Portable measurement system for FET type microsensors based on PSoC microcontroller

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Abstract. FET based microsensors have reached increasing importance in biomedical and environmental applications, due to their advantages over conventional sensors. These advantages are related with their small size, robustness, low cost, integrability, fast response time, and the small sample volumes required for their use. In this work, it is presented the design and implementation of a portable instrumentation system based on the CY8C29466 (PSoC) microcontroller for the measurement of ISFETs and CHEMFETs type microsensors in liquid samples. The system shows the measurement’s data on a display, also allowing storage of data for further analysis by coupling the system to a PC serial port.

1. Introduction
The use of microsensors for monitoring of environmental parameters and clinical diagnosis is gaining interest due to their advantages over conventional sensors. Among microsensors those based on semiconductor technology offer additional advantages such as small size, robustness, low output impedance and rapid response [1, 2]. Besides, the technology used allows integration of circuitry and multiple sensors in the same substrate and accordingly they can be implemented in compact probes for particular applications e.g., in-situ monitoring and/or on-line measurements. In this field, Ion Selective Field Effect Transistors (ISFETs) and Chemically Modified Field Effect Transistors (CHEMFETs) have a special interest. They are particularly helpful for measuring pH and other ions in small volumes and they can be integrated in compact flow cells for continuous measurements. They are also important in the field of diagnosis and clinical applications, where it is required to have equipments able to carry out measurements of diverse variables in complex samples like blood and urine [3, 4].

Microsensors based on FETs require a conditioning circuit that polarizes them appropriately [5]. The systems developed for data processing and visualization of the acquired signal usually include a data acquisition card (DAC) associated to a personal computer (PC) but it is also possible to use microcontrollers and virtual instrumentation to achieve this goal [5-7]. In that sense, systems based on Programmable System on Chip (PSoC) microcontroller allow the integration of certain analogical

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sections in the system’s digital design. This fact notably reduces the number of components and connections on the board circuit. The use of PSoC also reduces the implementation time of prototypes of complex systems [5] offering opportunities for designing very low cost systems for sensor applications. Among these, Programmable System on Chip (PSoC) by Cypress MicroSystems has a wide range of analog and digital integrated circuits in a single chip that allows designs with good performance, autonomy and flexibility.

The goal of this work is the design and implementation of a portable system, based on a PSoC microcontroller, associated to FET microsensors. The system is able to carry out measurements and the data can be shown in the liquid crystal display (LCD) of the portable system and alternatively can be stored in the PSoC, allowing its later recovery and analysis in the laboratory through the coupling to a PC.

2. Materials and Methods

2.1. ISFET Sensors

ISFETs are defined from the 1970’s as an adaptation of metal-oxide-semiconductor field-effect transistor (MOSFET). Such an adaptation consists on the substitution of the metal gate (G) by an ion sensitive membrane, an electrolytic solution and a reference electrode [1, 4, 5]. Figure 1 shows an ISFET schematic diagram.

![Figure 1. Schematic diagram of an ISFET.](image)

The ISFET similarity with a MOSFET made possible its integration in electronic systems. As a chemical sensor for measuring pH it has important characteristics like its robustness and durability, small size (contact area < 1 mm²), massive production potential, low output impedance, and low response time (1000 times minor in comparison with the glass electrode) [1, 6].

The ISFETs used in this work have been fabricated at the Instituto de Microelectrónica de Barcelona (IMB-CNM) clean room by using standard microfabrication techniques. It is a Si₃N₄ gate NMOS ISFET chip with 3x3 mm size. The chip is fixed in a printed circuit board and wire bonded to the pads for electrical connection. A polymer film is deposited by photolithographic techniques to cover all the electrical parts leaving open the gate area for liquid contact. To close the circuit an Ag/AgCl reference double junction electrode is used.

2.2. System’s design

The system is basically composed by two stages: the signal conditioning stage and the stage for processing, visualization and transmission of the data acquired by the sensor.

The conditioning stage should guarantee the adequate polarization of the microsensor. During the design the polarization circuit was carefully selected to avoid diverse unwanted effect. By this reason the polarization of the microsensors was done in the feedback mode, in which the compensation of the
gate-source potential variation ($V_{gs}$) is done by a feedback signal, applied through the reference electrode [5]. The polarization must guarantee a constant drain-source current ($I_{ds}$) and a constant drain-source voltage ($V_{ds}$) as well. As usual, the values used for $I_{ds}$ and $V_{ds}$ were 100 μA and 500 mV, respectively.

Figure 2 shows the electrical circuit used in the design of the system’s conditioning stage.

The microcontroller CY8C29466 [8] was used as the basic processing unit. This microcontroller belongs to the family of PSoC, devices of small size and low cost. The most remarkable property of this device is its capacity to integrate analog components in the digital section of the chip [9]. This characteristic allowed the partial implementation of the polarization circuit on the PSoC, making possible the integration and portability of the system. Other interesting characteristics of the PSoC microcontroller are: 24 MHz Central Processing Unit (CPU) M8C, Harvard 8 Bit architecture, 32 K of FLASH memory and 2 K of SRAM, 12 blocks in the analog section and 16 blocks in the digital one [8, 9]. The schematic design of the developed system is shown in figure 3.

To reach a wide nominal range for $V_{gs}$ measurement, it is important that the system can read negative values. For this reason it was necessary to modify the PSoC input signal as this device cannot measure negative voltages. To overcome this inconvenience, the amplifier A5 was included. This amplifier must be configured as a non-inverter summing to get the A5 output voltage equal to $V_{gs} + V_{LM385}$, with $V_{LM385}$ being equal to 1.2 V. In this way, even if the input nominal range for the
PSoC is always from 0 to 2.6 V [9], the nominal range of the system will be from -1.2 to +1.4 V, which allows measuring negative values of Vgs. In the diagram of figure 3 the operational amplifiers A3 and A4 are not part of the polarization circuit implemented in the PSoC.

The visualization of the data is carried out by means of a liquid crystal display (LCD) interconnected with the microcontroller. The FET microsensors obtained data is stored in the PSoC by the module E2PROM implemented in it. The transmission of these data towards a PC is made by a RS-232 serial port. The system reads the values of VGS, VDS and IDS with the PSoC. The values of VDS e IDS are only acquired to check the stability of the sensor operation point. The value of VGS is given as a function of the analyzed sample pH.

The configuration of the main microcontroller parameters and the integrated components was done using the PSoC Designer v4.3 software. For the programming, C language was used due to the advantages this language offers, among others, the facility to work with floating numbers and the option for re-programming the code or upgrading it. The modules implemented in the PSoC are shown in the figure 4. These modules are referred to a pair of digital/analogical converters (DAC); the E2PROM module to emulate this data storage memory in the microcontroller FLASH memory; a LCD module that establishes the interface with the LCD; three programmable gain amplifiers (PGA); an three entrances and three exits analog/digital converter (TRIADC), and the module UART for the communication with the serial port.

**Figure 4.** Modules implemented in the PSoC.

3. Results

A group of measurements for the calibration of the electronic designed system, was made after its implementation in a physical support system.

With the aim of verifying the main parameters of the polarization circuit, a simulation with the help of the design software Proteus v7.10, was carried out. By means of this simulation, it was possible to verify that the designed configuration gave the correct values of the operation point of the sensor, and it was also possible to verify that the Vgs values were under the required range. The measurements sweep a tension range between -1V and +1V in each canal. These measurements allow knowing systematic errors like sensitivity and zero errors in order to minimize them by software manipulations.

Figure 5 shows the comparison between the voltage values measured and displayed in the LCD of the system after calibration (V_PSoC), versus the values measured with a standard voltage measuring instrument (V_Standard). The data processing and the graphic shown in the figure 5 were carried out with STATGRAPHICS v5.1 software. The results obtained by the data processing software are shown in table 1.

The linear fitting, with linear correlation coefficient of 0.999997, is indicative of the excellent relation between the values shown in the LCD of the system, and the real values measured. It means that after the calibration the gain errors have practically null values. Furthermore, from the intercept value we can conclude that the errors related to zero have values of less than 2 mV.

| Calibration Parameters | Results       |
|------------------------|---------------|
| Slope (m)              | 1.0009 ± 0.0002 |
| Intercept (n)          | -1.9676 ± 0.1149 mV |
| Linear correlation coefficient (R²) | 0.999997 |
All these results demonstrate that the measurement system developed with the PSoC has the appropriate accuracy.

![Graph showing VGS after calibration](image)

**Figure 5.** Measurement of $V_{GS}$ after the calibration.

4. Conclusions
A portable measurement system for FETs microsensors based on a PSoC CY8C29466 microcontroller as the main element of the hardware was developed and validated. The use of the PSoC has contributed to considerably reducing the cost, size, and weight of the system while maintaining good performance, autonomy and flexibility. The portable system has an excellent linearity, accuracy and is also able to storage data for further transfer to a PC serial port using the PSoC facilities. The nominal range of voltage to be measure by this portable measurement system include negative and positive values from -1.2 V to +1.4 V.

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