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

![Graph showing output vs. pressure differential.](image)

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.

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

![Block diagram of a pressure sensor with current source.](image)

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

\[
R_B = (R + \Delta R + R - \Delta R) / (R + \Delta R - R - \Delta R) = R = \frac{V_B}{I_B} \quad (1)
\]

The above relationship clearly demonstrates that an ideal pressure sensor will not change its resistor value with changing pressure (\( \Rightarrow \Delta R \)), 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:

\[
\begin{bmatrix}
\frac{2R}{R^2 - \Delta R^2} \\
-\frac{2R}{R^2 - \Delta R^2}
\end{bmatrix}
\begin{bmatrix}
V_1 \\
V_2
\end{bmatrix} =
\begin{bmatrix}
1 \\
R + \Delta R
\end{bmatrix}
\begin{bmatrix}
V_B
\end{bmatrix}
\]

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

\[
V_D = V_1 - V_2 = \frac{\Delta R}{R} V_B 
\]

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
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:

\[
R_B = R_{(T_i)} = \left(1 + \frac{T}{\Delta T}\right) R_0 = \frac{V_B}{I_B} \tag{4}
\]

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 \(\Delta R\), 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:

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

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

The differential voltage \(V_D\) is now not only a function of pressure \((\Rightarrow \Delta R)\), but also a function of temperature \((\Rightarrow \Delta T)\). 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.
The signal flow for the above shown device is very simple: an incoming analog signal $V_{\text{Sense}}$ (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 I2C 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**

<table>
<thead>
<tr>
<th>Device</th>
<th>Int. Temp. Sensor</th>
<th>Ext. Sensor Input</th>
<th>$V_{\text{Ref}}$ I/O</th>
<th>1K Memory E2PROM</th>
<th>LU-Table Org.</th>
<th># DAC Outputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>X9530</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>Dual</td>
<td>Dual</td>
</tr>
<tr>
<td>X96010</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
<td>Dual</td>
<td>Dual</td>
</tr>
<tr>
<td>X96011</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>Single</td>
<td>Single</td>
</tr>
<tr>
<td>X96012</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>Dual</td>
<td>Dual</td>
</tr>
</tbody>
</table>

The internal temperature sensor’s ADC resolution will address an accuracy level of 6 Bit (64 values), which represents $\frac{K_{\text{step}}}{2}$ for a thermal range of $-40°C \leq T \leq +100°C$. Under normal conditions, this should be more than 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 $\pm 1.6$ mA with an accuracy of 8 Bit (256 values). This reflects a precision of $\frac{6.27 \, \mu A_{\text{step}}}{2}$. 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.