Multi-frequency Bioimpedance Monitoring Technique using Network Analyzer for Body Composition Analysis

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Abstract

Bioimpedance is a term used to describe the response of a living organism to an externally applied electric current. It is a measure of the opposition to the flow of that electric current through the tissues, the opposite of electrical conductivity. Body composition is an important part of the human life. The body composition parameters are helpful in monitoring the performance of body and bioimpedance is the major parameter for body composition analysis. The main objective is to study the composition of fluids and fats in the body. Bioimpedance analysis (BIA) is a potential field and clinical method for evaluating body mass and fat percentage. Methodology used for the analysis purpose is multi-frequency bioimpedance monitoring and is a widely used method to estimate body composition. The body composition parameters play an important role in keeping the health normal. It is concluded that the multi-frequency bioimpedance analysis using network analyzer is a relatively simple, quick and non-invasive technique to measure body composition.

Keywords: *Bioimpedance, Multi-frequency, Body composition, Network Analyzer, Extracellular water, Intracellular water.*

1. Introduction

Bioimpedance technique has been widely applied in many biomedical applications such as tissue characterization, physiological measurement, disease detection, biosensing, etc. It has the advantages of easy to use, low cost, and fast response. The tissue structure and its contents may exhibit different electrical characteristics. Due to the nature of tissues, the impedance may vary with the frequency of measuring signal. The impedance will decrease as the frequency increases. The relationship between the impedance and frequency is nonlinear. Both the resistivity and permittivity are frequency dependent. The higher the frequency, the lower is the impedance. Bioimpedance technology is an impedance measurement technology and has great potential in clinical applications. Impedance is a function of two components (vectors): the resistance of the tissues themselves, and the additional opposition (reactance) due to the capacitance of membranes, tissue interfaces, and nonionic tissues. Furthermore, the current pathway in the tissues is different for the varied frequency. Thus, a multiple-frequency bioimpedance measuring system plays an important role in the electrical property characterization of tissues. The accuracy of a BIA device depends primarily on the number of frequencies at which measurements are taken. That is why the choice of instrument is so important [16].

2. Review of literature

The study of human body composition is greater than 100 year old. Body composition studies were carried out in the first half of the 20th century an active period of research followed World War II and latest through the 1960s [17].

Bioimpedance is about the electrical properties of body, e.g. to what extent the body acts as a good conductor. Bioimpedance is a measure of how well the body impedes the electric current flow.

Body impedance (Z) is defined as the opposition of a conductor to the flow of an alternating current, and consists of two components: resistance (R) and reactance (X_c). Resistance (R) is the major opposition of the conductor and at usual low frequency (50 kHz),

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the extra-cellular part of non-adipose tissue works as a resistor. Reactance is an additional opposition or the storage of an electrical charge by a condenser for a short period of time; the lipid component of the membranes of the Body Cell Mass (BCM) behave as capacitors and reduce the flow of intracellular ions. In practice, impedance is the amount of dropped voltage when a small constant current (800 µA) with a fixed frequency (50 kHz) passes between electrodes spanning the body and multi-frequency bioimpedance measuring system could provide good performance over the frequency range over some Hz-MHz. However, lean tissue, which is rich in water and electrolytes, has minimal impedance and increases to a maximum when all lean tissue is replaced by fat/adipose tissue [11].

3. Methods and Materials

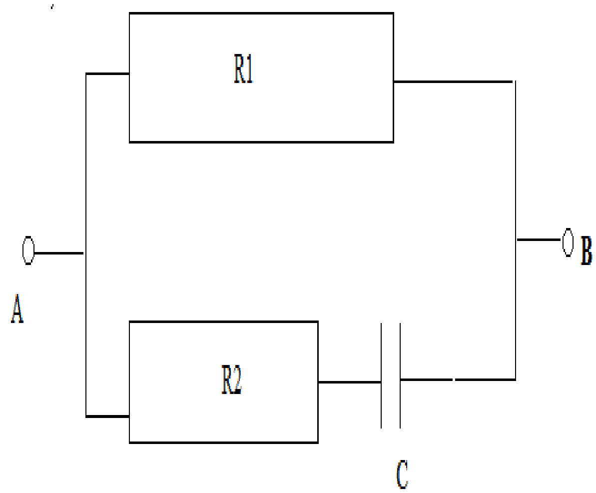
3.1. Necessity of multi-frequency

Bioimpedance measurements are carries out using single-frequency as well as multi-frequency. But there are certain drawbacks of single-frequency like low level currents with single frequency are limited to pass through only the ECF whereas the current with multi-frequency are able to pass through ECF as well as ICF and therefore it is very useful in various clinical applications.

3.2. Body compartment model

The bioimpedance analysis applying independently resistive and reactive vectors makes reference to multiple compartment models and it is indeed in a position to assess the compartmental changes. As already stated, the body fat-free tissues are preferential pathways for alternating electric current and oppose two faces of a different nature: resistance (R_z) deriving mainly from extracellular fluids and reactance (X_c) deriving from cell membranes, both forming the impedance modulus (Z) where $Z= \sqrt{R_z^2 + X_c^2}$ [1].

The BIA constant alternating current ranging from 0.8mA to 0.1 mA at single or multiple frequencies is applied to model shown in figure 1. which shows the flow phenomena coherent with the parallel conductors principles; where R1 is extracellular water resistive pathway, R2 is intracellular water resistive pathway and C is capacitance from cell membrane.



"**Figure 1.** Bioelectric resistance circuits" [1].

The body composition analysis is the clinical assessment of tissue and fluid distribution in the human body. The body is modeled as a series of tissue and fluid compartments as shown in figure 2.

Fat Mass (FM) is the total amount of stored lipids in the body and consists of the following types of fat:

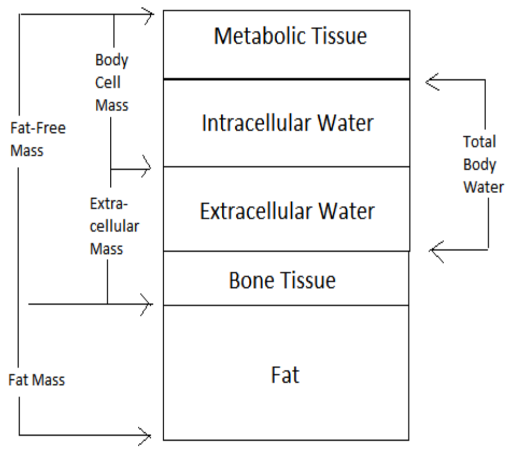
Subcutaneous fat is located directly beneath the skin. Subcutaneous Fat serves as an energy reserve and as insulation against outside cold.

Visceral fat is located deeper within the body. Visceral fat serves as an energy reserve and as cushion between organs.

Fat-Free-Mass (FFM), also called as Lean Body Mass, is the total amount of nonfat (lean) parts of the body. It consists of approximately 73% water, 20% protein, 6% mineral, and 1% ash. Fat-free-mass is further divided into body cell mass and extracellular mass:

Body Cell Mass (BCM) contains all metabolically active tissues (living cells) of the body, including muscle cells, organ cells, blood cells, and immune cells. BCM includes the "living" portion of fat cells, but not the stored fat lipids. BCM also includes water inside living cells. This water is called Intracellular Water (ICW). The main electrolyte of intracellular water is potassium.

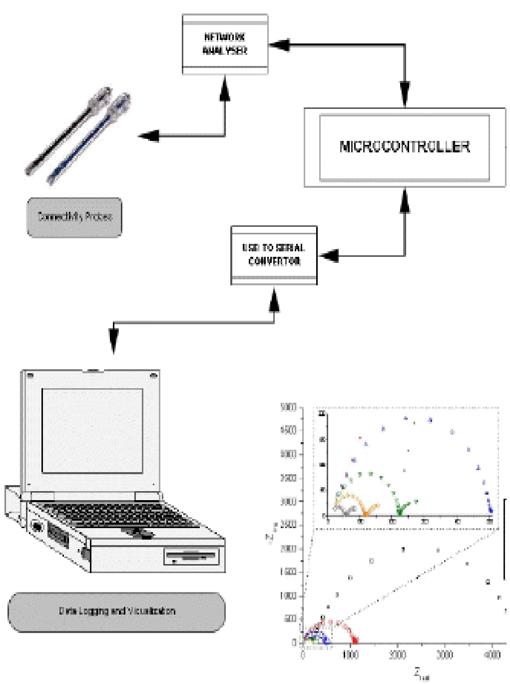
Extracellular Mass (ECM) contains all the metabolically inactive (non-living) parts of the body, such as bone minerals and blood plasma. ECM includes water contained outside living cells. This water is called Extracellular water (ECW). The main electrolyte of extracellular water is sodium. Fig.3. provides a representation of the relationship of mass and water distribution in the human body.



"**Figure 2.** Five-compartment model for human body" [20].

3.3. MF-BIA using network analyzer

The proposed system uses network analyzer which gives the impedance measurement directly for multiple frequencies. The block representation for impedance measurement is shown in figure 3.



"**Figure 3.** Block representation of multi-frequency –BIA using network analyzer".

Network analyzer, the AD5934 is a high precision impedance converter system solution that combines an on-board frequency generator with a 12-bit, 250 kSPS, and analog-to-digital converter (ADC). The frequency generator allows an external complex impedance to be excited with a known frequency. The response signal from the impedance is sampled by the on-board ADC and a discrete Fourier transform (DFT) is processed by an on-board DSP engine. The DFT algorithm returns a real (R) and imaginary (I) data-word at each output frequency. Once calibrated, the magnitude of the impedance and relative phase of the impedance at each frequency point along the sweep is easily calculated using the following two equations:

Magnitude = $\sqrt{(R^2 + I^2)}$

Phase = $\tan^{-1}(I/R)$

3.3.1 Processing of data from electrodes to PC The AD5934 can be used to inject a stimulus signal through body part via a disposable probe. The response signal is analyzed and the effective impedance of the cavity is tabulated. The AD5934 is ideal for this application because it allows the user to tune to the specific frequency required for each test [21].

• From the network analyzer data is given to microcontroller where coding is done for implementation on PC.
• PC application is written in Visual Basic.
• Microcontroller side coding is done using Embedded C.
• User selects START operation on PC.
• A command is sent to microcontroller over RS232 using serial port.
• Once the command is received, the microcontroller will start communication with AD5934 network analyzer.
• Microcontroller will set the initial frequency, final frequency and steps for increment and send start.
• The communication between microcontroller and network analyzer is done over I^2C protocol.
• I^2C performs chip-to-chip communications using only two wires in a serial interface, allowing ICs to communicate with fewer pins. The two wires in the I^2C Bus are called Clock (SCL) and Data (SDA). These two wires carry addressing, selection, control, and data, one bit at a time. The SDA wire carries the data, while the SCL wire synchronizes the sender and receiver during the transfer. ICs that use the I^2C Bus can perform the same function as their larger parallel interface counterparts, but with far fewer pins. This greatly reduces the size and cost of ICs based on the I^2C Bus.

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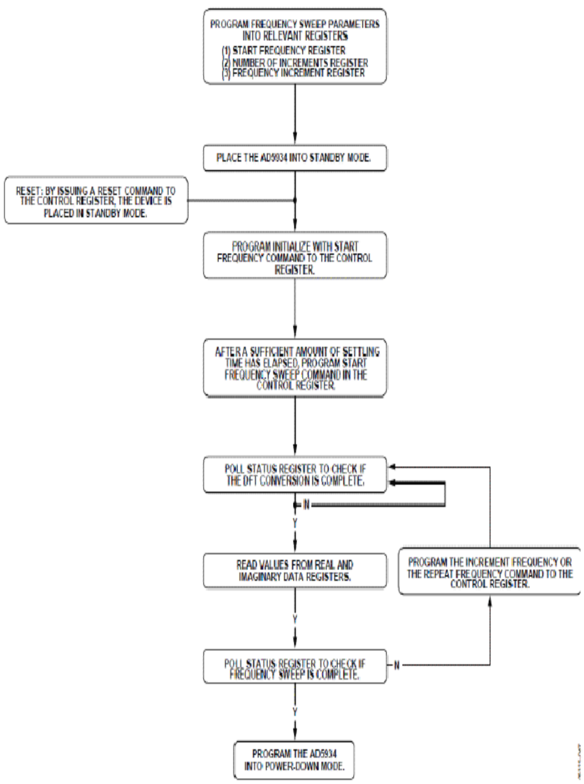
• Once the sweep is complete, the microcontroller will read the values (real and imaginary) from registers and send it to PC one by one.
• On PC, the received values will be stored in files (patient records) and a graph will be plotted for analysis.
• User can load multiple graphs (ones stored earlier) to analyze the dielectric material under test (tissue / metal etc.)

3.3.2. Flow chart Flow chart as shown in figure 4. follows the instructions mentioned and executes all the instructions to obtain the required parameters for monitoring bioimpedance using network analyzer for multiple frequencies.



"**Figure 4.** Flow chart of proposed system".

3.4. Results

3.4.1. Procedure Electrical properties of body fat and fluid measurements were made with patients sitting on a chair at different frequencies. The disposable probe was placed on the different patient's hand and foot and parameters of impedance real and imaginary, magnitude, phase angle were analyzed at different frequencies. Readings were taken on five different patients. In all cases, three separate sets of measurement of a position were made in succession in order to check reliability of the measurements. Following are the steps used for the measurements:

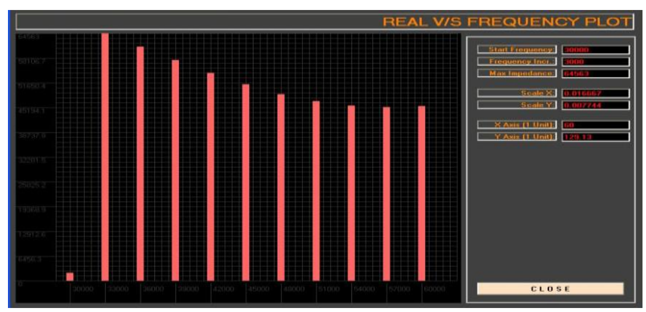
1. A disposable probe is placed on patient's right hand and right foot and is properly connected to the hardware.

2. Microcontroller is connected to network analyzer and power is switched on.

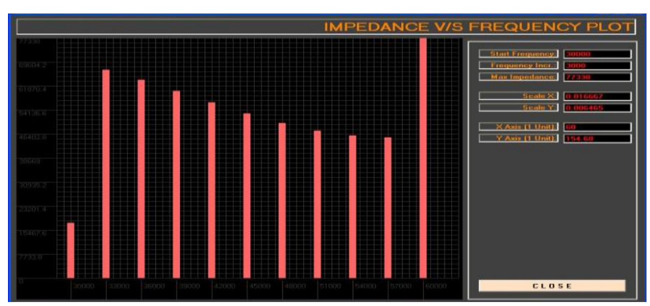
3. Network analyzer picks up signal from body tissue and displays the changes in electrical impedance with respect to frequency in the form of graphs on PC.

4. The data from two different patients can also be compared with help of this system.

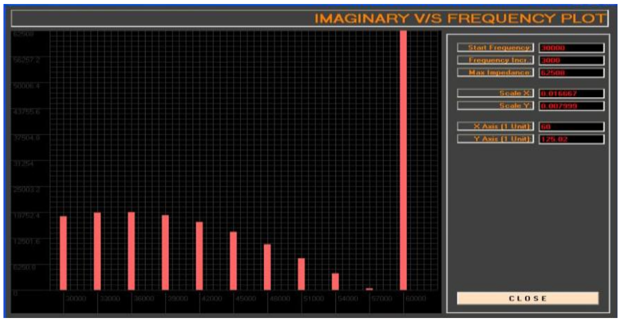
3.4.2. Result The results obtained from the subject are shown as a graphical representation. The relationship between impedance, resistance and reactance with the frequency is shown as graphical representation in figure 5., figure 6. and figure 7. respectively. It is observed that from fig.5. and fig.6. that the impedance decreases as the frequency increases and from fig.7. reactance first increases and then decreases as frequency increases.



"**Figure 5.** Real (resistance) v/s frequency plot".



"**Figure 6.** Impedance v/s frequency plot".



"**Figure 7.** Imaginary (reactance) v/s frequency plot".

4. Discussion and conclusion

The main goal of this study is to design a multi-frequency bioimpedance system for clinical applications. Hence the design of the system has two important considerations. One is the capability of multi-frequency measurements, and the other is the feasibility of multiple clinical applications. From the experimental results, it is shown that the proposed multi-frequency bioimprdance measuring system provides good performance over the frequency range up to 100 KHz as well as the extensible system architecture.

This proposed system is also designed with application software and friendly graphic user interface using Visual Basic. The operation functions implemented in software are designed to meet the requirement of application and specification of system hardware. Thus, all the information about the parameter setting and data measurement of the system can be controlled and provided through this software interface. The system provides a hardware and software integration solution for the bioimpedance measurements, which may be very useful and helpful in clinical applications.

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