

A Novel Method to Determine the Bio-Impedance

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Abstract: In this paper, we designed a circuit to determine the amplitude and phase of biological impediments. The circuit is simulated by the Proteus software and the amplitude and phase values are compared with the theoretical values. The theoretical value is calculated according to the Fricke model and Cole-Cole model at a frequency ranging from 10Khz to 1Mhz. The results of theoretical calculation are used to evaluate the accuracy of the designed circuit. The maximum error between simulation value and theoretical value is about 1.5% with Fricke model and about 1% with Cole-Cole model.

Keywords: Bioimpedance, measurement, simulation, Fricke model

1. Introduction

The electrical properties of biological tissues have been researched for many years and there have been many articles as well as practical applications [1] [2][3].

Impedance is a useful parameter to determine the properties of biological tissue because they are conductive. Based on this parameter, many investigations are conducted such as the detection of frozen meat [4], detection of fat rate [5][6], the PH evaluation [7], tenders evaluation [8] or meat aging evaluation [9][10][11].

There are many studies on amplitude and phase of biological tissue impedance. The design of a specific integrated circuit for the measurement of tissue impedances has been presented [12] [13][14]. An impedance system was built to differentiate fresh chicken breasts from those that had been frozen and thawed [4]. A technique for real-time monitoring of bio-impedances using a Voltage Oscillation (VO) methodology was proposed [15]. The amplitude and phase-frequency characteristics in the extended band up to 5MHz was determined for the diagnosis of functional state and structure of biological objects with weakly expressed irregularities [16].

In fact, the state and structure of biological objects are changed by time and the kind of tissues. Thus, the electrical properties of biological tissues will be changed. The measurements of electrical properties will give information about the electrochemical processes in tissues and can be used to characterize the tissue or monitor for physiological changes. It is clear that acquiring these parameters requires the use of an expensive impedance analyzer and post processing of the data.

The purpose of this work is to present a novel system for determining the amplitude and phase of the biological tissue impedance. The information of amplitude and phase of bioimpedance have been used to extract relevant information from a biological material for the purpose of getting some details.

The paper is organized as follows. Section II describes the materials and methods to measure the biological impedance. Simulation results and evaluation of the accuracy of the design system are discussed in section III. Section IV

concludes the paper.

2. Materials and Methods

2.1 Biological impedance models according to Fricke and Cole-Cole

To investigate impedance of biological tissue, it is necessary to view it according to an electrical model. The Fricke and Cole models are founded on the basis of the description given in Fricke [1][2] or Cole and Cole [17] [18]. The impedance Z is a complex function of alternating current frequency f :

$$Z = Z_{\text{real}} + i \cdot Z_{\text{imag}}$$

Where Z_{real} is the real part and Z_{imag} is the imaginary part of the impedance Z .

One of the first successful electrical models was proposed by Fricke [1] [2], which has been used extensively in research into cells or micro-organisms in suspension in a liquid medium [9]. Fricke considered biological tissue as ionized liquid medium (i.e. extracellular fluid (ECF)) suspending cells, which was intracellular fluid (ICF) enclosed by insulating membranes. Also, components of biological tissue (cell membranes, ICF, ECF) were represented by passive electrical elements [9]. The equivalent circuit represented tissue is shown in Figure 1. In which, R_e , R_i , C_m respectively are resistance of ECF, ICF and capacitance of membrane.

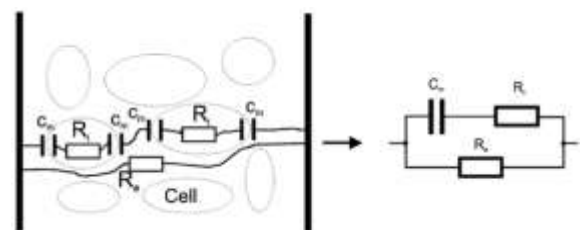


Figure 1: Electrical Fricke model with equivalent resistances R_i (ICF), R_e (ECF) and cell membrane capacitance, C_m

The other successful electrical model was proposed by Cole-Cole impedance model [3][17][18] which also has been widely used for characterizing the electrochemical properties of biological tissues [19]. The equivalent circuit represented tissue is shown in Figure 2.

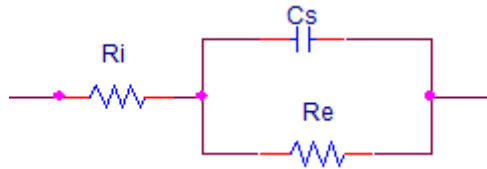


Figure 2: Electrical Cole-Cole model with equivalent resistances R_i , R_e and capacitance C_s

The following is our design circuit applied to measure the amplitude and phase of the complex impedance Z . For the purpose of testing system, the impedance Z is modeled like the Fricke model (Figure 1) and Cole-Cole model (Figure 2).

2.2 Circuit design

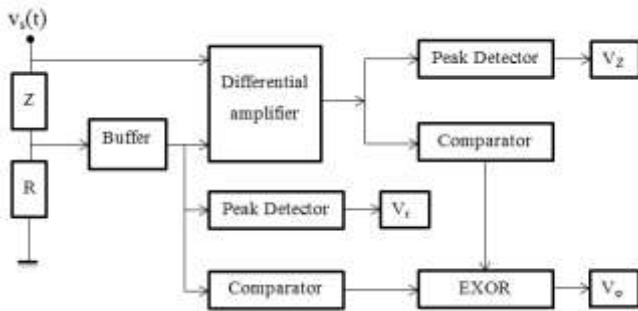


Figure 3: The block diagram of the circuit

The block diagram of system is shown in Figure 3. The value of R is known and V_s is taken from the AC source.

Our purpose is to define the real and the imaginary parts of the complex impedance Z , which can be presented in form of amplitude and phase.

Therefore, the current $i(t)$ through R and Z can be assumed by equation:

$$i(t) = I \cdot \sin(\omega t) \quad (1)$$

Suppose the voltage on the complex impedance Z is:

$$v(t) = Vz \cdot \sin(\omega t + \phi) \quad (2)$$

Where ϕ is the phase difference between the current and the voltage across the impedance Z . It is also the phase value need to find.

From (1) and (2), we have the formula for calculating the magnitude of the impedance Z :

$$Zx = \frac{Vz}{I} \quad (3)$$

Transform equation (3), we have:

$$Zx = \frac{R \cdot Vz}{R \cdot I} = \frac{R \cdot Vz}{Vr} \quad (4)$$

The voltage across the complex impedance Z , $v(t)$, is taken by a differential amplifier. Two voltage amplitude values V_z and V_r are determined by the wave peak detection circuit [20][21][22], as shown in Figure 4. This circuit uses two amplifiers, the difference between the peak and the current input level is forced across R_1 . In the event of a rising pulse, the first amplifier compensates for the drop across diode D_2 , forcing the voltage at non-inverting input of the second amplifier equal to input voltage, V_{in} . Diode D_1 is off and the voltage drop across resistor R_1 is zero. Capacitor C_3 speeds up the loop by providing the charge required by the input capacitance of the first amplifier, helping to maintain a

minimal voltage drop across resistor R_1 in the sampling mode. A negative going edge results in diode D_2 turning off and diode D_1 turning on, closing the loop around the first amplifier and forcing $V_{out} - V_{in}$ across resistor R_1 . The selection of capacitor C_2 and resistor R_2 is made by considering droop rate, settling time, and kickback. R_2 prevents overshoot from occurring at non-inverting input of the second amplifier. The time constants of R_2 , C_2 are roughly equal to achieve the best performance. Slower time constants can be selected by increasing the value of capacitor C_2 to minimize droop rate and kickback at the cost of increased settling time. When the peak detector is required to hold the value of the peak for a long time, the capacitor should be buffered. An op-amp U_2 , which should have high input impedance and low input bias current, is connected as a voltage follower.

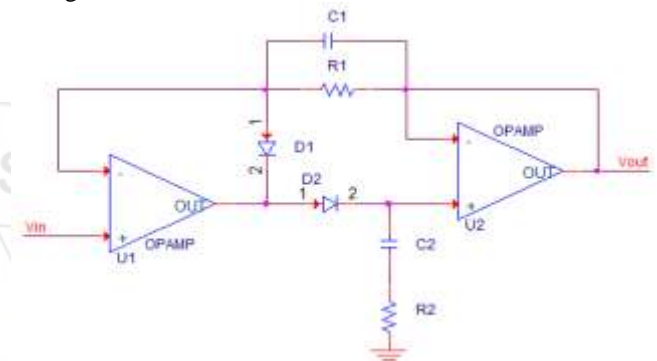


Figure 4: The wave peak detection circuit

We have the phase difference ϕ is also the phase difference between the voltage $v(t)$ and the voltage on the resistor R is $v_r(t)$. Transfer the two voltage signals above into two square-pulse signals using the comparators as shown in figure 5. If we feed the input of an EXOR gate with these two signals, it will be obtained a digital signal, V_ϕ , called voltage phase, which duty cycle, δ , is directly proportional to the phase to be measured [23].

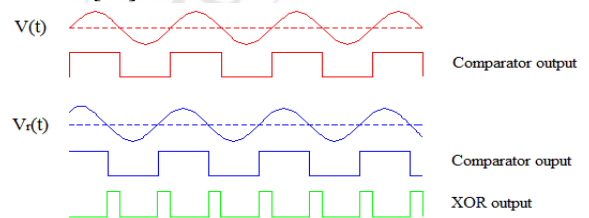


Figure 5: The image illustrates the process of obtaining the voltage V_ϕ

V_ϕ signal is passed through a second-order low-pass filter, shown in Figure 6, the output voltage is the voltage average value is proportional to the value of the phase to be calculated [24][25]. This second-order low-pass filter circuit has two RC networks, R_1-C_1 and R_2-C_2 which give the filter its frequency response properties. The filter design is based around a non-inverting op-amp configuration and the filter's gain is equal to 1. The values of the resistors and capacitors determine the cut-off frequency of the low pass filter.

The cut-off frequency of the filter is calculated by the formula:

$$f_c = \frac{1}{2\pi\sqrt{R1.R2.C1.C2}}$$

Here, $R1 = R2 = 10 \text{ (k}\Omega\text{)}$; $C1 = C2 = 47 \text{ (}\mu\text{F)}$.
 We have cut-off frequency, $f_c = 0.33 \text{ Hz}$.

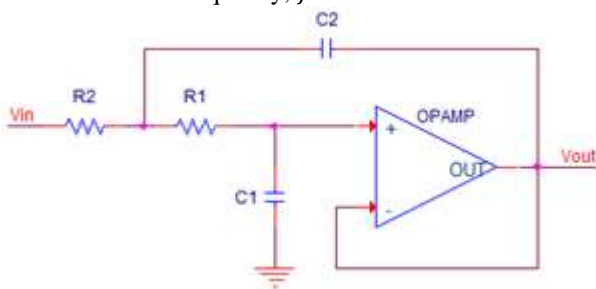


Figure 6: Second order low pass filter circuit

The formula for phase calculation is:

$$\varphi = \frac{V_{out}}{V_{dd}} \times \pi \text{ (rad)}$$

Where V_{out} is the average output voltage
 V_{dd} : Supply voltage of the XOR gate

3. Experiment Results

Circuits are designed and simulated on the Proteus software, shown in Figure 7. The circuit is used to investigate the complex impedance Z according to the Fricke model and Cole-Cole model.

With Fricke model in Figure 1, the values of components are chosen as $R_c = 2000\Omega$, $R_i = 1000\Omega$, $C_m = 1\text{nF}$. The frequency f is changed from 10KHz to 1MHz and the amplitude of the

AC power supply is 2 V.

The complex impedance Z has the theoretical value calculated by the formula:

$$Z = \frac{Re \times (Ri + Zc)}{Re + Ri + Zc}$$

In which:

$$Zc = \frac{1}{j.2\pi f.C_m}$$

Formula for error calculation:

$$Error = \frac{|S - T|}{T} \times 100\%$$

In which:

S: Simulation value
 T: Theoretical value

The results obtained from the simulation are compared with theoretical values, are shown in the Figure 8 and 9. Figure 8 shows the amplitude values and figure 9 shows the phase values of the Fricke model. The blue line shows the theoretical value and the red line shows the simulation value. The green line shows the error between the theoretical and simulation values.

From the results, we can see that the difference between simulation and theory can be negligible, with the errors between theoretical and simulation values are smaller than 1.5%.

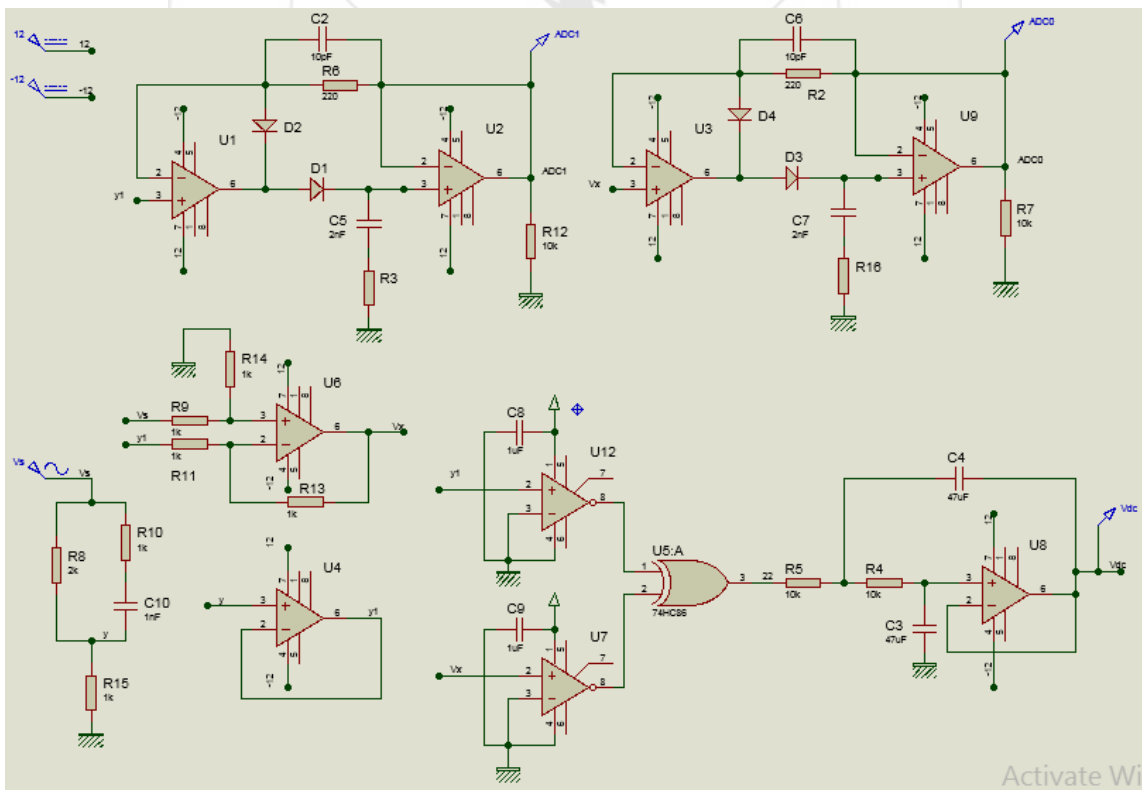


Figure 7: The circuit is designed on Proteus software

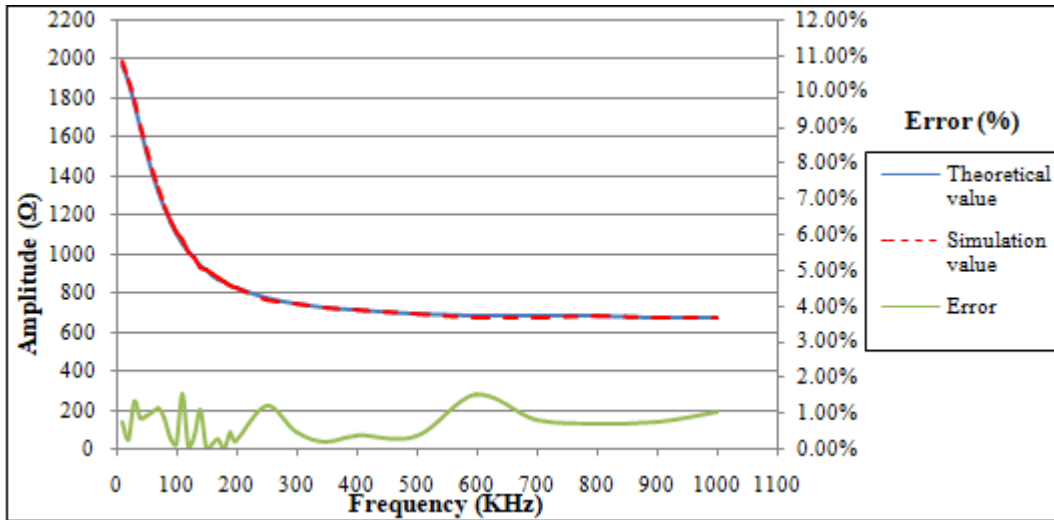


Figure 8: Change the impedance amplitude by frequency with Fricke model

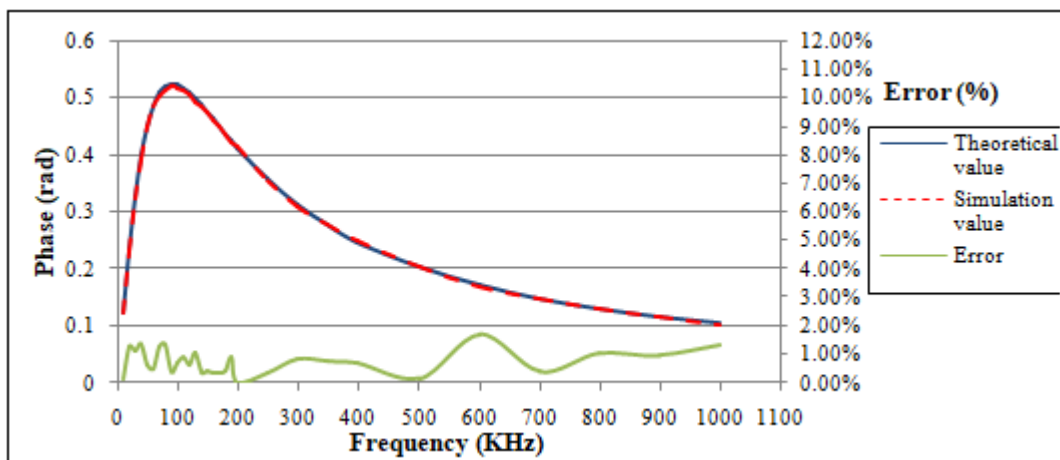


Figure 9: Change phase impedance by frequency with Fricke model

With Cole-Cole model in Figure 2, the values of components are chosen as $R_e = 2000\Omega$, $R_i = 1000\Omega$, $C_s = 1nF$.

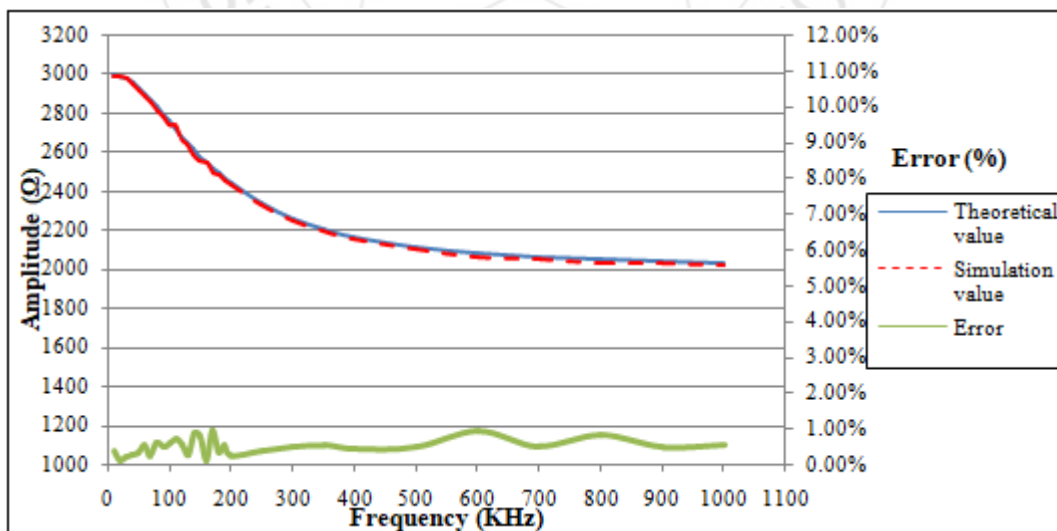


Figure 10: Change the impedance amplitude by frequency with Cole-Cole model

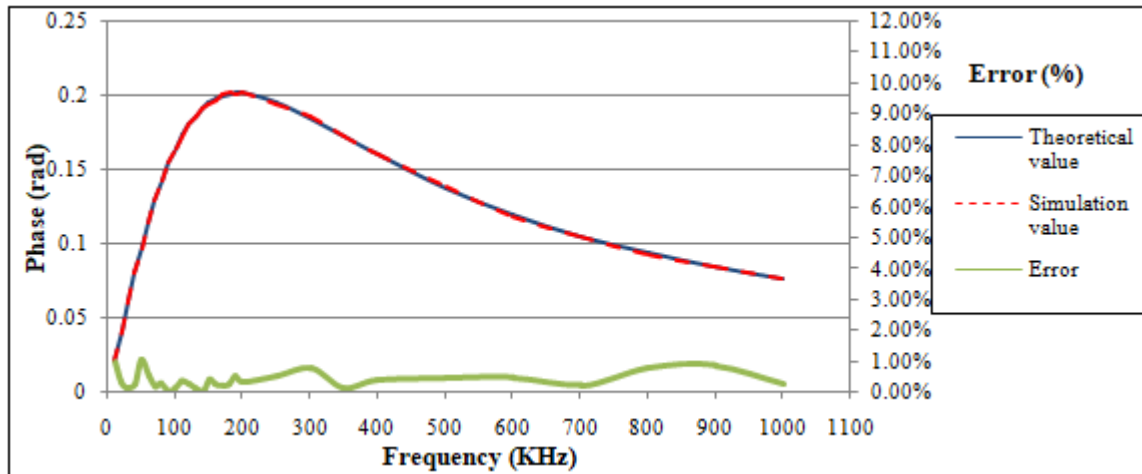


Figure 11: Change phase impedance by frequency with Cole-Cole model

The results obtained from the simulation are compared with theoretical values of Cole-Cole model, are shown in the Figure 10 and 11. Figure 10 shows the amplitude values and Figure 11 shows the phase values. From the results, we can see the errors between theoretical and simulation values are smaller than 1%.

4. Conclusion

This paper presents a simple method for identifying two amplitude and phase components in complex Z impedance, which may be equivalent to biological tissue, with frequencies varying from 10KHz to 1MHz. The simulation results obtained are promising for application circuit impedance measurement into practice with high accuracy. The maximum error value is 1.5% with Fricke model and 1% with Cole-Cole model. In the future, this circuit can be used in practice to evaluate the impedance of materials such as meats or fruits.

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