AMS 5812 - Measuring over- and underpressure bidirectionally with one sensor

In pressure sensor technology there is a difference between various physical methods of measurement, depending on the application. These include the measurement of absolute pressure, relative pressure, and differential pressure. Many users are not aware of the fact that two different things are understood by "differential pressure measurement". Taking the piezoresistive sensor AMS 5812 [1] as an example, the two versions relevant to practical application shall be illustrated in the following.

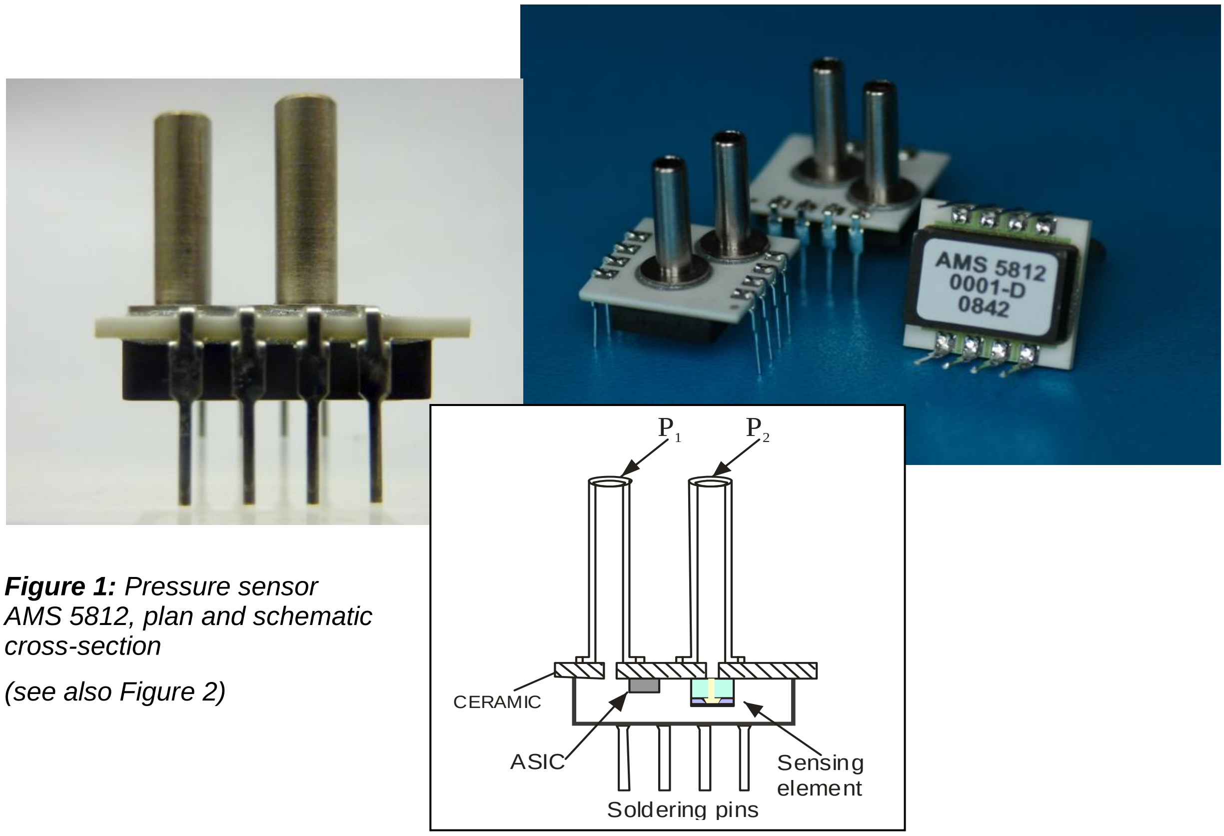

Figure 1: *Pressure sensor AMS 5812, plan and schematic cross-section*

(see also Figure 2)

To elucidate further, the various methods of pressure measurement and important terms relevant to silicon pressure sensing elements shall be described herein.

Measuring absolute pressure

When measuring absolute pressure (see *Figure 2*) pressure P_1 is recorded in relation to a referential pressure of P_2, which must be so low as to be negligible compared to the pressure P_1. In an ideal setup, this would be 0bar (P_2 would be the perfect vacuum). This means the sensing element has to place in a vacuum chamber and then hermetically sealed with the Pyrex (glass) substrate in a suitable vacuum of P_2. This low pressure of P_2 should permanently retain the same value for stability reason.

When pressure P_1 is applied to the upper surface of the membrane, this deforms towards the lower pressure. As $P_1 >> P_2$ applies, the membrane thus curves inwards into the etched area of the sensing element (see *Figures 2* and *3*). The piezoresistive effect causes a signal to be generated at the output of the implanted Wheatstone resistance bridge (*Figure 4*). This signal is proportional to the

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AMS 5812 - Measuring over- and underpressure bidirectionally with one sensor

applied pressure ($V_{OUT} = f(P_1, P_2)$, but offset and endpoint (full scale signal) are yet to be determined.

As in the production of absolute pressure sensors it is not possible to achieve a referential pressure of 0bar, the actual value of P_2 must serve as a pressure offset. This is brought about by setting the value of P_2 to the required output offset of e.g. 0.5 V, during calibration. This procedure is known as offset calibration.

At full pressure P_1 maximum a full-scale signal is issued at the output which in the signal conditioning electronics is calibrated to the required output value of 4.5 V, for instance.

One popular application involves the measurement of barometric pressure between 700 and 1,200mbar absolute, for example. In this case the offset is calibrated to 700mbar and the full-scale signal to 1,200mbar.

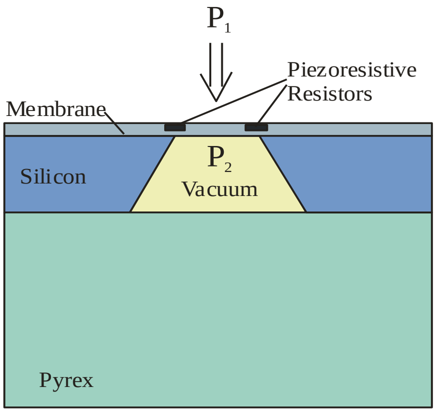


Figure 2: *Piezoresistive sensing element to determine absolute pressure P_1 with implanted resistors in a Wheatstone bridge*

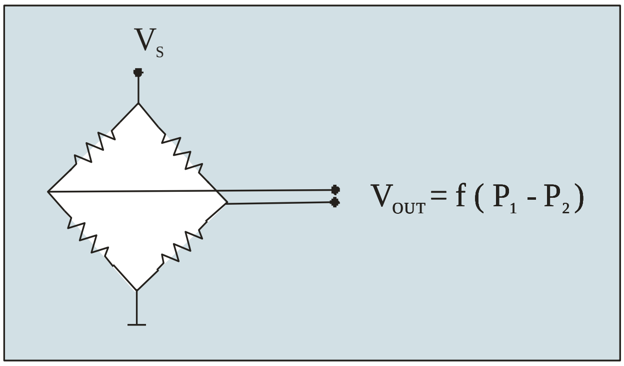


Figure 4: *Wheatstone bridge*

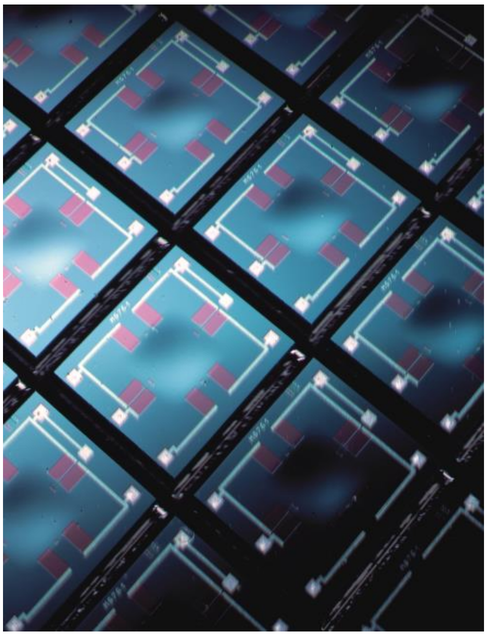


Figure 3: *Silicon pressure sensing element for the measurement of absolute pressure (plan)*

Light lines = aluminum conducting paths

Light squares = aluminum bond pads

Purple areas = implanted contact areas, with the piezoresistive hidden resistors between them

Area of the silicon pressure sensing element = 2 x 2 mm²

Height of the silicon pressure sensing element = 0.8 mm

AMS 5812 - Measuring over- and underpressure bidirectionally with one sensor

Measuring differential pressure

When measuring differential pressure, the two pressures P_1 and P_2 are compared which are applied externally through the relevant housing to the upper and lower side of the sensing element. The following applies: $P_1 \leq P_2$ or vice versa $P_1 \geq P_2$. With most sensors the requirement is that just one pressure ratio, i.e. $P_1/P_2 \geq 1$ or $P_1/P_2 \leq 1$ can be recorded and evaluated. In general, measuring pressure with this restriction is called "differential pressure sensing".

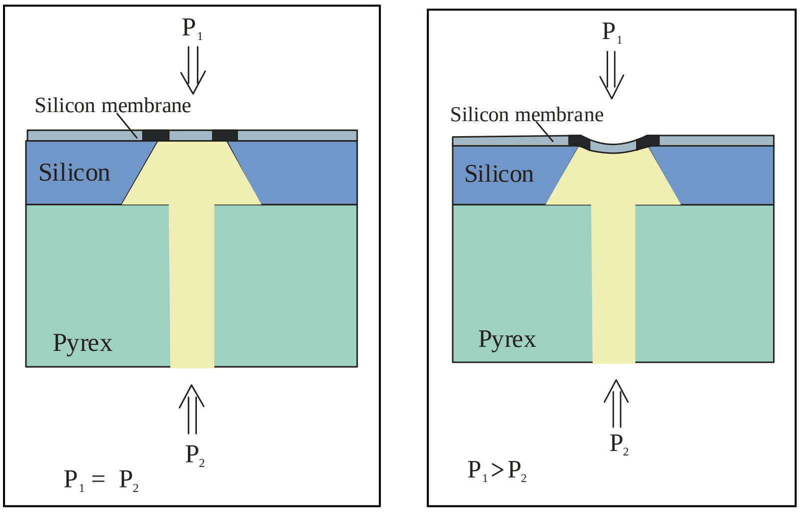


Figure 5: *How the membrane of a piezoresistivepressure sensor reacts when measuring differential pressure if $P_1 \geq P_2$*

The left graphic in *Figure 5* makes the situation $P_1 = P_2$ clear. The membrane is not deformed and the sensor generates no signal with the same pressure on both sides. But if there is a signal so it is the zero offset voltage which should be calibrated.

If $P_1 > P_2$ (right), when pressure is applied the membrane deflects towards the lower pressure area; in its piezoresistive bridge it produces an output signal proportional to the pressure of $V_{OUT} = f(P_1-P_2)$.

At the output of an amplified sensor such as AMS 5812-D the transfer characteristic shown in *Figure 6* is obtained after calibrating the offset and the fullscale signal.

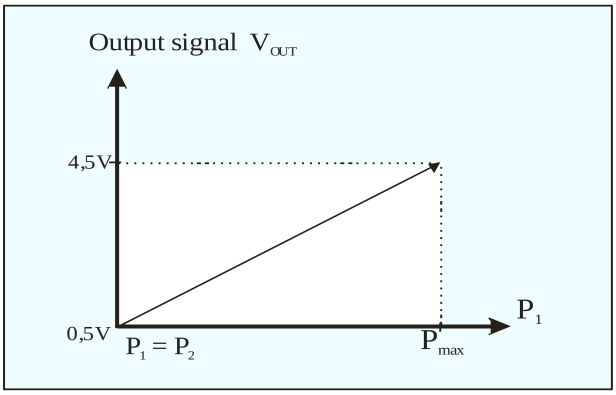


Figure 6: *Transfer characteristic of a pressure sensor when measuring differential pressure at $P_1 \leq P_2$*

In addition to the question of whether $P_1/P_2 \geq 1$ or $P_1/P_2 \leq 1$ should be recorded, for pressure sensors whose membrane has been optimized to suit the required pressure range the condition also applies that $P_1 - P_2 \leq P_{max}$ or $P_2 - P_1 \leq P_{max}$, with P_{max} limited by the given technical conditions e.g. package.

These boundary conditions must be heeded when the user fits pressure connections to the differential sensor and would like to measure differential pressure e.g. in filter control systems.

AMS 5812 - Measuring over- and underpressure bidirectionally with one sensor

Bidirectional differential sensors

Besides the measurement of differential pressure mentioned above there are also applications which require that both conditions $P_1 \leq P_2$ and $P_1 \geq P_2$ are met in one pressure system. These include, for example, ventilation and air exhaust systems, overshooting and/or undershooting a given liquid level, inhalation and exhalation setups, etc. As there is no generally recognized term for this kind of differential pressure sensing, AMSYS has decided to call sensors that can measure this type of differential pressure "bidirectional differential pressure sensors". These AMSYS sensors e.g. the AMS5812 are thus capable of measuring both negative and positive pressure.

Figure 7 is a schematic diagram of how the deformation of a differential pressure sensing element is to be perceived under the application of negative and positive pressure. The change in polarity in the output signal of the resistor bridge signifies nothing other than a change in the direction of the membrane deformation.

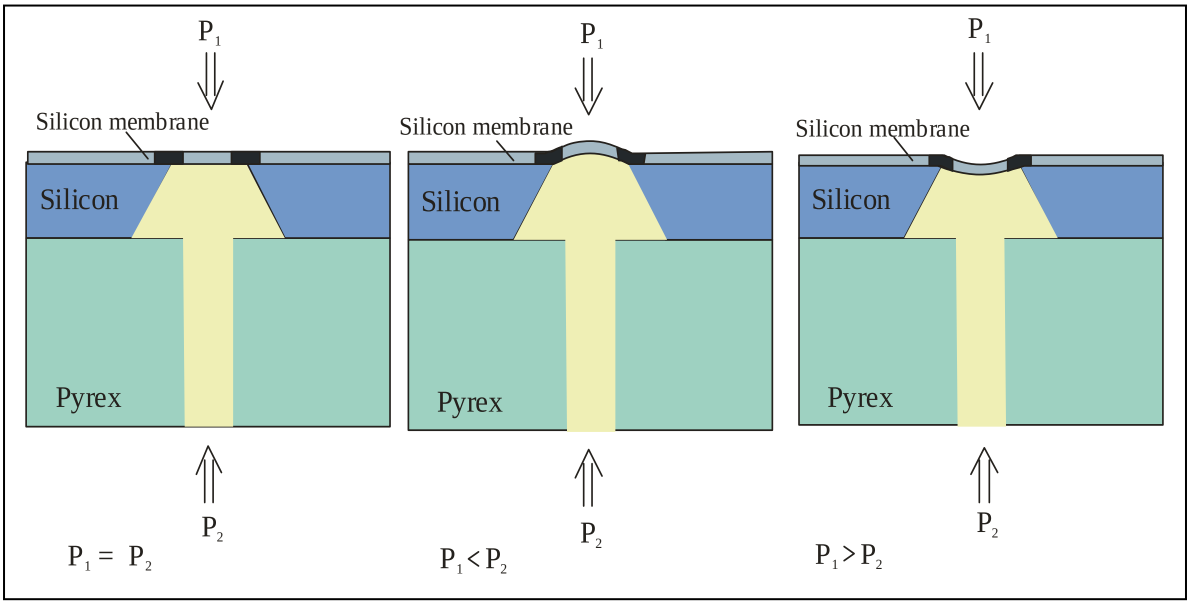
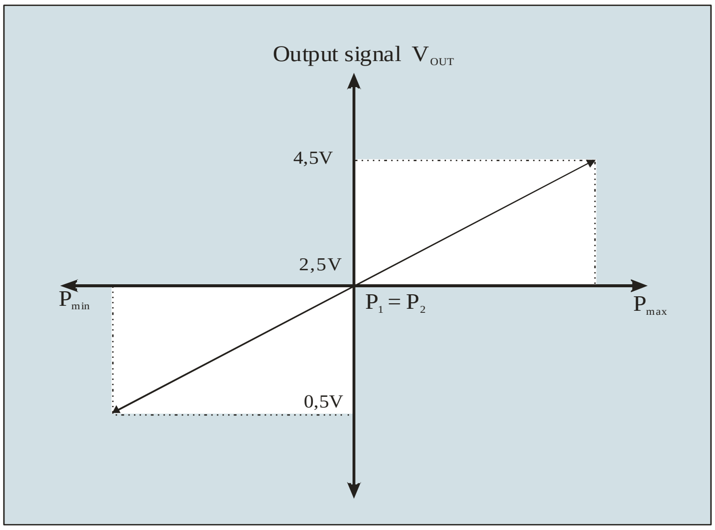


Figure 7: *How the membrane of the silicon sensing element reacts when measuring differential pressure if $P_1 = P_2$, $P_1 < P_2$ and $P_1 > P_2$*

With the sensing elements of these sensors, the differential pressure to be measured can have both a positive and negative polarity. This means that pressure P_1 at topside of the sensing element can be either greater or smaller than pressure P_2 at on the underside of the sensing element. The polarity can thus vary during measurement. For pressures P_1 and P_2 the following condition applies:

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

In the above formula P_{max} is the positive and P_{min} the negative ultimate pressure of the relevant pressure range (see Figure 8) for which the sensors have been designed. P_{System} is the maximum permissible system pressure, such as ambient pressure, which may be applied externally to the sensor and which is determined by the sensor assembly e.g. package or pressure port.



Figue 8: *Transfer characteristic for bidirectional differential pressure sensors at $P_1 = P_2$, $P_1 < P_2$, and $P_1 > P_2$*

AMS 5812 - Measuring over- and underpressure bidirectionally with one sensor

Bidirectional differential measurements are only possible when the following two sensor requirements are fulfilled:

the membrane structure must behave symmetrically in that it deflects on both sides, and

the transfer behavior of the signal conditioning electronics must suit the range of amplification in relation to the offset.

Regarding a): the membrane of a piezoresistive sensor is a thin semiconductor layer a few micrometers thick comprising several layerings. As a rule these are the film of silicon, an oxide coating and a passivation layer, with the latter two on the upper surface of the membrane. The layering is thus not symmetrical. Due to this asymmetrical layering the membrane behavior on pressure deflection can be direction dependent. In the worst case, when the direction changes it could be subject to the 'click' effect. This means that with a change in the direction of deflection the membrane demonstrates a discontinuity which is signaled to the user as strong non-linearity, particularly in the range of the offset pressure.

Manufacturers of silicon sensing elements which are to be used for the measurement of bidirectional differential pressure must therefore ensure that the membrane demonstrates a symmetrical behavior with both positive and negative pressure.

Regarding b): the transfer characteristic illustrated in *Figure 8* requires amplifier circuitry in which the instrumentation amplifier is not referenced to zero potential but instead set to half of the full-scale value. For example, in the bidirectional version of AMS 5812, which is to have an output signal of 0.5…4.5 V, the offset is set to 2.5 V so that the signal at $P_1 \leq P_2$ ranges from 0.5 to 2.5 V and at $P_1 \geq P_2$ from 2.5 to 4.5 V.

Measuring relative pressure

Should one of the active pressures P_1 or P_2 be equal to the effective ambient pressure, we then speak of relative pressure sensing, which is a variation on differential pressure measurement. In this case, the difference between measurement pressure P_1 and ambient pressure P_2 is then measured, for example, and $P_1 \geq P_2$ applies. As here we are measuring against ambient pressure, only one pressure port is required for the measurement pressure.

AMS 5812 - Measuring over- and underpressure bidirectionally with one sensor

Description of AMS 5812

One of the AMSYS sensors which is able to measure the differential and the bidirectional differential pressure is the AMS 5812 [1].

The AMS 5812 device described here is an OEM pressure sensor with two parallel outputs: an analog voltage output of 0.5…4.5 V or 2.5 V ±2 V and an I²C bus interface.

The output voltage signal is ratiometric to the supply voltage (5 V ± 5%). The pressure and temperature values can be set using the I²C interface. The sensor can be addressed through this interface and given an individual ID.

AMS 5812 devices are individually calibrated during manufacture and compensated for a temperature range of -25 to 85°C. Very accurate measurement, drift stability, and long-term stability are the result of high-quality piezoresistive pressure sensing elements combined with state-of-the-art signal conditioning circuitry in the form of a mixed-signal CMOS-ASIC.

A 15 x 15 mm^2 ceramic substrate with dual inline soldering pins and a ceramic housing give the pressure sensor high mechanical stability.

Different pressure ranges are offered:

AMS 5812: lowest pressure ranges, differential and bidirectional differential:
0–0.075; 0–0.15 PSI / ± 0.075; 0.15 PSI

AMS 5812: low pressure ranges, differential and bidirectional differential:
0–0.3; 0–0.8; 0–1.5 PSI/± 0.3; ±0.8; ±1.5

AMS 5812: standard pressure ranges, differential and bidirectional differential:
0–3; 0–5; 0–15; 0–30; 0–60; 0–100 PSI/± 3; ± 5; ± 15 PSI

AMS 5812: absolute pressure ranges: 0 -5 and 0 -30 PSI and barometric: 11–17.5 PSI

FEATURES	APPLICATIONS
• Relative, absolute, differential, and bidirectional differential pressure sensing • Wide pressure range (5mbar to 7bar) • Analog, ratiometric output voltage • Pressure measurement output through an I²C bus • Temperature output through an I²C bus • I²C bus interface with individual addressing • High accuracy in a wide operating temperature range • Large positive pressure range • Small package • No additional components	• Respirators and medical measurement technology in general • Gas flow and dynamic pressure measurements [2] • Heating, ventilation, air conditioning (HVAC) • Barometric measurements • Pneumatics • Vacuum measurement

AMS 5812 - Measuring over- and underpressure bidirectionally with one sensor

Summary

Besides the usual measurement of differential pressure, where a stipulated ratio between higher and lower pressure is measured ($P_1/P_2 \geq 1$ or $P_1/P_2 \leq 1$), there is also a variation known as bidirectional differential pressure sensing which permits both configurations to be measured simultaneously. This particular kind of differential pressure measurement which allows both positive and negative pressure to be measured, is called bidirectional differential pressure measurement and is explained in greater detail in the above, taking AMS 5812 as an example.

Further information

[1] Product information AMS 5812: https://www.amsys-sensor.com/products/pressure-sensor/ams5812-pressure-sensor-with-analog-and-digital-output/

[2] Application note on media compatibility AMS 5812: https://www.amsys-sensor.com/downloads/notes/ams5812-media-compatibility-of-silicon-pressure-sensors-amsys-508e.pdf

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