AN402

SENSOR CALIBRATION FOR LOW COST BAROMETERS APPLICATION NOTE

1 PURPOSE

The purpose of this document is to provide an estimation of the residual errors in a typical pressure sensor application caused by the process dependent production variations in sensor properties (e.g. Span, Offset, TCOffset). As these errors depend on the calibration strategy, different calibration methods are investigated.

The primary focus is on low cost barometer applications were only the trend is displayed and absolute pressure accuracy is thus of less importance compared to the temperature stability of the calibration.

Note that these calculations only consider the statistical part of the residual error caused by statistical variations of sensor Span, Offset, TC of Span and TC of Offset. Systematic effects (e.g. a constant nonlinearity of the sensor) are not taken into account as they can in principle be compensated for in the application software nor are statistics of higher order (e.g. variations in the nonlinearity versus pressure or temperature).

Some of the compensation calculations described below require knowledge of the sensor temperature. The calculations below do not consider the effect of errors in the temperature measurements on the compensated pressure. Even though these effects are small when the temperature measurement is calibrated together with the pressure calibration, they may have to be added to the total budget.

Errors caused by statistical variations of device parameters in the electronic circuitry are not taken into account either and might have to be added depending on the components used.

The numerical calculations are based on the datasheet of the MS7801-A.

2 APPROACH

The sensor output voltage Vp is assumed to follow a simple linear function:

$$Vp[p,T] = (p * Sens[T] + Off[T]) * Vs$$

P = pressure [mbar]
Sens = Sensitivity [mV/V/mbar]
Off = Offset [mV/V]
Vs = Supply-voltage [V]

For the Sensitivity and the Offset a simple linear temperature dependency is assumed:

$$Sens[T] = Sens0 * (1 + TCS * (T - 25C))$$
$$Off[T] = Off0 + TCO * (T - 25C)$$

Sens0 = Sensitivity at 25 °C
Off0 = Offset at 25 °C
TCS = TC of Sensitivty [ppm/K]
TCO = TC of Offset [mV/V/K]
T = sensor temperature in degC

The calibration of each individual sensor allows compensating for some or all of the process variations, depending on the complexity of the calibration. Mathematically the calibration corresponds to the creation of a new variable Vc[p,T] with some or all of the process variations eliminated. The exact form of Vc[p,T] depends on the calibration procedure (see below).

In order to estimate the residual error after calibration caused by the uncompensated process variations, the statistics of Vc[p,T] are calculated and transformed to the corresponding pressure error.

$$dP[p0,T0] = \sqrt{\sum_x \left(\frac{\partial Vc[p0,T0]}{\partial x} \frac{\partial p0}{\partial Vc[p0,T0]} \varepsilon_x\right)^2}$$

dP[p0,T0] corresponds to the distribution (e.g. 4*sigma) of the displayed pressure to be expected at p0, T0 on the ensemble of all sensors calibrated as described by the particular form of Vc[p,T]. □x is the process distribution (e.g. 4 sigma) of the sensor parameter x (e.g. Off, Sens).

For low-cost barometer applications the absolute pressure accuracy is of less importance compared to an apparent pressure variations caused by a temperature change (imperfect temperature compensation).

The distribution dTC[p0,T0] (e.g. 4*sigma) of the uncompensated temperature dependency of the displayed pressure (e.g. mbar/K) at T0, p0 on the ensemble of all sensors is calculated as:

$$dTC[p0,T0] = \sqrt{\sum_x \left(\frac{\partial^2 Vc[p0,T0]}{\partial T \partial x} \frac{\partial p0}{\partial Vc[p0,T0]} \varepsilon_x\right)^2}$$

In the following sections the properties dP[p0,T0] and dTC[p0,T0] will be calculated for different calibration strategies.

3 SENSOR DATA

For the numerical calculation the following properties of the MS7801-A have been derived from the datasheet DA7801_006:

Parameter	Value	Unit
Sens0	150/5/1000	mV/V/1000mbar
Off0	0	mV/V
TCS	-1900	ppm/K
TCO	0	µV/V/K
ε_{Sens0}	30/5/1000	mV/V/1000mbar
ε_{Off0}	40/5	mV/V
ε_{TCS}	400	ppm/K
ε_{TCO}	80/5	µV/V

ε_x was chosen such that +/- ε_x covers the whole spec. The calculated +/-dP[p0,T0] and +/-dTC[p0,T0] can thus also be considered to cover the distribution after calibration.

4 CALIBRATION

4.1 Single point calibration

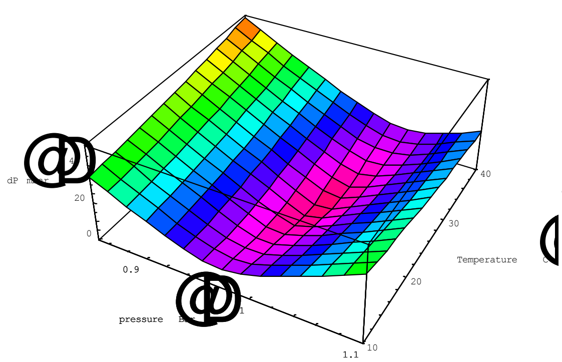
The calibrations in this section require calibration at a single point only (i.e. single pressure, single temperature).

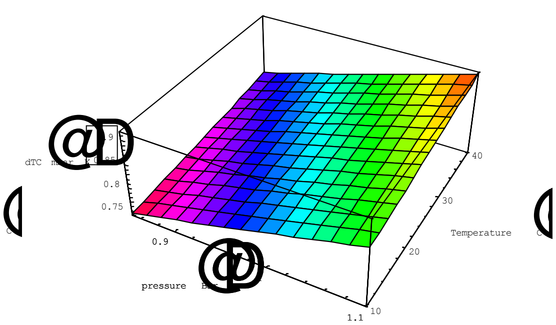
4.2 Span calibration

By defining

$$Vc[p,T] = \frac{V[p,T]}{V[1bar,25C]}$$

process variations of the span are largely reduced.
In this case the calculations described above yield:





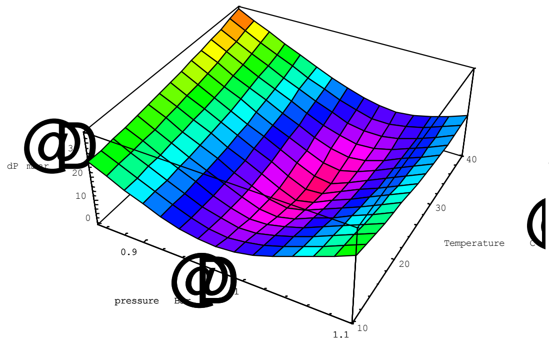
It can be seen that with this calibration concept absolute pressure errors of up to +/-45mbar and statistical TC variations of up to +/-0.9mbar/K have to be expected in the range 800mbar ... 1.1bar and 10C ... 40C.

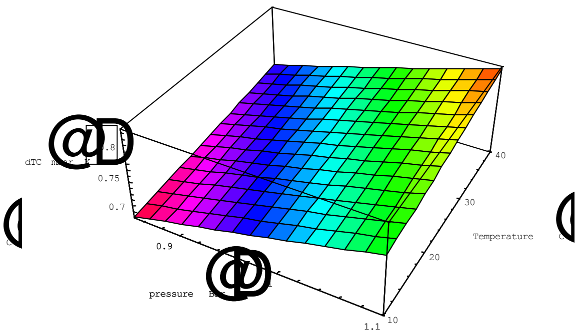
s4.1.2 Offset calibration

A different approach would be to eliminate most of the offset variations by defining

$$Vc[p,T] = V[p,T] - V[1bar,25C]$$

In this case the calculations described above yield:





In the considered range 800mbar ... 1.1bar and 10°C ... 40°C the results are very similar to the Span Calibration

4.2 2 points calibration

2 point calibrations include calibrations at 2 pressures and a single temperature or 2 temperatures for a single pressure.

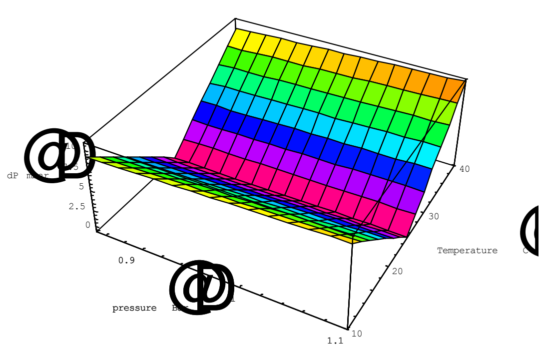
4.2.1 Calibrating Span and Offset by measurements with 2 pressures at a single temperature

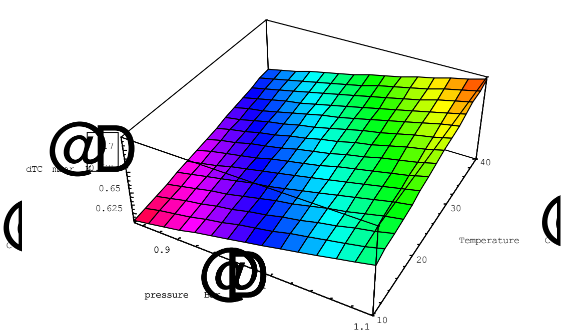
In most circumstances these kinds of calibration can be done more easily (quickly) than the opposite (i.e. 2 temperatures for the same pressure). Even if the temperatures for the 2 pressures are not exactly identical this can be compensated for. The goal is to have to significantly different pressures (compared to the pressure range of interest) while the 2 temperatures are close (compared to the temperature range of interest).

By defining

$$Vc[p,T] = \frac{V[p,T] - V[1bar,25C]}{V[1bar,25C] - V[0.8bar,25C]}$$

we obtain:





As can be expected the absolute error is zero at 25°C (the temperature of calibration). In the whole range of interest (800 mbar ... 1.1 bar and 10°C ... 40°C) the absolute error can rise to +/- 10 mbar. The maximum statistical TC is of about +/-0.7 mbar/K.

4.2.2 2 points Calibration at 2 different temperatures

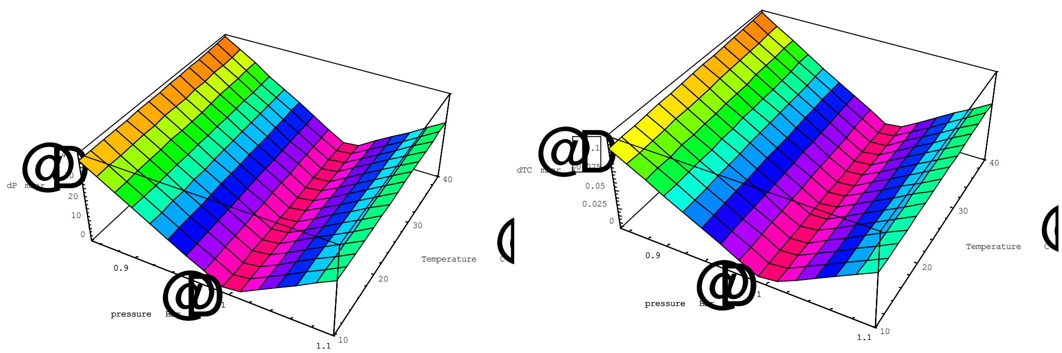
When deciding to calibrate with 2 measurements at 2 different temperatures it is possible to compensate for Offset variations or Span variations (similar as in the case of single point calibrations)

4.2.2.1 Calibrating Span at 2 temperatures

By defining

$$Vc[p,T] = \frac{V[p,T]}{V[1bar,10C] + \frac{V[1bar,40C] - V[1bar,10C]}{40C - 10C} * (T - 10C)}$$

we obtain



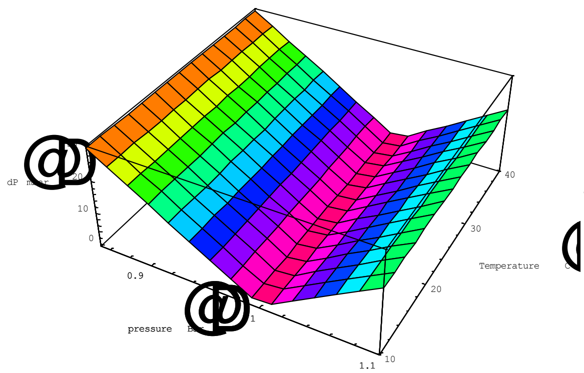
As can be expected the absolute error at 1 bar is zero for all temperatures. Over the whole range of interest (800 mbar ... 1.1 bar and 10°C ... 40°C) the absolute error is up to +/-40 mbar which is close to the result of a single point calibration. The statistic in uncompensated TC are however significantly better than for a single point calibration.

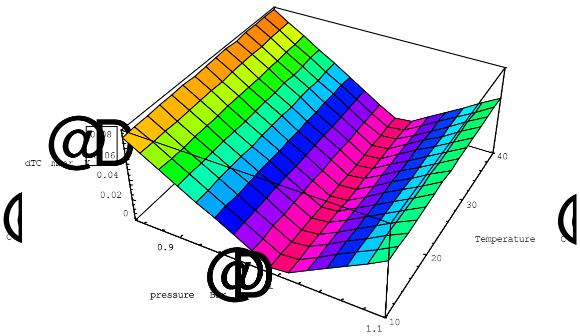
4.2.2.2 Calibrating offset at 2 temperatures

By defining

$$Vc[p,T] = V[p,T] - \left(V[1bar,10C] + \frac{V[1bar,40C] - V[1bar,10C]}{40C - 10C} * (T - 10C)\right)$$

we obtain:





Qualitativly the result is similar to the 2 point Span calibration. Quantitatively the result is slightly better in the range 800 mbar ... 1.1 bar and 10°C ... 40°C.

4. 3 4 pointCalibration

As the linear sensor model contains 4 independent parameters (i.e. Sens0, Off0, TCS and TCO) a calibration with 4 independent measurements allows eliminating all process variations.

By defining

$$Sens0C = \frac{V[1.1bar,25C] - V[0.85bar,25C]}{0.25bar} * \frac{1}{Vs}$$

$$TCSc = \frac{\frac{V[1.1bar,25C] - V[0.85bar,25C]}{0.25bar} - \frac{V[1.1bar,10C] - V[0.85bar,10C]}{0.25bar}}{15C * \frac{V[1.1bar,25C] - V[0.85bar,25C]}{0.25bar}}$$

$$Off0c = V[1.1bar,25C] * \frac{1}{Vs} - Sens0c * 1.1bar$$

$$TCOc = \frac{V[1.1bar,10C] * \frac{1}{Vs} - Off0C - 1.1bar * Sens0c(1 + (10C - 25C) * TCSc)}{-15C}$$

$$Vc[p,T] = \frac{(T - 25C)TCO + Off0Cs - V[p,T]/Vs}{Sens0C(1 + (T - 25C)TCSc)}$$

Both the absolute error and the statistical TC is zero according to the simplified model.

5 CONCLUSION

The above calculations show that according to the simplified linear model described above a single point calibration will result in sensor to sensor variations of the calculated pressure of up to +/-40 mbar. The TC of the calibrated sensor signal can vary by about +/-0.9 mbar/K from sensor to sensor. Thus a temperature change of 10 K could create an apparent pressure change of up to +/-9 mbar. This is probably unacceptable even for a low cost barometer displaying only trends.

A calibration at 2 pressures but only a single temperature reduces the absolute error to about +/-10 mbar. The uncertainty due to temperature changes is however only slightly reduced (about 0.7 mbar/K compared to 0.9 mbar/K for a single point calibration). For a trend displaying barometer application a calibration with 2 pressures at the same temperature is thus no significant improvement compared to a single point calibration.

With a 2 point calibration at 2 different temperatures the absolute error can be reduced to about +/-30 mbar. The uncertainty in the TC is reduced to about +/-0.08 mbar/K corresponding to an improvement of about a factor 10 compared to a single point calibration or a 2 point calibration at a single temperature.
This performance may just about be acceptable for a trend displaying barometer. For this type of calibration the compensation of the Offset is slightly preferable compared to the compensation of the Span.

With a 4 point calibration as performed by Intersema for the MS5534-C (2 pressures at 2 temperatures) all process variations of the simple model can be eliminated.

The exact choice of the calibration points is of less importance. They should be chosen to be sufficiently separated and symmetric with respect to the operating range.
It is also not absolutely necessary to set the conditions precisely to the preselected values as long as the calibration conditions are known and can be taken into account during calibration.

REVISION HISTORY

Date	Revision	Type of changes
17.12.2002	01	Initial release
15.10.2010	02	Change to MEAS logo and layout
20.06.2011	03	Insertion of the mention TM in the logo, modification of Shenzhen zip code

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