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Research Article

New Tetrapolar Method for Complex Bioimpedance Measurement

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Abstract

Complex bioimpedance measurement is an important key which enables to characterize the state of tissues and organs. Body fat content, tissue ischemia, skin hydration are some different areas where it is widely used. As compared to conventional methods, new tetrapolar method has been investigated to calculate the bioimpedance based on magnitude ratio and phase difference detection technique. Low power consumption, low cost and its simpler design make it more popular and efficient technique than traditional bioimpedance measuring system.

Keywords: *Bioimpedance, Imaginary value, Phase sensitive detector method, Real value, Tetrapolar.*

1. Introduction

Bioimpedance is a measure of how well the body impedes electric current.It is about the electrical properties of body i.e. to what extent body is a good conductor.It is used to investigate tissue structure(Pallas and Webster,1993)and is determined by measuring of voltage response to an excitation current flowing through a tissue or an organ(Min,*et al*,2007),(Kun,*et* al,1999).Several methods have been proposed for its measurement in which new tetrapolar method is better in accuracy than previous methods and has simpler design than phase sensitive detection method.Though it is good in accuracy as well as rapid method(Songer,2001),but practical realization of PSD method is difficult as it relies on analog demodulators in which components must be extremely well selected and matched,any mismatch causes phase errors(Ristic,*et al*,1995),(Kun,*et al*,1994).Even measurement system based on induced current method is not so popular as it needs design of antenna system that is small for medical applications which can focus induced eddy currents into a region of interest several centimeters below the skin surface(Kun and Peura,1998).

Impedance techniques have the following advantages; it is non-restrictive about measuring item and measuring part,it is non-invasive, measuring system is easy to handle and low cost(Yamamoto ,*et al*,1998),(Marin and Marin,2008).The new tetrapolar method adopts three independent voltages V_1, V_2, V_3 respectively from the two voltage electrodes and the sample resistor R, which is connected in electrodes. Here it can be seen that the real part Z_{real} and imaginary part Z_{imag} of the complex impedance between two voltage electrodes can be acquired from the modular ratios and phase differences through simple calculation. Realization is simple due to use of highly integrated electronic components(Yang and Wang,2005).Hence new tetrapolar method is most popular as it is based on highly integrated electronic components that provide better accuracy,wide frequency range.Sectin two deals with different methods to calculate bioimpedance and third section deals with the applications.Lastly the conclusion has been drawn.

2. Methodology

2.1 Induced Current Impedance Spectroscopy

It is a non contact impedance measurement system.When an electrically-conductive biological sample is placed in the magnetic field (B) of a radio frequency coil (antenna), the circulating (eddy) currents induced in the biological sample create an opposing field which weakens the original field,effectively lowering the coil's impedance.
When the local conductivity changes, the measured impedance will change.Thus, coil impedance variations are correlated to tissue conductivity changes

$$Z = \frac{4\pi^2 fNr[(imag(A) - j.real(A))]}{I} \quad (1)$$

where f represents the drive frequency, N is the number of coil turns, **r** is the coil radius, I is the total drive current, Re() and Im() are the real and imaginary parts, and A is the averaged magnetic vector potential over the cross-section of the coil

$$\nabla^2 A + \sigma \frac{\partial A}{\partial t} = -\mu_0 j \quad (2)$$

where σ i s the conductivity, J is the drive current density in the coil, and μ_0 is the permeability of free space. In this technique the only challenge is the design of antenna which can focus over desired area of interest. Hence phase

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sensitive detector method is better than this method as it makes the use of efficient electronics devices.

2.2 Phase Sensitive Detector Method

This method is fast computational method based on two phase reference coherent demodulation.voltage between voltage electrode is V_e (t)

$$V_e(t) = ZI\sin(\omega_0 t + \Theta) \quad (3)$$

where Z is the module of the bioimpedance, ϴ is the phase, and I is the amplitude of current source.

Due to the high input impedance of the instrument amplifier IA, voltage electrodes draw practically no current, so the tissue impedance measurement is uncontaminated by contact impedance. Output of IA Vz(t) can be represented as

$$LV_Z(t) = V\sin(\omega_0 t + \theta) \quad (4)$$

$$V_Z(t) = V\cos\theta\sin\omega_0 t + V\sin\theta\cos\omega_0 t \quad (5)$$

This $V_z(t)$ is multiplied with inphase signal $U\sin\omega_0 t$ and inquadrature signal $U\cos\omega_0 t$ in two multiplier.The DC level obtained are passed to low pass filter and then sampled with A/D converters.Two output Z_{real} is proportional to $V\cos\Theta/I$ and Z_{imag} to $V\sin\Theta/I$.

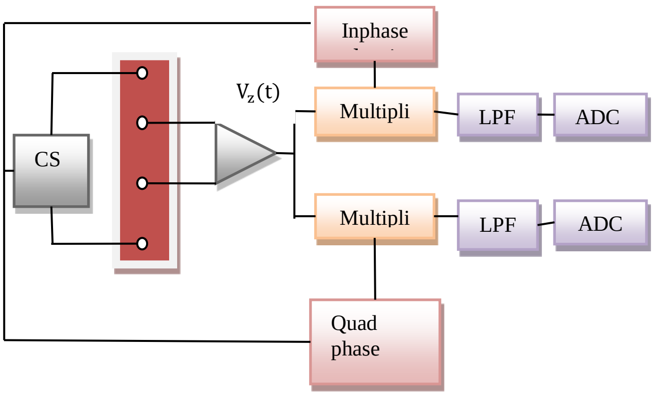

Fig.1. PSD technique to measure bioimpedance

But use of multipliers lead to phase errors if the component are not matched.In addition the total volume of the measurement system will not be suitable for hand held design for its complexity of realization.

2.3 New Tetrapolar Method

It is based on the use of phase gain detector which comprises phase detector and closely matched pair of demodulating logarithmic amplifier.

The circuit includes a current source, amplifiers, phase gain detector and analog to digital converter. Two electrodes are used to inject current to a biological tissue and two electrodes are used to pick up the voltage drop across it. The voltage across biological impedance, electrode impedance and across resistor R are amplified with the help of three identical instrument amplifiers.

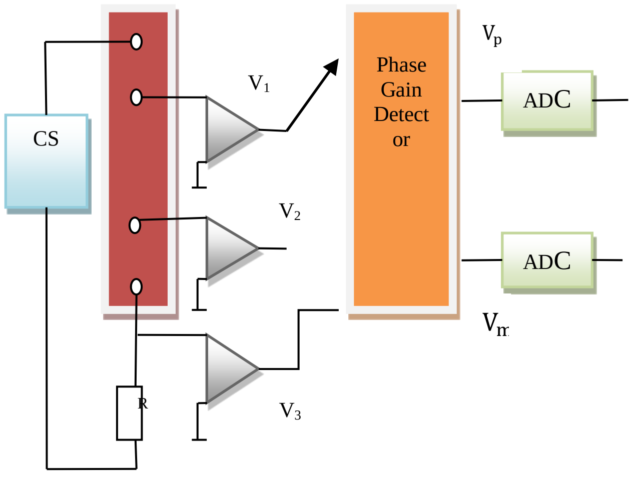

Fig.2. Tetrapolar method to measure bioimpdance Resistor R is also added in serial connection with current loop

They are then given to phase gain detector.The two DC output voltages V_{phas} and V_{mag} are proportional to phase difference and logarithmic ratio of the two inputs V_{i1} and V_{i2} respectively that is

$$V_p = K_P(\Theta_{i1} - \Theta_{i2}) \quad (6)$$

$$V_m = K_m.\log\left(\frac{V_{i1}}{V_{i2}}\right) \quad (7)$$

Where K_P and K_m are proportionality constant,if one of the PGD input is switched to instrumentation amplifier1 then

$$V_p = K_P(\Theta_1 - \Theta_3) \quad (8)$$

$$V_m = K_m.\log\left(\frac{A_1V_1}{A_3V_3}\right) \quad (9)$$

If switched to instrumentation amplifier2 then V_p is proportional to phase difference of $\Theta_2$and Θ_3 while V_m is proportional to logarithmic ratio of $A_2V_2$and A_3V_3 .By getting the modular ratio V_1/V_3 and V_2/V_3,phase difference $(\Theta_1 - \Theta_3)$ and $(\Theta_2 - \Theta_3)$,we can calculate Z_{real} and Z_{imag}.

$$Z_{real} = R(\frac{V_1}{V_3})\cos(\Theta_1 - \Theta_3) - R(\frac{V_2}{V_3})\cos(\Theta_2 - \Theta_3) \quad (10)$$

$$Z_{imag} = R(\frac{V_1}{V_3})\sin(\Theta_1 - \Theta_3) - R(\frac{V_2}{V_3})\sin(\Theta_2 - \Theta_3) \quad (11)$$

Thus the complex bioimpedance can be measured.

3. Applications

1.Assessing the extent of ischemia in organ transplants.
2.Detection and study of tumours.
3.Blood cell analysis.
4.Dental research(detection of decayed enamel).
5.Body fat content.
6.Skin hydration.

7.Cerebral monitoring.

4. Conclusion

For medical application, design of small antenna system in induced impedance spectroscopy is a tough task,hence phase sensitive detector method is preferred which reduces the computational time but the use of analog demodulators as one of the component in this method is responsible for phase error. Circuit design is also complex. Hence its use is also not popular for the measurement.

Compared to above methods new tetrapolar method is easy to implement, hence liberates the earlier used methods from the complexity of design. It provides higher accuracy, wide frequency range, small power consumption and low cost. It can be very beneficial in medical applications as this field needs portable and easy measurement techniques.

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