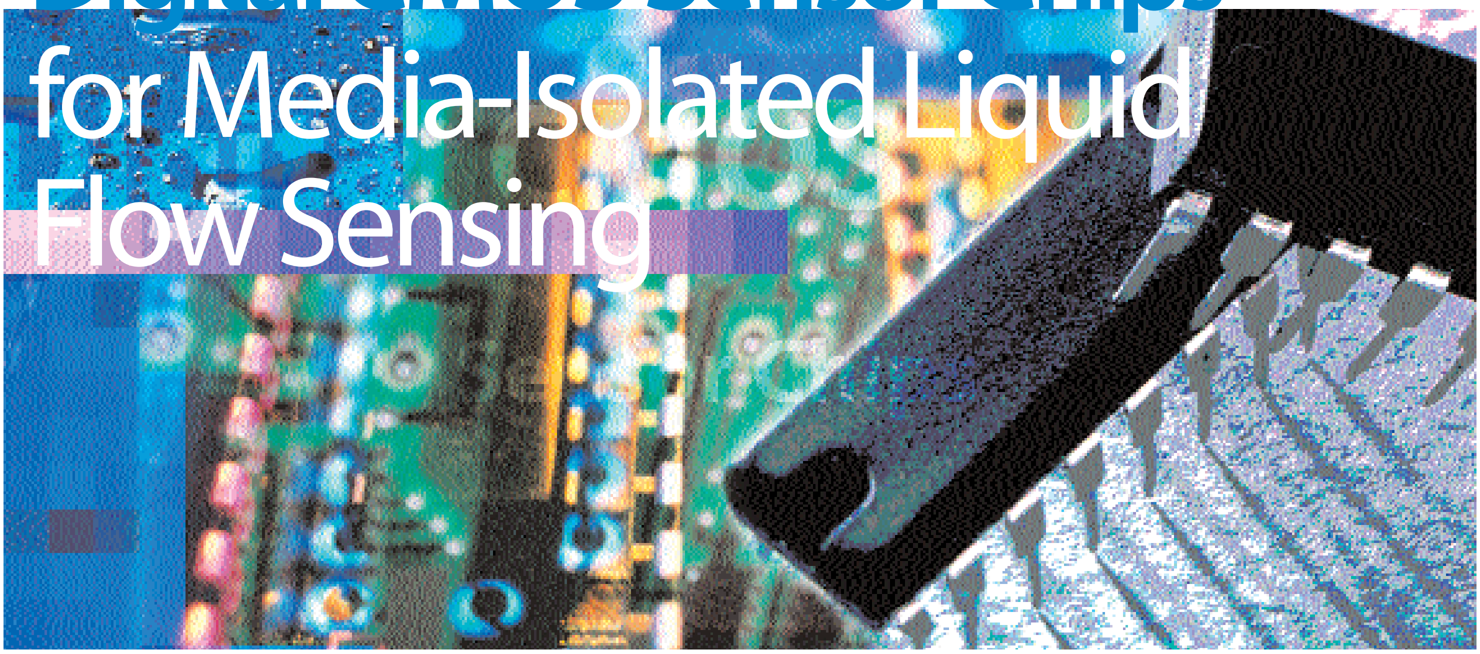
Digital CMOS Sensor Chips for Media-Isolated Liquid Flow Sensing



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New digital sensor technology that comes from semiconductor engineering enables media-isolated and extremely precise measurement of small mass flows in medical devices. The capabilities and potential of this technology are described.

Fusion brings new possibilities

New sensor technology, which is a fusion of digital semiconductor chips (CMOS) with sensor elements on one chip, enables high-precision sensor systems to be manufactured. In combination with specialised packaging solutions, the technology works with total media isolation and practically no dead volume. The digital sensor chip technology was originally developed for gas-flow rate measurement and a range of products based on this technology were introduced in autumn 2001.

Subsequently, the technology has been developed for noninvasive measurement of flow rates in the range of nanolitres to millilitres per minute. A digital liquid flow sensor based on this technology is already up to 100 times faster, 10 times smaller and 25 times lighter than previous conventionally built flow meters, and the potential for optimisation has not yet been exhausted. The typical response time for a digital liquid flow sensor based on CMOS chips is faster than 50 ms. A standard model has a weight of 33 g and dimensions of approximately 56 × 14 × 69 mm.

The benchmark data relative to the precision of the new sensor technology is similarly groundbreaking. Thus, battery-operated, low-power solutions are also conceivable as disposable devices for medical applications (Figure 1).

Figure 1: Media-isolated, 100% PEEK liquid-flow sensor based on novel sensor technology.

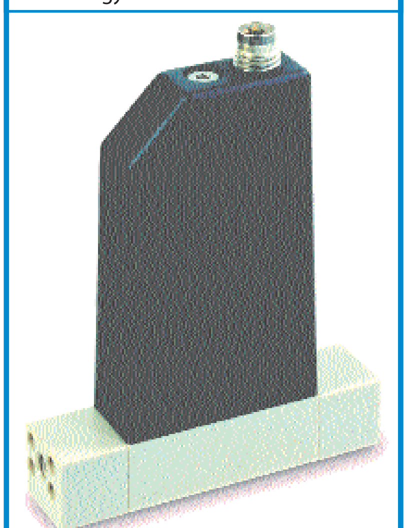
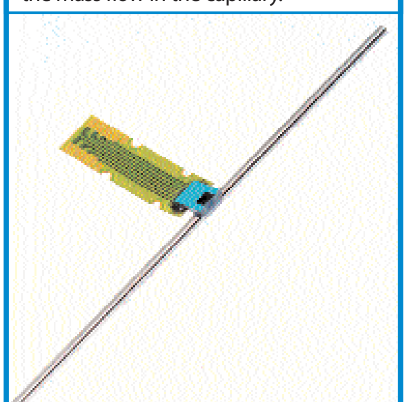


Figure 2: Digital sensor chip detects the mass flow in the capillary.



About CMOS

CMOS (Ce-mos) is a standard technology for producing integrated circuits. CMOS chips are generally known as semiconductor chips, silicon chips or computer chips. They are used widely in nearly all branches of daily life. One of the best examples of a CMOS chip is the Intel Pentium processor in the personal computer.

Taken together, these properties allow measurement and control in new fields of application that previously required other solutions because of the size, weight and cost of the measurement technology.

Core elements on one chip

The technology employs special microchips that detect the current mass flow to within a few milliseconds by means of a calorimetric principle. A miniaturised heat source on the silicon chip introduces a constant minimised amount of power into the medium. Two temperature sensors, one on the upstream side and one on the downstream side, provide information on the distribution of heat in the system. This is the fundamental information needed to calculate the actual total flow. Several additional details such as a minimised thermal capacity guarantee reliability and speed of measurement, and result in high repeatability of the measurements. The sensor element, amplifier, A/D converter, and parts of the digital signal processing form one unit on the same silicon chip. The digital signal processing associated with the sensor provides the output of a completely calibrated, temperature-compensated measurement signal. This enables conceptually simple processing of the output data by means of standard interfaces such as a RS 232 serial port. The maximum measurement error is equal to 1–3% of the measurement value, depending on the model.

A wide array of applications in the medical sector require the complete separation of the fluid medium from the surroundings and good sterilisation possibilities. With this technology, highly sensitive microchips can be positioned to detect flow rates directly and with precision in the range of a few millilitres or nanolitres per minute through the walls of plastic, steel or glass capillaries by means of special packaging that is isolated from the media (Figure 2). This means that for the fluid system the sensor is just a straight capillary without any obstacles. High reliability and perfect media isolation are ensured. The medium is only ever in contact with the tubing material.

New possibilities

The availability of this highly sensitive sensor technology creates new possibilities for medical technology and process engineering. Certainly, the most important field of use is determining exact amounts of agents in small, but also larger, amounts of fluid. In many cases up until now, the actual flow in the system could only be known indirectly, if at all, and only in the laboratory. The current volume flow could be determined, for example, by means of a drop in pressure in the system or the mechanical motion of a piston. In many cases, this new technology can provide additional meaningful information and simultaneously enables the unambiguous detection of leaks in the system.

A continuous integration of the measurement values detected over a range of a few milliseconds (200 measurement values per second), directly at the site of action, provides a digital output, at any time, of the actual amount of fluid that has moved. Because of the high speed and the small overall size of the sensors, this technology offers the opportunity to significantly increase the reliability and possibilities of monitoring a wide array of different processes (Figure 3).

For detecting larger flow rates, the measurement values can be determined indirectly by means of corresponding bypass systems. The sensitivity of the chips enables additional functions. The sensors can detect fluid or recognise larger air bubbles in microfluid systems; this has previously been a difficult task. In analytical applications, the new information can generate an immediate response, which increases the reliability of the process. Blood–gas analysers for example could possibly benefit from this (Figure 4).

Likewise, the detection of amounts for fluid transfer in laboratory automation is an interesting possibility. The motion of a fluid medium during separation of a drop from a pipette tip can be measured with the sensor chip mounted at a distance of a few centimetres. It is for the developers of process-engineering and analysis-engineering systems to devise additional applications.

Gas-flow applications

The technology also offers interesting new possibilities for gas-flow measurement. An inexpensive, gas-tight mass-flow controller (MFC) for 200 L_N/min based on this technology distinguishes itself with some unique characteristics. Compared with →

Figure 3: Custom-specific sensor solution.

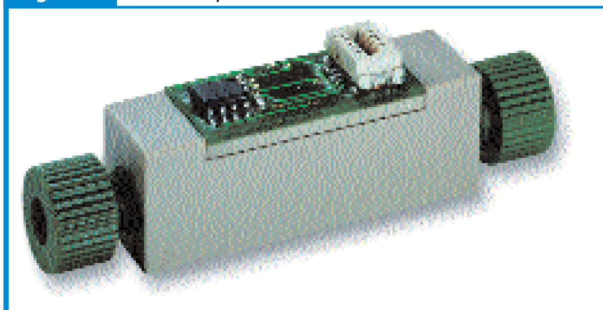
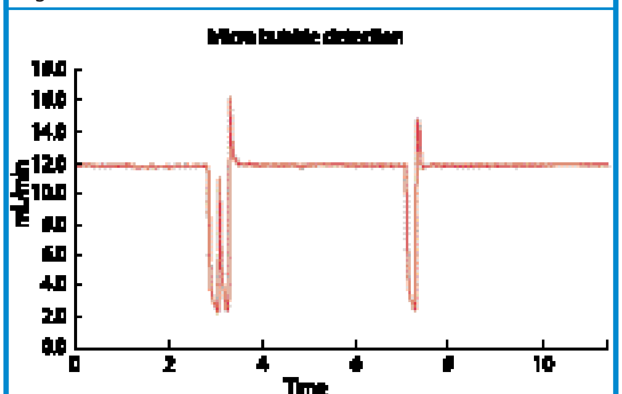


Figure 4: Three large bubbles in the system generate a clear signal.

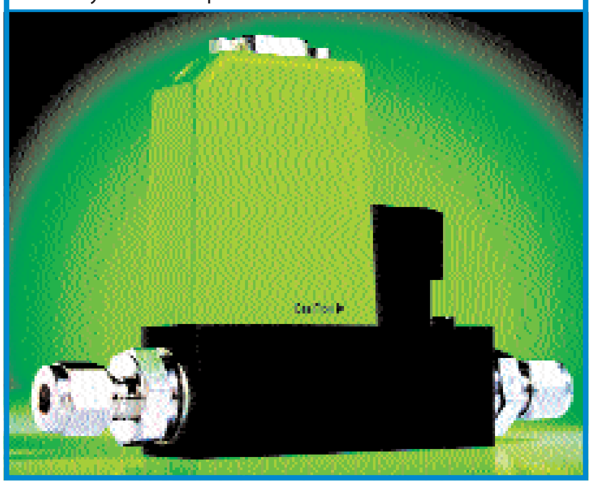


conventional instruments, the thermal reaction of the mass-flow sensor is faster. The signal generated on the chip is linearised and temperature-compensated every 0.5 ms, hence, control with a MFC is 10 times faster. A typical MFC based on this technology offers control times below 150 ms (Figure 5).

Other features of this type of MFC are its accuracy and repeatability. The stability and resistance of the signal-conditioning circuitry to disturbances and the sensor's offset flexibility are especially important. The symmetry of the sensor element and the offset-compensated signal-conditioning circuitry built into the sensor chip allow this type of gas-flow sensor to attain an offset stability of <0.01% of the limit value per year. Thus, the new MFC operates across a dynamic measuring range of 1:200 with an accuracy of 2% of the measurement value, and even these values can be improved if necessary.

Subsequent developments have demonstrated how the variable mixed ratio of two media within a medical process can be managed using the digital CMOS chips. The special design of the chip in use facilitated the development of a solution that allowed the mixed ratio and throughput of two gases to be accurately measured simultaneously with up to 3% accuracy using the same sensor. Physical data are also established for the mixed ratio, and the same sensor can determine the exact mass flow within the system.

Figure 5: Gas-tight MFC based on digital CMOS sensor chips: accuracy 0.8% of set point.



Reaching the unattainable

This digital sensor technology represents a significant advance in the field of sensors for medical devices and analysis engineering. High measurement speed, total media isolation for liquid flow sensing, high precision and the completely digital, calibrated output signals are properties that were previously unattainable. This technology can be used in systems that were once limited in capability because of the lack of measurement technology. The potential for disposable applications and the robustness of the technology are particularly important for medical applications. It will be interesting to see in which fields this technology is applied. In addition to customised solutions employing this technology, a standard sensor realised with a 100% PEEK capillary, supplies a digital, fully calibrated, linear output signal for flow rates up to 1.5 mL/min with measurement error of typically 3% of the measurement value in a response time of 20 ms. mdt

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