Pressure sensors with a 0.5…4.5V output for industrial 3-wires current loop (4…20mA) applications

Analog - Digital
Micromechanical
Sensor Systems

Application:

Adapting a pressure transmitter with an Uout = 0.5…4.5V and a 5V supply to suit a 4…20mA industrial current interface powered by 24V.

Depending on the given boundary conditions of an application, such as space, cost, degree of accuracy etc., there are a number of different ways of generating an analog industrial current signal from a voltage source with a 0.5...4.5V output.

The following article gives an example* for a circuit using a pressure transmitter and one single additional IC with very few components, providing an inexpensive solution. We aim to show how a sensor with a standardized current output of 4...20mA can be easily realized as a 3-wire device based on an 0.5...4.5V pressure transmitter in combination with an IC (AM462) from Analog Microelectronics GmbH.

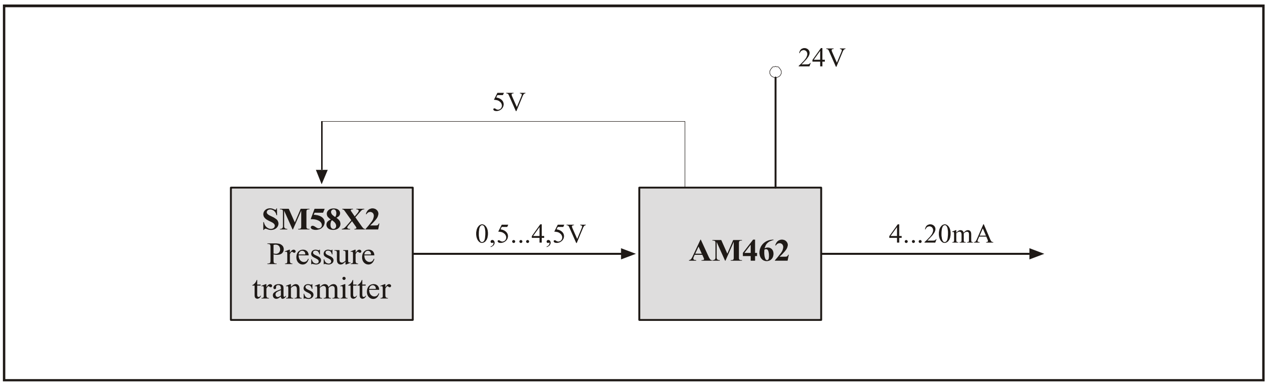

Figure 1: *Example application with a pressure transmitter and only one IC*

**The application is given here as an example only; the pressure transmitter can be substituted by other transducers which have a single ended 0.5...4.5V output.*

Pressure transmitters

The pressure transmitter used here is one of the MS58X2 series (see *Figure 2*) manufactured by Silicon Microstructures Inc. and distributed by AMSYS in Mainz, Germany. The MS58X2 transmitters are a combination of a piezoresistive sensing element and a signal conditioning IC which amplifies and compensates the signal for temperature and calibrates the signal setup to output values of 0.5V (offset) and 4.5V (full scale).

Compensation (within a temperature range of 0 to 70°C) and calibration are performed on the basis of various measurements of temperature and pressure during the manufacturing process. Permissible pressures for these transmitters range from 0,15 to 100PSI. In accordance with these pressure ranges differential, relative and absolute measurements of pressure are possible.

The pressure transmitter is sold as both a DIL-version and an SMD-version. The MS58X2 series is also available in a number of various pressure connections.

This application features an MS5812-015-G which comes as a relative pressure transmitter suitable for 15PSI .

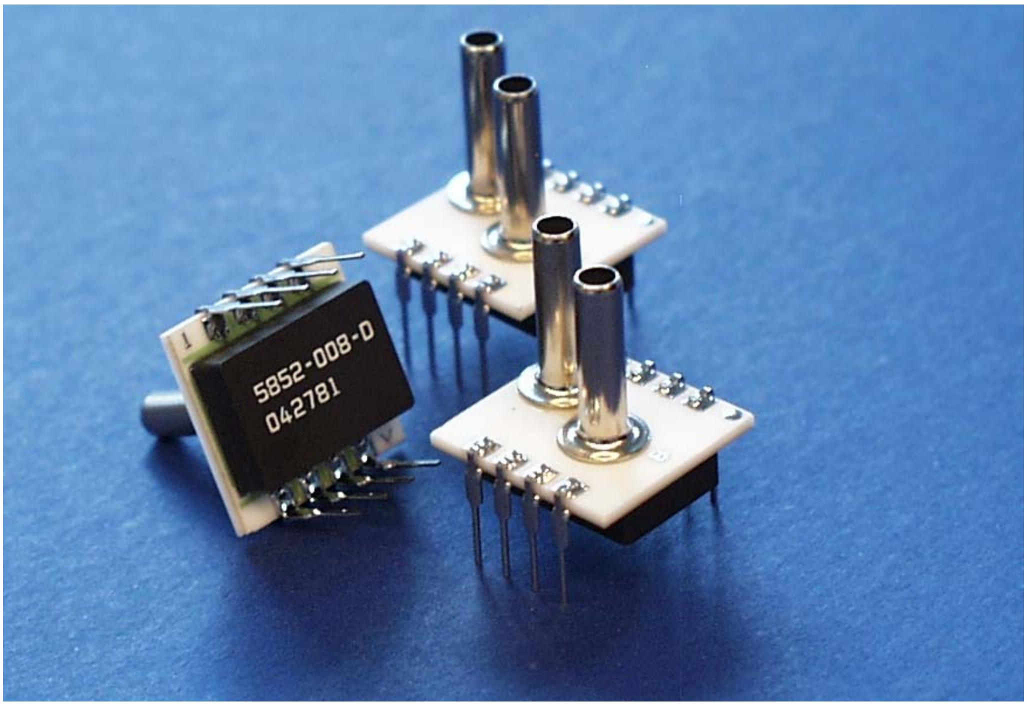

Figure 2: *Pressure transmitters of the SM58X2 series*

Voltage-to-current converter IC AM462

IC AM462 (see *Figures 3 and 4*) from Analog Microelectronics is a voltage amplifier circuit with a number of additional and protective features. The IC consists of different function groups (modules) which can be accessed via pins. These modules are individually specified and can be operated separately or in combination as the application requires.

These are: *an operational amplifier stage, a V/I converter stage, a bandgap reference and an operational amplifier.*

Analog-Digital
Micromechanical
Sensor Systems

Pressure sensors with a 0.5…4.5V output for industrial 3-wires current loop (4…20mA) applications

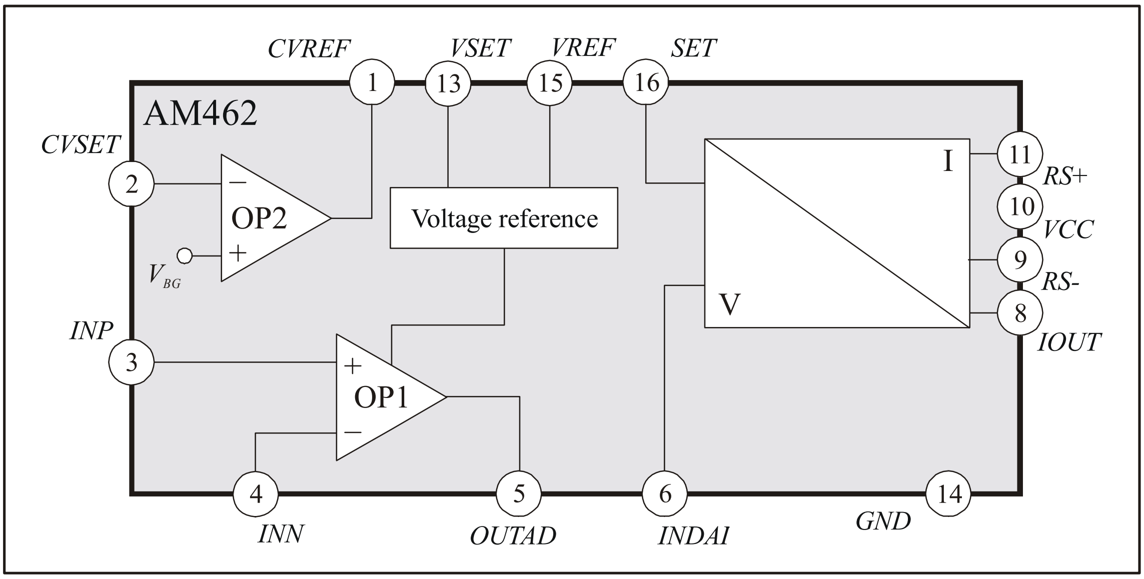

***Figure 3**: Block diagram of the voltage amplifier IC AM462*

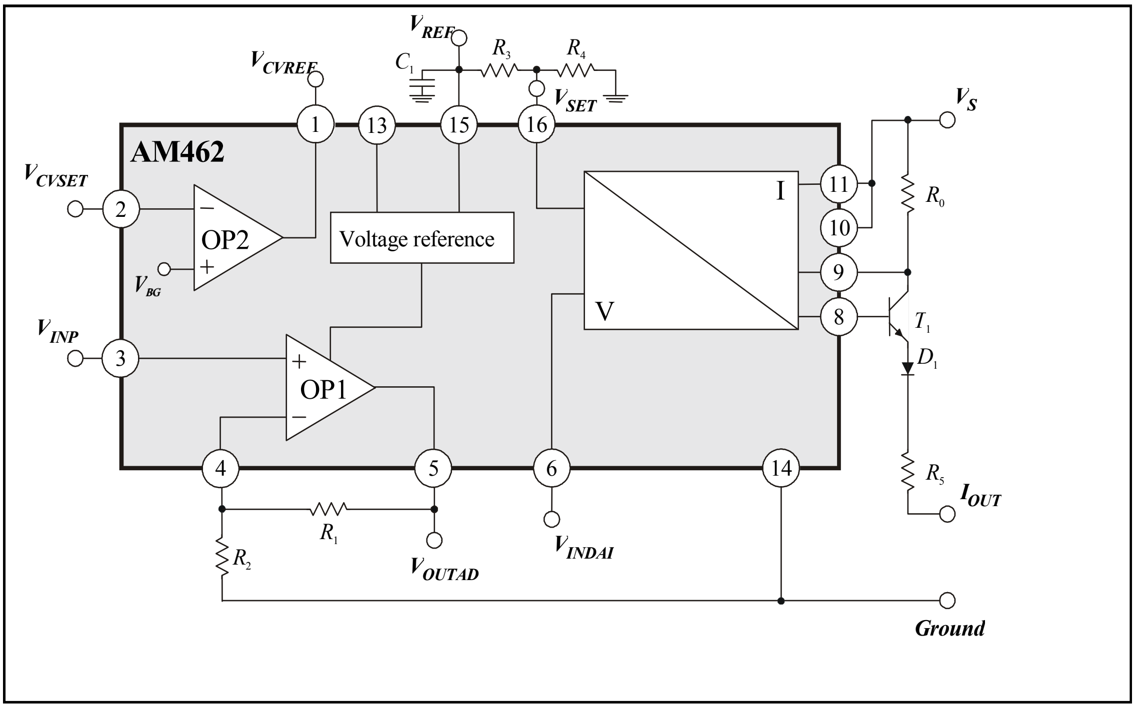

***Figure 4:** General example circuit for a voltage-to-current converter circuit*

The AM462 IC is suitable for both 2- and 3-wire operation.

Pressure sensors with a 0.5…4.5V output for industrial 3-wires current loop (4…20mA) applications

Analog-Digital
Micromechanical
Sensor Systems

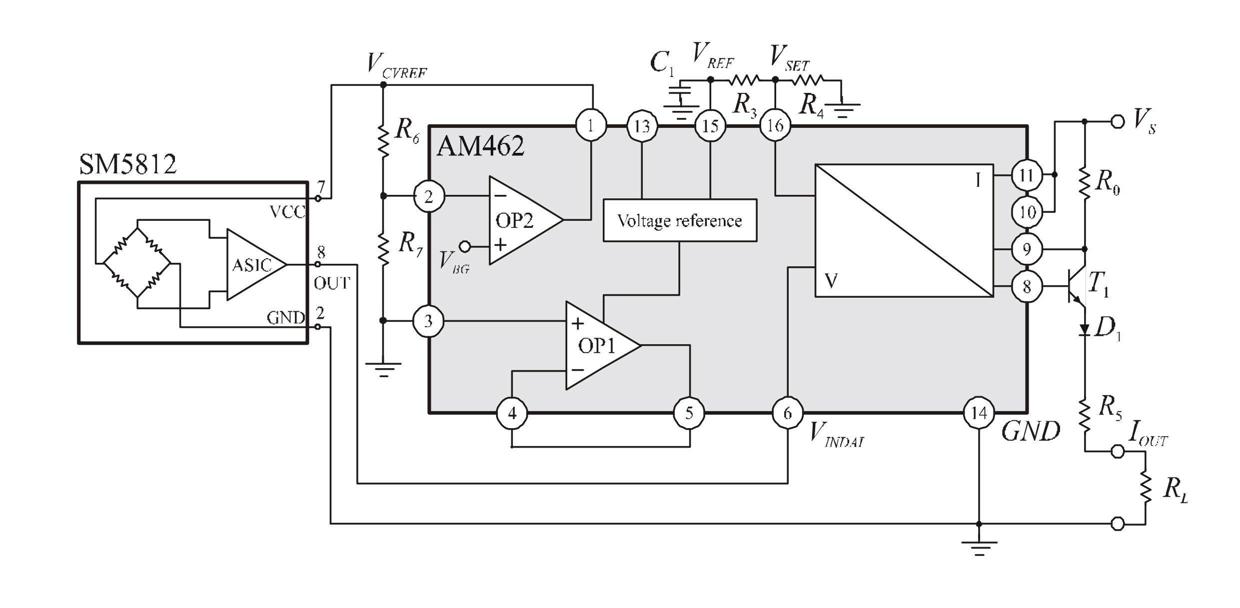

Figure 5: *Example industrial current loop application based on an 0.5…4.5Volt source*

Description of the application

Pressure transmitter SM5812's output signal of 0.5V…4.5V is to be converted into an output current signal of 4…20mA as a 3-wire version. A 24V supply voltage is available. The load resistance is given as 600Ω.

Compensation strategy

Assuming that there is an FS output signal from the pressure transmitter of 4.5V at P = Pmax. = 15 PSI, the output current I_{OUT} = 20 mA (see *Figure 5*) is fixed with the setting of resistor R_0. This R_0 value then gives the output current for the minimum output value of the pressure transmitter (0.5V at P = Pmin. = 0PSI). In order to be able to achieve the required output current of 4mA, however, an additional current I_{SET} must be added to the present current, which is dependent on R_3, R_4 and also R_0.
This means that the entire circuit is determined when R_0, R_3, R_4 and I_{SET} have been set.

Besides the actual current conversion process the IC AM462 also supplies the pressure transmitter with 5V with the help of the additional operational amplifier OP2, rendering a separate voltage regulator superfluous. The bias voltage is set using an external voltage divider (R_6 and R_7).

Analog-Digital
Micromechanical
Sensor Systems

Pressure sensors with a 0.5…4.5V output for industrial 3-wires current loop (4…20mA) applications

Dimensioning

This article refrains from going into detail as to the derivation of the equations used here; the relevant data sheets should instead be consulted. Further information is available either from Analog Microelectronics direct or on the internet at **http://www.analogmicro.de**

The default values of external discrete elements D_1, T_1, C_1 and R_5 in *Figure 5* are given according to the AM462 data sheet:

- For resistor R_5: 39 Ω
- For capacitor C_1: 2.2 µF
- For transistor T_1: $\beta_F \geq 50$, $V_{CE} \leq 35$ V (e.g. BCX54/55/56)
- For diode D_1: $V_{BR} \geq 35$ V (e.g. 1N4148)

The values of the remaining resistors R_0, R_3, R_4, R_6 and R_7 are determined by the application described here and explained in greater detail in the following.

Determining R_0

Resistor R_0 can be calculated from the required current swing of ΔI_{OUT} at the output and a voltage swing of ΔV_{INDAI} at the input of the V/I converter using Equation 11 in the data sheet:

$$\Delta I_{OUT} = \frac{\Delta V_{INDAI}}{8R_0} \Rightarrow R_0 = \frac{\Delta V_{INDAI}}{8\Delta I_{OUT}} \Rightarrow R_0 = \frac{4.5V - 0.5V}{8(20mA - 4mA)} = 31.25\Omega$$

Determining R_3 and R_4

The minimum output current I_{OUT}min, which is determined by an input signal of 0.5V, is calculated using Equation 2 in the AM462 data sheet:

$$I_{OUT} = \frac{V_{INDAI}}{8R_0} + I_{SET} \quad \text{with } I_{SET} = 0 \quad \Rightarrow I_{OUT\,\min} = \frac{V_{INDAI\,\min}}{8R_0} = \frac{0.5V}{8 * 31.25\Omega} = 2mA$$

To achieve an output current of $I_{OUT} = 4$ mA, a current of $I_{SET} = 2$mA must be added to I_{OUT}min.

Current I_{SET} is set by the voltage divider which is formed by the two resistors R_3 and R_4. The ratio of R_3 to R_4 is calculated using Equation 5 in the AM462 data sheet.

$$\frac{R_3}{R_4} = \frac{V_{REF}}{2R_0 I_{SET}} - 1 \quad \Rightarrow \frac{R_3}{R_4} = \frac{5V}{2 * 31.25\Omega * 2mA} - 1 = 39$$

In keeping with the boundary conditions given in AM462's data sheet R_4 is set to 1kΩ. This results in a value of 39kΩ for R_3.

Determining R_6 and R_7

The additional operational amplifier OP2 can be easily used as a voltage reference for the 5V supply to the transmitter according to Equation 10 in the AM462 data sheet:

$$V_{CVREF} = V_{BG}\left(1+\frac{R_6}{R_7}\right) = 1.27V\left(1+\frac{R_6}{R_7}\right)$$

$$\Rightarrow \frac{R_6}{R_7} = \frac{5V}{1.27V} - 1 \approx 2.94$$

Taking the required current into consideration, a value of 16kΩ is recommended for resistor R_7. R_6 thus assumes a value of 47kΩ.

Resistor R_5 = 39Ω is a protective resistor which stabilizes the setup in the case of a short circuit. Diode D_1 protects the external transistor against reverse polarity.

The error of the IC is not taken into account during dimensioning and can be disregarded here in comparison with the error of the pressure transmitter.

Results

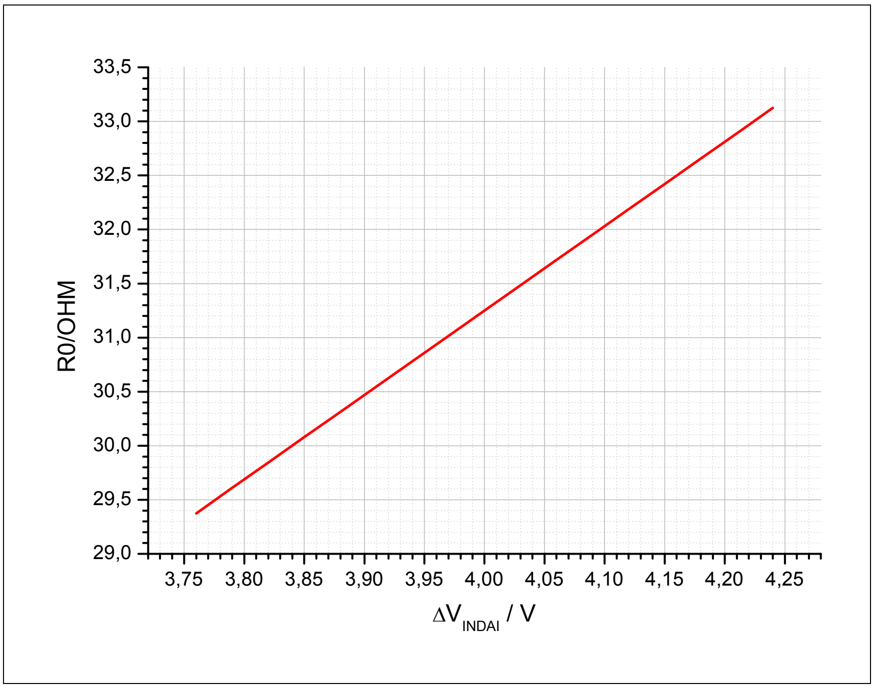

Figure 6: *Dependence of R_0 on ΔV_{INDAI}*

Figure 6 gives the functional correlation between R_0 and the difference in output voltage of the pressure transmitter: $\Delta Vout = \Delta V_{INDAI}$.
This means that by adapting resistor R_0 the calibration accuracy in the transmitter output signal can be compensated for and the overall precision of the sensor thus improved. In the equitation for R_0 4.5...0.5V must then be replaced by the measured value for ΔV_{INDAI}.

The curve in *Figure 6* applies to the output current range of 4 to 20mA.

Accuracy

Figure 7 gives the typical measured temperature dependencies of pressure transmitter SM5812 (without the AM462). To this end both the temperature-dependent offset (*TCO*) and span (*TCS*) are plotted to the same scale. Within a range of -25 to 85°C the resulting offset drift is thus 0.01%FS/K and the span drift 0.017% FS/K.

An adequate measurement of the temperature dependencies of the sensor system: pressure transmitter SM5812 plus AM462 is shown in *Figure 8*. The measurement illustrates that adding an AM462 the IC has no significant effect on the drift values. By combining SM5812 and AM462 a temperature drift of ca. 1.5% across 100°C is achieved (0.015%/°C).

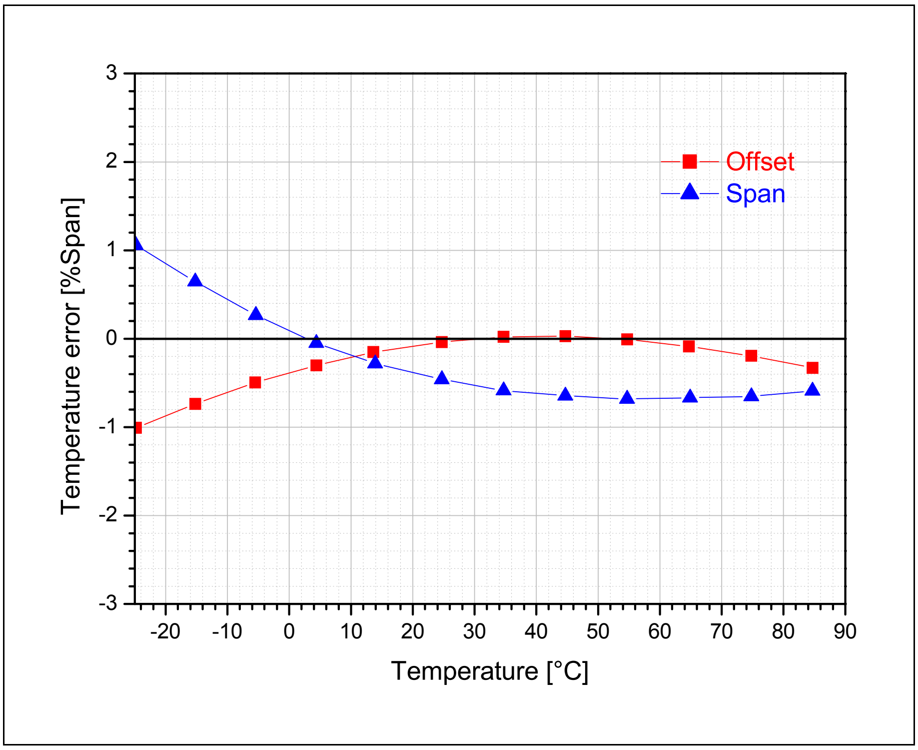

Figure 7: *Temperature drift of SM5812 within a range of -25°C to 85°C*

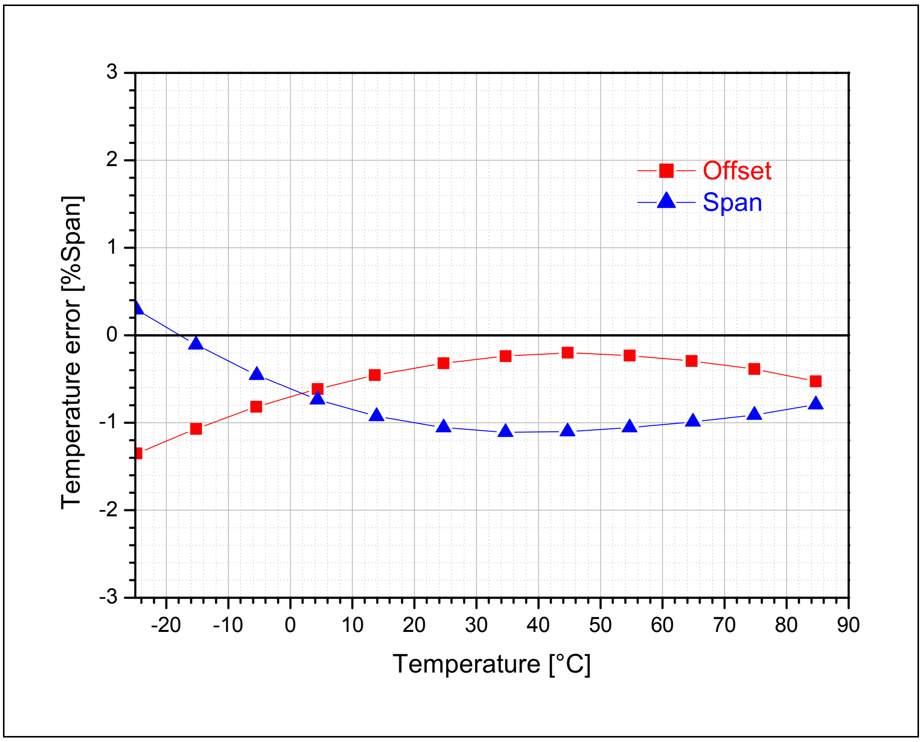

Figure 8: *Temperature drift of SM5812 plus AM462*

Regarding the calibration error of the pressure transmitter the calibration tolerance of the transmitter offset (0.5±0.02V) can be compensated adjusting the offset current (4mA). The span error (4±0.08V) can be corrected by setting R_0. The resulting error then depends on the precision of the settings and the temperature coefficients of the resistors used.

By selecting a suitable temperature-stable resistor for R_0 and a stable 5V transmitter supply the precision of the overall system can also be considerably improved with regard to its temperature behavior.

Conclusion

There are many possible ways of measuring pressure and of converting it into a corresponding industrial current. The application described here illustrates how using a standard IC and a serial 0.5...4.5V pressure transmitter the voltage output signal can be converted into a 4...20mA output current (3-wire variant).

The advantage of this system lies in the easy adjustment of the absolute error – undoubtedly thanks to the AM462 IC used here. Furthermore, this particular setup is also favorable in that it can be operated with few external components due to the high integration density of the integrated amplifier circuit AM462 and is thus an economic solution for small systems.

Further information is available at:

http://www.amsys.de/products/analog.html

http://www.amsys.info/products/sm58x2.htm

http://www.analogmicro.de/english/standard/index.html