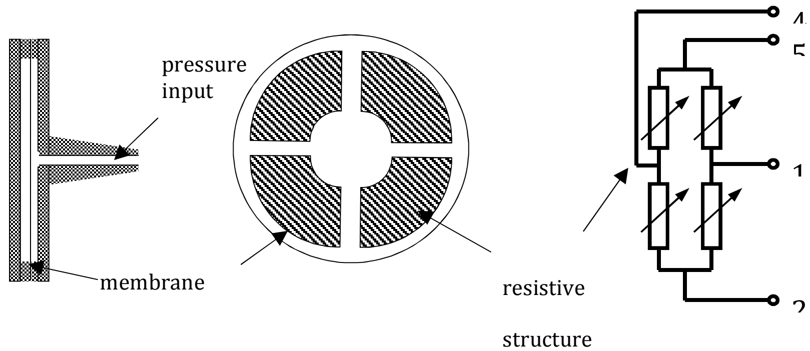
Introduction to the principals of **S**mart **P**ressure **D**evices

1 Basic principles

Pressure sensors are based on the principle of bending a membrane caused by the pressure in a liquid or gas. On the membrane is a very thin conductive screened layer that that follows the bending of the membrane. This bending can be measured in two different ways:

First one can measure the distance between the conductive (and resistive) layer on the membrane and a reference layer in the housing of the sensor (see Fig 1b) The two layers form a capacity and the change in the distance show a change in the capacitive value can be measured
Secondly, the resistance of the conductive layers is changed when the membrane is bent. A smart mechanical layout of four resistive structures can form a stable Wheatstone bridge, comparable with the classical strain gauge sensors. (see fig 1a)

Both ways of measuring the pressure are widely used. The Smartec line of pressure sensors is based on a resistive structure screened on the membrane.



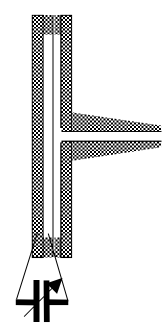


Fig1a. Principle of a pressure sensor gauge resistor

Fig 1b capacitive measurement based on strain of bending membrane.

The bending of the membrane (and also the layer) is very small (<< 1 mm), but is still large enough to measure the changes in the resistive values. The resistive structures on the surfaces can be compressed or stretched depending what direction the membrane is bent. When the layer is compressed the resistance value will decrease and when stretched this value will increase. In practice this means that the Wheatstone bridge is imbalanced in a positive and in a negative way respectively.

In general the screened resistors are also sensitive to temperature which means a compensation for temperature effects is required.

In the rest of this introduction we will only address the type of pressure measurement by means of changer of resistance, and not the capacitive way of measurement.

2 Types of pressure sensors

The membrane will be bent if there is a difference in pressure on both sides of the membrane. There are three types of pressure sensors: the **gauge** type, the **absolute** type and the **differential** type; each type with their specific field of application. In short:

gauge sensor measuring the difference of the medium and the atmospheric pressure, therefore one side of the membrane is always atmospheric pressure.

absolute type is referenced to vacuum, so one side of the membrane is vacuum.

differential sensor is referenced to another pressure and can measure the difference between the two pressures, so both sides can be anything.

Smartec has all three types in its product lines. Each will be discussed in detail in the sections below.

2.1 The gauge pressure sensor

Fig 2 shows the principle of the **gauge** type pressure sensor. One side of the membrane is pressurized liquid or gas type medium that has to be measured and the other side of the membrane is open to the atmosphere. This means the pressure measured is referenced to the atmospheric pressure. This connection to the atmosphere is generally called the **ventilation hole**.

This implies that the only interface between the "outside world" and the pressurized side is the membrane. Should this membrane be damaged (e.g. due to a pressure shock) the pressurized side is directly connected to the ventilation hole which means gasses or liquids flaring out can cause a dangerous situation. For measuring pressure of hazardous gases this type of sensor is not used and the absolute type is preferred (see section 2.2).

All gauge sensors have a ventilation hole that connects one side of the membrane to the atmosphere. In case this hole is closed or clogged due to for example pollution, readout errors may occur. In case these types of sensors are mounted into a ruggedized housing a ventilation hole must always be left open.

As example car tire pressure equipment are typical gauge type pressure sensors.

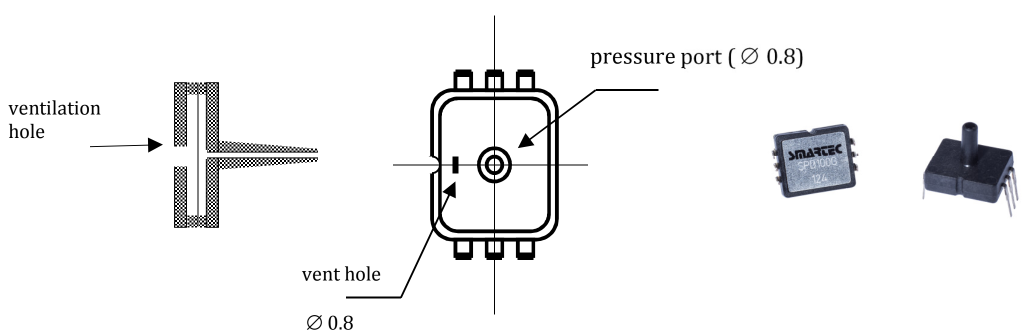


Fig. 2, principle of a gauge type pressure sensor

2.2 Absolute pressure sensor

The absolute version of the pressure sensor has no ventilation hole and that side of the membrane is vacuum. Therefor it measures against vacuum and hence the name: Absolute sensor. Figure 3 shows the principle of the absolute pressure sensor.

It is very hard to create such a "chamber" with an absolute vacuum (it does not exist actually). However the pressure in the vacuum reference chamber of the Smartec sensors is very low (25.10^{-3} Torr or 5.10^{-4} PSI).

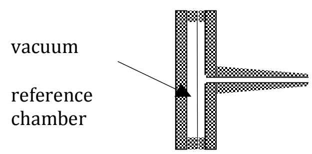


Fig 3, Principle of the absolute pressure sensor.

As is well-known, the vacuum must be high to prevent disturbing effects by differences in temperatures in the "almost" vacuum chamber. By warming up of the residue the pressure in the vacuum chamber will increase.

This kind of sensors is especially suited for use in explosive areas like LPG and LNG. The housing can be closed completely and mounted inside e.g. a pressurised gas tank. In case the membrane cracks (e.g., due to a pressure shock) only the vacuum chamber is connected to the media. The sensor is broken but no dangerous situation will occur. A special kind of Absolute sensor is the **Barometric** sensor. This sensor may be considered as an absolute sensor with a limited range. In principle this range is between about 1000 mBar and 0 mBar. But for more resolution **Barometric** sensors are designed for a range of 1000 – 800 mBar and are generally used to measure the atmospheric pressure.

As example car LPG-tank pressure equipment are typical absolute type pressure sensors.

2.3 Differential pressure sensor

The differential sensor has inputs to each side of the membrane, one for the positive input and the other one for the negative pressure input. The bending of the membrane is related to the difference of the pressure on each side. In figure 4 shows the principle of the differential pressure sensor.

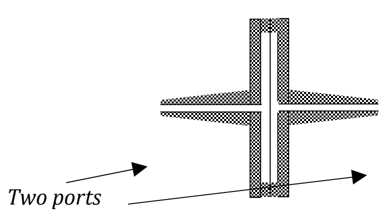


Fig 4, Principle of differential pressure sensor.

3 Output configuration

The output of the Wheatstone bridge has a certain value in case of absence of pressure or in case there is no difference in pressure on both sides of the membrane. This value is called the offset. The range of pressures (from min to max pressure) that the sensor can be used is called the span.

This bridge is not only sensitive to the bending of the membrane but also to temperature changes. This means in case of an accurate measurement both the offset and span (when pressurized) has to be compensated for temperature effects. Therefore the change in offset by the change in temperature is specified as well as the temperature coefficients of the span. If a lower accuracy is required, the bridge output voltage can be used without compensation.

To solve this problem user has to compensate for temperature effects.

The pressure sensors of some other suppliers have a kind of resistive compensation in the bridge circuit. Only **Smartec** sensors with the bridge output have to be compensated externally by the user. Other versions with analogue as well as digital output are compensated internally in our factory. This temperature compensation is maintained by means of the built-in signal processor so for the user there is no need to compensate anymore.

3.1 Bridge

As described above, the basic element of the sensor is the screened bridge on the membrane. This bridge is not only sensitive to the bending of the membrane but also to temperature changes. This means in case of an accurate measurement both the offset and span (when pressurized) has to be compensated for temperature effects. Therefore the offset is specified as well as the temperature coefficients of the offset and span. If less accuracy is required, the bridge output voltage can be used without compensation.

3.2 Analogue

The **Smartec** pressure sensors with analogue output are internally compensated for temperature effects. This compensation is factory based and runs over a certain temperature range by means of a look-up table that can be installed in the microcontroller. This means the sensors with an analogue output are very accurate and also have a stable offset. Due to the signal-processing inside the device there is some delay between the physical pressure and the output. In general this delay is in the range of 1 to 2 ms.

In the analogue version of the **differential** pressure sensor an extra definition is required. That is the point where pressure on both ports are the same, i.e. the pressure difference is zero. In that specific case the output voltage (offset) can be in the "middle" (halfway Gnd and Vcc) **or** the offset output voltage can be zero (GND level). The former version is called **differentia**l and the latter is called **single**. This means that the differential pressure can be measured only in one direction and the output swing for this direction is a factor two higher compared to the **differential** pressure sensor.

3.3 Digital

The digital data on line output is a 14 bits digital word. In data transfer terms this means there are two words of 8 bits each. The upper two bits of the highest data byte are not used and always zero. Be aware of the fact that the accuracy of the sensors is limited by the physical structure of the element and digitisation (14 bit) can never improve the analogue precision of the sensor.

We always restrict the range to between 10 and 90% of the 14 bits to detect clearly under and overflow of the sensor.

For a detailed description we refer to the specific datasheets of the products.

4 Some important definitions

Absolute pressure	this the pressure relative to vacuum
Atmospheric pressure	this is the outside air pressure relative to absolute vacuum. This pressure depends on the geographical location, altitude and weather conditions. Also called **Barometric** pressure.
Gauge pressure	this is the pressure relative to the **Atmospheric** pressure
Differential pressure	the difference in pressure between two locations
Span output	the difference between the output at maximum pressure level and the output at minimum pressure level applied.
Best straight line	the mathematically derived straight line best on multi-measurement of defined pressure levels. From each pressure point the output is averaged. The straight line is taken based on the minimal quadratic error.
Zero Offset	for an **absolute** sensor the Zero Offset is the output value on a pressure of 0 PSI (vacuum) while for **gauge** and differential sensors the Zero Offset is the output value when the sensor is applied to the **Atmospheric** pressure.
Pressure range	the difference between the maximum pressure applied and the minimum pressure applied.
Accuracy	the deviation between the best straight line output and the one found based on volume tests. In the accuracy all errors are included. (in general expressed in a percentage of the full scale output)
Linearity	how much a set of measured pressure points deviate from the best straight line (in general expressed as a percentage of the full scale)
Ratio metric	means the output of the sensor (analogue) is related to the power supply voltage. This means when the Vcc drops fi. 10% the output voltage also drops 10%

Response time the time needed to settle the output (95%) as a response of a step in the applied pressure.

Pressure overload is the maximum pressure that can be applied without effecting the specifications

Temperature compensating is the temperature range where the sensor is compensated by the built-in signal processor. Outside this range the specifications are not guaranteed. (Also called: **compensated temperature range**)

5 Nomenclature

Due to the wide range of possibilities of input and output it is useful to standardize the nomenclature of our sensor range. This means most of the sensors can have a specific code that matches the type of product.

The Generic code of the Smartec pressure sensor is:

SPDppptohhh<H>

All references start with SPD (**S**mart **P**ressure **D**evice).
The '**ppp**' field indicates the pressure range in PSI (three digits).
The '**t**' field indicates the **type** and equals A, G or D, meaning **A**bsolute, **G**auge or **D**ifferential.
The **'o'** field indicates the **output** and equals B, G,I or D, meaning **B**ridge, **A**nalogue, **I²C** or **D**igital or **S**ingle.
The **'hhh'** field indicates the **housing**: DIP, SIP, SOC or TO5
If a capital **'H'** is present in the product reference (normally at the end of the code), this means that the product is a **Hybrid** (MEMS made) component.

Please note that 'ppp' field that indicates the pressure range of the sensor and which holds three digits normally represents the pressure range in psi. However, because of the very low pressure range of the SPD102DADIPH sensor, an exception was made in this case, and the 'ppp' field indicates the pressure in mm H_2O. (102 mm H_2O = 0,15 psi)

Some Examples:

Reference Code	Pressure range	Type	Output	Packaging
SPD015GBDIP	15 PSI	Gauge	Bridge	Dual in line
SPD102DAhyb	102 mm H_2O	Differential	Analogue	Dual in line
SPD002GASIP	2 PSI	Gauge type	Analogue	Single in line

6 Units

Below you find some relevant units related to pressure measurement. According to the SI standard the pressure definition is Pascal. However many clients use the PSI (pounds per square Inch) definition. Another unit widely used is the Bar or kgf/cm^2

Please find below an overview of the different units.

1 Bar = 14.5038 PSI (in practice 15 PSI)

1 Bar = 1 kgf/cm2

1 Bar = 10^5 Pa = 10^5 N/m^2

1 Bar = 10 m H_2O = 10^4 mm H_2O

100 mm $H_2 0$ = 10 mBar

1 Pa = 0.145038*10 $^{-3}$ PSI

1 PSI = 6.89476*10^3 Pa

In order to simplify calculations we consider 15 PSI as 1 Bar.

QUESTIONS? **Please, send your mail to: support@smartec-sensors.com**