ASIC FOR ELECTRO-CHEMICAL SENSOR CONDUCTIVITY MEASUREMENT USING BIPOLAR PULSE METHOD

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The microelectronic measuring system for conductivity electrochemical sensor measurement of liquid materials properties was designed in CMOS technology. The main parts of the system are current source with switchable ranges, the sensor switches allowing change of the current polarity in compliance with the bipolar pulse method, which was developed specially for this measurement purposes at the Dept.of Microelectronics. The most important part of the system is a sensor voltage drop measuring circuit using opamp offset switched compensation.

Keywords: Electro-chemical measurement, bipolar pulse method, offset compensation

1. INTRODUCTION

Chemical sensors have been used for many years in analytical laboratories. They create an important part of very expensive instruments and need skilled service. Nowadays the cheap chemical sensors have started to expand into practice use. The accuracy of these sensors is not enough sufficient yet. They need correction in the known water solutions and then the usage is possible under a very small range of conditions only. Therefore the research is focused on retrieval of suitable methods and technologies to produce sensors with high accuracy as the expensive types have, and low cost as the second ones have. This work is focused on electrical measurements of water solutions conductivity. Two electrodes immersed into a liquid solution provide the measurement. The sample of such sensor is presented on Fig.1. This case is called the chemical cell and where the chemical processes pass off on electrodes and inside of solution. All these processes impact impedance responds of the chemical cell and to know all of them are very important for determination of a suitable measuring method [1].

2. THE CHEMICAL CELL ELECTRICAL MODEL

Chemical cell behave as a serial-parallel connection of a resistor and capacitor. Resistance and capacity depend on frequency, on solution structure and on continuous chemical reaction in the contrast of classical electronics. These cause a non-linearity system. The equivalent circuit is presented in Figure 2. Resistor R_X is shared for both electrodes and presents the resistance of the measuring electrolyte. C_{DL} is double layer capacitance. The chemical reaction starts by inserting the electrodes into the electrolyte, which is caused by charges disequilibrium. This is immediately straightening by moving the ions charges to electrode until the charges equalize. Around the electrode, there is a double layer created by a charge of ions on the first side and an opposite charge of ions on the other side. This double layer behaves as a charged capacitor with certain potential. The measuring method must suppress the C_{DL} influence while $\boldsymbol{R}_{X}$ is the desired measured parameter.

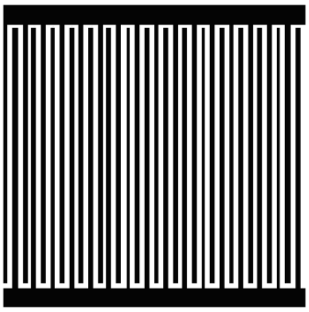


Fig. 1: The comb electrode structure of the sensor

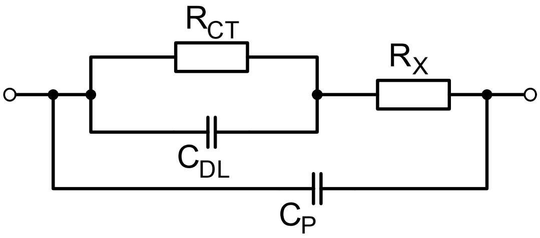


Fig. 2: The chemical cell equivalent circuit

3. BIPOLAR PULSE MEASUREMENT METHOD

For the measuring of the conductance of water solution, it can be used direct and alternative methods. As known the direct method is absolutely unsuitable in consequence of the cell behavior as a serial capacity. The other limitation is the voltage amplitude must be lower than 100 mV, because of risk of electrolytic process.

The technique of the bipolar pulse belongs to methods for high accurate measurement. The principle and voltages on the sensor are given in Figure 3.

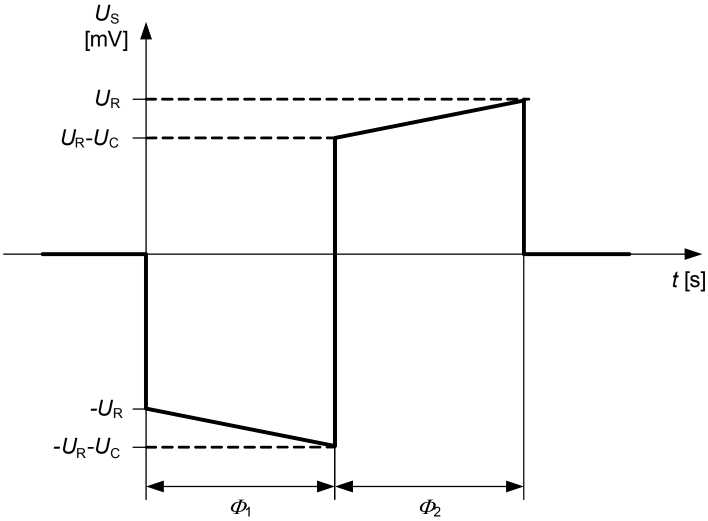


Figure 3: Principle of the proposed method

Method principle is built up on following idea, the negative current pulse with precisely defined amplitude and period T1 (phase Φ_1), is leaded on electrodes of the cell. At the beginning of the phase Φ_1 the voltage on the sensor is corresponding to R_X and current amplitude, but it is very difficult to measure it in this short time.

If $T1 \ll C_{DL}R_X$, the C_{DL} will be charged slowly and in the end of the pulse, the cell is charged up to the voltage ($-U_R-U_{CDL}$). In this time the positive current pulse of the same amplitude and duration (phase Φ_2) is leaded on electrodes of the cell discharging exactly the C_{DL} capacitance charge and on the end of this phase the voltage in between sensor terminals is given by measured R_X and sensor bias current amplitude product. In this time we sample a measure the value.

4. METHOD IMPLEMENTATION

The circuit realisation of the microsystem, which uses the modified bipolar pulse method, is described in this section. During the design process the attention was paid to characteristics of the measurement method and the goal was to design the microsystem structure, which used the advantages of this method. The block schematic is shown in Figure. 4.

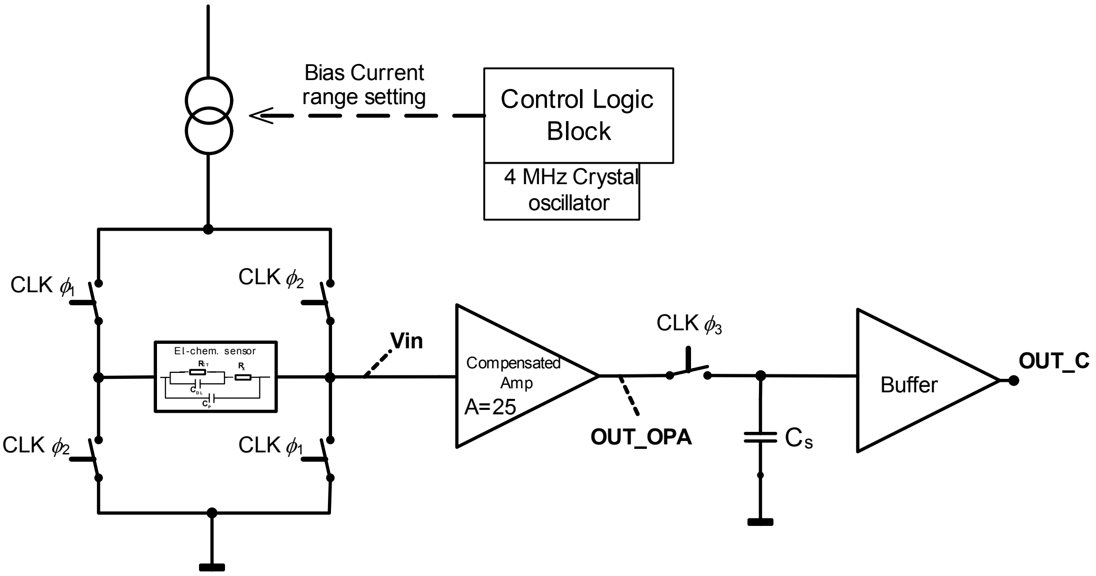


Figure 4: Implementation block structure

The sensor is connected to the bridge of switches those allow to change polarity of the bias current flowing through the sensor. The current direction depends on the CLK phase. In phase Φ_1 there is just voltage drop of the sensor switch at the amplifier input. The value is just used for amplifier calibration as it is described in Section 4.1. During the phase Φ_2 there is a potential that consists of switch voltage drop and voltage across the sensor terminals at the amplifier input. After the previous calibration only the sensor voltage is then amplified and sampled into capacitor C_S and further buffered to the output.

The measured Rx value appears in the range of 10Ω – 100kΩ. Because of the chemical limitations the maximum allowed voltage across the sensor is 100mV. Therefore the four ranges of the sensor bias currents were decided from 1uA to 1mA divided by decade those induce sensor voltage drop on sensor from 10mV to 100mV. The switchable bias current source consists from highly matched resistors in MOS current mirror sources, which limit the edge effect of transistors. Then the switching range error is lower then 0.5%

The very low voltage level (10 mV) is not possible to measure by usual integrated operational amplifier with offset about 10mV, therefore the opamp offset compensation circuit was designed that, in proper connection, can simply compensate both the opamp offset and sensor switches voltage drop as well. Its function is described in section 4.1.

4.1 Opamp Offset Compensation

The schematic of the connection is shown in Fig. 5 and its timing diagram is introduced in Fig. 6. Here there is a brief functionality description. During the first phase Φ_1 (CLK1 = log1) the opamp is connected as a follower with input connected to the reference voltage (usually analog ground, but it can be any suitable potential) and its input offset is stored in capacitor CC. In the second phase Φ_2 (CLK2 = log1) the opamp is connected as the non-inverting amplifier with gain corresponding to the resistor divider in the feedback. Voltage at the capacitor CC is added to the divider reference voltage and compensates the opamp offset. Ideally this circuit compensates the offset fully, but in reality some systematic error appears during the charging parasitic opamp input capacitance (taking charge from CC). To minimize this inaccuracy the ratio of the opamp input capacitance and storage capacitor CC must be minimized as well as the difference between opamp input potentials in two working phases.

Sometimes the topology with capacitor located in series to the input can be used, but in this project no input current (for charging CC) was allowed.

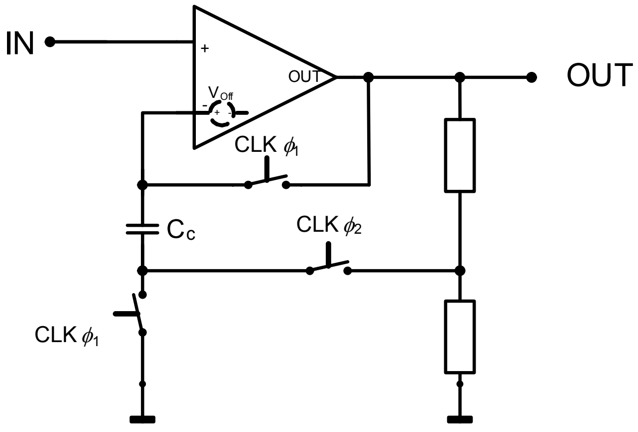


Figure 5: Schematic of the amplifier using the opamp offset compensation

This type of offset compensation allows us to compensate not just the opamp offset but also eliminate the parasitic voltage drop at the sensor switches. The trick is very simple. During phase Φ_1 (compensating phase) the input of the opamp is not connected to ground (AGND) but between the switch and sensor. Then the system is calibrated to the potential of the switch voltage and the sensor voltage drop and they are then eliminated from subsequent processing. The gain of the used amplifier was set by the resistive divider to 25.

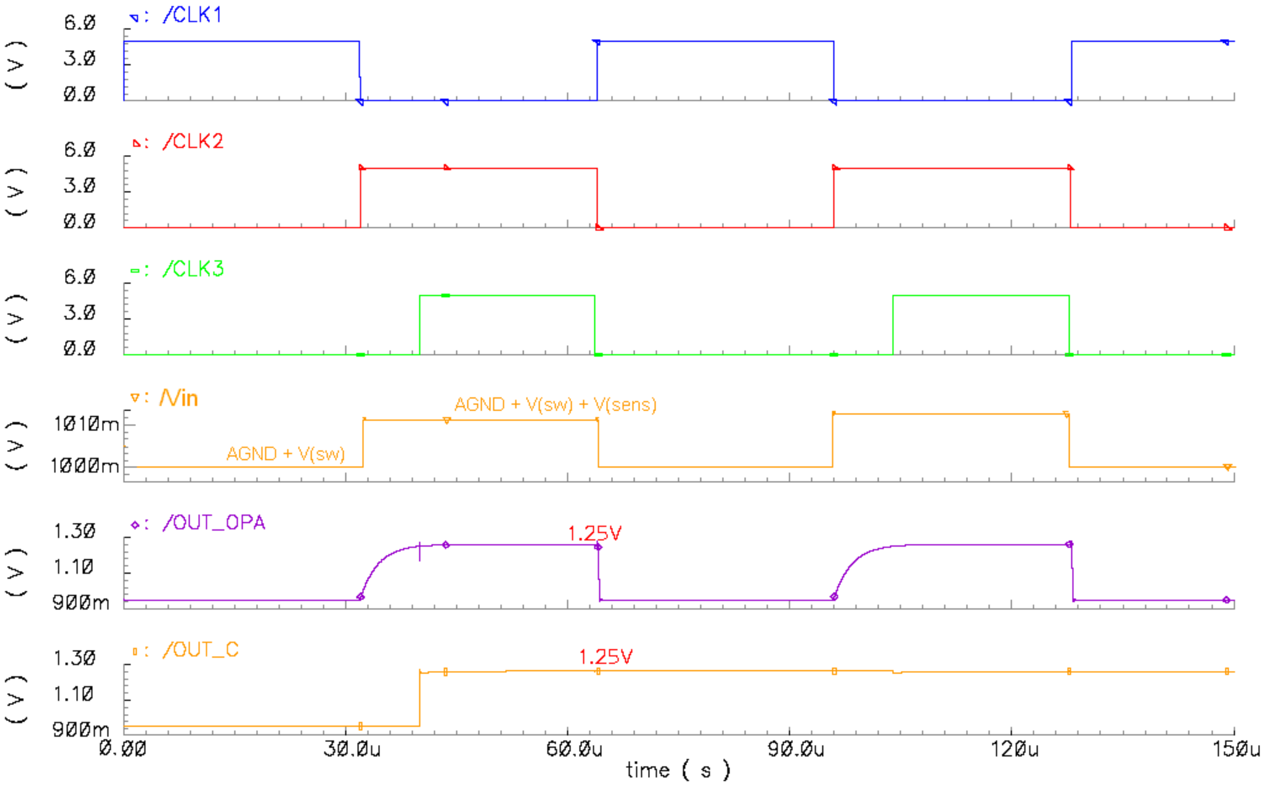
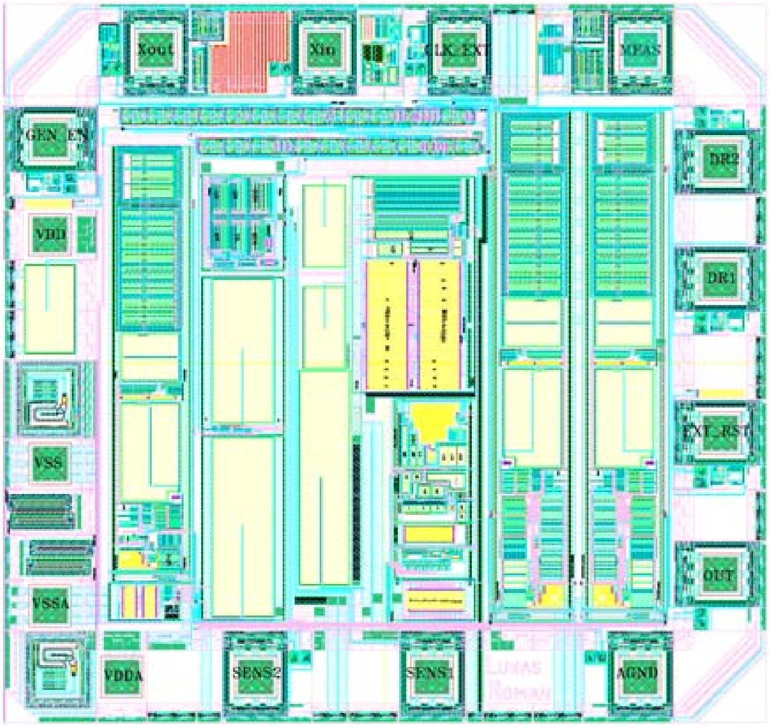


Fig. 6: Single switched mode compensated opamp operation Cadence simulation

5. CONCLUSION

The ASIC designed for current bipolar method of the sensor conductivity measurement was designed and manufactured in AMIS CMOS07 technology under the EUROPRACTICE project and its parameters are now under testing. It looks we are able to measure the above mentioned sensor conductivity (*R*x parameter) almost undependably on the used opamp offset and switch resistance with the worst case accuracy up to 4%, which is sufficiently better



then possible sensor deviation. Because the error is mostly systematic and known, the error can be decreased by additional error correction.

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