Bioelectrical Impedance: A Future Health Care Technology

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ABSTRACT
Impedance measurement is a fast and cheap method to characterize any matter. Unlike various complicated methods, bioimpedance measurement technique is simple, less time consuming and non-invasive method for various applications including medicine, biotechnology and food industry. However, despite of intensive research in this field of more than six decades, only a few applications have been established. This paper presents a review of the major steps taken towards the development of Bioelectrical Impedance Analysis technique as a future health care technology.

KEYWORDS
Electrical bio-impedance, multi-frequency bioimpedance, differential signal processing, instrumentation amplifier

1. INTRODUCTION
In biomedical engineering, bioimpedance is 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 [1]. It is one of the best methods for measuring blood flow and body composition, being a non-invasive method. We can easily determine total body water and fat free mass with BIA [2].

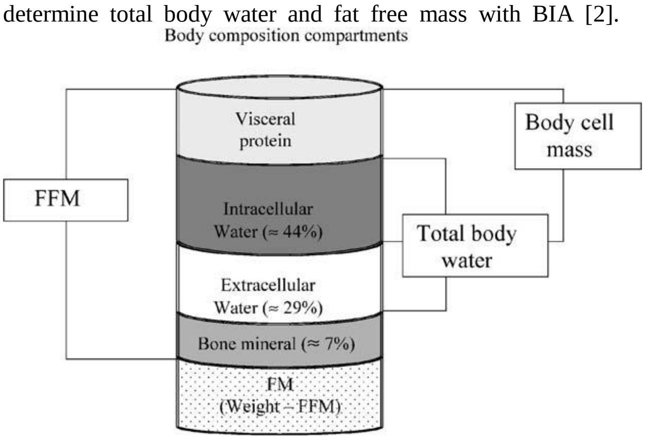

Fig. 1. Body Composition Compartments

Fat Free Mass (FFM) is everything that is not body fat.

In muscle and body water, current can flow easily, so they behave as conductors while fat acts as an insulator [3].

The basic principle in bioimpedance analysis is that impedance of an isotropic conductor is related to length and cross-sectional area of the conductor for constant signal frequency.

$R = \rho L/A$ or
$R = \rho L^2/V$
(1)

At low frequency, the current does not penetrate the cell membrane, which acts as a capacitor, and therefore the current passes through the extracellular fluid, which is responsible for the measured capacitive reactance of the body. At a very high frequency, this membrane behaves as near perfect capacitor [4].

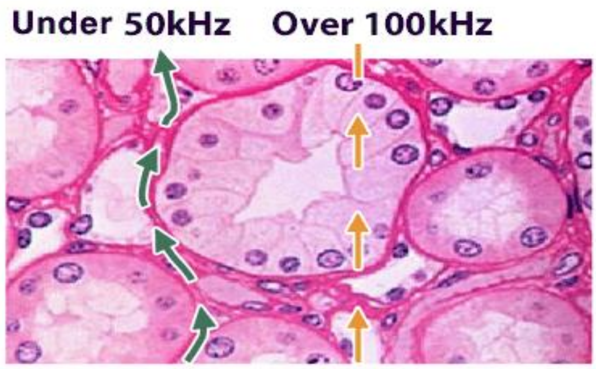

Fig. 2. Flow of current through intracellular and extracellular fluid

The body behaves as if these segments are in series with each other. Body offers two types of impedance: capacitive and resistive, capacitance is due to cell membranes while resistance is due to fluid present inside and outside the cell called intracellular and extracellular water, respectively [5] [6].

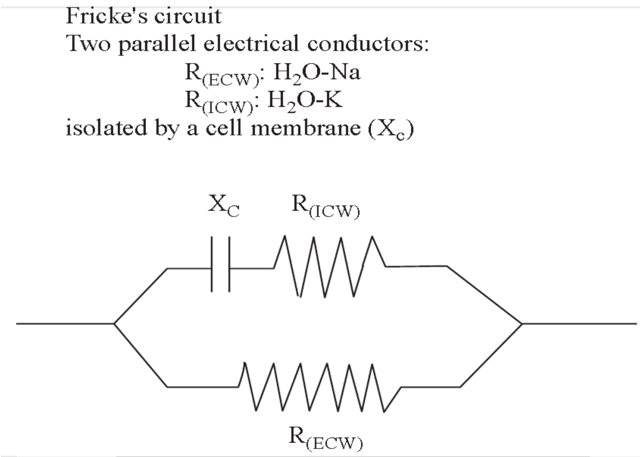

Fig. 3. Equivalent circuit

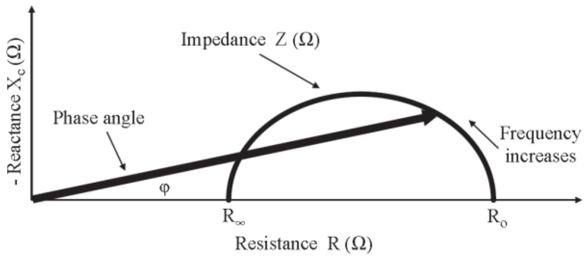

Fig. 4. Diagram of the graphical derivation of the phase angle; its relationship with resistance (R), reactance (X_c), impedance (Z) and the frequency of the applied current.

Methods used for BIA are Single frequency BIA (SF-BIA) and Multi-frequency BIA (MF-BIA).

In single frequency BIA, at 50 kHz, BIA is measuring weighted sum of extra-cellular water (ECW) and intracellular water (ICW). SF-BIA permits to estimate fat-free mass (FFM) and TBW, but cannot determine differences in ICW [1].

Multi-frequency BIA (MF-BIA) uses different frequencies (0, 1, 5, 50, and 100, 200 to 500 kHz) to evaluate FFM, TBW, ICW and ECW [7]. At frequencies below 5 kHz, and above 200 kHz, poor reproducibility is obtained [8].

2. INVESTIGATED METHODOLOGIES

2.1 Detection of fake fingers in security system

According to a survey, 80% of security systems can be easily fooled with fake fingers. Fingerprint recognition system is now not only used in high security application but also used in consumer applications [9].

A proper method would be to use a live finger detection technique based on simultaneous measurement of impedance of various skin layers.

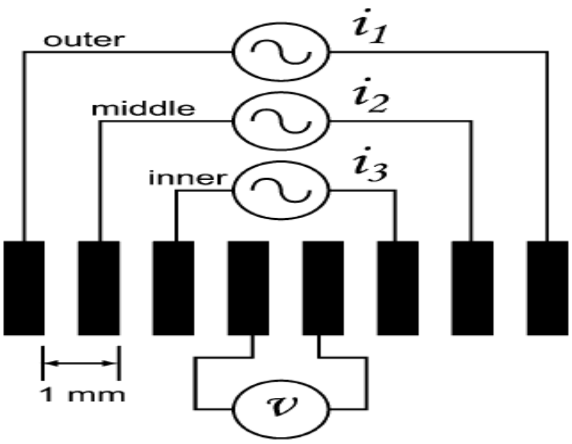

Fig. 5. Electrode array with three alternative current injecting electrode sets and one set of voltage pickup electrodes

The figure 5 shows that the differential output voltage is connected to an impedance analyzer, and internal oscillator is connected to three other electrode pairs. The analyzer performs three successive four electrode measurements. In this method, three frequency scans were done using root mean square voltage of 10mV at different frequencies from 10 kHz to 1 MHz. Inner electrode produces a higher impedance dominated by the properties of stratum corneum, while those electrodes which are far apart allow more current through them, thus lesser impedance.

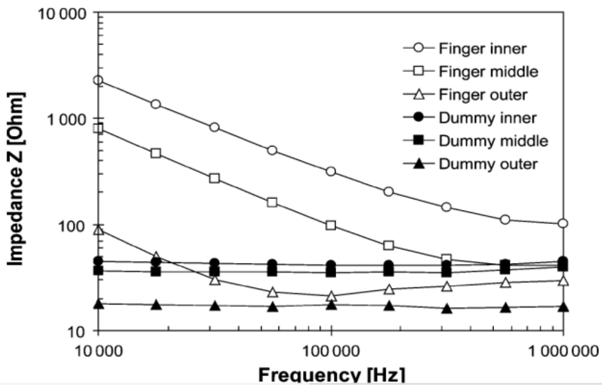

Fig. 6. Measured impedance modulus response for one live finger and fake finger

So, fingerprint recognition along with a frequency analyzer using electrical bioimpedance of different skin layers provides a reliable method for the detection of a fake finger in biometric fingerprint [10].

2.2 Heart rate measurement

Bioimpedance measurements allow us to non-invasively obtain information about the stroke volume, cardiac output, venous circulation, arterial compliance, and heart rate. A very small and safe AC current is injected into the body through the soles and basal impedance is measured which gives body composition [11]. Because of very low amplitude of change of impedance due to heart related variation, it requires a high SNR. All blood vessels are distensible which result in an arterial volume change in each heart beat. The relationship between impedance variations to the changes in blood volume and blood resistivity in limbs, assumed to be cylindrical, leads to

$$V = -\rho L^2(\Delta Z_p + \Delta Z_V)/Z_o^2$$
(2)

Where ΔV is the arterial volume change, L is the length of the arterial section between the voltage electrodes, ρ is the blood resistivity, and Z_O is the basal impedance of the non pulsatile tissue. ΔZ_P and ΔZ_V are the impedance variations due to the blood resistivity change and the impedance variations due to the volume change, respectively.

Tetra polar electrode system is used to minimize contact resistance between skin and electrodes. Single-ended current source based on a Wien bridge and a current conveyor circuit, which generates a 10-kHz, 1-mA (rms) current can be used.

Differential Signal Processing is required to process the obtained signal and hence the first amplifier stage is a fully differential AC-coupled amplifier**.** Fig. 7 shows that this amplifier has no direct connection to ground, which results in a very high CMRR at the measurement frequency;

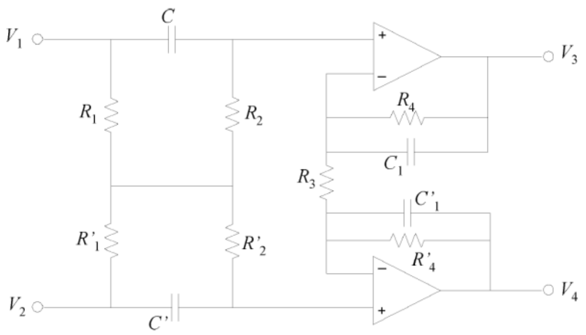

Fig. 7. Fully differential AC amplifier

It is necessary to amplify the AC component obtained because of the low level heart-related impedance variations. So it needs a large gain which must not be very high as to lead to output voltage saturation because of voltage offsets from the amplifiers. We can use passive, second-order, low pass filter with corner frequency 10 Hz. So, heart-related impedance variations due to arterial blood circulation can be detected by measuring bioimpedance changes between both feet [12].

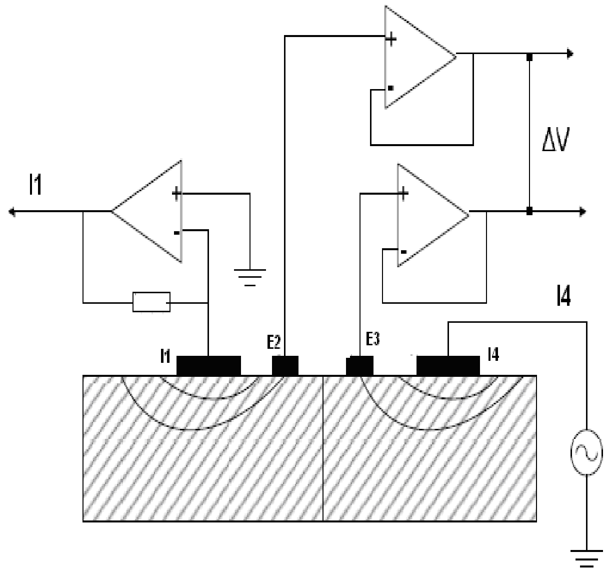

Fig. 8. Four - electrode system: I1 – I4 injection current; the position of the electrodes E2-E3 tissue segment measured.

Current source must have very high output impedance and very low stray capacitance. Measurement of bioimpedance is possible at any location in the body to enable early detection of abnormalities in various tissues and organs.

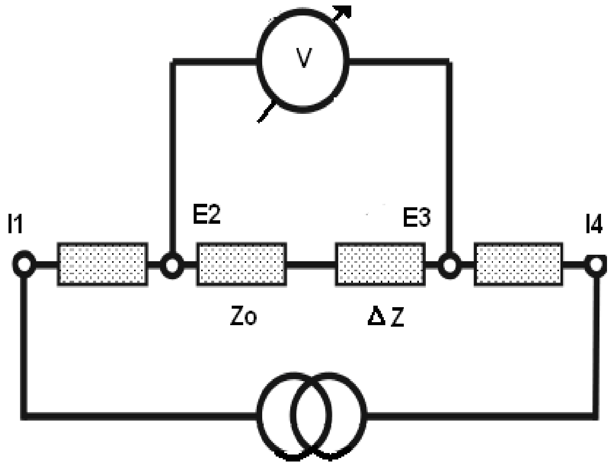

Fig. 9. Tetra-polar electrode configuration - equivalent electrical circuit

2.3 Hemodynamic Monitoring Using Peripheral Impedance Plethysmography

The older instrumentation device was bulky and expensive. So, a medical device was designed which could estimate the blood flow and calculates hemodynamic parameters for its study. An AC generator is used as a current source, series resistor limits the current. Frequency of current is between 10 kHz to 250 kHz. As Skin impedance increases with increasing frequency, a small energy is delivered to the patient, ensuring the safety of the system. The electrical impedance changes with the change in blood volume. This property can be used in Impedance plethysmography. Impedance plethysmography is a technique which measures the change in blood volume for a specific body segment. Measurement of the changes in blood volume can be used by physicians to detect the blood flow disorders such as arterial occlusive diseases, early stage arterioscleroses, functional blood flow disturbances, deep venous thromboses, migraines and general arterial blood flow disturbances [13]. In impedance plethysmography tetra polar measurement system is mainly used.

2.4 Electrical Bioimpedance Cerebral Monitoring

Brain damage is the second commonest cause of death in the world and probably the leading cause of permanent disability. There are various methods for brain monitoring, but most of them are invasive, and thus introduce the risk of brain infection and damage. The various types of damages and their effect on impedance are discussed below:

Hypoxic Damage: During the cellular adaptation and the reversible injury phase, the total impedance of the tissue changes because of the ionic redistribution in the cellular environment, the accumulation of catabolites in the intracellular space, the cell swelling and the consequent shrinkage of the extracellular space. The shrinking of the extracellular space will reduce the surface available for the charges to flow through, increasing the value of the tissue impedance. An increment in the cell radius will also change the capacitance effect of the cell and consequently the reactance of the tissue.

Ischemic Damage: along with cell swelling, there is also the effect of the reduction or even complete lack of blood in the ischemic region during this type of damage leading to increase in the resistance.

Hemorrhagic Damage: In this case, blood from the cerebro-vascular system leaves the brain arteries and veins to invade the intracellular space, causing a hematoma. The resistance of the hematoma region decreases as blood exhibits a dielectric conductivity much larger than white and gray matter tissues [14].

2.5 IMPEDANCE SPECTROSCOPY SYSTEM

There have been developments in compact impedance measurement systems based on a two-phase lock-in technique as shown in figure 10. In this technique a sinusoidal voltage is generated and applied to the sample under test, while the current flowing through it is measured using a low noise amplifier, whose output signal is demodulated by two multipliers with 90° and 0° phase shift with respect to the excitation signal. The output of the multipliers is converted into a binary signal and applied to low pass filter to obtain the real and imaginary part of the admittance of the sample under test. The system produces high signal-to-noise ratio and flexibility in the required measurement frequency and temporal resolution. The voltage applied to the sample can be very precisely controlled [15].

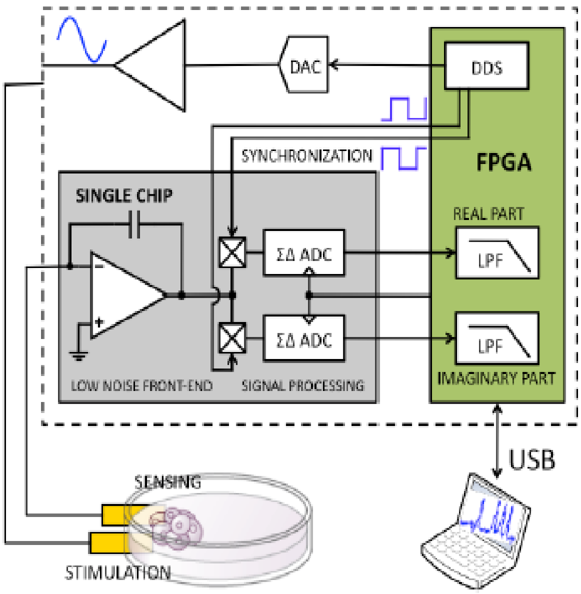

Fig. 10. Scheme of the impedance measurement system: the lock-in technique is implemented including a DDS based excitation voltage generation, an Integrator to convert current into voltage, two square waveform multipliers coupled with two ADCs and a digital low-pass filter. The circuit is controlled by an FPGA that provides USB connection.

3. PROPOSED SYSTEM

A cheap, simple and accurate circuit for current source can be obtained by using Op-amp as Wein bridge oscillator.

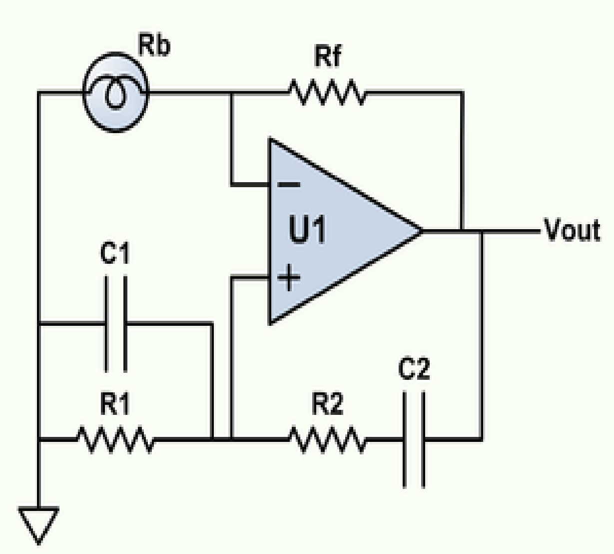

Fig. 11. Simple and cheap sine wave generation using Wein bridge oscillator.

Wein bridge oscillator will generate sinusoidal wave with frequency given by

$$f_o = 1/\{2\pi\sqrt{R_1R_2C_1C_2}\} \quad (3)$$

If it is assumed R_1=R_2=R and C_1=C_2=C and thus, the equation 3 simplifies to:

$$f_o = 1/\{2\pi RC\} \quad (4)$$

This oscillator can be viewed as a positive gain amplifier combined with a band pass filter that provides positive feedback [16].

The research on BIA so far has been carried out mostly using sinusoidal current sources. It is proposed to use a measurement system having a current source capable of generating sine, square and triangular wave. The experimental setup is under investigation. It is hopeful to get bioimpedance data based on different shapes of injected current signals resulting in more information about the impedance changes in the tissues under study. This method would lead to greater information about impedance of tissues, thus increasing the accuracy of diagnosis.

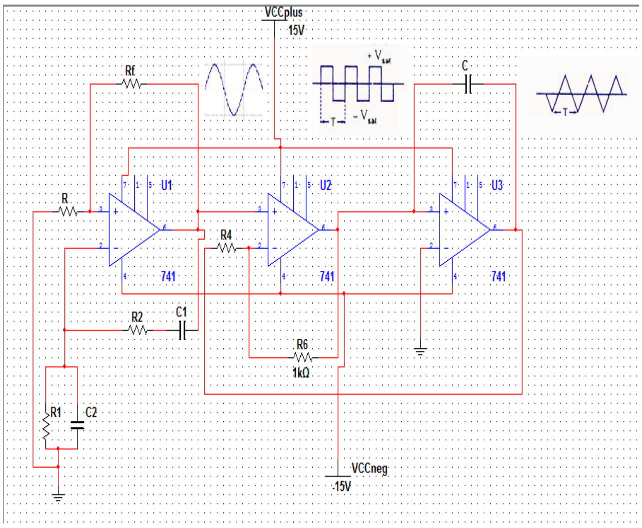

Fig. 12. Proposed system for generation of sine, square and triangular wave.

4. CONCLUSION

Research is needed to improve the accuracy of Bioelectrical Impedance Analysis (BIA). Further validation of BIA is necessary. BIA is a promising method for predicting changes in body composition and hence has the potential of replacing the conventional methods of detection and diagnosis of diseases in near future. It will become one of the most widely used methods because the BIA equipment is portable, safe, simple and non-invasive. The results are reproducible and are rapidly obtained. Specialized training is not required for the use of the equipment and the technique is relatively inexpensive. However, it suffers from a lack of standardized methods and quality control procedures. Standardization of the type of electrodes used and their placement as well as the errors due to contact resistance are the major concerns to be dealt with.

5. ACKNOWLEDGMENT

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