Simple calibration for ceramic sensing elements using an ME651

This article describes in detail a simple electronic circuit based on a suitable IC and few external components to amplify and to calibrate the offset- and fullspan-signal of ceramic sensing elements. The aim is to create a ready-to-mount sensor system with a ratiometric output signal and a suitable level of precision without a temperature compensation.

Sensor system

(ME651 and AM457)

In the example application described here a monolithic ME651 ceramic resistive pressure measurement cell [1] with a thick-film resistance Wheatstone bridge is used as a sensing element (see Figure 1). The pressure range is 2bar, gage and bridge resistance is specified as being 10kΩ and the supply voltage is set to 5V.
The example is not fixed in the ME651, it is applicably to all ceramic sensing elements.

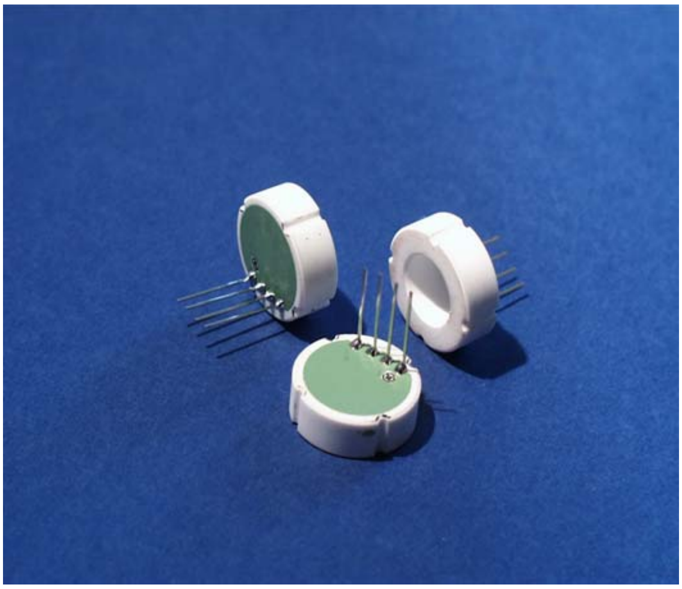

Figure 1: **Ceramic sensing element ME651**

In order to be able to amplify and to calibrate the offset and span of the sensing element a simple network was developed using the high-precision amplifier AM457 from Analog Microelectronics in Mainz, Germany (see Figure 2). The whole signal conditioning circuit consists of the ceramic sensing element, the integrated circuit AM457, also 4 resistors and a minimum of 2 capacitors (see the AM457 data sheet [2]).

The AM457 IC is used as a ratiometric amplifier to convert the ME651 output signal from ca. 10mVFS to an output signal of 4.5V. The zero point value is 0,5V and the full scale signal is 4,5V.

The electronic components were able to be mounted on a round printed board (Ø 14mm) which was adapted to correspond to the assembly guidelines for the ceramic sensing element.

Using the components listed above a compact module was developed which is hereinafter referred to as the sensor system. This system can be mounted onto a package whose proportions are given on the AMSYS website.

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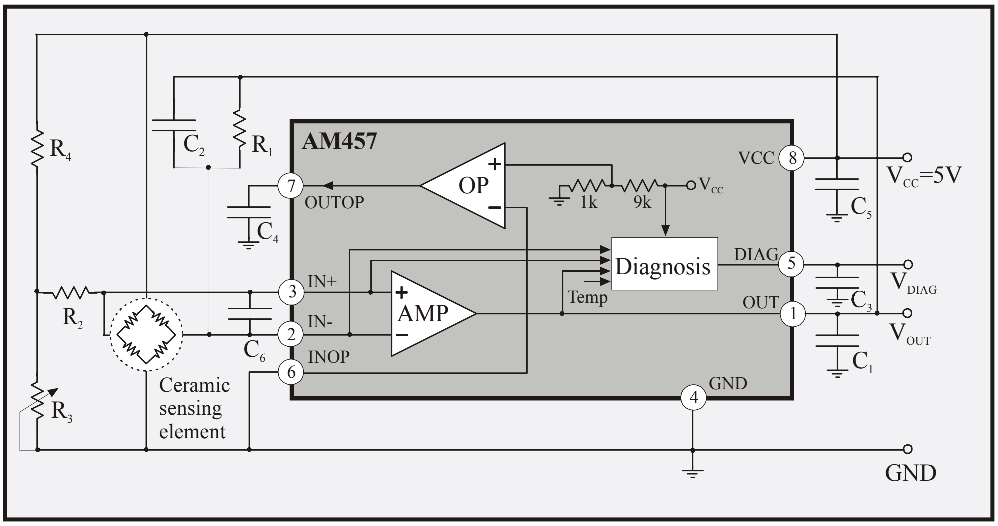

Figure 2: Circuit for the signal conditioning of the ceramic sensing element ME651 using the AM457 amplifier IC

Dimensioning

The circuit can be dimensioned with the aid of formulae (1) to (3). These are calculated using a model which is based on the classic Wheatstone bridge circuit of four resistors. These three simple equations allow us to calibrate the system with a minimum of data pertinent to the sensing element.

The formulae used are:

$$R_1 = R_2 = \frac{2 \cdot R_B}{5 \cdot d_{RS}} \text{ (k}\Omega\text{)} \qquad \text{Span adjustment} \quad (1)$$

$$R_4 = \frac{R_1}{100} \text{ (k}\Omega\text{)} \qquad \text{Auxiliary resistor} \quad (2)$$

$$R_3 = \frac{(-8 \cdot d_{RO} + d_{RS}) \cdot R_4}{8 \cdot d_{RO} + 9 \cdot d_{RS}} \text{ (k}\Omega\text{)} \qquad \text{Zero point adjustment} \quad (3)$$

whereby the following applies to the individual sensing elements:

R_B – Bridge resistance in ohms
d_{RS} – Span/supply voltage in mV/V
d_{RO} – Offset/supply voltage in mV/V

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In order to calculate the discrete adjusting resistors the offset, span and bridge resistance of the sensing element to be calibrated are first determined at room temperature and a supply voltage of 5V. The sensing element is then connected up to an AM457 to form the circuit illustrated in Figure 2. Resistors R_1 to R_4 are dimensioned according to the given formulae. The values of the capacitors are selected according to Table 1.

Name	Value	Notes
C_1	1nF	
C_2	100pF	
C_3	3.3nF	Optional
C_4	1nF	Optional
C_5	100nF	Optional
C_6	470pF	Optional

Table 1: Capacitor values

Using the calculated resistances the zero point U_{FP1} and the full scale signal U_{FS1} are now set with a good precision for a sensing element with a four resistors Wheaststone bridge.

As standard ceramic sensing elements have extra resistors in addition to the four bridge resistors there is a discrepancy between the model and the sensing element, demonstrated by the fact that the zero point U_{FP1} and the full scale signal U_{FS1} do not yet match the setpoint. They should thus be treated as approximations.

This discrepancy is accounted for in the calibration procedure described in the following by correcting the discrete adjusting resistors.

The obtained zero point value U_{FP1} is corrected to the target value of U_{FP2} = 0.5V by trimming resistor R_3 (e.g. potentiometer). As the zero point- and full-scale signal are dependent in a linear correlation, when the offset is adjusted the full-scale signal also changes to the value U_{FS2}. So that this value can be corrected the relevant span resistors R_1 and R_2 must then be adjusted. As the given formulae designate linear functions, these resistors can simply be corrected to the obtained full-scale value of U_{FS2} using the ratio Target(Full-scale)Value U_{SOLL}, whereby the circuit is now set.

Dimensioning example

1. Determining the offset, span and bridge resistance of the ceramic sensing element

The measurement results of the sensing element are:

Offset (0 bars) = -0.096mV
FS (2 bars) = +11.53mV
Span = +11.63mV
R_B = +10.56kΩ

2. Calculating d_{RO} and d_{RS}

d_{RO} = Offset/5V = -0.019mV/V
d_{RS} = Span/5V = +2.33mV/V

3. Dimensioning resistors R_1, R_2, R_3 and R_4

Dimensioning the span resistors according to Formula (1):

$$R_1 = R_2 = \frac{2 \cdot R_B}{5 \cdot d_{RS}} = 1.81\,\mathrm{M\Omega}$$

According to Formula (2) auxiliary resistor R_4 is calculated as follows:

$$R_4 = \frac{R_1}{100} = 18.1\,\mathrm{k\Omega}$$

Dimensioning offset resistor R_3 according to Formula (3):

$$R_3 = \frac{(-8 \cdot d_{RO} + d_{RS}) \cdot R_4}{8 \cdot d_{RO} + 9 \cdot d_{RS}} = 2.17\,\mathrm{k\Omega}$$

NB: Discrepancies between the setpoint value and the theoretical value enter the offset error proportionally. It is thus recommended that the resistors are partitioned as graded series resistors.

With the real resistors R_1 = R_2 = 1.81MΩ, R3 = 2.17kΩ and R_4 = 18.18 kΩ the following measurement values are obtained for the sensor system:

P_{MIN1} (0 bars) → U_{FP1} = 0.70V
P_{MAX1} (2 bars) → U_{FS1} = 4.48V

4. Correcting the resistances of resistors R_1, R_2, R_3 and R_4

Looking at these values we can see that the zero point value U_{FP1} for P = 0 bars is ca. 40% too high with regard to the setpoint of 0.5V; this is down to the discrepancy between the model and the actual resistor structure of the ceramic sensing element. The next step in the process is thus to adjust offset U_{FP2} for P = 0 to the setpoint by trimming the resistance of R_3. In the given example the value U_{FP2} = 0.5V has been set using $R_{3,KORR}$ = 1.2kΩ.

Measurement values for P = 0 and P = 2 bars after trimming R_3 to $U_{OFF2} = 0.5V$:

P_{MIN2} (0 bars) → $U_{FP2} = 0.50$ V
P_{MAX2} (2 bars) → $U_{FS2} = 4.28$ V

Due to the linear dependency of the zero point offset and full scale signal in the network developed here U_{FS} changes by the same amount as U_{FP}. For production purposes this means that the value P_{MAX2} (pressure measurement) no longer has to be measured.

As the correlations are linear, resistors R_1 and R_2 can also be corrected linearly.

Calculating the X_{FS} correction factor for resistors R_1 and R_2:

$$X_{FS} = \frac{U_{FS,SOLL}}{U_{FS2}} = \frac{4.5V}{4.28V} = 1.05$$

Calculating the new corrected values for R_1 and R_2:

$$R_{1,KORR} = R_{2,KORR} = \frac{2 \cdot R_B}{5 \cdot d_{RS}} \cdot X_{FS} = 1.90\text{M}\Omega$$

Measuring the new calibrated $U_{FS,KAL}$ voltage with corrected resistances $R_{1,KORR}$ and $R_{2,KORR}$:

P_{MIN2} (0 bar) → **U_{FP2} = 0.493V**
P_{MAX2} (2 bar) → **$U_{FS,KAL}$ = 4.468V**

Calibration errors:

Zero point error:
0.493V – 0.5V = -0.007V which is equivalent to 0.16%FS

Full scale error:
4.468V – 4.5V = -0.032V which is equivalent to 0.71%FS

Measurements

The sensor system compensated for using corrected resistors R_1, R_2, R_3 and R_4 was characterized with regard to pressure and temperature. Figure 3 gives the output signal and its dependency on the applied pressure at T_R and V_{cc} = 5V.

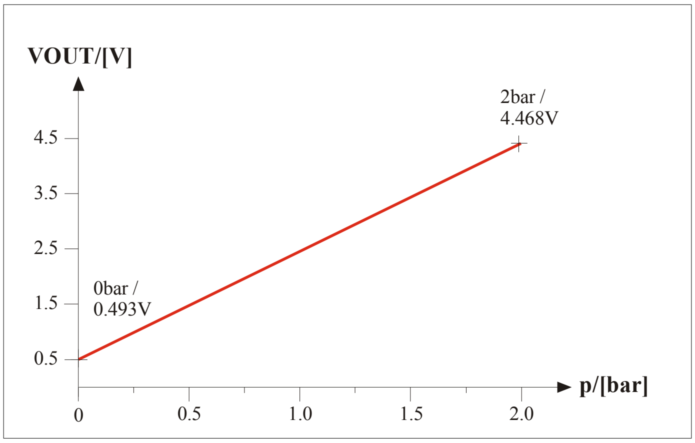

Figure 3: Output of the sensor system (AM457+ME651) dependant of the applied pressure at T = 25°C

Using 1ppm/K resistors the zero point and the full scale voltage of the sensor system were measured for the industrial temperature range.

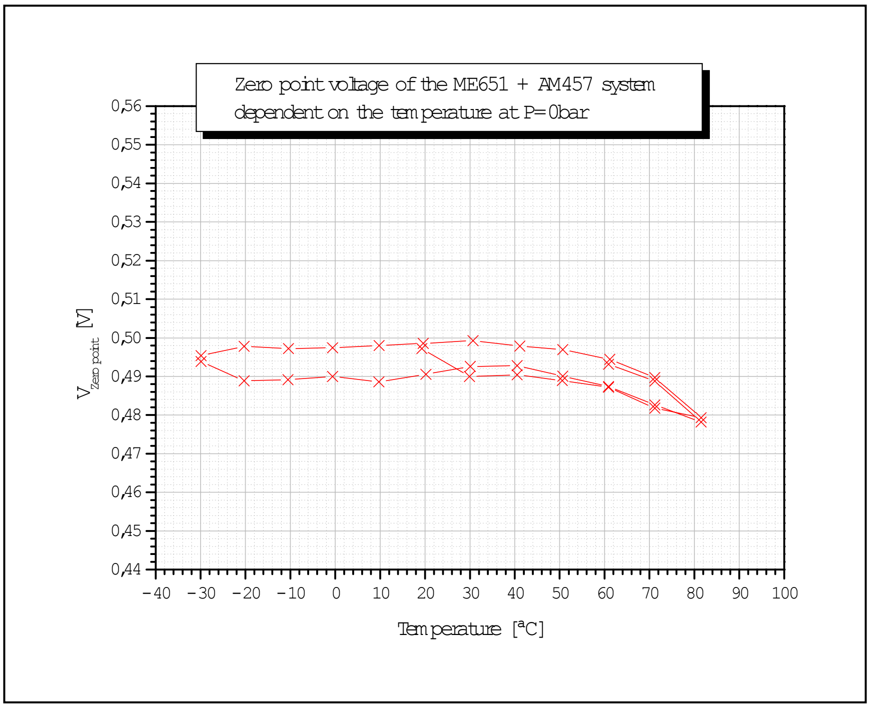

Figure 4: Temperature drift of the zero point voltage at the system output

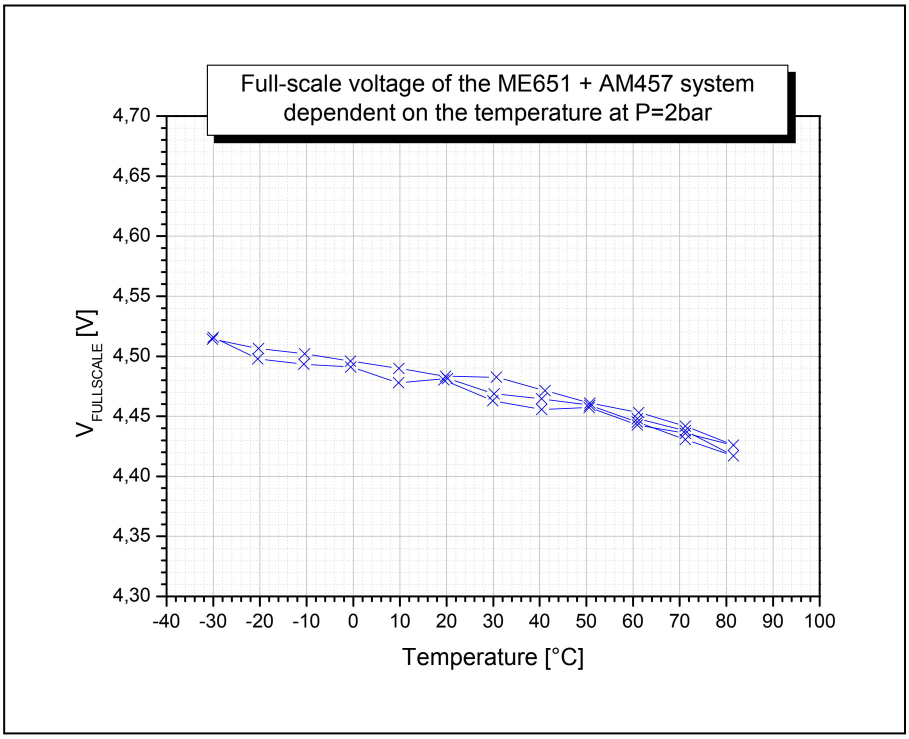

Figure 5: Temperature drift of the full scale voltage at the system output

With a non-selected sensing element an zero point temperature drift of 0.004%FS/K and a full scale temperature drift of 0.02%FS/K was determined at the system output.

This example deliberately refrains from compensating for the temperature coefficients of the zero point (TCO_S) and full scale (TCS_S) of the sensor system. The reason for this lies in the fact that calibrating temperature at system level is time-consuming and expensive; the level of accuracy achieved is usually sufficient for most applications without temperature compensation.

With regard to the system the primary temperature errors are the TCO and TCS of the sensing element. With its excellent temperature behavior IC AM457's contribution to the temperature error is marginal.

Even if no compensation for temperature is necessary, the temperature drift of the adjusting resistors, which directly affects the TCO_S and the TCS_S, should nevertheless be taken into consideration. For this reason it is recommended that resistors with a suitable temperature coefficient are used.

Should the achieved accuracy of temperature not be sufficient, both the TCO and TCS of the sensing element can be calibrated by the manufacturer.

Conclusion

The given example illustrates how a ceramic sensing element was calibrated using an AM457 and some discrete resistor components. It was possible to determine the necessary resistances by making just one single iteration.

The suggested calibration method using discrete resistors is suitable and has a sufficient accuracy for all ceramic sensing elements

- which permit calibration with resistors
- which have an output signal of ±5mVFS…±100mV FS
- where the span signal is greater than the offset.

AM457's diagnostic unit was not used in this example; it can be applied without change of the presented results.

Further reading

http://www.amsys.de/ [1] The ME651 data sheet
http://www.analogmicro.de/ [2] The AM457 data sheet