The 24-bit revolution in pressure sensor technology

Sensor module MS5607 with a digital interface
Practical application: measuring altitude

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The altitude can be accurately measured using a number of different physical methods. These include optical (laser measuring instruments), electronic (microwave detectors), and barometric procedures. The following article outlines how altitude can be measured with an impressive resolution of the barometric pressure using an (ultra-)miniaturized, silicon-based pressure sensor, the MS5607.

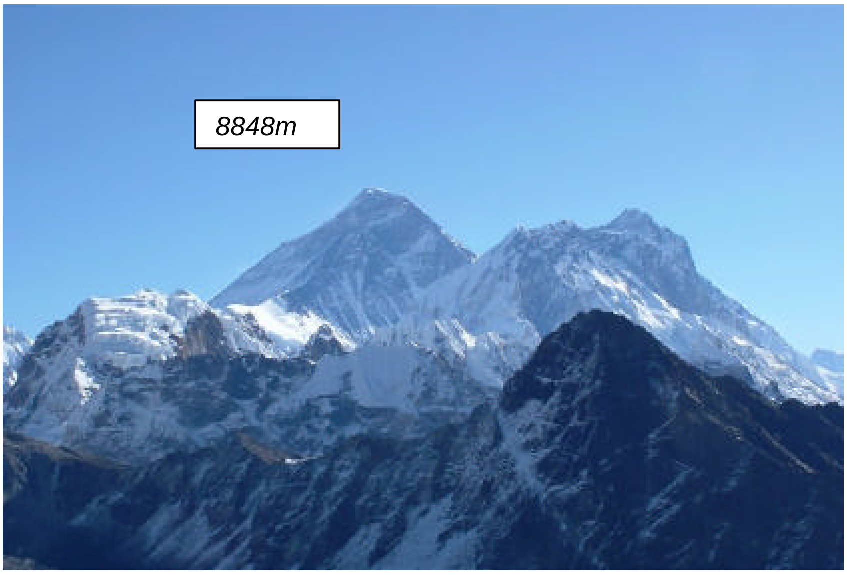

Figure 1: *Mount Everest*

The term "atmospheric pressure" is a local variable that describes the pressure generated by the weight of the layer of air that surrounds the Earth at that point. As air is a compressible medium, the atmospheric environment must be denser towards the Earth's surface and the column of air thus heavier than vice versa. The pressure of air thus de-creases with an increase in altitude from its zero point (sea level) at 1013 mbar. Measured from sea level, atmospheric pres-sure changes at approximately 1 mbar/8m. This is only an approximation as there is a non-linear correlation between the atmospheric pressure and the altitude due to the compressibility of air. At the summit of Mount Everest, for example, 8848m above sea level, the atmospheric pressure is thus 310mbar. The barometric pressure means the local dependent superposition of the atmospheric pressure and the weather correlated pressure influence. If the barometric pressure is measured, the functional correlation between height and atmospheric pressure (barometric formula) can be used to determine altitude.

Pressure sensors as altimeters

Most of the altimeters commercially available are based on absolute pressure sensors with digital signal conditioning and have an instrument range of -100 to 4,000, 5,000 or 9,000 meters with a resolution of several meters. They can therefore not be described as being particularly precise. The most of these sensors have a digital signal conditioning unit and they operate on a 14-bit ADC basis. 14-bits of ADC do not auto-matically mean that the signal can be resolved with 14bits. Depending on the signal span, the offset, and the signal evaluation electronics, possibly 10 to 12 bits are available for signal conditioning.

Until now, achieving a better level of resolution was only possible using complex pressure sensing systems – and was thus a costly undertaking.

Taking into account the fact that resolution must not be confused with precision, with a reliable altimeter which is also to be used to determine the absolute height, the calibration accuracy and offset drift – and with changing temperatures the temperature behavior in the offset and in the span signal – must also be considered when assessing the quality. Further important practical factors pertinent to mobile systems are their size and the power consumption. Regarding industrial production, there is also the requirement that the price/performance ratio is favorable. All these requirements are realized in the:

Absolute pressure sensor MS5607

The absolute pressure sensor MS5607 is based on an advanced semiconductor (ASIC) and microstructure technology (MEMS). The chief component of the sensor is a piezoresistive silicon sensing element. It has a thin membrane as its pressure-sensitive element that is etched anisotropically from the silicon chip. At suitable points local foreign atoms are implanted in the silicon crystal, creating zones with a changed electrical conductivity so that electrical properties of resistors exist. When pressure is applied to the sensing element, the thin silicon membrane is deformed. The internal forces this generates cause the molecular structure of the crystal to change in a reversible process. Particularly in the resistor area are marked shifts in potential in the crystal structure that lead to a measureable change in electrical value (the piezoresistive effect). These resistors are connected up as a Wheatstone bridge so that a pressure-dependent, electrical voltage is obtained by voltage or current excitation.

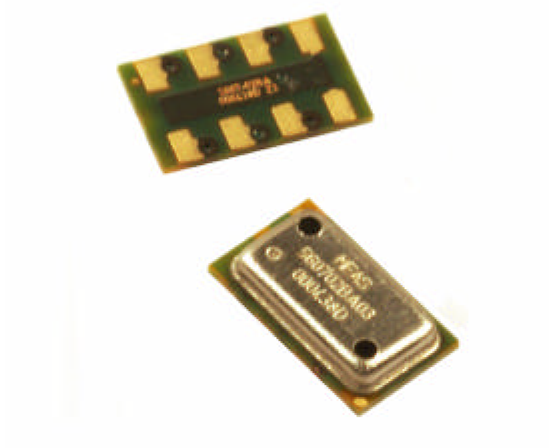

Figure 2: Pressure sensor module MS5607 (Bottom and top view)

The piezoresistive silicon sensing element is mounted on a PCB and protected by a gel coating. Like the ASIC (signal conditioning) it is electrically connected to the substrate solder pads by gold wires (see *Figure 2* above). The design is such that the use of standard SMD equipment with pick-and-place robots and reflow or vapor phase soldering of the pressure sensor module are possible.

The sensing element and ASIC are protected against contact and dirt by a stainless steel cap. The outer dimensions of the sensor module are 5.0 x 3.0 x 1.0 mm³.

Signal evaluation circuitry

Besides the sensing element the module also contains an application-specific integrated circuit (ASIC). This ASIC (*Figure 3*) amplifies the analog signals of the measurement element and converts them with help of a 24-bit precision ADC into digital values for pressure and temperature. It consists of a programmable amplifier, a multiplexer, a 24-bit sigma/delta A/D converter, an EPROM and a digital output with an SPI and I^2C interface.

Special drive technology (pulsed excitation) enables the sensor to operate with very low power consumption. This causes a negligible rise of the temperature in the sensitive sensing element, resulting in outstanding stability of the output signal.

The ASIC conditions the output voltage of the sensing element and its temperature. The temperature signal is used on the one hand to compensate the temperature-dependent influence and permits on the other hand the device to act as an extremely high-resolution thermometer.

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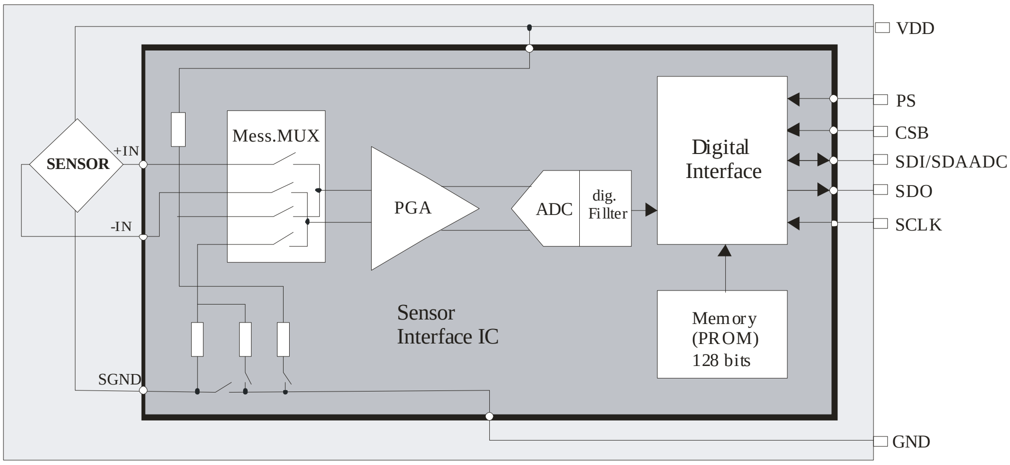

Figure 3: Principle circuitry of the CMOS ASIC in the MS5607

The 24-bit sigma/delta A/D converter has been optimized so that it has an excellent linearity and low noise across the entire supply voltage and temperature range. This enables high-resolution altimeters with a resolution of 20cm to be easily realized without the need for any averaging. By averaging a resolution of a few centimeters can even be achieved.

On-chip correction

The internal ASIC has two significant functions. The main function is to convert the uncompensated analog output voltage from the piezoresistive pressure sensor to a 24-bit digital value, as well as providing a 24-bit digital value for the temperature of the sensor. The second function is to read out the stored correction coefficients. During manufacture for every sensor deviations from the ideal transfer function, caused by manufacturing tolerances, such as offset shift, variations in sensitivity, non-linearity, and tolerances in the IC, are individually measured under defined pressure and temperature conditions. As a result, 6 coefficients necessary to compensate the pressure and temperature measurement values and all temperature influences are calculated with a special algorithm and stored in the 128-bit PROM.
In operation, these correction coefficients are automatically read out from the EPROM after a power-on reset. Following this, the non-compensated pressure and temperature are alternately provided at the output in a loop. A simple computation with just one multiplication calculates the corrected pressure and temperature values in the external processor.

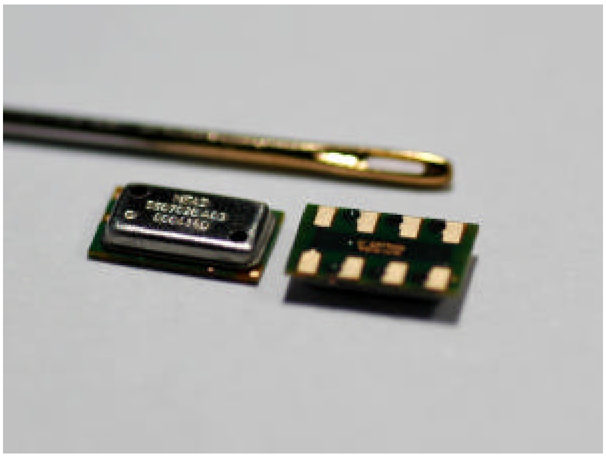

Figure 4: **MS5607 compared to a sewing needle**

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The fact that the sensor can be calibrated and compensated on the basis of individual internal correction data and with the help of a simple external processor with a three-wire (SPI) or two-wire (I^2C) interface gives the user maximum flexibility in his or her system architecture. The sensor is thus of particular interest for those applications that use a processor for systems reasons.

Resolution, Accuracy and power consumption

The new MS5607 pressure sensor attains due to the 24-bit ADC a pressure signal resolution of 0.024mbar within a range of 10 to 1.200mbar. The overall measurement accuracy, which plays more of a role in the stationary measurement of absolute pressure, is 0.2% FS between -20 and 85°C.

As well as determining pressure, the sensor module can also measure temperature at a resolution of 0.01°C.

Using MS5607 as an altimeter in a digital watch is a good demonstration of just what the pressure sensor can do. At a pressure measurement per second the average power consumption is 0.9µA. In stand-by mode 0.02µA of current are used. Even with a very small CR1215 (3V/36mAh) lithium cell, the battery will last for several years.

Dimensions

The entire pressure sensor is supplied as a QFN package with a metal cap (5.0 x 3.0 x 1.0mm^3) and is thus of a suitable size even for watches and small mobile phones. The particular advantage of the new sensor module is that no external components (such as oscillators) are required.

Pricing

The MS5607 has been designed for large production volumes and production optimized accordingly. This means that this sensor module can be priced to match the material costs of comparable sensors, making it a truly low-cost product.

The high resolution, low total errors, a minimal power consumption, small size, and low unit price: all of these characteristics are combined in the new MS5607 24-bit pressure sensor from MEAS Switzerland S.A. (sold through AMSYS in Mainz, Germany). The (ultra-)miniaturized absolute pressure sensor has been designed as a digital altimeter for mobile applications. It is also suitable for other mobile use, such as in personal navigation and search devices (in avalanche accidents), and for individual position monitoring (in medicine and for the rescue services), for example.

The MS5607 can of course be used in all applications that require the measurement of absolute pressure up to 1.2bar.

Conclusion

Modern silicon pressure sensors have almost completely usurped the traditional mechanical barometric cells. The combination of modern microstructure technology (MEMS) and integrated electronic signal conditioning (ASIC) has now obtained a level that even satisfies the demand for a precision of up to 24bits. This has been illustrated in the above article by the example of barometric pressure sensor ME5607 used as an altimeter.

The height of Mount Everest was most recently measured in May 2005 by an expedition from China. The altitude of the summit was recorded as being 8,844.43meters, with an inaccuracy of ±2centimeters. Radar detectors, laser measuring instruments, and a satellite positioning system were used. Using the new MS5607 and a more accurate barometric formula, in theory the altitude could also have been calculated to within < ±20cm.