A High-Performance Measurement System for Conductivity Sensors

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***Abstract* — This paper presents a low-cost and accurate measurement system for four-electrode conductivity sensors. The system mainly consists of an analog front-end, a voltage-to-time-period converter and a microcontroller. The analog front-end is used to provide a controlled excitation voltage for the sensor and to convert the sensor signal (conductivity) into a voltage signal. The UTI acts as an asynchronous converter for the sensor voltage employing a relaxation oscillator which output is a period-modulated signal. The microcontroller will measure the period-modulated signal from the UTI, calculate the conductance and communicate with, for instance, a PC. Experimental results over a conductance range of 0.1 μS to 10 mS show a resolution of 0.45 μS and a systematic error of 0.19 μS for a measurement time of 110 ms Due to the use of the UTI a battery operated conductivity sensor can be made for less then USD 10..**

I. INTRODUCTION

Conductance measurements are required in many applications, including medical and biomedical applications, fields of process chemistry, environment monitoring, agriculture and food production, etc. The accuracy and resolution of the conductance measurement are mainly affected by chemical, physical and electrical nonidealities. Regarding to the chemical and physical effects, the main nonidealities concern:

- contamination of the electrode surface of the sensor,
- electro-chemical effects,

Considering the electrical effects, the main nonidealities concern:

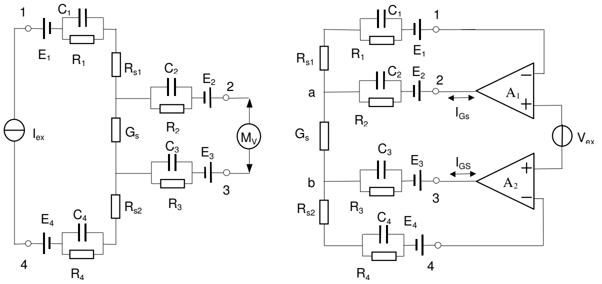
- series impedances caused by the wires and cables,
- effects of DC drift and Seebeck voltages,
- effects of multiplicative and additive errors of the system.

To overcome those nonidealities, in this paper a high-performance measurement system for four-electrode conductivity sensors is proposed, in which many advanced techniques are applied. The use of Smartec's UTI makes the system not only very accurate and simple but also low -cost

II. MEASUREMENT PRINCIPLE

Figure 1(a) shows a simple electrical model of a four-electrode conductivity sensor with a constant AC current excitation I_{ex}. In this model, the G_s represents the conductance of the object, which should be measured by the conductivity sensor. R_1 ~ R_4 and C_1 ~ C_4 represent the impedances of the electrode-object interface.

Potentials E_1 ~ E_4 represent the contact potentials. The values of these potentials are depending on the materials of the electrodes and the object. Mostly, these potentials are not equal and not stable. R_{S1} and R_{S2} represent the impedance path through the object between the force and sense electrodes of the sensor.



(a) (b)

Figure 1 Four-wire measurement of four-electrode conductivity sensor, (a) constant current excitation, (b) constant voltage excitation.

The effect of the contact potentials on the measurement of the G_S can be eliminated by using an AC excitation signal for the sensor. To eliminate the effect of the impedances R_1 ~ R_4, R_{S1} and R_{S2} as well as the effect of the wiring resistance, a four-wire measurement is applied (see Figure 1). In figure 1(a), the four-electrode sensor is excited with a constant AC current source I_{ex}. The voltage over the conductivity sensor G_S is measured with high input-impedance volt meter M_V. In this measurement, when the measured conductance G_S is low the voltage over G_S can be very high due to the use of the constant excitation current. This will result in a measurement which is out of the linear range. Moreover, the voltage between the electrodes 2 and 3 exceeds the free corroding potential.

To overcome this drawback, the conductance G_S can be measured using a constant AC voltage excitation V_{ex} (see Figure 1(b)). In this circuit, the voltage V_{Gs} over the conductance is tied to the value of V_{ex} by the feedback loop of amplifiers A_1 and A_2. Once the voltage V_{ex} is controlled, the measured conductance G_S is directly proportional to the current flow I_{Gs} through the measured conductance, $G_S = I_{GS} / V_{ex}$.

Figure 2 shows a schematic diagram of the system, which mainly consists of an analog front-end, a Universal Transducer Interface (UTI) and a microcontroller.

The current flow I_{Gs} through the conductance G_S, which is equal to the current through the resistor R_{ref} or R_4, is measured as a voltage signal across the resistor R_{ref}. The voltage V_{Gs} is equal to the voltage across the resistor R_2.

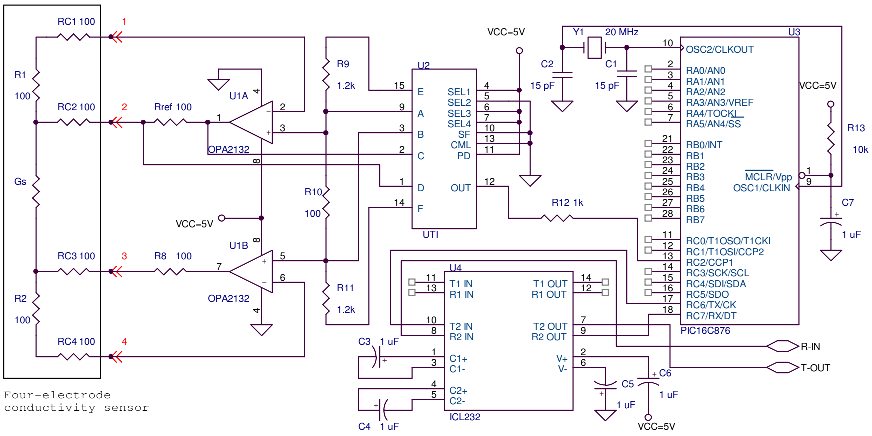


Figure 2 Circuit diagram of the measurement system.

The controllable AC square-wave excitation signal is generated by the UTI, which has an amplitude of $\pm R_{10}/(R_9+R_{10}+R_{11})V_{CC}$.

The UTI linearly converts the sensor signal (voltage) and the reference signal (voltage) into period-modulated signals. As that presented in, the periods of the output signal of the UTI, T_{VGs}, T_{IGs} and T_{off}, corresponding to the measurement of V_{ex}, V_{Rref} and V_{off}, are given by

$$T_i = KV_i + T_{off}\,. \qquad (1)$$

Then, the measured results for the conductance of the conductivity sensor is found by the equation:

$$G_s = \frac{T_{IGs} - T_{off}}{T_{VGs} - T_{off}} \cdot \frac{1}{R_{ref}}\,, \qquad (2)$$

In this way, the system is auto-calibrated for additive or multiplicative errors. Even in the case of drift or other slow variations of the offset and the transfer factor, these effects are eliminated. The calculation can be implemented using, for instance, a microcontroller.

III. EXPERIMENTAL RESULTS

The proposed sensor system has been implemented and tested, using the circuit shown in figure 2. The system is powered by a single 5 V supply voltage.

The resolution and the accuracy of the system have been tested for the case that R_{ref} = 100.076 Ω and G_s = 0.1 µS to 10 mS with a measurement time of about 110 ms. The controlled excitation voltage V_{ex} is applied with an amplitude of 200 mV. Depending on the electro-chemical properties, the amplitude of the excitation signal can be adjusted for a value less than the free corroding potential. Figures 3 and 4 show the resolution and the systematic error for the measurement of conductance G_s, respectively.

It is shown that the system has a systematic error of 0.19 µS over a conductance range of 0.1 µS to 10 mS and a measurement time of about 110 ms.

IV. CONCLUSIONS

In this paper, a measurement system for conductivity sensors has been presented. A low-cost system with a high accuracy and good long-term stability has been realized by applying advanced techniques, including four-wire measurement technique, AC square-wave excitation, chop-ping and auto-calibration. The use of a controllable excitation voltage for sensors will prevent the occurrence of electrolysis. Tests have been performed over the conductance range of 0.1 µS to 10 mS. It is shown that the system can measure the conductance with a resolution of 0.45 µS and a systematic error of 0.19 µS.

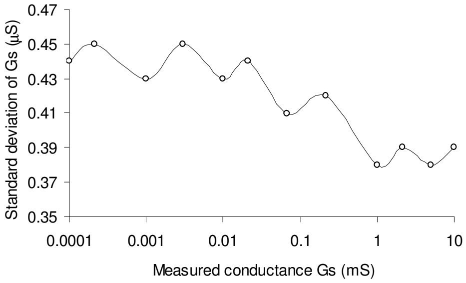


Figure 3 The resolution of the interface.

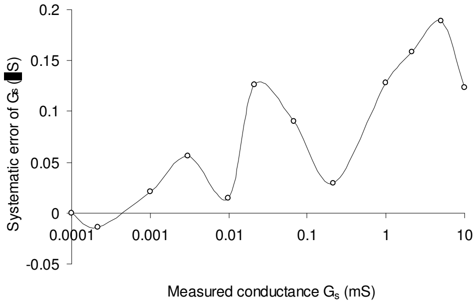


Figure 4 Systematic error of the interface.