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Experimental Study of Electrode Design and Configuration for Bioimpedance Measurement

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Abstract. Each material has different electrical characteristics. One of the electrical characters of materials is impedance. This characteristic used to specify the components of the material. To determine the impedance value of materials frequently used method is the injection of current through a pair of electrodes. This study will make effective electrode designs. The electrode designs used are circular with 1mm, 5mm, and 15mm diameter variations, with 3mm, 7mm, and 11mm configurations. The electrode material used is a copper plate (PCB). The results of the graph on mineral water show that the 11mm configuration produces a logarithmic graph. This result is due to the total impedance of mineral water affected by the resistance component and capacitance at the electrode. The measurement of sugar solution shows that 5mm diameter is more sensitive than 15mm diameter. Then the effective electrode design for impedance measurement is 5mm diameter with an 11mm configuration.

1. Introduction

The physical characteristics of a material can determine by observing its changes when given an electric current or magnetic field around the material [1] [2]. Each material has different electrical characteristics according to the polarity, material content, molecular bonds, and other components [3]. These characteristics can be used as a reference in the process of determining the components of a material. One of the electrical characteristics of a material that is often used is its impedance value [4] [5] [6]. The method of monitoring physiology through the impedance value (bio-impedance) is one of the new techniques used [7]. The analysis of impedance values (bio-impedance) is an approach applied in measuring the composition of materials [8], conductivity, dielectric, magnetic, and others [9] [3].
Bio-impedance is defined as a passive electrical property in the components of a material that opposes the flow of an electric current. Estimation of the components of a material, tissue or cell is one of the important parameters that provide information about the structure of the material[10]. The measurement of the bio-impedance value of a material can be done by several methods such as the current injection method [11], the AC bridge method, optical methods and other methods. Of these methods, one of the preferred methods to determine the impedance value of a material is the current injection method [12] [13]. This current injection method is a method that is simple, inexpensive, and does not damage the material used as the measurement sample (non destructive) [14] [15] [16]. Because of these advantages, this method is often used for several applications in the fields of agriculture, food and medicine, geophysics, and bio-medicine [17] [18].

The current injection method applies a pair of electrodes to inject an electric current [19], while the potential difference generated through the electrode pairs is measured using an instrumentation amplifier [20]. The electrode configuration and geometry is one of the main things in measuring impedance [21]. Often, there is an incorrect position of the electrode which can affect the flow of electric current [22]. Thus in this study, the design and configuration of the electrode for impedance measurement using a parallel plate will be made because the resulting electric field is well distributed.

2. Experimental Methods

The current injection method is simple and easy to use. Thus, this study uses the current injection method. In the first stage, the measurement system design is made (Figure 1). The block diagram in Figure 1 shows the components in the bio-impedance measurement. The main component in this measurement is the picoscope S5000 which is a data acquisition system (DAQ) equipped with an AC voltage generator with an operating frequency of up to 20MHz. In the process of working, this picoscope is fully controlled by the software that has been installed on the computer (PC). In addition to the DAQ component, there is an instrumentation system for bio-impedance measurement, namely, the V to I converter module (Figure 2).

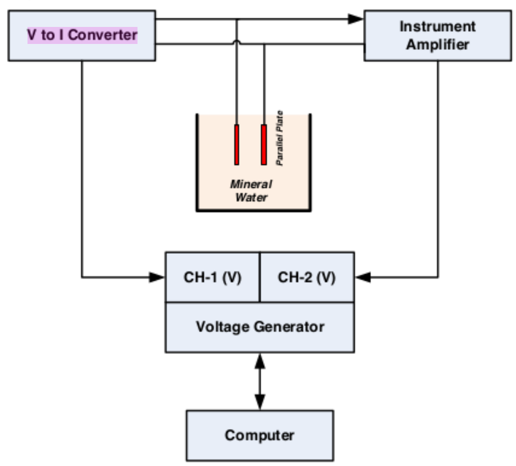

Figure 1. Bioimpedance measurement system design

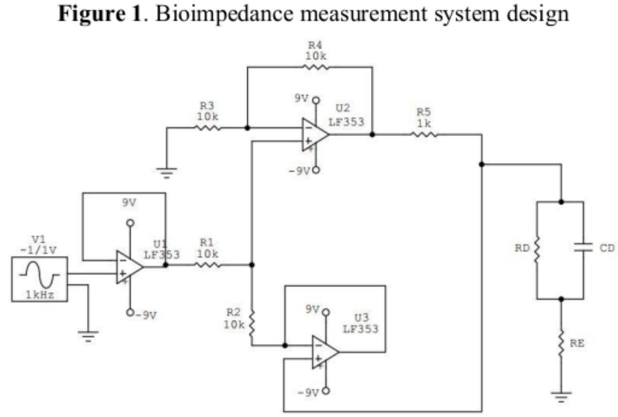

Figure 2. V to I Converter Module Series

The V to I converter module and Instrument Amplifier are built using the LF353 op-amp. Based on Figure 2, to determine the current value to be injected into the test material is determined by the resistor value in the I-selector section, these values have presented in table 1.

The next step after making the V to I converter module is to make a design for the electrode that will be used as a bio-impedance measurement sensor. The electrode design has presented in Figure 3. In the figure, there are 2 (two) electrode shapes, that are a circle and a rectangle and with 3 (three) sizes, that is, 1mm, 3mm, and 5mm.

Table 1. I-Selector Configuration for Current Injection

Resistor	Arus
1MΩ	1μA
100kΩ	10μA
10kΩ	100μA
1kΩ	1mA

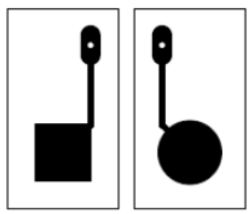

Figure 3. Electrode Design

3. Result and Discussion

The implementation of the method described in the previous section is applying the electrode design to the copper plate (Figure 4) and implementing the V to I converter module circuit (Figure 5). After all, parts are ready, then the configuration of the electrodes is carried out, where the electrodes have arranged opposite 3mm, 5mm, and 7mm and 11mm configurations for impedance measurements.

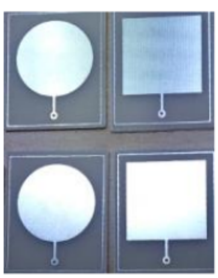

Figure 4. Electrode Design Implementation

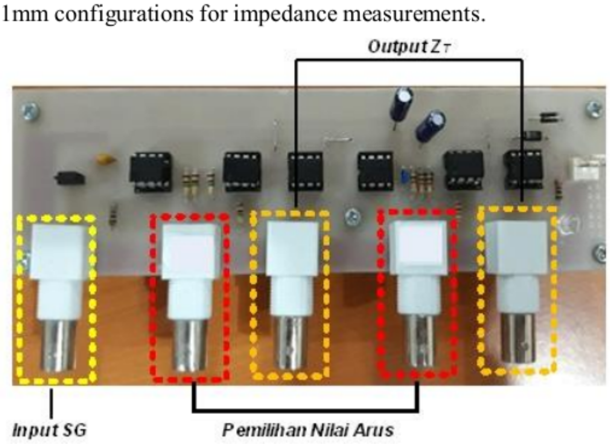

Figure 5. Implementation of the V to I Converter Module Series

The test material used is mineral water to see the electrode response in each shape, size and configuration. Figure 6 is the result of testing the electrode configuration for a circle with a size of 15mm. As can be seen in the graph, the current injection is carried out from a frequency of 1 Hz to 1MHz, the graphic results show that the wider the electrode area, the greater the measured impedance value. In addition, the graph also shows the trend of the logarithmic test results, this is because the total impedance value of the solution is influenced by the resistance and capacitance components on the electrodes in accordance with the results of the analysis of the solution that is in contact with the electrode. In accordance with the test results, if a current is injected with a very small frequency, the value of X_C becomes infinite, thus the capacitor is an insulator. With this condition, it can be concluded that there is no current passing through the capacitor, the current only passes through the resistor. But if the current is of large frequency then the value of X_C is zero. This is caused by the current that only pass through the capacitor so that the capacitor acts as a conductor.
In Figure 6, the graph shows that the impedance value tends to be constant at a frequency of 1kHz - 1MHz. This is because at this frequency there is no influence on the capacitor, so the impedance value is only affected by the resistance of the solution. In the previous discussion focused on the electrodes used, then based on Figure 7 the configuration of the electrodes tested with sample frequencies of 1kHz, 10kHz, and 100kHz will be discussed. In Figure 7, it shows that when the electrode configuration is getting bigger, the impedance value will also be greater, while in Figure 8, each frequency has the R2 results close to 1. This result shows that the three sample frequencies used have a good correlation with the impedance value that is measurable.

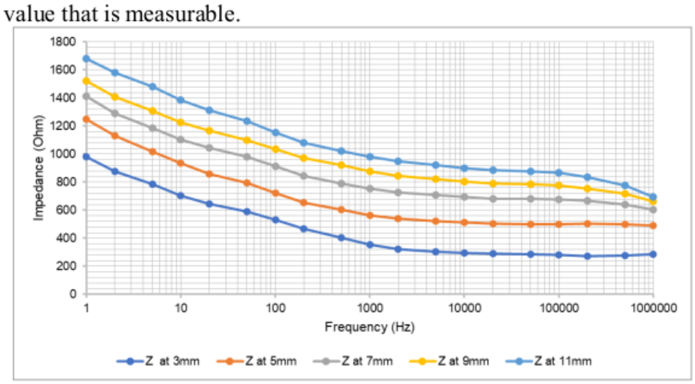

Figure 6. Impedance Vs Frequency graph for each electrode (Mineral Water)

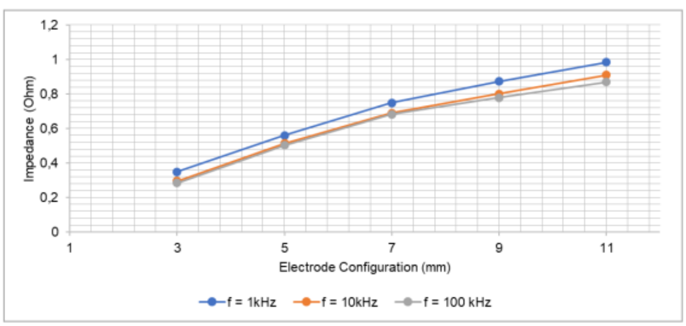

Figure 7. Impedance Vs Electrode Configuration at each Frequency (Mineral Water)

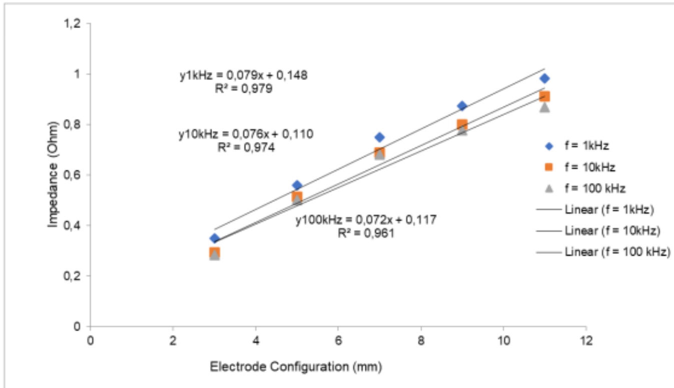

Figure 8. Impedance Linearization Graph (Mineral Water)

4. Conclusion

This research is an experimental study of developing electrode design for impedance measurement. Based on the results of experiments that have been carried out, the electrode materials used are circular and rectangular copper with sizes of 1mm, 5mm, and 15mm and configurations of 1mm, 3mm, 5mm, 7mm, and 11mm. The experimental results show that the circular electrode shows better results. Besides, a good electrode size is shown at 5mm. Where the size of 5mm is more sensitive because it shows a different impedance trend-line at each frequency, making it easier to determine the impedance value of a solution. This also shows that the smaller the cross-sectional area of the electrode, the greater the impedance measured and the greater the sensitivity. Whereas the 15mm electrode shows the measured impedance value is getting smaller and less sensitive. In addition, it can also be seen in the correlation process, the 5mm electrode produces a better correlation with a larger R2 value and is closer to the 1 value than the 15mm electrode.

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