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THE STUDY OF A LOW–POWER CONSUMPTION POTENTIOSTAT

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Abstract: **This paper presents a simple, sensitive and low–power consumption potentiostat. The paper presents some new requirements and trends concerning applications with potentiostats. We show also some experimental studies of this apparatus.**
By using the commercially available device and the circuitry that we have developed,
other researchers can easily developed.

Keywords: *potentiostat, low power consuption.*

INTRODUCTION

Chemists may be required to setup, troubleshoot, repair and sometimes construct the instruments they use for analytical measurements. Chemical micro instrumentation serves as the interface between the transducer and the user. It measures the sensor signal, processes the data, and either locally stores or transmits this data to a centralized source.

The need for small, reliable, and accurate microsystems that can remotely monitor earth and extraterrestrial environments has increased demand for single-chip micro instruments with long lifetimes. The reduced size, added sensitivity, and ability to provide redundant or comparative analyses makes miniaturized chemical transducers very attractive for monitoring in extraterrestrial environments and remote earth locations.

Most electrochemical work with an electrochemical cell is achieved using what is called a potentiostat. For this reason this paper presents a simple, sensitive, monolithic and low–power consumption potentiostat. A potentiostat is an electronic device that controls the voltage difference between a working electrode and a reference electrode. Both electrodes are contained in an electrochemical cell. The potentiostat implements this control by injecting current into the cell through an auxiliary, or counter, electrode.

In an electrochemical cell, any change in the potential of the cathode electrode, results in a flow of current in the electrolyte so the potential of the electrode is maintained. In almost all applications, the potentiostat measures the current flow between the working and auxiliary electrodes. The controlled variable in a potentiostat is the cell potential and the measured variable is the cell current [1,2].

2. POTENTIOSTAT DESIGN

We have designed a potentiostat circuit that accepts an electrical signal, proportional to current flowing through the electrolyte (in the electrochemical cell) and measure the time it takes to charge or discharge a capacitor. In an electrochemical cell, any change in the potential of the cathodic electrode, results in a flow of current in the electrolyte so the potential of the electrode is maintained. We used a class-II current converter to convey input current at a low-impedance terminal (X) to a high-impedance output terminal (Z) while maintaining a constant voltage at the second input terminal (Y). Predominant component of the electrode control is a three-stage operational amplifier in low- power design. The analog output voltage is linear dependent on the working electrode current. The polarization voltage can be applied in a wide range, in DC, AC or CV-mode. Due to the wide redox current input range a variety of electrode types are allowed to use. For construction of suitable potentiostat we must study a simplified one. We can be seen below a simplified schematic of a Gamry Instruments' Potentiostat. A potentiostat is an electronic device that controls the voltage difference between a working electrode and a reference electrode. Both electrodes are contained in an electrochemical cell. The potentiostat implements this control by injecting current into the cell through an auxiliary electrode. [3, 4].

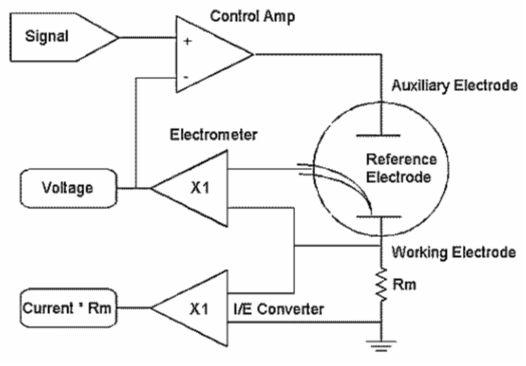

Fig. 1. A Gamry Instruments' Potentiostat

In almost all applications, the potentiostat measures the current flow between the working and auxiliary electrodes. The controlled variable in a potentiostat is the cell potential and the measured variable is the cell current.

A potentiostat typically functions with an electrochemical cell containing three electrodes and that is true for both field probes and lab cells:

- Working Electrode: Electrochemical reactions being studied occur at the working electrode. This is analogous to testing using weight loss coupons. The working electrode can be bare metal or coated.
- Reference Electrode: A reference electrode is used in measuring the working electrode potential. A reference electrode should have a constant electrochemical potential as long as no current flows through it.
- Auxiliary Electrode: The Auxiliary electrode is a conductor that completes the cell circuit. The auxiliary (counter) electrode in lab cells is generally an inert conductor like platinum or graphite. In field probes it's generally another piece of the working electrode material [5].

Additional components are:

- Electrometer: The electrometer circuit measures the voltage difference between the reference and working electrodes. Its output has two major functions: it is the feedback signal in the potentiostat circuit and it is the signal that is measured whenever the cell voltage is needed. An ideal electrometer has zero input current and infinite input impedance.
- I/E Converter: The Current to Voltage (I/E) converter in the simplified schematic measures the cell current. It forces the cell current to flow through a current measurement resistor. The voltage drop across that resistor is a measure of the cell current.
- Control Amplifier: The control amplifier is a servo amplifier. It compares the measured cell voltage with the desired voltage and drives current into the cell to force the voltages to be the same. Under normal conditions, the cell voltage is controlled to be identical to the signal source voltage.
- The Signal: The signal circuit is a computer controlled voltage source. It is generally the output of a Digital to Analog (D/A) converter that converts computer generated numbers into voltages.
- Galvanostats and Zero Resistance Ammeters (ZRAs): Most laboratory grade potentiostats can also be operated as galvanostats or ZRAs(Zero Resistance Ammeter). Galvanostat is an electronic instrument that controls the current through an electrochemical cell at a preset value, as long as the needed cell voltage and current do not exceed the compliance limits of the galvanostat. Also it is called "amperostat."

An interesting application is when the coupling current between two nominally identical electrodes is measured.

If both electrodes were identical then very little coupling current would flow.

In real situations these electrodes will be slightly different, one being more anodic or cathodic than the other and a small coupling current will exist.

The features of our low–power consumption potentiostat are:

Supports two- and three- electrode measurements
Amperometric and voltammetric mode
Amplification part in sc- technique
Low power consumption

A low power single-chip potentiostat supporting both two and three-electrode measurement techniques was developed.

This signal processing chip can be mounted either on the same substrate as the sensor electrodes or in a plug where it is shielded from the measurement environment.

Due to the fabrication of the potentiostat in a standard CMOS process, both chip size and costs are kept to a minimum.

The features of electrical performance mean the control part of the circuit and it is realized by an analog controller (fig. 2).

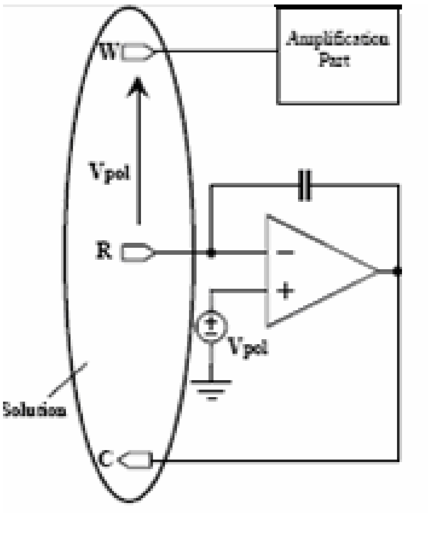

Fig. 2. The control part of the circuit

The counter electrode potential is adjusted in a way that the potential difference between the reference electrode and the working electrode is always close to the applied polarization voltage.

Since the reference electrode impedance is very high (>10 GΩ), the inevitable potential drop is reduced to a minimum[6,7].

The block diagram of the CMOS Potentiostat is given in Fig. 3.

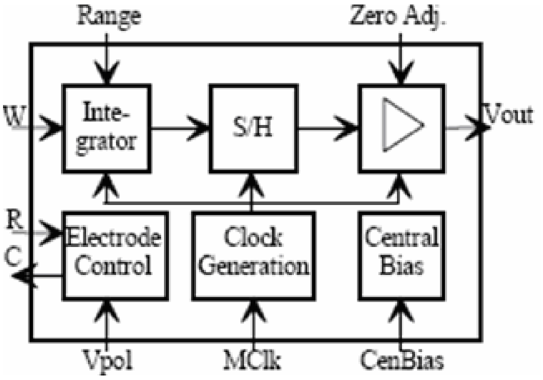

Fig. 3. The block diagram of the potentiostat

The circuit is realized in switched-capacitor technique.

The amplification part of the potentiostat has a time-continuous rail to-rail voltage output.

The amplification is scaled by the sampling period Ts = 1 / (2 fc), where fc is the master clock frequency. The transfer function of the complete amplification part is thus inverse proportional to the master clock frequency.

In this way we obtain an easy mode to adjust the potentiostat to the input current.

In summary, the amplifier of the potentiostat converts the input current over a range of four decades from +/- 200 pA up to +/- 3000 nA into an output voltage with a maximum slope of approximately 250 mV/nA.

3. EXPERIMENTAL DETERMINATIONS

The experimental measurements were accomplished using physical methods of conductivity and potentiometry.

For low current densities, the error arising from the dependence of the potential from the cell current may be neglected and a two-electrode set-up is sufficient for amperometric investigations.

The constructed converter exhibits good linearity in the nanoampere current range that is relevant for many chemical and biosensor electrodes.

This particular design has a very low-power consumption, and may easily be adapted to meet the requirements of different electrode-based amperometric sensors. It was measured the dependency between the current and frequency and the results obtained are shown in table 1.

Table 1.

f [Hz]	15	20	40	60
I[nA]	50	65	120	180
f [Hz]	90	120	150	200
I[nA]	270	340	420	620

We processed the experimental data by making use of a TBLCURVE and ORIGIN SOFT. In Figures 7, 8 and 9 there is represented the dependency between the current-to-frequency calibrations curves obtained for the potentiostat.

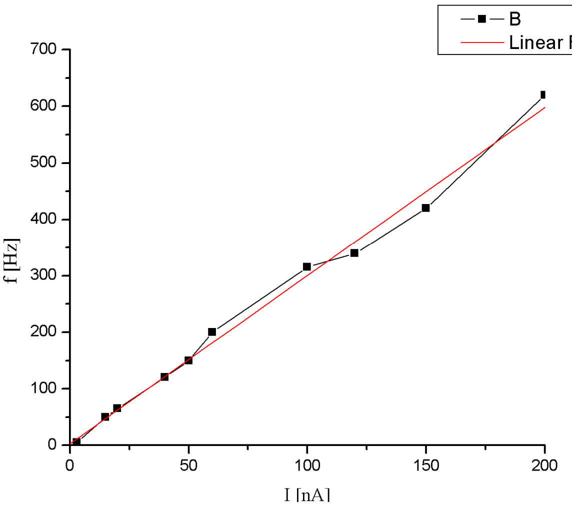

Figure 4. The current-to-frequency calibration curve of the potentiostat obtained by making use of a ORIGIN SOFT-(a) Linear current range,

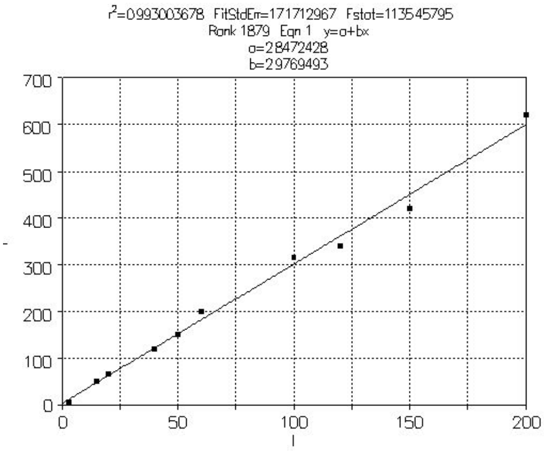

Figure 5. The current-to-frequency calibration curve of the potentiostat. obtained by making use of a TBLCURVE SOFT-(a) Linear current range,

Different currents were sequentially set with high-ohmic thick-film resistors connected acroos the working and counter electrode terminals of the potentiostat.

The current value was calculated from the radio of the measured electrode potentional difference to the measured value of the applied resistance [8, 9].

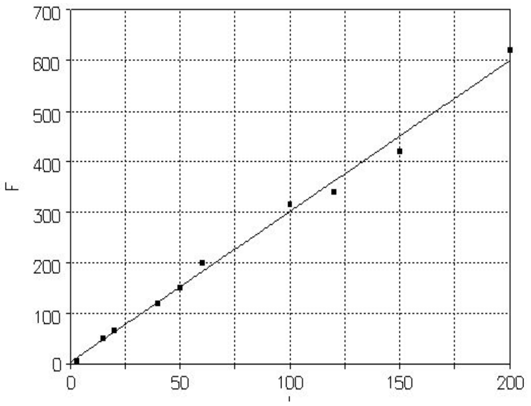

Figure 6. The current-to-frequency calibration curve of the potentiostat. obtained by making use of a TBLCURVE ORIGIN SOFT, with resistive loading ot the electrode terminals.

By processing the experimental data by making use of a TBLCURVE and ORRIGIN SOFT there was established the equation of the curve of dependency of the current-to-frequency.

The Figures 7, 8, 9 shows that the current-to-frequency transfer function is linear between approximately 4 and 200 nA, and extends up to currents of 700 nA. In the linear region, after processing the experimental data,the output frequency there was obtained by the the following equation:

$$f_{out} = 2.8472 + 2.9769\ I_{cell}, \qquad (1)$$

where Icell is the electrode current in nA.

We find that the zero offset of the converter is 2.8472 nA, and the sensitivity is 2.9769 Hz/nA.

A more reasonable approach is to use an equivalent circuit model of an electrode that more closely accounts for cell capacitance and the effects of non-Faradaic charging at the electrode-electrolyte interface[10].

These phenomena can be approximated with a lumped equivalent circuit model, consisting of a resistance and parallel capacitance.

The current-to-frequency calibration curve canges are dramatically under capacitive loading.

The current required to operate the potentiostat was determined experimentally as 200 μA, with a Vdd to Vss potential difference of 2.5 V.

This yields a calculated power consumption of 500 μW. Loading the electrode terminals with different complex impedances had no effect on overall power consumption [11].

4. CONCLUSIONS

In conclusion, it is a fact that the biosensors require low-power electronics for providing the interface between biological electrode and signal processing devices. In our experiment the accuracy and lifetime micro systems, however, could be increased by improving its resolution and reducing its power dissipation. So, we worked toward increasing the instrumentation's resolution while reducing the area and power consumption of the system.

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