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Low cost electrochemical sensor module for measurement of gas concentration

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Abstract. This paper describes a low cost electrochemical sensor module for gas concentration measurement. A module is universal and can be used for many types of electrochemical gas sensors. Device is based on AVR ATmega8 microcontroller. As signal processing circuit a specialized integrated circuit LMP9l000 is used. The proposed equipment will be used as a component of electronic nose system employed for classifying and distinguishing different levels of air contamination.

1. Introduction

In recent years, gas sensors are used in more and more applications. Gas sensors, which are commercially available or under development, have a lot of merits, such as rapid detection speed, high sensitivity and durability. What is the most important, they are very inexpensive. There are many sensor constructions working based on various concepts [1]. Electrochemical gas sensors can be divided into three main classes according to the operating principle: amperometric, potentiometric, and conductometric sensors. Gas sensors working based on amperometric principle provide relatively high analytical performance at modest cost [2, 3].

Amperometric gas sensors develop a current response signal by reaction of a measured gas at an electrode. This response can be measured at a fixed or variable electrode potential, although a fixed potential is usually used. The reaction rate, reflected by the current at the sensing electrode, occurs at a thermodynamically determined potential for any given reaction and, when operated under appropriate diffusion-limited conditions, is simply proportional to the concentration of the measured gas concentration. The relationship between current and concentration is linear, typically over 3 orders of magnitude, and measurements with high sensitivity are possible.

Amperometric sensors, in order to work properly at a fixed potential, require to be controlled by a potentiostatic circuit. In the worldwide market such devices in the form of professional instruments are available (eg. Solartron Analytical 1287 electrochemical interface) and usually used in stationary conditions for purposes of science. These devices usually are very sophisticated and offer excellent capabilities. However, due to a high complexity they are very expensive. There is a strong need to develop a portable and low-cost devices for measuring gas concentration with amperometric sensors.

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In this paper a relatively simple and inexpensive module for measurement of gas concentration with amperometric gas sensors is proposed. Lack of selectivity is usually a common shortcoming of most of sensor available. Such sensors reacts not only with the selected gas but also with other gases. Various techniques for selectivity improvement can be used such as special sensor construction [4], sophisticated mode of operation [5-7], sensor operating temperature modulation or sensor response fluctuations measurement [8]. It seems that improvement of selectivity can be obtained using sensor arrays combining several sensors along with some pattern recognition algorithms as well. Extensive research based on concept of improving selectivity by combining a few not selective sensors response analysis have been done since the 80-ties of 20th century. A new type of device called an electronic nose have been proposed [9]. Thus a proposed system is designed in such way that several modules can be easily connected into one system for measuring response of amperometric gas sensors matrix. Other modules already designed include gas sampling controlling module or electrochemical impedance spectroscopy analyzer.

2. Amperometric sensor module

A potentiostat circuit required for amperometric sensor proper operation can be designed from analogue components. However, the continuing progress in integrated chip technologies results in combing many systems on a single chip. Today, a system on chips (SoC), an integrated circuit that integrates all components of a computer or other electronic system into a single chip are becoming more common in the market. Such components may contain digital, analog or mixed-signal functions—all on a single chip substrate. This technology provides new possibilities, especially due to their relatively low cost and low power consumption.

SoC microsystems can realize many functions. One interesting application is impedance measurement with AD5933 chip [10]. Such chips not only provides possibility for miniaturized and low-power applications, but greatly simplifies system. Thus, in this paper as signal processing circuit a specialized integrated circuit LMP91000 produced by Texas Instrument is used. The LMP91000 is a programmable Analog Front End for use in micro-power electrochemical sensing applications. It provides a complete signal path solution between a sensor and a microcontroller that generates an output voltage proportional to the sensor 3-elecrode cell current. The LMP91000's adjustable cell bias and transimpedance amplifier gain are programmable through the I^2C interface. Based on this chip a module for measurement of gas concentration based on AVR ATmega8 microcontroller is proposed (Figure 1).

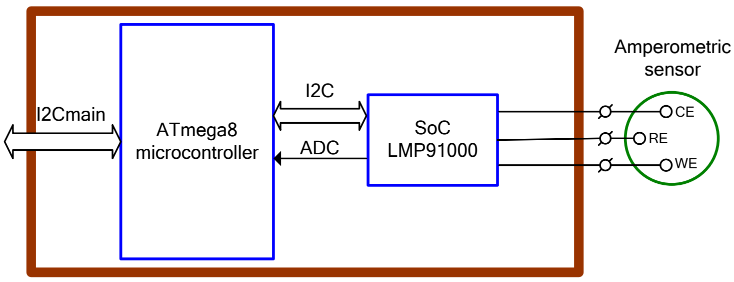

Figure 1. Block diagram of the amperometric sensor module.

One module measures response of single amperometric gas sensors. ATmega8 is a heart of proposed module. Microcontroller is responsible for communication with the rest of the system (I2Cmain). Microcontroller build in Two Wire Interface (TWI) bus, which is I^2C compatible, is used. Microcontroller is acting on this bus as a SLAVE device with individually set slave address. The ATmega8 also responds to I^2C General Call Address. This solution allows connecting multiple analysers to the same bus and control them separately (using address) or all at the same time (using General Call Address).

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For configuration of the SoC, two unused pins of microcontroller are controlled using software procedures. This way communication of ATmega8 and SoC is manually realized in MASTER mode. It is possible to configure various parameters such as: the range of the output voltage, the voltage of potentiostat circuit, gain of transimpedance amplifier, load of gas sensors and many others which are more described in datasheet for LMP91000 [11]. Generally, one set of adjustments correspond to certain type of electrochemical sensor. If it is necessary to use other type of sensor, it is possible to do it by changing the programmable parameters within the LMP91000 integrated circuits.

Last task of the module is to measure the voltage at the SoC output pin, which is proportional to the concentration of the target gas. The voltage is converted to digital format via a 10-bit ATmega8 internal analog digital converter (ADC). Software averaging was used, thus low ADC resolution did not affect the measurements accuracy.

3. Tests and results

A prototype board of proposed amperometric sensor module was realized. Dedicated software for PC and AVR microcontroller have been developed. An ammonia - sulphur dioxide amperometric sensor with solid polymer electrolyte of our own design was used for a test. Details of the experiment and sensor construction can be found elsewhere [12]. The response of this sensor in mixture of high purity gases, namely synthetic air and 100 ppm SO_2, is presented in Figure 2. The sensor response in both forms is presented, voltage measured by module and calculated current. Continuous measurements were made with averaging of 100 ADC conversions. Change in the composition of the gas mixture was carried out at a period of 20 minutes.

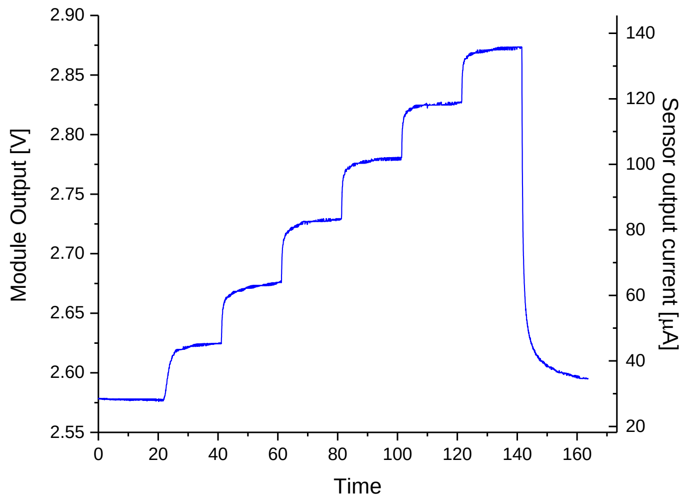

Figure 2. The response of the amperometric sensor to different concentrations of SO_2 measured by module

It can be seen that sensor reaction to the toxic gas concentration change is clearly visible. The obtained curve is smooth. The measured current by module related to almost stable sensor response for given SO_2 concentration is presented in Figure 3. Obtained relationship is almost linear. Slope of the curve, that correspond to the sensor sensitivity, equals to 0.73µA/ppm and is similar to results obtained with laboratory stationary electrochemical interfaces. The obtained results allow concluding that the work proposed in the framework of the measuring module is suitable for use with amperometric gas sensors.

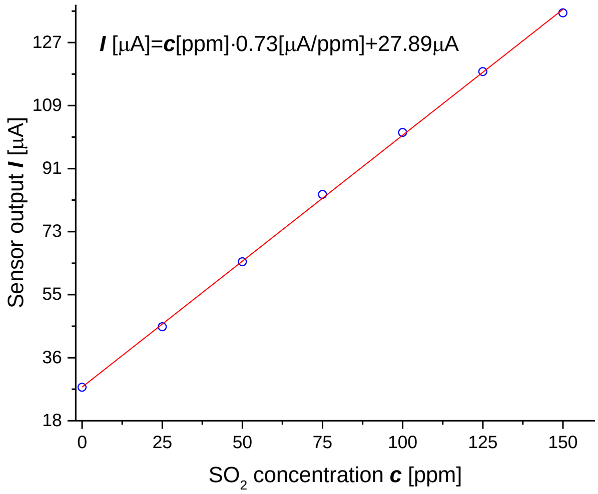

Figure 3. Calibration curve for measurement in Figure 2.

4. Conclusions

The paper presents scalable, flexible measurement system designed for measurement of amperometric gas sensors response. The hardware part of the system consists of a number of independent, single-board modules working in parallel. They are connected each other using I^2C bus, which can be controlled by software of supervising module. Flexibility and scalability as well as a low price of proposed system have been achieved.

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