AMS 4712 – What to know about bidirectional differential pressure sensing

In pressure sensor applications several terms have come into use which describe various different physical methods of pressure measurement. These include absolute pressure, relative pressure and differential pressure sensing. The fact that a number of different concepts are covered by the term "differential pressure sensing" alone is not one familiar to many users. Taking piezoresistive sensors as an example the following article attempts to explain the diverse terminology. In particular a frequently needed version shall be outlined herein which AMSYS refers to as a " bidirectional differential pressure sensor".

To help us better understand the matter we shall first describe the various methods of pressure measurement which are based on silicon pressure sensing elements. In practice it goes without saying that these sensing elements are mounted with suitable equipment in the relevant packages, partly in clean room conditions; it is these packages which permit the pressure to actually be measured (*Figure 1*).

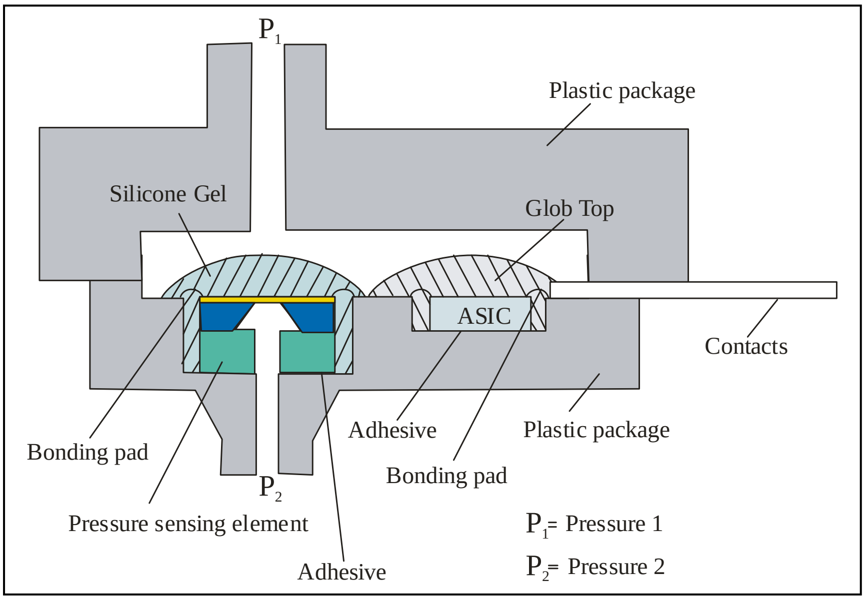

Figure 1: *Schematic diagram of a typical piezoresistive, differential pressure sensor with a signal conditioning IC beside and gel protection*

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Micromechanical pressure sensors made of silicon

The micromechanical measuring cells (sensor elements) based on silicon (see *Figure 2*) are produced using semiconductor technology and sometimes even on the IC production line, they meet the high demands concerning reliability and economy, requirements which also distinguish integrated circuits as a whole. All micromechanical piezoresistive pressure sensing elements have a silicon chip as their pressure-sensitive element with a thin membrane which today is usually anisotropically etched from the chip (forming a cavity). At the high stress points on the membrane atoms are locally implanted in the silicon crystal so that zones with an altered conductivity are formed which electrically function as resistors. As soon as pressure is applied externally onto the membrane the molecular structure of the crystal is deformed when the thin silicon membrane dents. In the resistor areas the mechanical crystal shifts create a measurable change of their electric value (the piezo effect). If these integrated resistors are connected up as a Wheatstone Bridge *(Figure 2*), when current or voltage is impressed a pressure-dependent, differential signal in millivolts is generated.

With a little modification these pressure sensing elements are used for the various types of pressure measurement. So there is a difference between the absolute pressure, the relative pressure and the differential pressure sensing.

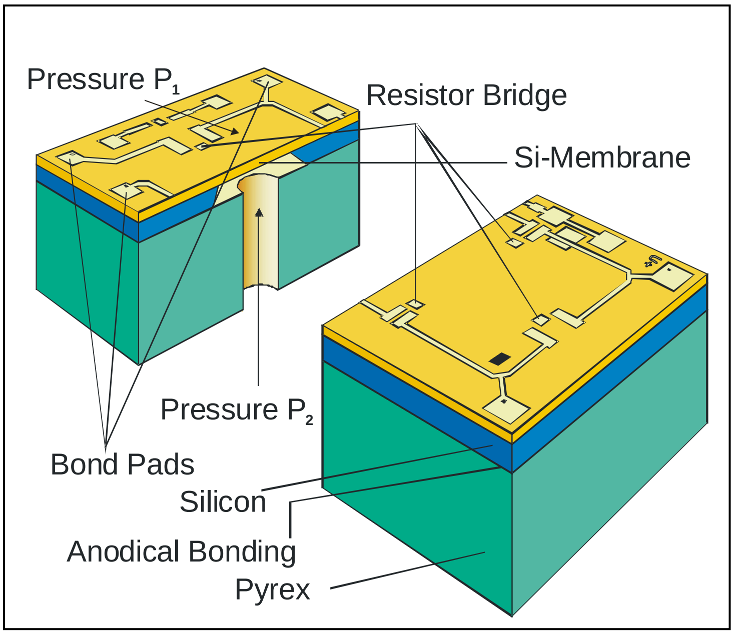

Figure 2: *Typical pressure sensor design (edge ca. 2mm) for the measurement of differential pressure*

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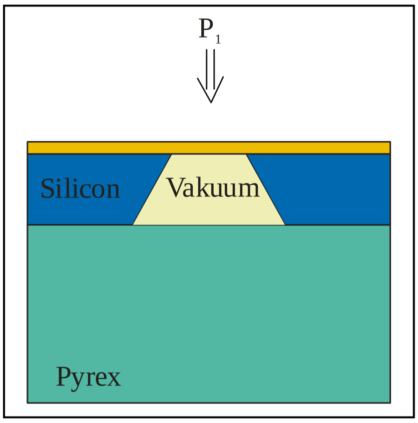
Absolute pressure sensing

In absolute pressure sensing a pressure P1 is applied against a reference pressure P2 which should be so low that it is negligible compared to the pressure to be measured. Ideally this would be 0bar (P2 = negative or low pressure = vacuum). This means that during manufacture the sensing element is hermetically sealed on a permanent basis at the relevant lower pressure (see *Figure 3*); here, the leakage rate is an important quality criteria.

When pressure is applied through P1 to the membrane this bends in the direction of the lower pressure. As P1>>P2 applies, it follows that this dents inwards into the cavity (see *Figure 4*). Due to the piezoresistive effect a signal is produced at the sensor bridge output which is proportional to the applied pressure. With this proportionality the gradient of the transfer characteristic is recorded (V_{OUT} = f (P1, P2) but not the offset nor the full-scale signal As it is not possible to achieve a pressure of 0 bar during manufacture the actual value of P2 (in practice < 50 mbar) must act as the pressure offset. This occurs by the desired output offset of e.g. 0 mA or 0V being set (calibrated) during calibration. At higher external pressures the vacuum pressure can be ignored while taking the required error into account.

At full pressure P1 a full-scale signal is generated at the output which is calibrated to the required output value (e.g. 10 V or 20 mA in current loop applications) in the back-end electronics.

One popular application is the measurement of a barometric pressure of between 700 and 1200 mbar. In this instance 700 mbar is calibrated to the offset and 1200 mbar to the full-scale signal.



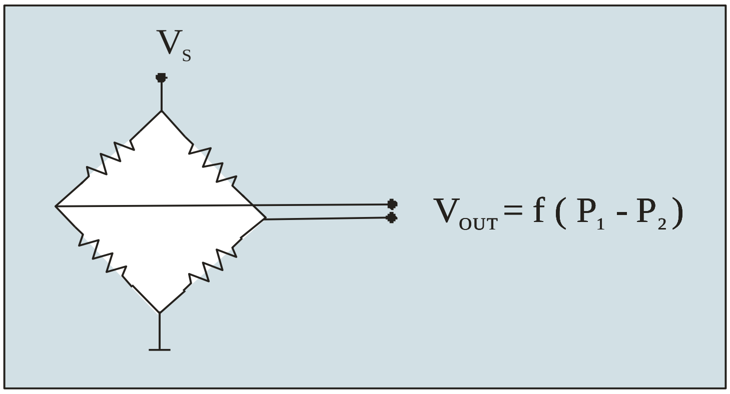


Figure 3: *How a piezoresistive sensing element functions for the measurement absolute pressure*

In *Figure 3* the dent in the membrane of the absolute pressure sensing element with the application of ambient pressure is obvious.

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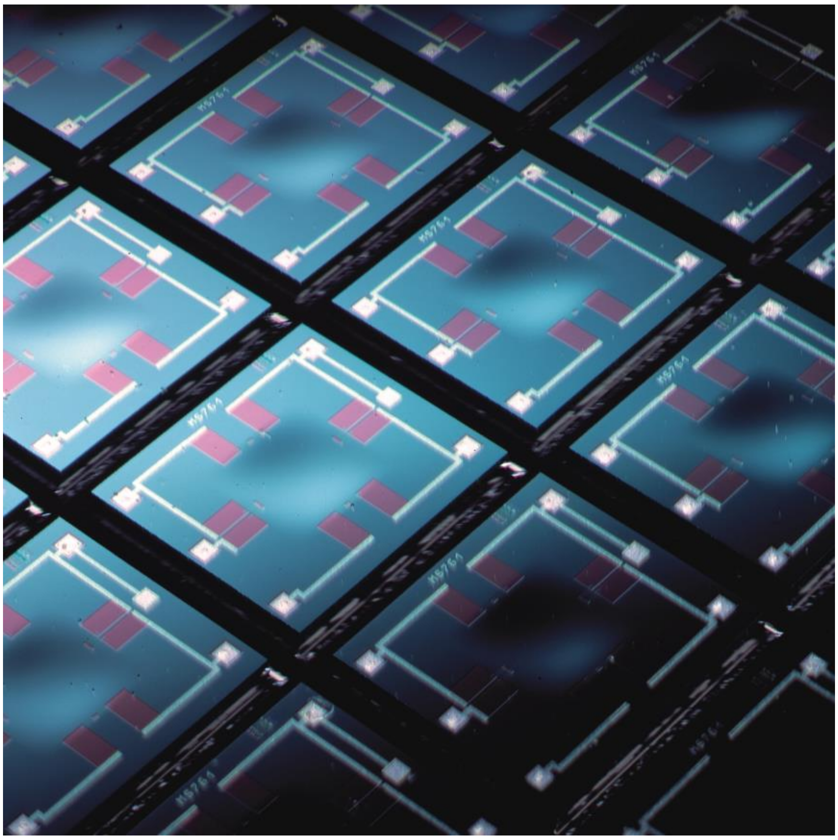

Figure 4: *Silicon pressure sensing element for absolute pressure measurement*

Differential pressure sensing

When measuring differential pressure two pressures P1 and P2 are compared, which are applied externally via the relevant package to the upper and lower side of the sensor element. In general, P1 ≤ P2 or P1 ≥ P2. With most sensors, due to the reasons given below it is often the case that only one pressure ratio, namely P1/P2 ≥1 or P1/P2 ≤ 1, can be logged and evaluated. The measurement of pressure under these conditions is usually referred to as "differential pressure measurement".

For pressure sensors whose membrane has been optimized to suit the relevant range of pressure the condition generally also applies that P1-P2 ≤ Pmax or P2-P1 ≤ Pmax, where Pmax is determined by the technical conditions and is specified.

These conditions must be taken into account when the user connects up the pressure to the sensing element or assembled sensor.

Figure 5 is a schematic diagram of what let understand the deflection of the differential pressure sensing element membrane under varying pressure conditions. The change in sign in the output signal means nothing more than a reversal in the direction of the deflection in the membrane.

The question of whether P1/P2 ≥1 or P1/P2 ≤ 1 is logged has significant consequences when we take media sensitivity with piezoresistive sensing elements into account. The upper side of the membrane has tiny metal bonding pads made of high-purity aluminum (the purple rectangles in *Figure 4*) which are not resistant against corrosion effects. These are normally protected by a layer of silicone gel. As only selective protective gels are available, universal protection cannot be guaranteed. It must thus be ensured that the planned sensors are protected against all media which comes into contact with them [2].

The reverse of the silicon sensing element is extremely media resistant as the aluminum pads mounted on the front are lacking. It is thus often advisable to mount any critical media on the underside of the sensing element, a fact which must be observed when selecting sensors with regard to application safety.

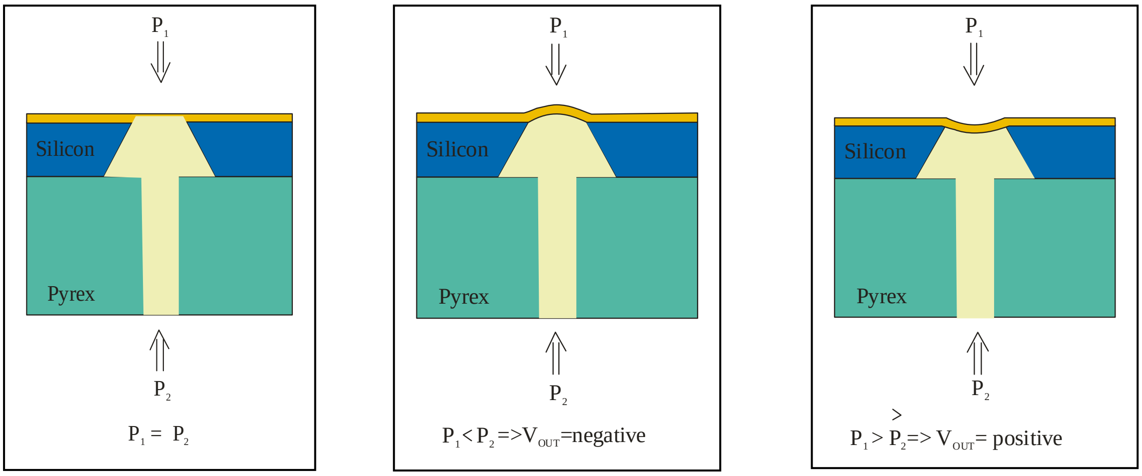

***Figure 5:** How a piezoresistive sensing element functions for the measurement of differential pressure*

Relative pressure sensing

Should one of the two applied pressures P1 or P2 be equivalent to the applied ambient pressure, we call this "relative pressure sensing" which in effect is merely a variation on differential pressure sensing. In setups such as these the difference between measurement pressure P1 and ambient pressure P2 is measured.

Signal conditioning

As the silicon measurement elements in standard bridge circuits can only generate a differential signal of ca. ≤ 150 mV maximum as a full-scale signal (depending on the sensitivity of the membrane), an instrumentation amplifier is required for signal conditioning purposes. This amplifies the signal with a low offset and offset drift so that it can be further processed without any trouble. In the follow-on single-ended conversion stage the differential signal is referred to a fixed potential. A zero value is usually selected as a reference so that with differential sensing elements (ideally with the same resistors) a value of 0 V is measured as an output signal without pressure being applied In the back-end signal conditioning unit this value is either digitized and calibrated or set to the required offset value in volts or milliamps via a voltage or current output stage. In 2-wire current loop applications, for example, this value is 4 mA.

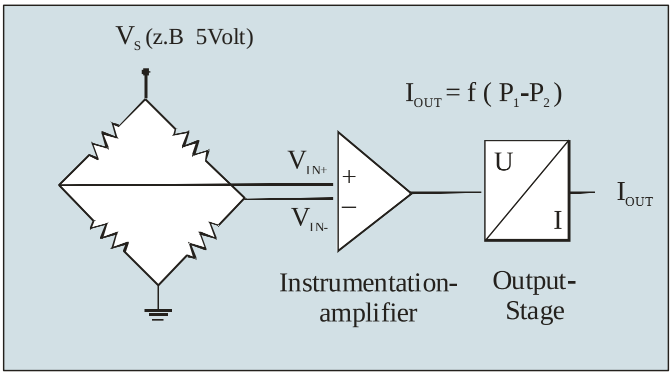

Figure 6: *Electronics for signal conditioning with an analog current output stage*

If the instrumentation amplifier is configured in such a way that it can only boost positive input voltages and the higher voltage is at its positive input, the transfer characteristic shown in *Figure 7* is obtained, where P1>P2.

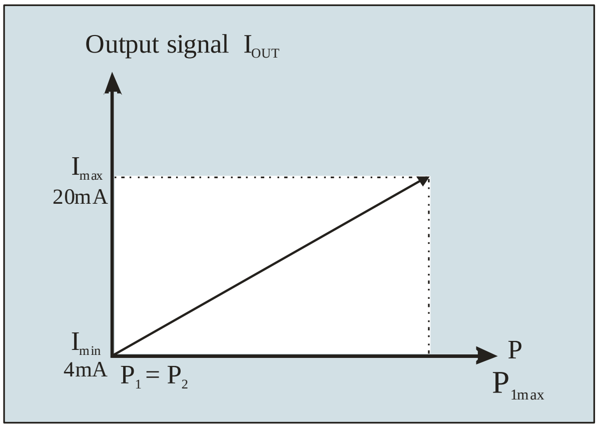

Figure 7: *Transfer characteristic with a positive input signal*

Negative input signals are not recognized as signals. If these are applied, the output signal remains set to zero.

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Input signal

If, with electronics which have been developed for P1 ≥ P2, a negative value is connected to the input of the instrumentation amplifier (e.g. V(P1) ≤ V(P2) or if a negative offset exists (e.g. an amplifier offset), the output signal will display a value of zero or one corresponding to such (e.g. 4 mA) until the output signal fulfills the condition V(P1) ≥ V(P2), i.e. the input signal is greater than the negative bias voltage.

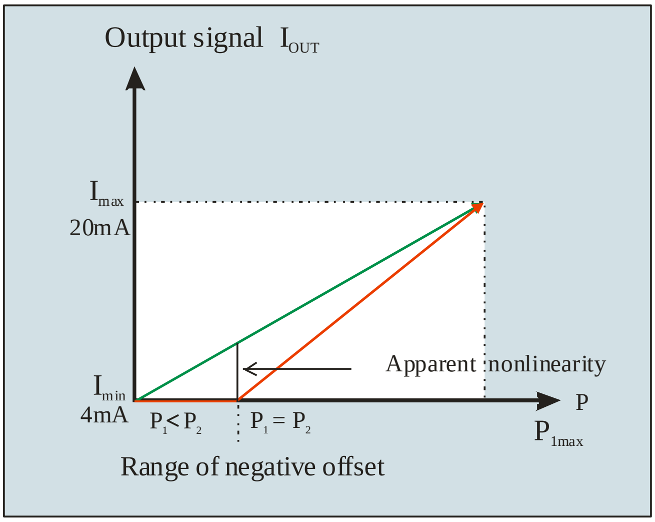

Figure 8: *Transfer characteristic with a negative input offset or P1<P2*

To the user the negative offset available at the amplifier input appears to be misaligned in the transfer characteristic of *Figure 8*, for example, which with two-point measurement (offset and full-scale signal) can be treated as nonlinearity. This mismatch (negative input signal) must be taken into account by the detection electronics and corrected.

Bidirectional differential sensors

In addition to the applications described above there are practical demands which also bear weight if, for example, both conditions P1 ≤ P2 and P1 ≥ P2 occur within one pressure system (e.g. ventilation and deventilation, undershooting or overshooting a liquid level, inhalation and exhalation). As there is no generally recognized term for this type of pressure sensing, AMSYS calls sensors which can measure this type of differential pressure " bidirectional differential pressure sensors". They are capable of measuring both negative and positive pressure.

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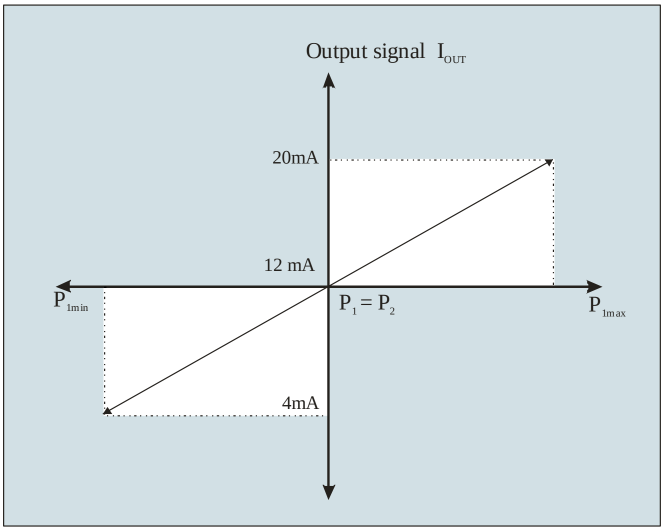

Figure 9: *Transfer characteristic for bidirectional differential pressure sensors*

With this kind of sensor the differential pressure to be measured can have both a positive or a negative sign, i.e. pressure P_1 at connector 1 (e.g. the upper side of the sensing element) can be both greater or less than pressure P_2 at connector 2 (the underside of the sensing element). The sign can vary during measurement. The following condition applies for pressures P_1 and P_2 at the connector:

$P_{min} \leq |P_1 - P_2| \leq P_{max}$ *with the given condition that* $P_1, P_2 \leq P_{System}$.

Here, P_{max} *is the positive and* P_{min} *the negative output pressure of the pressure range for which the sensors have been designed.* P_{System} *stands for the maximum permitted system pressure in conjunction with the effective ambient pressure which may be applied externally to the sensor connector.*

This bidirectional differential measurement is only possible when the following two sensor system requirements are met:

The membrane structure must have a symmetrical pattern of behavior with regard to its deflection to either side and

The detection circuit must be adapted in its transfer behavior with regard to the offset to suit the range of amplification.

Notes on a)

The membrane is a thin semiconductor layer of a few micrometers consisting of several different layers. As a rule these are a layer of silicon, of oxide and a passivation layer. For this reason membrane behavior can depend on the direction of the deflection.

In the worst instance this can result in the jump effect. For bidirectional sensors manufacturers of silicon sensing elements must thus guarantee symmetrical membrane behavior with both a positive and negative deflection.

Notes on b)

The transfer characteristic given in *Figure 9* needs amplification electronics where the zero potential is not set as the reference for the instrumentation amplifier but whose reference must be connected to half of the full-scale value. For example, with sensors which require an output signal of 4...20 mA and with bidirectional differential pressure sensors the offset is configured to 12 mA, so that a signal P1 ≤ P2 of 4..12 mA and a signal P1 ≥ P2 of 12..20 mA are displayed. See *figure 9.*

AMS 4712: new pressure sensors

Just one of AMSYS's new series, the AMS 4712 [1], meets this condition and more, namely:

It permits all variations of pressure measurement. AMS 4712 is ready to use and suitable for both internal and external assembly without the need for any additional components. It comes with an industrial 4...20 mA current output in a 2-wire version and can be powered by a supply voltage of 9 to 35V [3].

During manufacture both the offset and span are calibrated and the offset and span drift compensated for. Due to the digital calibration process high levels of accuracy at room temperature and a low total error across the entire operating temperature range are guaranteed.

AMS 4712 is available for 10, 20, 50, 100 and 200 mbar and in its new bidirectional version also for ranges of ±5, ±10, ±20, ±50 and ±100 mbar.

Figure 10: *Pressure sensor AMS 4712 which permits both differential and bidirectional differential pressure measurement*

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Applications

This opens up areas of application otherwise not accessible to standard differential pressure sensors. As mentioned above the latter can only measure a fixed ratio between the two applied pressures. With differential bidirectional pressure sensors air flow measurements can be easily carried out, in which pressure can be reversed compared to the prevailing differential pressure by activating valves, for example. In the dynamic sensing of pressure a negative pressure can occur during suction with regard to the difference in pressure to be measured; this, too, must be recorded. The differential bidirectional pressure sensors in the AMS 4712 series have been specially designed for such measurements with reciprocal pressure conditions. Furthermore, AMSYS also offers a series of transmitters with 0-5 V and 0-10 V outputs in a plastic housing (AMS 4711 and AMS 4710) [4], such as another series in a robust metal housing (AMS 3011 and AMS 3010) [5].

Summary

Based on the absolute pressure measurement, the term differential pressure measurement was explained, where two pressures P1 and P2 are applied from the outside via the corresponding housing at the bottom and top of the sensor element. The construction of a piezoresistive pressure cell, its mode of operation and the processing of the signal, as well as the calibration and linearization of the output signal, were presented. Also, the membrane structure and its deflection in the case of simple differential pressure measurement and the bidirectional differential pressure measurement have been explained.

Further information

[1] Product information AMS 4712: https://www.amsys-sensor.com/products/pressure-sensor/ams4712-analog-pressure-transmitter-4-20ma-output/

[2] Application note media compatibility AMS 4711: https://www.amsys-sensor.com/downloads/notes/ams4711-media-compatible-pressure-transmitter-for-industrial-applications-in-matchbox-format-amsys-515e.pdf

[3] Application note two-wire current loop pressure sensors AMS 4712: https://www.amsys-sensor.com/downloads/notes/ams4712-two-wire-current-loop-with-the-example-of-a-4-20-ma-pressure-transmitter-amsys-518e.pdf

[4] Product information AMS 4711: https://www.amsys-sensor.com/products/pressure-sensor/ams4711-analog-pressure-transmitter-5v-output/

[5] Product information AMS 3011: https://www.amsys-sensor.com/products/pressure-sensor/ams3011-pressure-transducer-5v-in-metal-housing/

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