Dynamic Temperature Compensation For Pressure Sensors

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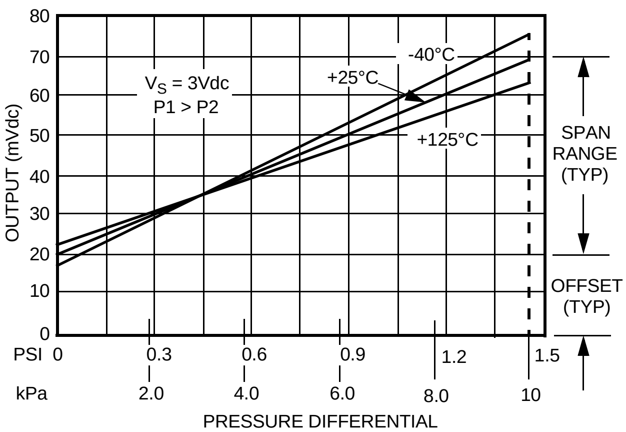
Introduction

One of the fundamental tasks when dealing with any type of sensors would be the compensation of offset and span *drift* in regards to *temperature*. Looking at a typical pressure sensor, we may come across the following thermal behavior:

Figure 1. Output vs. Pressure Differential[1]



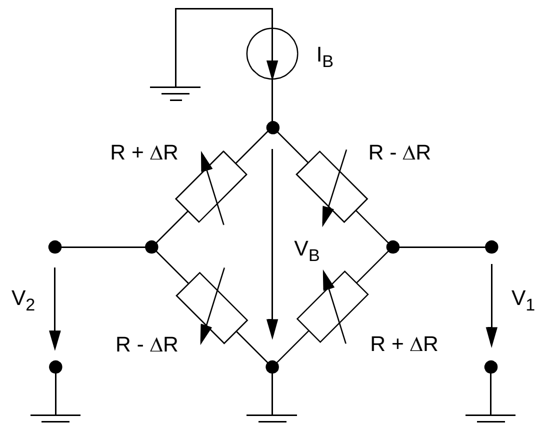
The above curve easily demonstrates the relationship between temperature, offset and span: with the increase of temperature, span is reduced while offset is increased. The traditional way to deal with this drift would be to build up a simple signal conditioning circuit that would be calibrated at a reference temperature (usually at 20°C), followed by a characterization of the complete (analog) system (sensor + signal conditioner) across the whole dynamic temperature range. The measured curve would then be uploaded in a nonvolatile lookup table that provides a compensational value. This value would then be used in order to correct the drift in the digital domain. More complex systems could also use this value in order to retune span and offset in the analog domain as a function of temperature in a dynamic way.[2]

Another alternative way to deal with this issue would be by using a *dynamic* current source, with a thermal behavior that compensates the sensor's drift. With this analog approach, the sensor's overall performance would dramatically increase.

The Pressure Sensor

The typical block diagram for a standard pressure sensor driven with a current source could look as follows:

Figure 2. Pressure Sensor Block Diagram



Under *ideal* conditions both resistor parameters *R* and Δ*R* would be exactly the same for each sector of the bridge; the total resistor value R_B for one sensor would then be:

$$R_B = (R + \Delta R + R - \Delta R) \parallel (R + \Delta R + R - \Delta R) = R = \frac{V_B}{I_B} \quad (1)$$

The above relationship clearly demonstrates that an *ideal* pressure sensor will not change its resistor value with changing pressure (=>Δ*R*), but *should be totally balanced*. In such a case, the differential voltage $V_D = V_1 - V_2$ could be determined with the following matrix:

$$\begin{bmatrix} \frac{2R}{R^2 - \Delta R^2} & - \\ - & \frac{2R}{R^2 - \Delta R^2} \end{bmatrix} \bullet \begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} \frac{1}{R - \Delta R} \\ \frac{1}{R + \Delta R} \end{bmatrix} \bullet V_B \quad (2)$$

This term leads to the following relationship between V_1 and V_2:

$$V_D = V_1 - V_2 = \frac{\Delta R}{R} V_B \quad (3)$$

1. Motorola MPX (V) 10
2. For further details on how to dynamically calibrate and compensate span and offset in the analog domain by using a *constant voltage source*, pls. refer to *Adaptive Sensor Biasing*, Intersil App-Note, April 2002, by Dr. Axel Kleinitz

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The Impact of Temperature

The above mentioned discussion did not take into consideration any possible thermal drift, since we were initially dealing with ideal components. However, as Figure 1 clearly pointed out, a standard pressure sensor will face *significant* changes in terms of its span and offset with temperature. Assuming a linear behavior[1], this impact will have an effect on equation (1) in the following way:

$$R_B = R_{(T)} = \left(1 + \frac{T}{\Delta T}\right) R_0 = \frac{V_B}{I_B} \qquad (4)$$

Instead of dealing with a constant value we now add a temperature depending, proportional factor. Equation (3) essentially implies a linear dependency of V_D with respect to ΔR, that is, the effect of pressure. However, assuming a first order characteristic[2] of the offset in regards to temperature, equation (3) needs to be modified in the following way:

$$V_D = V_{D(\Delta R,T)} = \frac{\Delta R}{R_{(T)}} V_B + \left(1 + \frac{T}{\Delta T}\right) k V_B \qquad (5)$$

1. This assumption is valid, at least within the operating temperature range
2. In analogy to equations (1) and (4)

While $\frac{R_0}{\Delta T}$ would represent the Temperature Coefficient (= TC) of the bridge resistor value, $k\frac{V_B}{\Delta T}$ reflects the TC of the sensor's offset. Using both terms, equation (4) and (5) we will get a useful expression in order to demonstrate to link between V_D and I_B in the following way:

$$V_D = V_{D(\Delta R,T)} = \left[\Delta R + \left(1 + \frac{T}{\Delta T}\right)^2 k R_0\right] I_B \qquad (6)$$

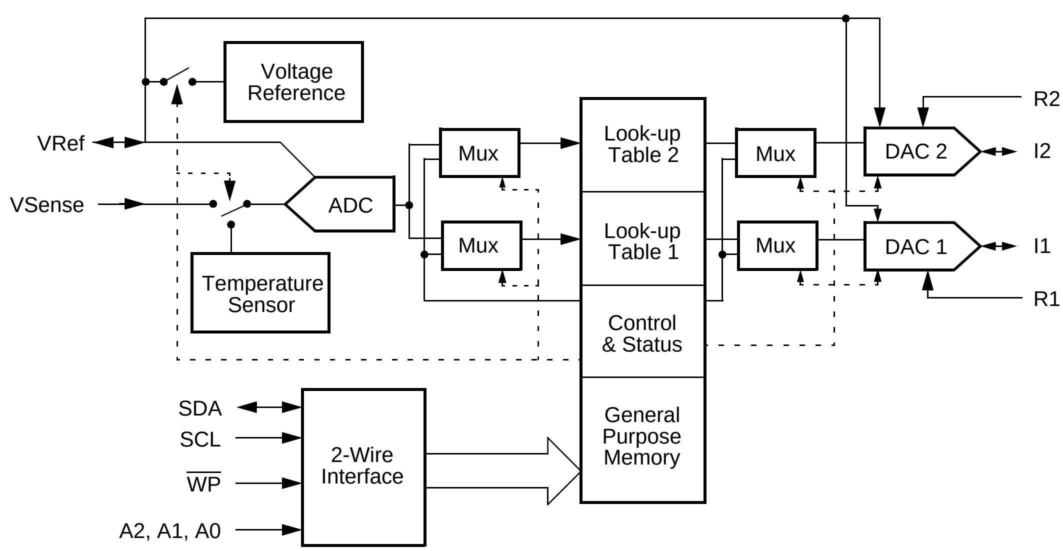
The differential voltage V_D is now not only a function of pressure ($\Rightarrow \Delta R$), but also a function of temperature ($\Rightarrow \frac{T}{\Delta T}$). This drift has to be compensated by a *dynamic* I_B.

The Solution

The requirement of a *dynamic current source* would traditionally be solved with a VBE-Multiplier right on top of the sensor bridge. The main issue in such a case would be the correct selection of the transistor (TC characteristic) and proper resistor values (voltage divider value of the transistor's Basis) in order to provide an adequate thermal characteristic that would compensate the sensor's drift.

An alternative, more elegant approach would be using a lookup-table driven current source, such as the X9530 of Intersil. The block diagram of this concept is shown below.

Figure 3. X9530 Block Diagram



The signal flow for the above shown device is very simple: an incoming analog signal V_{Sense} (like the voltage provided by a temp sensor) or the value provided by the internal thermal sensor will be converted into a digital value through the ADC. This will represent a specific address of the look-up-table that will contain a compensational value. Once the correction has been finished the corresponding output DAC 1 or 2 will be recalibrated.

Keeping in mind what had been said before, the only action that is required would be the storage of appropriate compensational factors in the memory sectors 1 and 2 based upon the relationship pointed out through the equation (6). This can be performed through the I^2C interface. However, once the proper values are uploaded, there won't be any further need for an interacting µC. If desired, the measured temperature value can be requested and read out through the same interface. Finally, two independent outputs can simultaneously be driven based upon two independent table sectors in order to correct two unlinked analog parameters.

This product is available with a variety of options, as pointed out in the next matrix:

Figure 4. Sensor Conditioners Product Range

Device	Int. Temp. Sensor	Ext. Sensor Input	V_{Ref} I/O	1K Memory E^2PROM	LU-Table Org.	# DAC Outputs
X9530	yes	yes	yes	yes	Dual	Dual
X96010	no	yes	yes	no	Dual	Dual
X96011	yes	no	no	no	Single	Single
X96012	yes	yes	yes	yes	Dual	Dual

The internal temperature sensor's ADC resolution will address an accuracy level of 6 Bit (64 values), which represents $2.22\frac{K}{step}$ for a thermal range of -40°C ≤ T ≤ +100°C. Under normal conditions, this should be more then enough for these type of applications. A limitation of the operating temperature range would obviously increase the available ADC's precision.

The maximum DAC output current would be of ± 1.6 mA with an accuracy of 8 Bit (256 values). This reflects a precision of $6.27\frac{\mu A}{step}$. The DAC's polarity can independently be selected in order to provide a current sink or current source.

Depending upon the complexity of the system and the board's physical dimensions, a solution with internal temp sensor, internal reference voltage, general purpose memory and one or two independent DAC outputs has to be selected.

Conclusion

The above concept combines therefore the advantages of a digital approach (flexibility through programmability) and the benefits of an analog solution (reduction of total error). The available options and combinations will help to select best fitting solution for a given system. The above presented solutions are meant to cover the traditional requirements of sensor signal conditioning.

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