Application description AN1012: AM457 Amplifier IC for ceramic sensing elements

This article describes an electronic circuit using the IC AM457 to amplify and calibrate the output signal of a ceramic pressure sensing element with a Wheatstone resistance bridge. The aim is to obtain a ratiometric output signal Uout of 0.5…4.5V with a voltage supply of 5V. The sensing element is calibrated using an external network of four resistors.

Sensing element plus amplification circuit

In order to be able to calibrate the offset and span of a resistance bridge circuits with low sensitivity (±5mVFS…±100mVFS) a special network was developed using the integrated circuit AM457 (see Figure 1). The sensor system consists of the ceramic sensing element ME651 (AMSYS, Germany)[2], the integrated circuit AM457, 4 resistors and mini. 2 capacitors (see the AM457 data sheet). The bridge resistance is specified as being 10kΩ and the supply voltage is set to 5V.

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 signal has to be 0.5V and the full scale signal 4.5V.

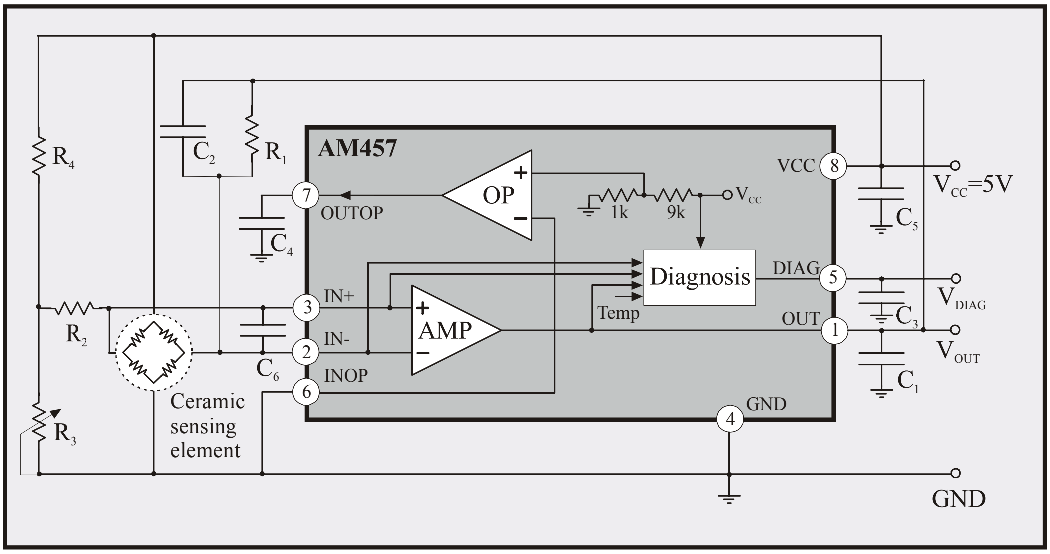

Figure 1: Schematic circuit diagram for amplification and calibration of a ceramic sensing element using the AM457

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Dimensioning

The formulae (1) to (3) used here to adjust the offset and the span (calibration) of a ceramic sensing element are calculated using a model which is based on the classic Wheatstone bridge circuit of four resistors. These three simple equations allow to calibrate the system with a minimum of data pertinent to the sensing element.

All standard ceramic sensing elements have in addition to the four bridge resistors their own resistors, which are used to adjust the specified values. Therefore there is a discrepancy between the four resistor model and the real sensing element, which is taken into consideration in the calibration process described in the following by correcting the calculate adjusting resistors.

The formulae used are:

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

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

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

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

In order to calculate the discrete adjusting resistors the offset, span and bridge resistance of the sensing element are first determined. The sensing element is then connected up to an AM457 to form the circuit illustrated in Figure1. Resistors R_1 to R_4 are dimensioned according to the given formulae. The capacitors are selected according to the datasheet AM457.

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

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Using the calculated resistances offset U_{FP1} and span U_{FS1} are set to a first approximation.

In the next stage of the dimensioning process the obtained zero point value U_{FP1} may have to be corrected to the target value of U_{FP2} = 0.5V by trimming resistor R_3. As the zero point signal and full-scale signal are dependent in a linear correleation, 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 adjust. 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.

Example: Determining d_{RO} and d_{RS} of the ME651ceramic sensing element at V_{CC} = 5V and T = 25°C

Offset (0 bar)	= -0.096mV	→	d_{RO} = offset/5V = -0.019mV/V
FS (2 bar)	= +11.53mV		
Span	= +11.63mV	→	d_{RS} = span/5V = +2.33mV/V
R_B	= +10.558kΩ		

Dimensioning the span resistors according to (1):

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

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

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

Dimensioning the offset resistors according to (3):

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

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 = 18.18kΩ the following measurement values are obtained at T = 25°C and V_{DC} = 5V:

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

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Looking at these values we can see that zero point value U_{FP1} for P = 0 bar is ca. 40% too high with regard to the setpoint of 0.5V; this is down to the discrepancy between the model and the real resistor structure of the ceramic sensing element. The next step in the process is thus to adjust the setpoint U_{FP2} for P = 0 (0,5V) 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. With the new $R_{3,KORR}$ the Full Scale value U_{FS1} is changed into U_{FS2}.

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

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

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

Calculating the 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:

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

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

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Measurements

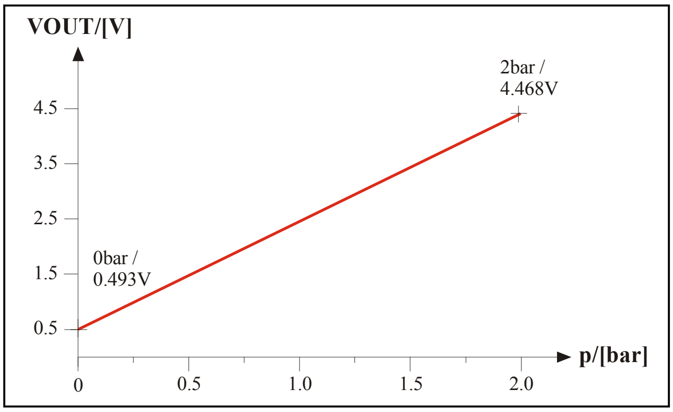

Figure 3: Measurement of the output signal (AM457+ME651) as a function of the applied pressure at T = 25°C

Temperature behavior

This example deliberately refrains from compensating for the temperature coefficients of the zero point (TCO_S) and span (TCS_S). 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. 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 TCS_S of the sensor system, should nevertheless be taken into consideration. For this reason it is recommended that resistors with a suitable temperature coefficient are used.

Using 1ppm/°C resistors, the behavior of the offset and the full-scale signal of the ME651 + AM457 system was measured for the industrial temperature range. The results are shown in Figures 4 and 5.

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

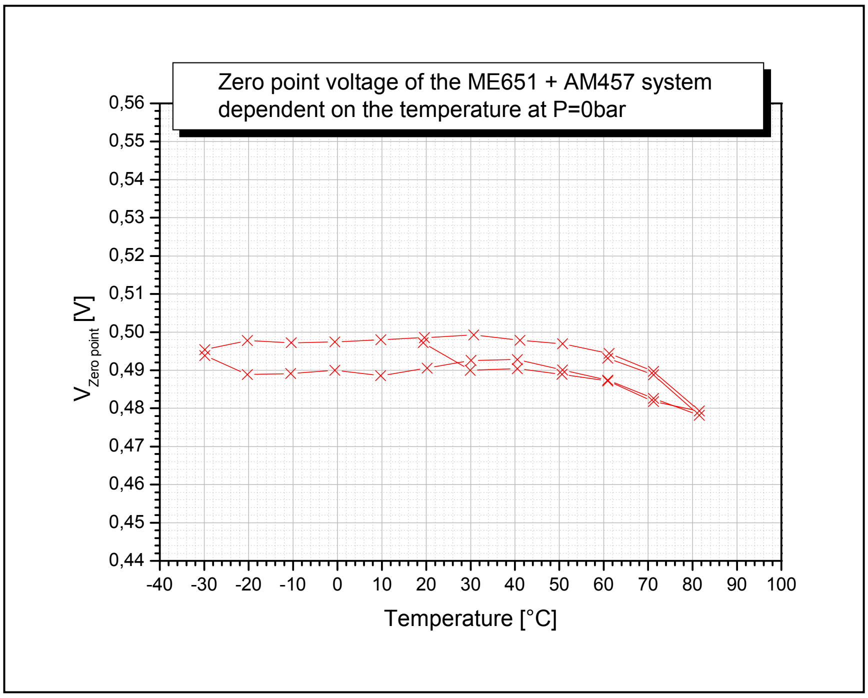

Figure 4: Temperature behavior of the zero point at the output of the sensor system (AM457)

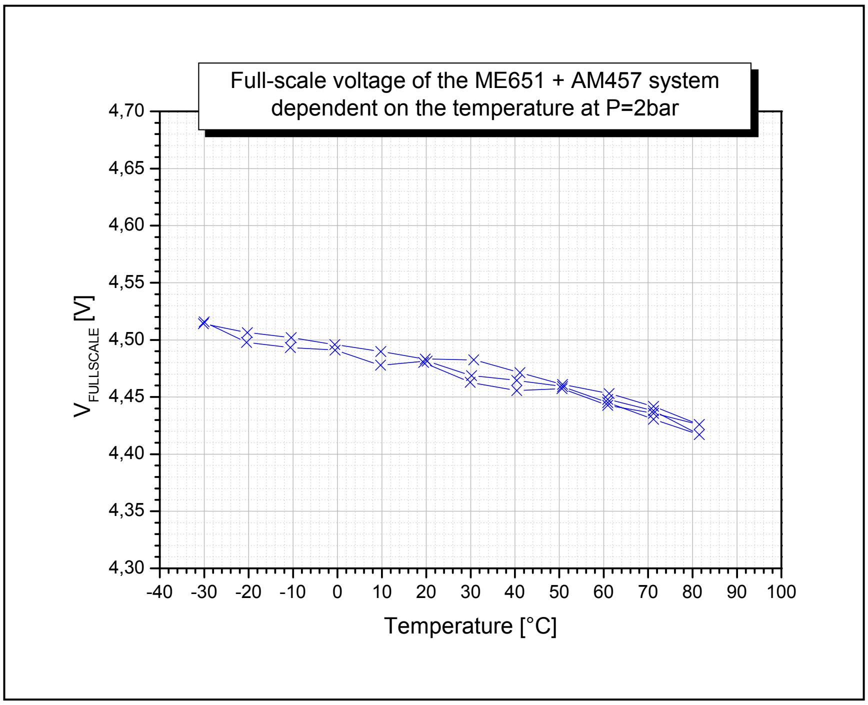

Figure 5: Temperature behavior of the full-scale signal at the output of the sensor system (AM457)

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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 measured.

The calibration suggested in this article 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 ±5mV…±100mV FS
- where the span signal is greater than the offset.

AM457's diagnostic unit was not used in this example, but it can be applied without changing the presented results.

Further reading:

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

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

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