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SIMPLE OPAMP-BASED CIRCUIT FOR MEASURING ELECTRO-CONDUCTIVITY OF ELECTROLYTIC SOLUTIONS IN HYDROPONICS SYSTEM

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Abstract. *The electro-conductivity measurement is proposed to identify electro-conductivity in electrolyte solutions. The method uses technique the zero and span circuit for expansion range of electro-conductivity measurement in electrolytic solutions. The proposed system consists of the EC sensor made of the two carbon electrodes and the circuit of measurement system. As a result, the proposed system can be used to well measure electrical conductivity continuously. Using the zero and span circuit, the error value is low, in range between −0.075 to 0.075 mS/cm, and the average error is approximately equal to 3.3% when the calibration with standard solution.*

Keywords: Electrical conductivity, Zero and span circuit, Electrolytic solutions

1. **Introduction.** Measuring the electrical conductivity (EC) of electrolytic solutions is significant in hydroponics cultivation. Electric conductivity, which indicates the concentration of the solution and is proportionate to its concentration, is determined by the density of electrolyte in water. Therefore, if the concentration of electrolyte is large, the value of electrical conductivity is large as well. One example of applications is that the electrical conductivity indicates the amount of mineral component in hydroponic cultivation system. Another example is that, it is utilized as an indicator of water pollution, that is, the electrical conductivity of a polluted river from industrial factory. Therefore, researchers were interesting in the measurement of electrical conductivity of the electrolytic solution. For example, Inoue et al. [1] proposed an on-line identification of electro conductivity in electrolytic solutions, whose method uses a model of a cell of electrolytic solutions in a micro reactor modeled by an electronic circuit and on-line calculation. Futagawa et al. [2] proposed a multi-modal sensor with pH, EC and temperature sensing areas for agriculture application. The pH, EC and temperature sensors were integrated using CMOS logic technology on a small Si chip, at which such sensors can be used to measure electrical conductivity in a small range. Another example is that, Meráz et al. [3] proposed a method using an electronic circuit model. His method identifies the parameters in the circuit by using resonance to sinusoidal wave inputs and is not on-line calculation, but batch calculation. Therefore, this paper proposes the improvement for

expansion range of electro conductivity measurement in electrolytic solutions using technique of zero and span circuit. Such proposed paper consists of two parts: the EC sensor made of two the carbon electrodes and the circuit of measurement system.

2. Principles.

2.1. Principle of zero and span circuit. The zero and span circuit is served to transmit and refine the signal between output and input signal. It will change the slope and position of the zero of the system to the conditions that the system requires. The circuit shown in Figure 1 consists of summing and inverting amplifiers.

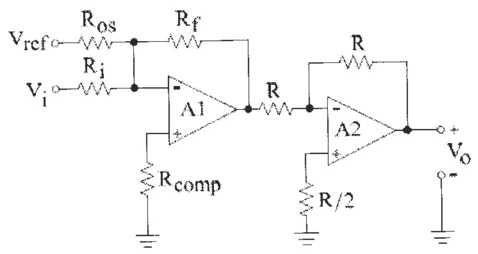

FIGURE 1. The zero and span circuit

A relationship between input and output of the zero and span circuit can be considered as

$$V_o = \left(\frac{R_f}{R_i}\right) V_i + \left(\frac{R_f}{R_{os}}\right) V_{ref} \tag{1}$$

From Equation (1), a relationship between input and output of the zero and span circuit is in the form of linear equation $y = mx + c$, where R_f/R_i is slope of the equation and $(R_f/R_i)\,(V_{ref})$ is constant, i.e., the zero position of circuit.

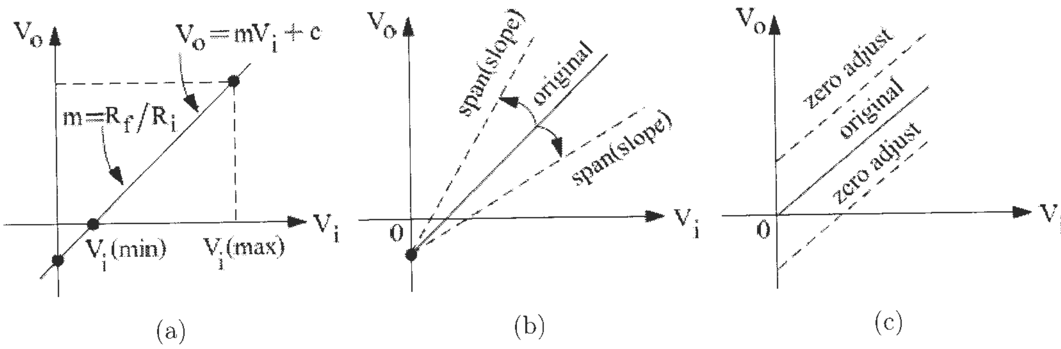

FIGURE 2. Characteristic of the zero and span circuit

2.2. Conductivity and electrical conductivity measurements in electrolytic solution. The electrical conductivity of the electrolytic solution is the inverse of resistance which can be shown by the following formula:

$$R = \rho\left(\frac{L}{A}\right) \tag{2}$$

where ρ is the electrical resistivity, L is the length of the piece of material and A is the cross-sectional area. From Equation (2), conductivity σ is defined as the inverse of resistivity:

$$\sigma = \frac{1}{\rho} = \frac{1}{RA} \tag{3}$$

Conductivity has SI units of siemens per meter (S/m). From Equation (3), the electrical conductivity can be measured using two carbon electrodes; distance between carbon electrodesis L, the cross-sectional area is A. Therefore, the cell constant becomes as L/A. When we feed the sine wave signal with the fixed amplitude to such carbon electrodes, the exchanging charges between carbon electrodes occur. Therefore, we can measure the electrical conductivity, as shown in Equation (4), and the measurement process is shown as Figure 3.

$$\text{Conductivity} = (\text{electric Current/Voltage}) \times (\text{Length/Area}) \tag{4}$$

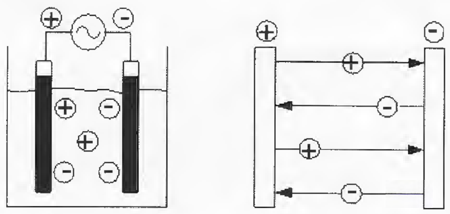

FIGURE 3. The measurement of electrical conductivity in the electrolytic solution.

The DC is not used because it causes the concentration of ions to be not uniform; as a result, measurement of electrical conductivity has high errors.

2.3. **The proposed EC sensor.** The EC sensor proposed consists of conductor that contacts and does not react with the electrolytic solution. Moreover, it does not rust which causes the error in measurement. The EC sensor made of two carbon electrodes are illustrated in Figure 4.

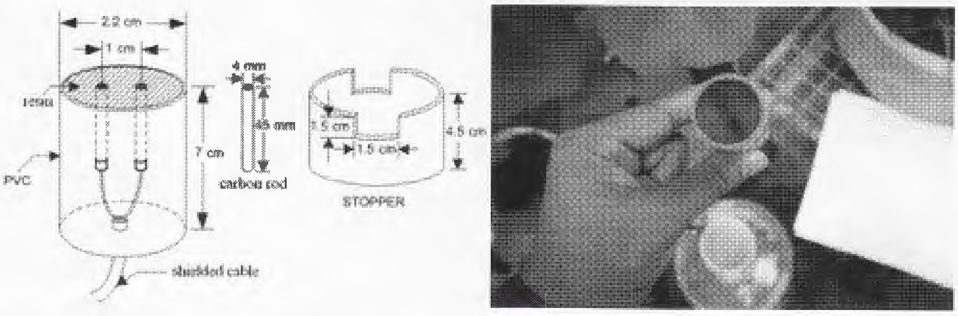

FIGURE 4. The EC sensor proposed

Since the EC measurement is defined as mS/cm, then, the distance between carbon electrodes is equal to 1 cm. Finally, we use the resin to hold these electrodes together.

3. **The Proposed Circuit.** The block diagram in Figure 5 illustrates a measurement system. It consists of seven sections. The first one is a sine wave oscillator circuit. The output of this circuit is the input of the second one, namely a wheatstone bridge circuit; it determines the floating voltage. The value of the floating voltage depends on conductivity of an electrolytic solution. The third one is a differential amplifier circuit; its output is sine wave signal whose amplitude varies with a concentration of electrolytic solution. The fourth one is an absolute circuit which is used to inverse the output of the third one to the full wave signal. The fifth one is low pass filter that is made by RC component. The output of this circuit is the DC that varies with concentration of electrolytic solution. The sixth one is a zero and span circuit; this circuit amplifies the voltage output of the

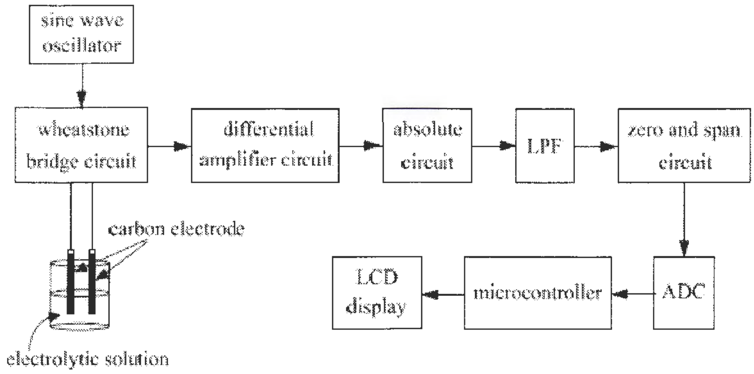

FIGURE 5. Block diagram of measurement system

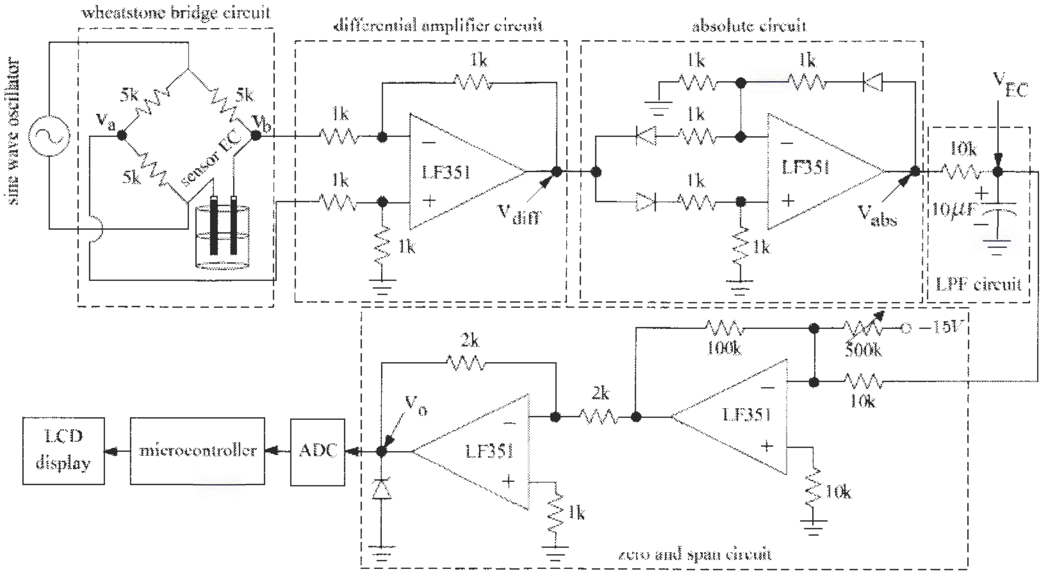

FIGURE 6. The proposed EC measurement circuit

fifth one to be range 0 V to 5 V to reduce the error from measurement. The amplified signal is fed to analog to digital converter circuit before it is processed by microcontroller, which shows on LCD display. The scheme proposed in this article is illustrated in Figure 6.

From Figure 6 the relationship between voltage due to varying electrolytic solution and voltage output of the zero and span circuit can be written as Equation (5).

$$V_o = \left(\frac{R_f}{R_i}\right)(|V_a - V_b|) + \left(\frac{R_f}{R_{os}}\right)(V_{ref}) \tag{5}$$

4. **Experimental Results and Discussion.** In order to confirm that proposed circuit is valid, we set up an experiment as following. First, the standard solutions with concentration from 0.2 to 3.2 mS/cm, increasing by 0.2 mS/cm, are prepared, then we feed the sin wave voltages with the frequency of 5 kHz, and voltage of ±9 V to the input of wheatstone bridge. Voltage V_{EC}, the output of wheatstone bridge circuit, varies with the concentration of the electrolytes solution, and this voltage signal is entered the zero and span circuit to adjust it. Then the adjusted signal is sent to the ADC circuit to convert as digital signal for the following process. Finally, the concentration of the electrolytes

solution will be shown on the LCD display. These can be presented by the figures as follows.

From the graph in Figure 7, the slope of graph is 5, so R_i and R_f in Figure 6 were chosen as: 20 kΩ and 100 kΩ, respectively and when V_o is 0, the constant of Equation (5) is -5 V; R_{os} and V_{ref} in Equation (5) are chosen as 250 kΩ and -15 V, respectively.

From Figures 8 and 9, the error of the proposed electrical conductivity measuring device is low which is in range between -0.075 to 0.075 mS/cm. Figure 10 shows the proposed device that is applied in hydroponics cultivation system.

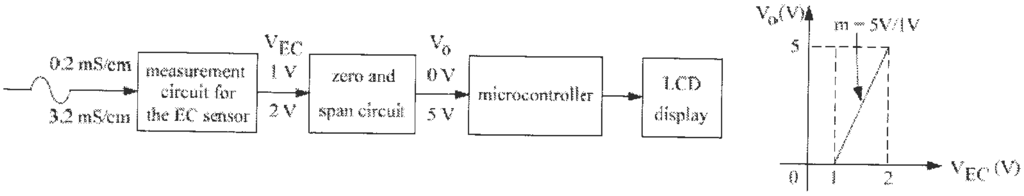

FIGURE 7. Process of measuring the electrical conductivity of the electrolytes solution and graphs showing properties of the modified signal by the zero and span circuit.

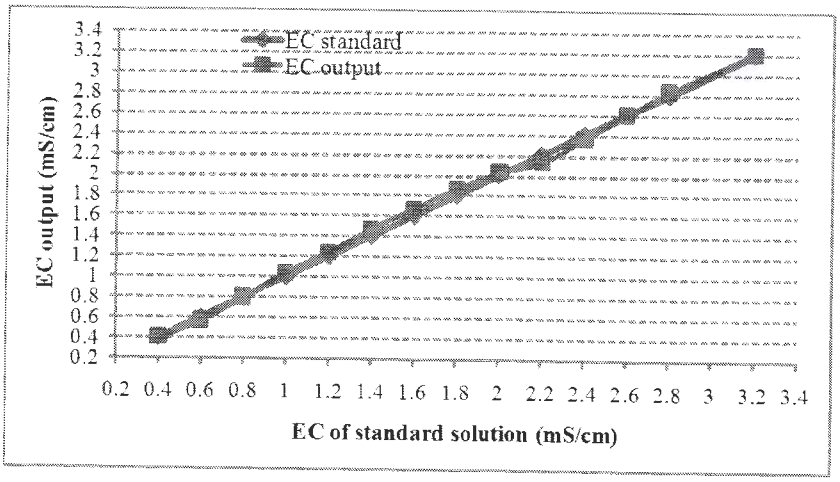

FIGURE 8. Experimental results of measuring the electrical conductivity of the electrolytes solution

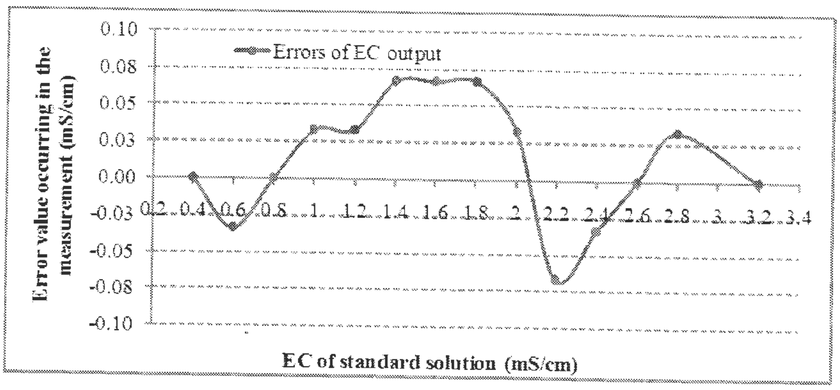

FIGURE 9. Error value occurring in measuring the electrical conductivity of the electrolytes solution

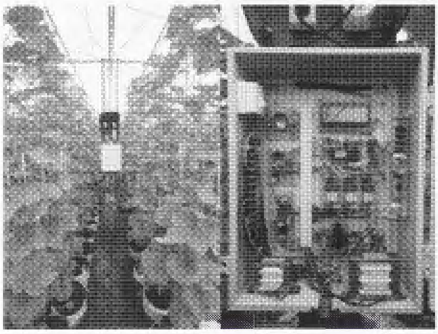

FIGURE 10. Application in hydroponics cultivation system

5. **Conclusions.** In this paper, a new improved circuit for measuring electrical conductivity of the electrolytes solution based on alternating electrical current techniques is proposed. The invented sensor can be used to well measure electrical conductivity continuously without the mineral coating on sensor. Using the zero and span circuit, the error value is low, in range between -0.075 to 0.075 mS/cm, and the average error is approximately equal to 3.3% when the calibration with standard solution.

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