{OFF} + S*P.$$

Here, V_{OUT} is the voltage output of the sensor, V_{FSO} is the full–scale output, V_{OFF} is the offset, P_{MAX} is the maximum pressure and P_{REF} is the reference pressure. Note that ($V_{FSO} - V_{OFF}/P_{MAX} - P_{REF}$) can be thought of as the slope of the line and V_{OFF} as they y–intercept. The slope is also referred to as the sensitivity, S, of the sensor.
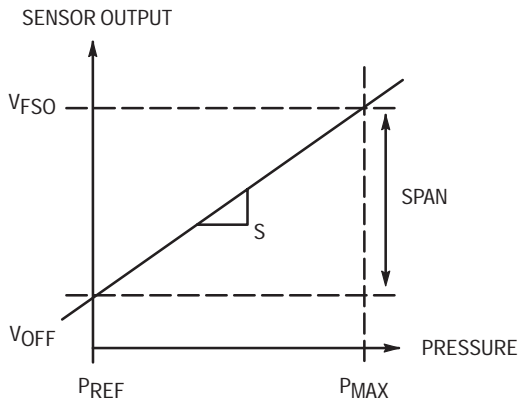

SENSOR OUTPUT

**Figure 1. Definition of Span, Full–Scale Output,
Offset and Sensitivity**

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A two–point pressure calibration can be performed to accurately determine the sensitivity and get rid of the offset calibration errors altogether. However, this can be very expensive in a high volume production due to extra time and labor involved. The system designer therefore designs a pressure sensor system by relying on the sensitivity and offset data given in the data sheet and using a linear equation to determine the pressure. Using the later, the sensed pressure is easily determined by:

$$P = (V_{OUT} - V_{OFF})/S.$$

If an offset error is introduced due to device to device variation, mechanical stresses, or offset shift due to temperature (the offset has a temperature coefficient or TCO), those errors will show up as an error, ΔP, in the pressure reading:

$$P + \Delta P = [V_{OUT} - (V_{OFF} + \Delta V_{OFF})]/S.$$

As evident in Figure 2, offset errors, ΔV_{OFF}, have the effect of moving the intercept up and down *without* affecting the sensitivity. *We can therefore correct this error by sampling the pressure at zero reference pressure (atmosphere) and subtracting this from the sensor output.*
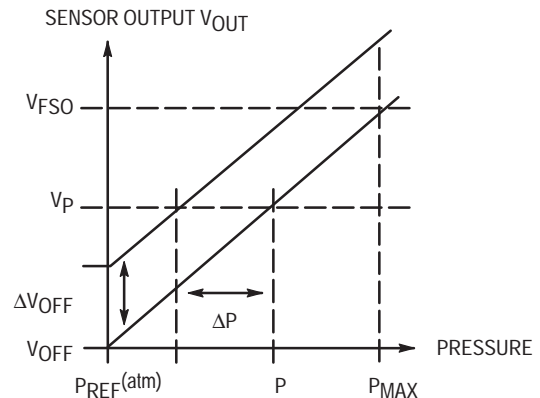

Figure 2. Effect of Offset Errors

AUTO–ZERO CONSIDERATIONS
IN APPLICATIONS

There is an important consideration when implementing auto–zero. In order to use this technique, *a zero pressure reference condition must be known to exist in the system.*

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There are a lot of applications that will lend themselves naturally to auto–zeroing. Typical applications are those that:

- experience a zero–pressure condition at system start up,
- are idle for a long time (zero pressure), take a pressure measurement then go back to idle again.

For example, in a water level measurement in a washing machine application, there is a zero pressure reference condition when the water in the tub is fully pumped out. Another application that is perfect for auto–zeroing is a beverage fill level measurement; a zero reference condition exists before the bottle is filled. HVAC air flow applications can also use auto–zeroing; before system start up, an auto–zero can be initiated. In other words, it can be used in applications where a zero pressure condition can exist in order to auto–zero the system.

An auto–zero command can be automated by the system or can be commanded manually. Each system will have a different algorithm to command an auto–zero signal. For example, using the beverage fill level measurement as an example, the system will auto zero the sensor before the bottle is filled.

IMPLEMENTATION OF AUTO–ZERO WITH A MICROCONTROLLER

Auto–zero can be implemented easily when the integrated sensor is interfaced to a microcontroller. The auto–zero algorithm is listed below:

1. Sample the sensor output when a known zero reference is applied to the sensor (atmospheric pressure is a zero reference for gauge type measurement). Store current zero pressure offset as CZPO.

2. Sample the sensor output at the current applied pressure. Call this SP.

3. Subtract the stored offset correction, CZPO, from SP. The pressure being measured is simply calculated as:

$$P_{MEAS} = (SP - CZPO)/S.$$

Note that the equation is simply a straight line equation, where S is the sensitivity of the sensor. The auto–zero algorithm is shown graphically in Figure 3.
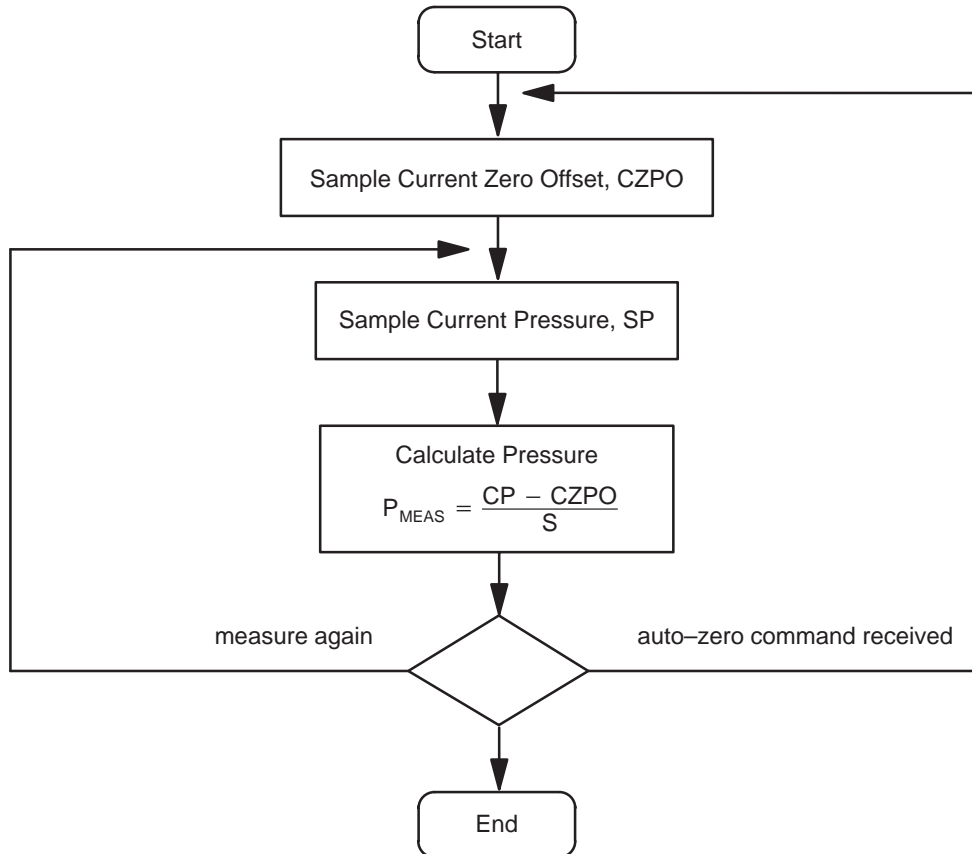

Figure 3. Flow–Chart of the Auto–Zero Algorithm

IMPROVEMENT ON OFFSET ERROR

In the following calculations, we will illustrate how auto–zero will improve the offset error contribution. We will use the MPX5006 interfaced to an 8–bit A/D as an example. When auto–zero is performed, the offset errors are reduced and the *resulting offset errors are replaced with the error (due to resolution) of the A/D.* We can categorize the offset error contributions into temperature and calibration errors.

Temperature Coefficient of Offset Error

The offset error due to temperature is due to Temperature Coefficient of Offset, or TCO. This parameter is the rate of change of the offset when the sensor is subject to temperature. It is defined as:

$TCO = (\Delta V_{OFF}/\Delta T)$.

The MPX5006 has a temperature coefficient of offset (normalized with the span at 25°C) of:

$\Delta TCO = (\Delta V_{OFF}/\Delta T)/V_{FS@25°C} = 0.06\%$ FS/°C.

As an example, if the sensor is subjected to temperature range between 10°C and 60°C, the error due to TCO is:

$\Delta TCO = (0.06\%$ FS/C$)*(60°C - 10°C) = \pm 3.0\%$ FS.

Offset Calibration Errors

Even though the offset is laser trimmed, offset can shift due to packaging stresses, aging and external mechanical stresses due to mounting and orientation. This results in offset calibration error. For example, the MPX5006 data sheet shows this as:

$V_{OFF\ MIN} = 0.100$ V,
$V_{OFF\ TYPICAL} = 0.225$ V and $V_{OFF\ MAX} = 0.430$ V.

We can then calculate the offset calibration error with respect to the full scale span as:

$\Delta V_{OFF\ MIN,MAX} =$
$(V_{OFF\ TYPICAL} - V_{OFF\ MIN,MAX})/V_{FS}$.

This results in the following offset calibration error,

$\Delta V_{OFF\ MIN} = 2.7\%$ FS and
$\Delta V_{OFF\ MAX} = 4.5\%$ FS.

A/D Error

As mentioned above, we can reduce offset errors (calibration and TCO) when we perform auto–zero. These errors are replaced with the A/D error (due to its resolution),

$\Delta OFFSET_{AUTOZERO} = \Delta TCO + \Delta OFFSET = \Delta A/D$.

Typically, a sensor is interfaced to an 8–bit A/D. With the A/D reference tied to $V_{RH} = 5$ V and $V_{RL} = 0$ V, the A/D can resolve 19.6 mV/bit. For example, the MXP5006 has a sensitivity of 7.5 mV/mmH$_2$0, the resolution is therefore,

$A/D_{RESOLUTION} = 19.6$ mV/bit)/(7.5 mV/mmH$_2$0)
$= 2.6$ mmH$_2$0/bit.

Assuming $+/-1$ LSB error, the error due to digitization *and* the resulting offset error is,

$\Delta A/D = \Delta OFFSET_{AUTOZERO} = 2.6$ mmH$_2$0/612 mmH$_2$0
$= +/- 0.4\%$ FS.

It can be seen that with increasing A/D resolution, offset errors can be further reduced. For example, with a 10–bit A/D, the resulting offset error contribution is only 0.1% FS when auto–zero is performed.

If auto–zero is to be performed only once and offset correction data is stored in non–volatile memory, the TCO offset error and calibration error will not be corrected *if* the sensor later experiences a wide temperature range or later experience an offset shift. However, if auto–zero is performed *at* the operating temperature, TCO error will be compensated although subsequent offset calibration error will not be compensated. It is therefore best to auto–zero as often as possible in order to dynamically compensate the system for offset errors.

CONCLUSION

Auto–zero can be used to reduce offset errors in a sensor system. This technique can easily be implemented when an integrated pressure sensor is interfaced to an A/D and a microcontroller. With a few lines of code, the offset errors are effectively reduced; the resulting offset error reduction is limited only by the resolution of the A/D.

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