New Applications for Integrated Pressure Sensors

Application Note

Rev. 1.1, 2011-12-22

Sense & Control

Edition 2011-12-22

Published by
Infineon Technologies AG
81726 Munich, Germany

Revision History	
Page or Item	**Subjects (major changes since previous revision)**
Rev. 1.1, 2011-12-22	
Revision History	Update of Trademarks
Figure 3	Picture updated

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1 Introduction

The precise measurement of pressure is a requirement of many applications in different fields of the market. From an altimeter in the consumer area to gas meters in the industry to engine management in the automotive field, the requirements of the application towards pressure range, accuracy and type of output signal will be different from system to system.

With the long experience of Infineon as a semiconductor company, we are able to offer a wide portfolio of pressure sensors of different types and different pressure ranges. Infineon's integrated pressure sensor family uses a unique design of multiple surface micro-machined capacitive sensor cell arrays, that allows implementation of powerful features like sensor self diagnostics. The monolithic integration onto one chip allows a state-of-the-art production using a standard automotive qualified BiCMOS process. The combination of sensor cell design with fully digital signal conditioning and processing with the methods of a high volume standard production flow ensure superior quality over lifetime.

Infineon's pressure sensors can be classified as absolute pressure sensors, where the output signal is proportional to the applied pressure, or relative pressure sensors, where the sensor output is proportional to a change of the applied pressure. The following application note will give an overview about some new applications in the market and will give some suggestions of Infineon's pressure products.

Detailed information about the full Infineon pressure sensor portfolio can be found at **www.infineon.com/pressure**.

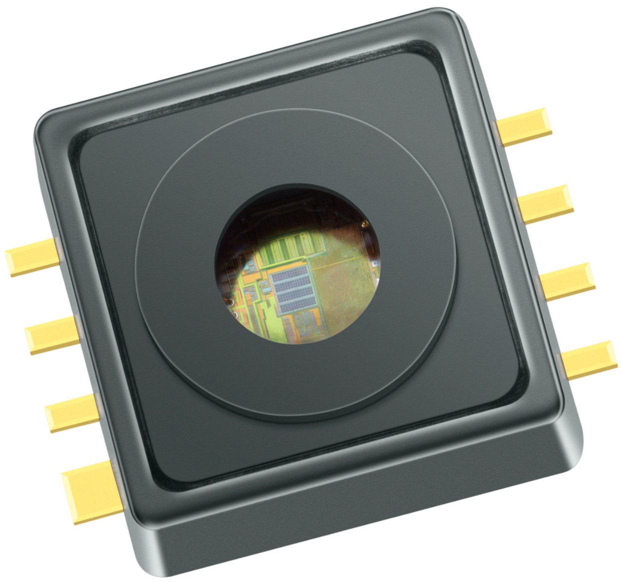

Figure 1 Infineon's monolithic pressure sensor

2 Automotive applications for absolute pressure sensors

Infineon's absolute pressure sensor family provides a signal proportional to the pressure to which the sensor is exposed. They can be used to measure pressures both above and below ambient atmospheric pressure. Pressures below ambient atmospheric pressure are often referred to as "vacuum". The output signal may be an analog voltage or a digital value. In either case, Infineon's sensors are designed to interface directly with standard micro controllers, providing a low system cost. Every sensor in the family is calibrated and temperature compensated in order to provide the highest accuracy without the need for additional circuitry or microprocessor signal processing. In addition, each sensor includes a gel passivation layer to provide resistance to common chemicals found in automotive applications, such as gasoline, diesel fuel, oil and exhaust by-products.

2.1 Brake booster

Modern automotive hydraulic brake systems utilize a vacuum booster or vacuum servo to amplify the braking force applied by the driver to the brake pedal. The servo is composed of two chambers divided by a flexible diaphragm. At equilibrium, both chambers hold an equal vacuum (pressure lower than atmospheric pressure). This is accomplished by a connection to a vacuum source such as the vehicle intake manifold or a vacuum pump. When the brake pedal is depressed, an air valve opens which allows atmospheric pressure into one chamber of the booster. The higher pressure on one side of the diaphragm, along with the motion of the brake pedal, causes the diaphragm to deflect, increasing the force applied to the master cylinder.

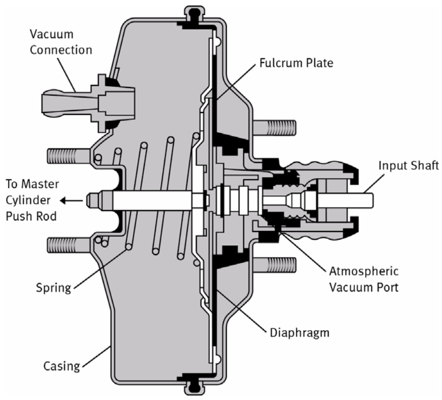

Figure 2 Drawing of a vacuum power brake booster

One potential failure mode of this system is an air leak between the booster assembly and the external environment. Such a leak may be present at the seal with the brake pedal, the connection to the vacuum source, or the casing itself. In the event of a leak, insufficient vacuum will be developed in the chambers while driving and the system will not be able to provide the necessary assist to the driver's foot force during braking. An absolute pressure sensor can be used to monitor the vacuum within either chamber, and provide a warning to the driver in the event of this dangerous condition.

Another potential failure mode is a torn or otherwise damaged diaphragm between the chambers. In this case, proper vacuum will still be developed within the chambers while driving. However, during braking the leak path between the chambers will serve to equalize the pressure between the two chambers. As the pressure differential between the chambers is the source of diaphragm deflection and hence amplification of the driver's foot force, such a leak will also reduce the effectiveness of the vacuum assist. Once again, an absolute pressure sensor can be used to monitor the vacuum within the air chamber. The rate of pressure change during braking operation can be measured to verify the proper functionality of the brake booster.

Infineon's family of absolute pressure sensors is well-suited to this application. Among the analog interface components, the KP21x MAP sensor family (manifold absolute pressure) can measure pressures as low as 10 kPa (approximately 10% of sea level atmospheric pressure). The KP21x family is fully automotive qualified and can operate across an extended temperature range, from -40 °C to +125 °C.

2.2 Engine management system

To keep a modern combustion engine running efficiently an engine management system (EMS) is used. The EMS is a type of electronic control unit (ECU) that determines the amount of fuel, ignition timing and other parameters. To do this, many input values like engine speed or the position of the accelerator pedal is used. For an engine with fuel injection, the quantity of fuel to inject must also be defined. Besides the engine temperature, the manifold air temperature, the throttle position and several other parameters, measurements of the manifold air pressure and the barometric air pressure are needed. The information of both pressure values is important for calculating the amount of fuel to be injected to ensure the correct air fuel mix.

The pressure inside the manifold is measured by the manifold absolute pressure sensor (MAP). For this application the Infineon's KP21x family of absolute pressure sensors is well-suited.

For turbo charged combustion engines the manifold air pressure is measured after the turbocharger. In this case measurement of pressures up to 400 kPa is needed. Here, the Infineon's KP22x family of TurboMAP sensors is available.

Figure 3 Picture of a MAP module with an Infineon KP21x sensor inside

As mentioned, for a correct calculation of the fuel amount to be injected, measurement of the ambient pressure is also necessary. This information is provided by the barometric absolute pressure sensor (BAP). This sensor is typically located inside the ECU. For this application, Infineon offers the KP23x absolute pressure sensor family with an analog output signal and the KP25x family with a digital SPI interface.

2.3 Particle filters for diesel engines

To reduce diesel particulate matter or soot from the exhaust gas of a diesel engine, a diesel particulate filter (DPF) is used. In addition to collecting the particulate, a method must exist to clean the filter (filter regeneration). A typical principle is burning off the accumulated particulate either through the use of a catalyst (passive system), or through an active technology. This active principle is either based on fuel burner which heats the filter to soot combustion temperatures or through engine modifications. As soon as the filter load reaches a pre-determined level, the engine is set to start a specific program either to heat the exhaust gases, or to produce high amounts of nitrogen oxide (NOx), which will oxidize the particulates at relatively low temperatures. In the active filter regeneration systems, the exhaust gas pressure is measured before and after the diesel particulate filter either by a relative pressure sensor or by two absolute pressure sensors. The pressure difference is directly linked to the filter load.

Infineon is currently developing a family of pressure sensors with a new passivation gel, which is resistant to the chemical acids how they exist in exhaust gas.

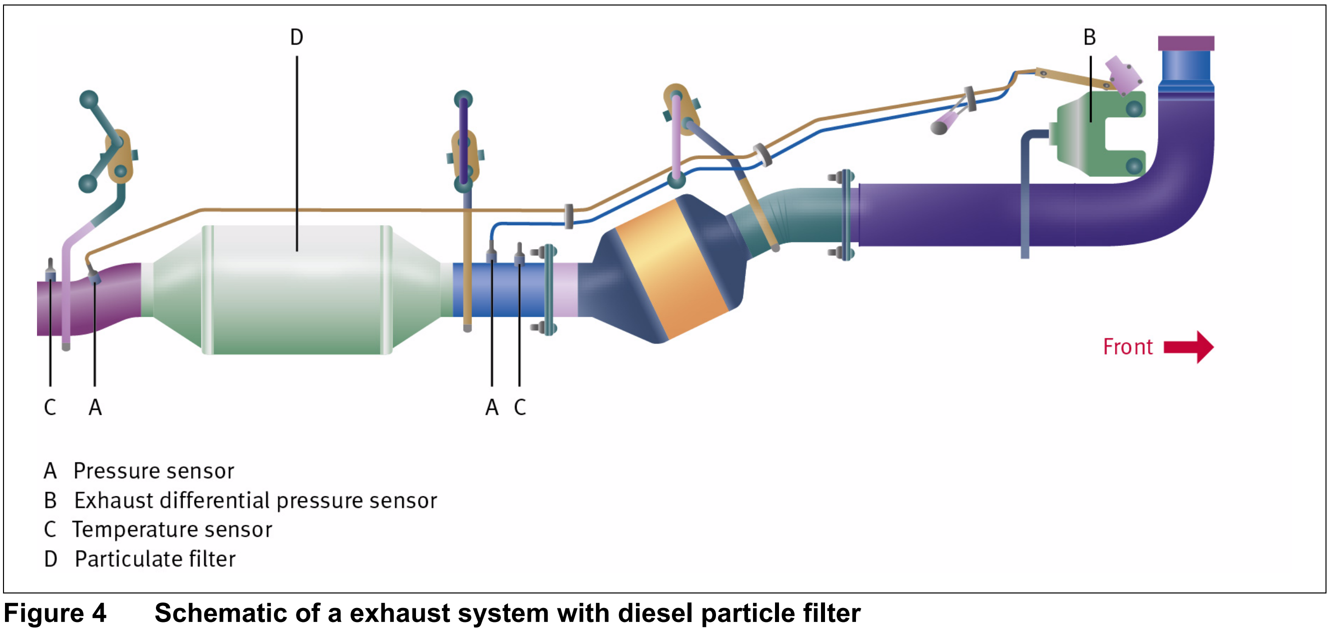

Figure 4 Schematic of a exhaust system with diesel particle filter

2.4 Secondary air valve

After a cold start, a catalytic converter fails to achieve any purifying effect until the correct operating temperature of 300°C to 350°C is achieved. The secondary air system enhances the catalytic converter during the engine's warm-up phase to reach the correct operating temperature by injecting secondary air into the exhaust gas manifold. The secondary air increases the exothermal oxidation of the unburned carbons and carbon monoxides. The heat released in the process allows the converter to reach its operating temperature more readily.

After the warm-up phase when the catalytic converter reaches its operating temperature, the pump of the secondary air system is switched off. When the system is switched off, a valve is used to seal the pump unit against the aggressive exhaust gas condensate. A pressure sensor is placed between the pump unit and the valve to ensure the correct operation of the valve.

Infineon's KP21x MAP sensor family with analog output is a perfect match for this type of application.

2.5 Exhaust gas recirculation (EGR)

In order to be able to comply with future emission limits, stiff requirements are applied to combustion engine systems. To reduce nitrogen oxide (NOx) emissions, a portion of an engine's exhaust gas will be recirculated back into the combustion engine. In a diesel engine, the exhaust gas replaces some of the excess oxygen in the precombustion mixture; in a gasoline engine the exhaust displaces the amount of combustible matter. Both principles reduce the combustion chamber temperature which finally reduces the amount of NOx the combustion generates. In addition, fuel consumption of gasoline engines under part-load conditions is reduced. A pressure sensor is used to control the EGR valve.

Infineon is currently developing a family of pressure sensors with a new passivation gel, which is resistant to the chemical acids how they exist in exhaust gas.

2.6 Fuel vapor

Vapors are created within automotive fuel systems. The vehicle's evaporative emission control (EVAP) system helps reduce emission of these vapors into the atmosphere. This is accomplished by utilizing a sealed fuel system which does not vent directly to the atmosphere. Rather, the vapors are routed to an evaporative system canister where they are adsorbed by the activated carbon within the canister. When the engine is running, fresh air is passed through the canister, allowing the adsorbed vapors to be burned in the engine rather than released directly into the atmosphere.

Environmental regulations in the US require the EVAP system to be monitored for leaks. An absolute pressure sensor located in the fuel tank communicates with the electrical control unit (ECU), allowing this diagnostic function. The KP23x family with analog output or the KP25x family with digital SPI output are a perfect match as reference sensor in this application.

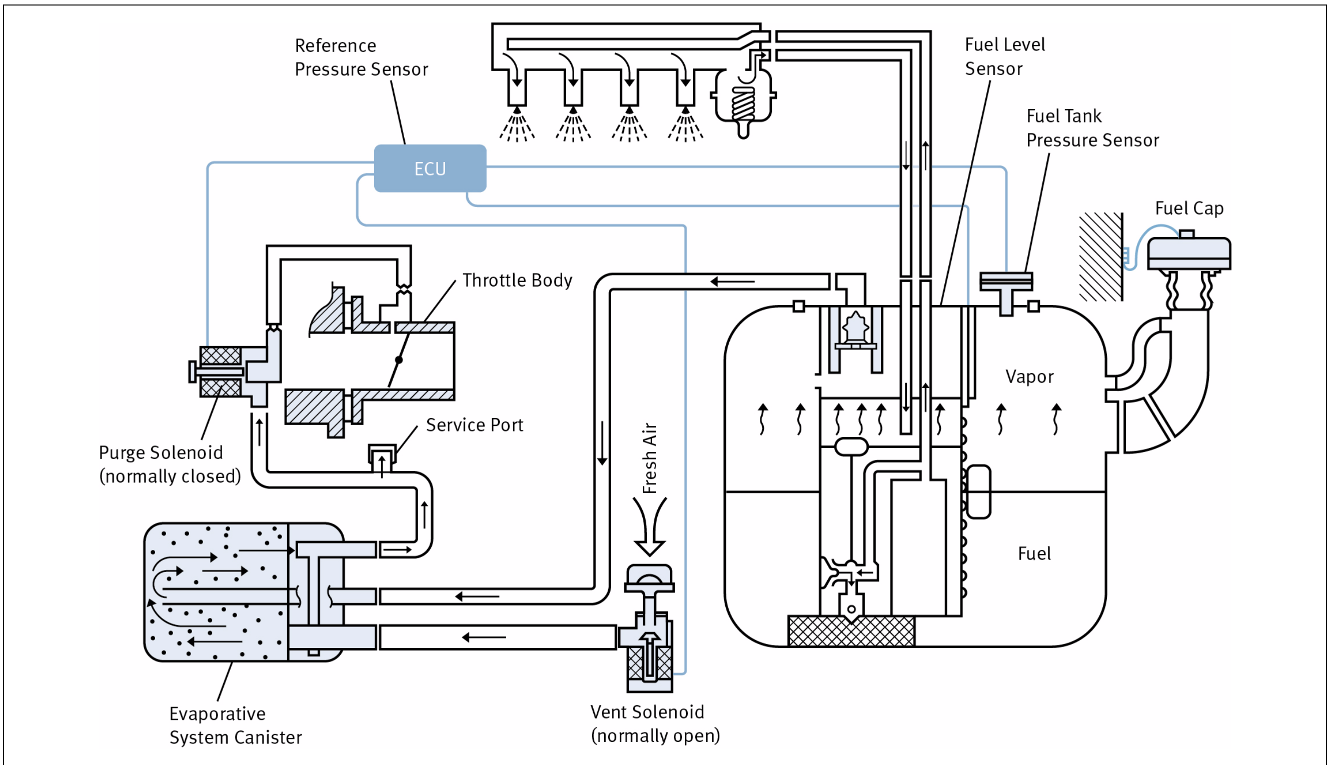

Figure 5 Schematic of a fuel vapor control system

3 Automotive applications for relative pressure sensors

Infineon’s relative pressure sensor family provides a signal which is proportional to the pressure change inside a fixed volume ($\Delta p/p_0$). The amplitude of the signal is independent of the ambient pressure, but is dependent on the relative pressure change. This is achieved by dividing the absolute pressure change by the ambient pressure. The division is performed on-chip. The ambient pressure is calculated with a low pass filter from the absolute pressure. The sensor provides the relative pressure as output signal. This cost optimized configuration allows autonomous operation of the sensor without any further logic ICs.

Several versions with different sensitivity, absolute pressure range and output protocols are available. For details see the Infineon web page at **www.infineon.com/pressure**.

3.1 Side crash detection for side airbag firing

Side impacts account for approximately 30% of all car accidents and still causes about 35% of the fatalities[1)]. Due to the smaller crumple zone on the side of a car, the firing decision of a side airbag needs to be much faster than for a front crash (**Figure 6**). There are advanced guidelines available on how to perform crash tests with a defined side impact.

Tests with different sensor types have shown that the fastest way to detect a side impact is to measure the pressure change of the air volume inside the door, which is deformed during the crash (**Figure 7**). Infineon’s side airbag pressure sensor family (SAB) is especially designed for the use as a pressure satellite in a door module located within the car’s side door.

When the door is compressed due to a side impact, the sensor provides a signal pulse proportional to the pressure change inside the door. Infineon’s KP200 sensor for example, provides the relative pressure as a digital Manchester encoded output signal. With this sensor, Infineon is the first manufacturer to conform to the latest PSI5 and AK LV-29 standards for air bag systems.

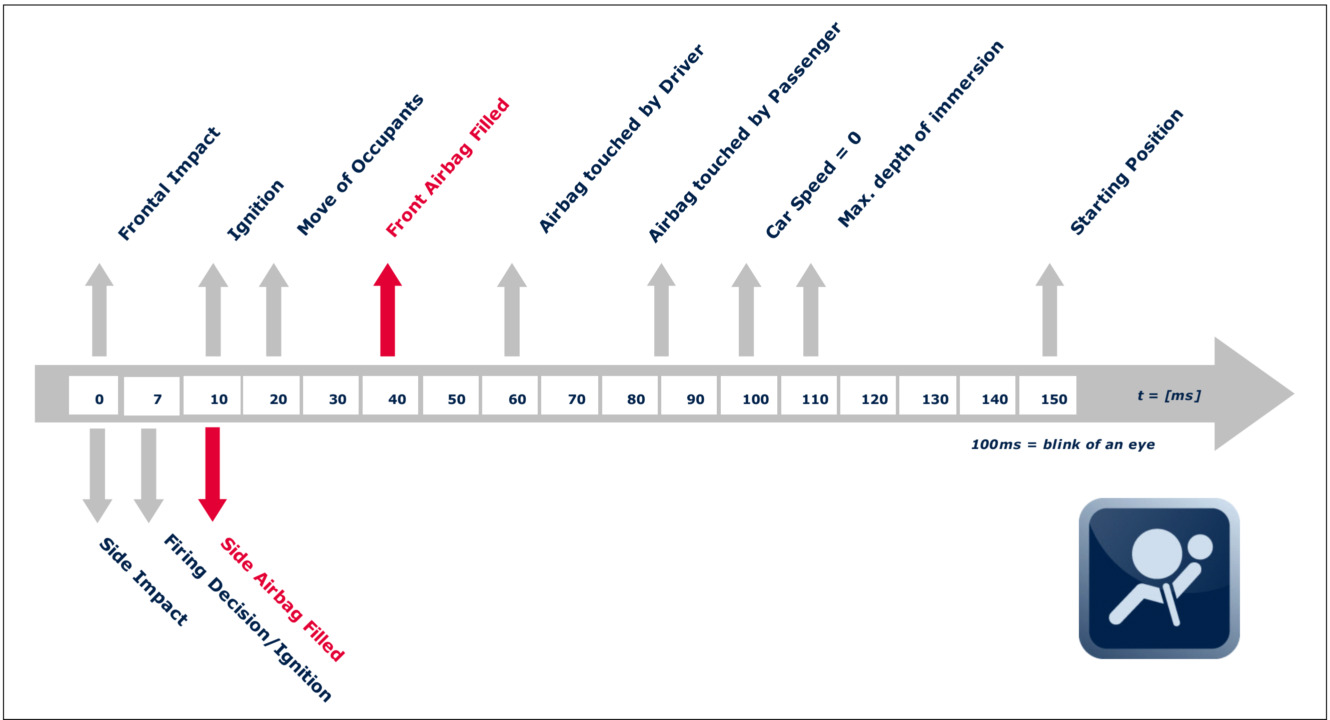

Figure 6 Airbag timing during different types of car accidents

1) Source: German In Depth Accident Study - GIDAS, National Automotive Sampling System - NASS & BMW accident databases

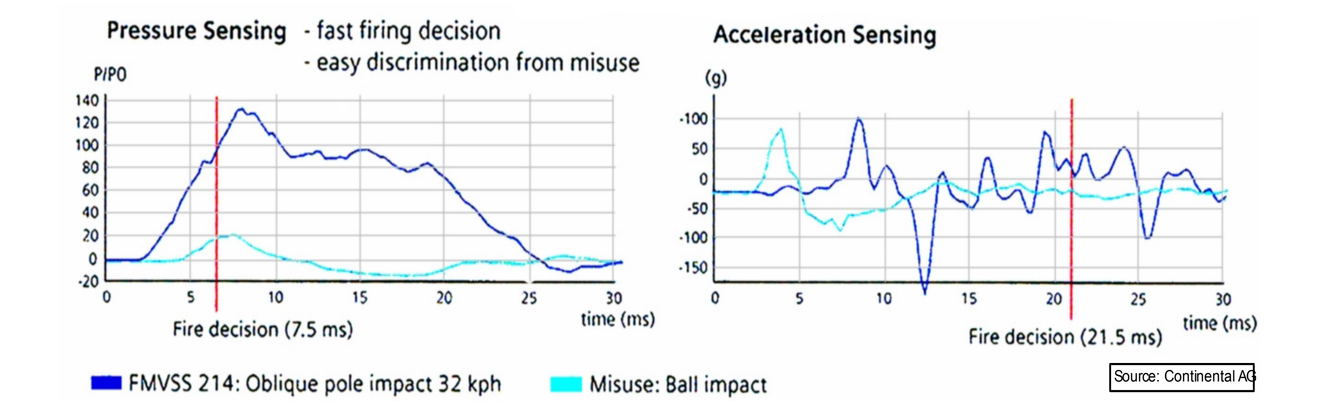

Figure 7 Comparison of the signal response between a KP200 pressure sensor and an acceleration sensor

3.2 Pedestrian protection

A new application for the KP200 pressure sensor with pulse activation is pedestrian protection. During a collision with a pedestrian, a sealed air hose integrated into the front bumper is distorted. Two KP200's at either end of the hose detect the collision via the resulting pressure change and transmit this to a central processing unit. This unit then activates a mechanism to raise the bonnet of the car towards the pedestrian. This lifting action not only softens the pedestrian's impact but prevents them from impacting the engine block through the hood.

The Infineon KP200 relative pressure sensor prevents false activations by automatically compensating for ambient pressure variations caused by weather changes or changes in the altitude of the vehicle.

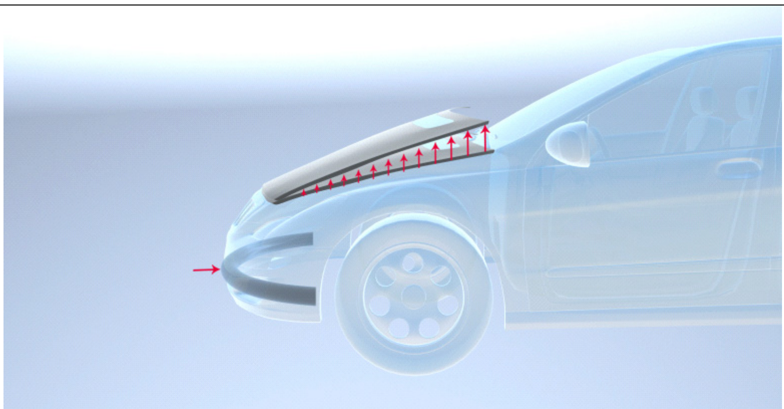

Figure 8 Active pedestrian protection

3.3 Pinch protection for doors and windows

Due to the increased electrification of doors and windows, the need for safe monitoring of the closing door / window is increasingly important. An optical monitoring system is very vulnerable to dirt and debris.

A new way of pinch protection is to mount a sealed air hose on the edge of the door. The pressure inside this hose can be monitored by Infineon's KP200 relative pressure sensor. In case an object is blocking the door or window while automatically closing, the pressure inside the hose will change. The output of the KP200 is proportional to the pressure change and the door/window control can react accordingly. By changing the stiffness of the hose, the sensitivity of the pinch protection can be chosen.

4 Industrial and consumer applications

With the miniaturization and cost reduction of pressure sensors, a wide field of new applications have arisen in the industrial and consumer market where pressure sensors play an important role. The following chapter lists some of the new applications.

4.1 Gas meter

The most common type of gas meters in residential and small industrial installations is the diaphragm meter. Inside the meter, there are two or more chambers separated by a movable diaphragm. The gas flow through the meter is directed by the intake valves and fills the first chamber, while the moving diaphragm deflates the other chamber. Once the first chamber is completely filled, the valve changes position and the second chamber is filled, while the first chamber is deflated again. The linear movement of the diaphragm is transferred via a mechanical crank shaft into a rotary movement, which then can drive an odometer-like counting mechanism. The amount of gas flowing through the gas meter is then reduced to a simple counting of the filled volumes inside the meter.

The volume of gas is highly influenced by the pressure and the temperature. Therefore the overall accuracy of the gas meter will increase when these two parameters are measured with high accuracy to correct for these variations.

Infineon’s KP253 absolute pressure sensor with its small accuracy error of less than 1 kPa and high 12-bit resolution is perfectly suited for the use in diaphragm gas meters. The passivation gel used in Infineon’s KP25x family is stable against the chemical agents occurring in natural gas.

4.2 Altimeter

The ambient pressure of the atmosphere varies as a function of altitude. Through the use of an absolute pressure sensor, the atmospheric pressure can be directly measured. This provides a simple method for determination of elevation in portable or fixed electronics.

This pressure measurement as a function of elevation is characterized by the following equation, which also includes the variation of the temperature with the altitude:

$$p = p_0 \cdot \left(1 - \frac{L \cdot h}{T_0}\right)^{\frac{g \cdot M}{R \cdot L}} \tag{1}$$

Table 1 Parameters

Parameter	Description	Value	Unit
p_0	Sea level standard atmospheric pressure	101.33	kPa
L	Temperature lapse rate	0.0064	K / m
T_0	Sea level standard temperature	288.15	K
g	Earth-surface gravitational acceleration	9.8067	m / s^2
M	Molar mass of dry air	0.028964	kg / mol
R	Universal gas constant	8.3145	J / (mol * K)
h	Altitude above sea level		m
p	Pressure at given elevation		kPa

Rearranging **Equation (1)** toward the altitude h will result in the equation:

$$h = \frac{T_0}{L} \cdot \left(1 - \frac{p}{p_0} \right)^{\frac{R \cdot L}{g \cdot M}} \tag{2}$$

By using the constant values from **Table 1** we get the **Equation (3)**. For a pressure measured in kPa, this equation directly provides the altitude in meters:

$$h = 45023 \cdot \left[1 - \left(\frac{p}{101.325} \right)^{0.18734} \right] \tag{3}$$

A plot of altitude vs. atmospheric pressure is given below:

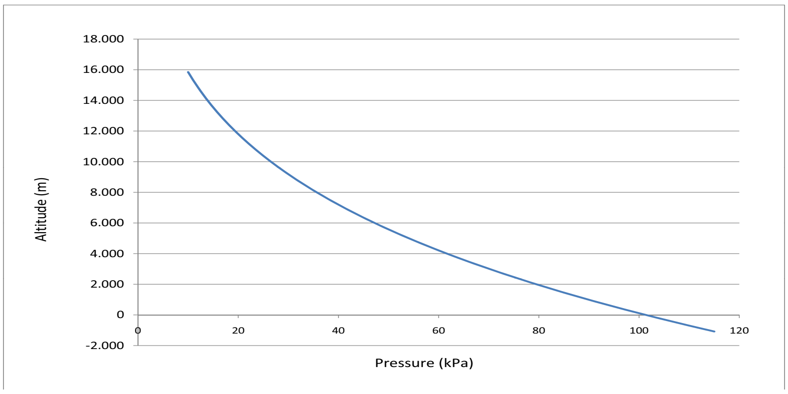

Figure 9 Graph of the altitude versus pressure

Note that although the relationship between pressure and altitude is not linear across the full 15 to 115 kPa range, for small changes in altitude the pressure change can be assumed to be linear.

Infineon's KP23x ratiometric analog pressure sensors, and KP25x digital pressure sensors, can measure altitude from -2000 meter up to 13000 meter range. The sensors are temperature compensated and individually calibrated to provide the highest accuracy while reducing the calculation burden within the customer's microprocessor.

4.3 Weather stations

Although the standard atmospheric pressure at sea level is 101.325 kPa, the ambient atmospheric pressure changes with the weather. The surface pressure at sea level has been measured as low as 87.0 kPa (25.69 inHg) and as high as 108.57 kPa (32.06 inHg).

Low pressure areas are generally associated with clouds, precipitation and inclement weather. High pressure areas generally are associated with clear skies. These facts can be used to forecast weather from measured atmospheric pressure.

For a weather station at a fixed location, a simple approach is to compare the instantaneously measured pressure to the standard atmospheric pressure for the current altitude. **Equation (1)** in **Chapter 4.2** provides a formula for calculating the standard pressure for a given altitude. A variation on this simple approach is to measure the change in pressure over an extended time of several hours. This eliminates the need for the user to enter the weather station altitude.The following table provides a weather forecast for a given difference between the measured pressure and the calculated standard pressure.

Table 2 Simple weather forecast algorithm

Measured Pressure – Standard Pressure or Pressure change within some hours	Weather Forecast
> +0.25 kPa	Sunny
-0.25 kPa to +0.25 kPa	Variable
< -0.25 kPa	Cloudy / Rain

A more sophisticated algorithm would determine the rate of change of pressure over time:

Table 3 Sophisticated weather forecast algorithm

Change in Measured Pressure	Weather Forecast
> +0.25 kPa/h	Unstable intermediate high pressure system
+0.05 kPa/h to +0.25 kPa/h	Stable fair weather
-0.05 kPa/h to +0.05 kPa/h	Current conditions will continue
-0.25 kPa/h to -0.05 kPa/h	Stable rainy weather
< 0.25 kPa/h	Thunderstorm

With accuracy error of less than 1 kPa and built-in temperature compensation, Infineon's KP23x and KP25x barometric absolute pressure sensors are an excellent choice for the use in weather stations.

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