World Academy of Science, Engineering and Technology
International Journal of Biomedical and Biological Engineering
Vol:4, No:6, 2010

Determination of Electromagnetic Properties of Human Tissues

Iliana Marinova, Valentin Mateev

Abstract— In this paper a computer system for electromagnetic properties measurements is designed. The system employs Agilent 4294A precision impedance analyzer to measure the amplitude and the phase of a signal applied over a tested biological tissue sample. Measured by the developed computer system data could be used for tissue characterization in wide frequency range from 40Hz to 110MHz. The computer system can interface with output devices acquiring flexible testing process.

Keywords— Electromagnetic properties, human tissue, bioimpedance, measurement system.

I. Introduction

THE electromagnetic properties of human tissues as electric permittivity - ε, magnetic permeability - μ and electric conductivity – σ are of paramount importance for computer modeling of electromagnetic fields in human body. The electromagnetic field computations inside the human body allow designing an optimized system for an effective treatment.

In this paper an experimental computer system for electromagnetic property measurements of human tissues is designed.

The proposed system is multi frequency bioimpedance measurement system. It employs Agilent 4294A precision impedance analyzer to measure the amplitude and the phase of a signal applied over a tested biological tissue sample. The frequency range from 40Hz to 110MHz is covered. Also different measurement test-fixtures are included in measurement system design.

Measured by the developed computer system data can be used for tissue characterization in wide frequency range. The developed experimental computer system can interface with output devices acquiring flexible testing process.

II. Bioimpedance

Bioimpedance can be broadly defined as the impedance of biological specimens ranging from the whole human body impedance to the impedance of DNA. Bioimpedance analysis enables detection of physiological changes in cell–cell, cell matrix interactions caused by the effect of virus and bacterial infections [1–4], environmental parameters [5], toxicity [6] and the effect of pharmaceutical compounds [7].

I. Marinova is with the Technical University of Sofia, Bulgaria. (phone: +359 2 965 3873; fax: +359 962 41 96; e-mail: iliana@tu-sofia.bg).

V. Mateev is with the Technical University of Sofia, Bulgaria. (e-mail: vmateev@tu-sofia.bg).

The human body offers two types of impedance to an electrical current: capacitive X (reactance), and resistive R (simply called resistance). The capacitance arises from cell membranes, and the resistance from extra- and intracellular fluid.

A circuit that is commonly used to represent biological tissues in vivo, shown in Fig. 1, is one in which the R_i of extracellular fluid is arranged in parallel to the second arm of the circuit, which consists of capacitance C_i and R_s of intracellular fluid in series. The resistance R_i and capacitance C_i can all be measured over a range of frequencies. At zero or low frequency, the current does not penetrate the cell membrane, which acts as an insulator, and therefore the current passes through the extracellular fluid, which is responsible for the measured resistance of the body. At very high frequency the capacitor behaves as a perfect (or near perfect) capacitor, and therefore the total body impedance reflects the combined of both intracellular and extracellular fluid.

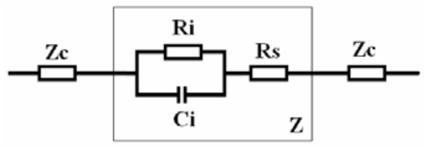

Fig. 1. Electrical model of the tissue impedance.

The system was tested on a simple electrical model of skin with underlying tissues as shown in Fig. 1. The values for the elements were chosen on the basis of investigation [6] approximately suit the impedance of the living human tissue. The values were $R_i = R_s = 33\Omega$ and $C_i = 100nF$.

The impedance Z represents live tissue

$$Z = R_s + \frac{R_i}{(1 + j\omega C_i)} \quad (1)$$

where ω is an angular frequency.

III. Methods of Measurements

Different methods of impedance measurements can be chosen. Measurement requirements and conditions are considered, and then the most appropriate method, while considering such factors as frequency coverage, measurement range, measurement accuracy, and ease of operation, is chosen. Considering only measurement accuracy and ease of operation, the auto balancing bridge method is the best for measurements up to 110 MHz.

The auto balancing bridge method is commonly used in modern Low Frequency (LF) impedance measurement instruments. Its operational frequency range has been extended up to 110 MHz and Agilent 4294A precision impedance analyzer is used.

When interconnecting an object under the test to the measurement terminals of the auto balancing bridge instrument, there are several connection configurations. The four-terminal (4T) configuration can reduce the effects of lead impedances because the signal current path and the voltage sensing cables are independent as shown in Fig. 2. Accuracy for the lower impedance measurement range is improved typically down to 1 Ω. When the tested object impedance is lower than 1Ω, large signal current flows through the current path and mutual coupling to the voltage sensing cable will cause an error.

The four-terminal pair (4TP) configuration solves the mutual coupling problem because it uses coaxial cable to isolate the voltage sensing cables from the signal current path. Since the return current flows through the external conductor of the coaxial cable, the magnetic flux generated by the inner conductor is canceled by that of the external conductor (shield). The measurement range for this configuration can be improved to below 1Ω. The impedance measurement range realizable for this configuration depends on the measurement instrument and on how well the 4TP configuration is strictly adhered to up to the connection point of the tested object. If the cables are not connected properly, measurement range will be limited, or in some cases, measurement cannot be made.

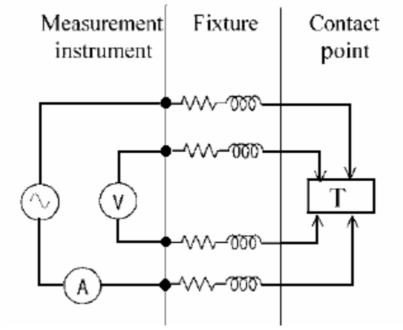

Fig. 2. Schematic diagram of four terminal measurements.

An often used method of bioimpedance measurement is a four-electrode method [2]. The current is injected into the sample through one pair of electrodes and the other pair of electrodes is used to measure the resulting voltage drop. If no current flows through the voltage measurement electrodes there is also no voltage drop across these electrodes and the measured voltage is the same as the voltage under the electrodes.

IV. Measurement System

The system architecture and scheme are presented in Fig.3 and Fig.4. The system contains: Impedance analyzer, measurement test fixtures, personal computer and additional power supply block.

A. *Impedance analyzer*

The heart of the system is Agilent Technologies 4294A precision impedance analyzer with frequency range 40 Hz - 110MHz, impedance range 10mΩ - 100MΩ. The test signal level range is 5mV to 1V rms or 200μA to 20mA rms, DC bias range is 0V to ±40V or 0mA to ±100mA, accuracy ±0.08%. The accuracy range is presented in Fig. 5.

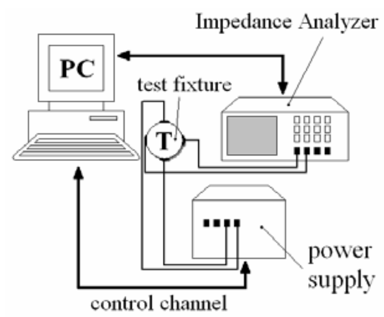

Fig. 3. Scheme of impedance measurement system.

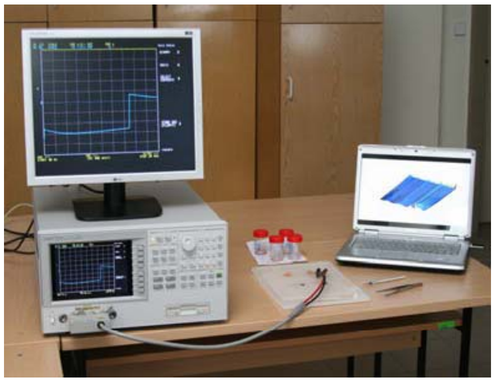

Fig. 4. Impedance analyzer outlook.

B. *Test fixtures*

The test fixture plays an important role in impedance measurement both mechanically and electrically. The quality of the fixture determines the limit of the total measurement quality. The contact terminals of the test fixtures is 4-terminal that are suited to different applications. Key points to consider when producing a test fixture are

(1) Residuals must be minimized. To minimize the residuals, the 4TP configuration should be maintained as close as possible to the tested object. Also, proper guarding techniques eliminate the effects of stray capacitance.

(2) Contact resistance must be minimized. Contact resistance cause additional error and it directly affects the measurement result. The contact electrodes should hold the tested object firmly and should always be clean. Corrosion-free material for the electrodes is used.

(3) Contacts must be able to be opened and shorted. Open/short compensation easily reduces the effects of the test fixture residuals. To perform an open/short measurement, it must be open and short the contact electrodes. For an open

measurement, the contact electrodes should be located the same distance apart as when the tested object is connected. For the short measurement, a lossless (low impedance) conductor should be connected between the electrodes, or contact electrodes should be connected directly.

Electrical investigations of biological materials are performed using two types of electrodes: conventional electrodes and microelectrodes. Microelectrodes allow small currents; hence, these electrodes are generally nondestructive to the solution and species under investigation. This advantage is significant in biological samples and for in vivo measurements, where such destruction should be eliminated. A commonly used impedance measurement device in biophysical investigations is the Electrical Cell-substrate Sensing (ECSTM) device [3]. The ECSTM impedance measurement device consists of a 250µm electrode and a counter electrode. Impedance changes due to the fractal motion of cells during their spreading and adhesion can be recorded as impedance changes [1-7]. Multiple electrode systems are also used for recordings of statistical data correlation in homogenous samples. For cells and tissues with anisotropic impedance distribution, this device can facilitate impedance data recording at several measurement points.

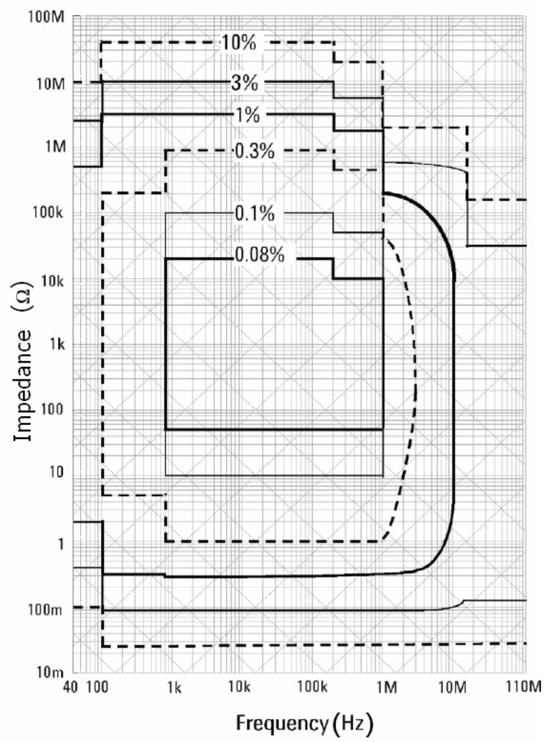

Fig. 5. Examples of calculated impedance measurement accuracy at four-terminal pair of the Agilent 4294

C. Power supply

Additional power supply is used for higher then ordinary voltages or currents specific test requirements.

D. Personal computer

Computer configuration is used for system elements control functions and measured data storage and processing. Also it is used for signal processing, which is nowadays mostly done by digital signal processing software and processors.

Further, the system employs demodulation method or devices to measure the amplitude and the phase of a multiple contact pairs.

V. Impedance mesurements of tissue

Impedance measurements were performed on cancer human tissue samples. For each tissue type a pair of samples are acquired, one for the tumor and second for normal tissue.

Probes of breast, ovary and rectum cancer are investigated. Samples are presented on Fig. Fig. 6-8.

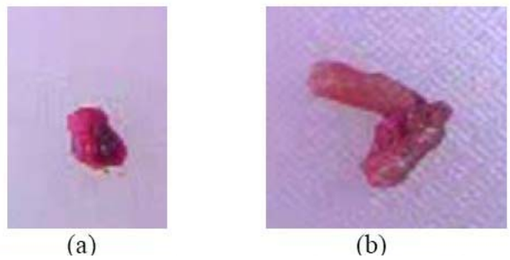

Fig. 6. Rectum samples (a) normal tissue, (b) tumor tissue.

Fig. 7. Breast samples (a) tumor tissue, (b) normal tissue.

Fig. 8. Ovary samples (a) tumor tissue, (b) normal tissue.

Samples are shaped according to Fig.9 with $S=3.14mm^2$ and $\ell=8mm$.

Electric impedance of each tissue type is measured with the proposed system. Impedance amplitude and phase angle are stored and visualized for broad frequency range from 100Hz to 10MHz.

Impedance amplitude and phase angle of rectum tissue samples are shown in Fig-Fig. 10-11. Normal tissue conductivity is better then tumor tissue in low frequency range, up to 10kHz.

Impedance amplitude and phase angle of ovary tissue samples are shown in Fig-Fig. 12-13, here the tumor tissue is with better conductivity in whole frequency range.

Impedance amplitude and phase angle of breast tissue samples are shown in Fig-Fig. 14-15, here the normal tissue is with better conductivity in whole frequency range.

Impedance character of all samples is capacitive according to model shown on Fig.1.

Tumor and normal tissues can be distinguished on their impedance frequency spectrums.

VI. Electromagnetic Properties of Tissue

Electrical conductivity σ and electrical permittivity ε due to current flow or polarization induced by an electric field in matter under investigation are measured. These properties are determined by measurement of bioimpedance using known shape and sizes of samples. In complex materials such as biological tissue, the distance scale of interest depends on the needs of a particular investigation. The developed approach is proposed for characterizing of the electromagnetic properties by applying sinusoidal fields.

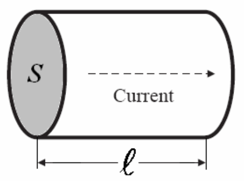

Fig. 9. Cylindrical sample with length ℓ and cross section S

For cylindrical tissue sample shown in Fig. 9 the main electrical properties with concentrated parameters are

$$R = k_s \frac{\ell}{\sigma S} \tag{2}$$

where k_s is frequency dependant coefficient representing the skin effect.

$$C = \varepsilon \frac{S}{\ell} \tag{3}$$

In case of positive phase angle the inductive character of the sample can be described with (4).

$$L = \mu \frac{S}{kP} \tag{4}$$

where P is the perimeter of investigated cylindrical sample;

k – shape dependant coefficient;

R, C and L are obtained from measured Z by (1). Using (2)-(4) the anisotropic σ, ε and μ are reconstructed.

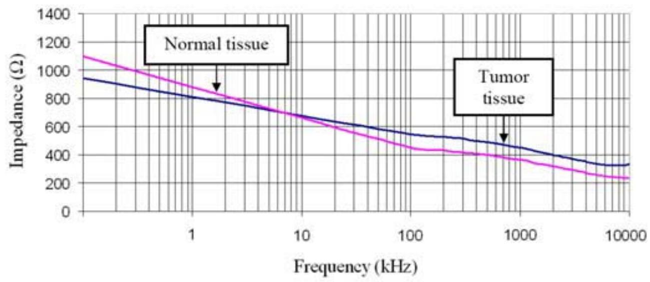

Fig. 10. Impedance amplitude of rectum tissue samples.

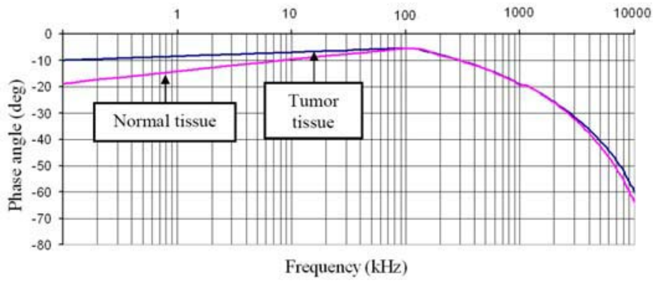

Fig. 11. Impedance phase angle of rectum tissue samples.

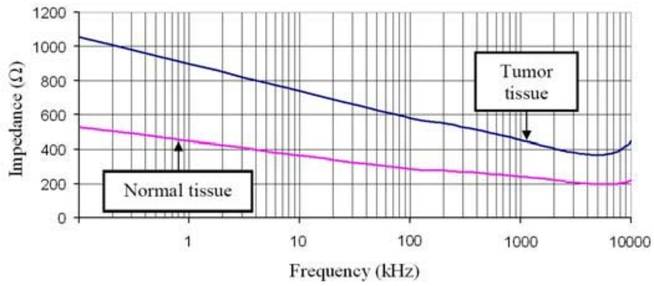

Fig. 12. Impedance amplitude of ovary tissue samples.

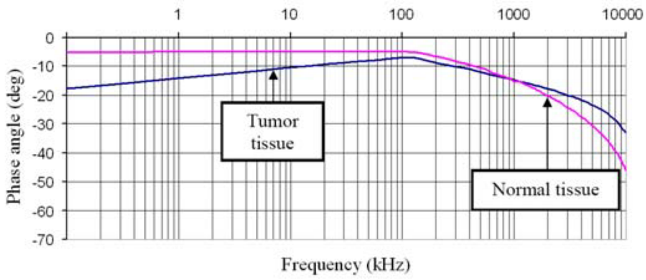

Fig. 13. Impedance phase angle of ovary tissue samples.

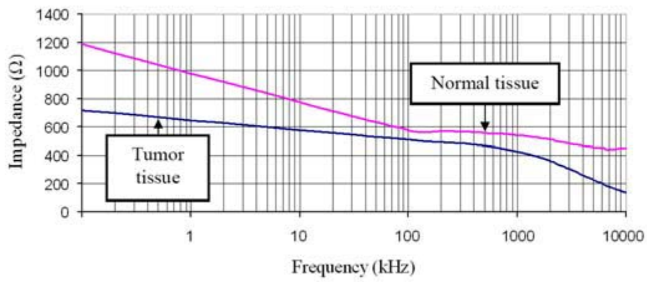

Fig. 14. Impedance amplitude in breast tissue samples.

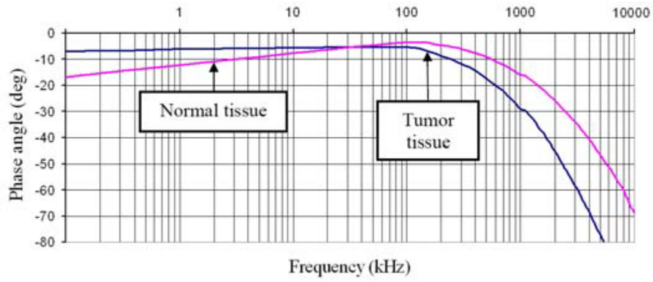

Fig. 15. Impedance phase angle of breast tissue samples.

VII. Conclusion

Computerized measurement system for electromagnetic field property determination based on bioimpedance measurements is proposed. The architecture of the developed measurement system is composed of impedance analyzer, test fixture, power supply and computer system. It employs Agilent 4294A precision impedance analyzer to measure the bioimpedance of different human tissues samples. The computerized measurement system can be used for human tissue characterization, electromagnetic properties determination and etc. in this frequency range. The developed computer system can interface with output devices acquiring flexible testing process. Also different measurement test-fixtures are included in measurement system design. The appropriate measurement method is chosen and tested.

Impedance measurements were performed on cancer human tissue samples. The electric impedance and electromagnetic properties of various human tissues are determined at different frequencies. Tumor and normal tissues can be distinguished on their impedance frequency spectrums.

Acknowledgment

This research is supported by the National Science Fund of the Ministry of Education and Science under Contract “D002-157/2008”.

References

[1] G. O. Young, “Synthetic structure of industrial plastics (Book style with paper title and editor),” in *Plastics*, 2nd ed. vol. 3, J. Peters, Ed. New York: McGraw-Hill, 1964, pp. 15–64.
[2] T. Dudykevych, E. Gersing, F. Thiel, “Impedance analyzer module for EIT and spectroscopy using undersampling”, *Physiol Meas*. Vol. 22, No. 1, 2001, pp. 19-24.
[3] L. Geddes, “Who introduced the tetrapolar method for measuring resistance and impedance?”, *IEEE Eng. Med. Biol.*, Vol.15, No. 5, 1996, pp. 133-134.
[4] S. Grimnes, O. Martinsen, *Bioimpedance and Bioelectricity Basics.* Academic Press, 2000.
[5] T. Yamamoto, Y. Yamamoto, “Electrical-properties of epidermal stratum-corneum”, *Med. Biol. Eng.,* Vol. 14, No. 2, 1976,. pp. 151-158.
[6] J. Rosell, J. Colominas, P. Riu, “Skin impedance from 1 Hz to 1 MHz”, *IEEE T Bio-Med Eng.*, Vol. 35, No. 8, 1988, pp. 649-651.
[7] F. Pliquett, U. Pliquett, “Passive electrical properties of human stratum corneum in vitro depending on time after separation”, *Biophys. Chem.*, Vol. 58, No. 1-2, 1996, pp. 205-210.
[8] E. Gersing, “Measurement of electrical-impedance in organs - measuring equipment for research and clinical-applications”, *Biomed. Tech.,* Vol. 36, No. 1-2, 1991, pp. 6-11.
[9] Agilent Technologies. *Agilent Technologies Impedance Measurement Handbook*, July 2006.

Iliana Marinova. (M’82), Ph.D in Electrical Engineering (1989), DSci in Electrical Engineering (2010), Associate Professor at Department of Electrical Apparatus, Faculty of Electrical Engineering, Technical University of Sofia, Bulgaria. Research interests are focused in inverse problems in electromagnetics and biomagnetics, electromagnetic fields, numerical methods, finite element method, boundary integral equation method, computer-aided design, optimization, image processing, visualization.

Valentin Mateev. M.Sc. in Electrical Engineering (2004). Assistant at Department of Electrical Apparatus, Faculty of Electrical Engineering, Technical University of Sofia, Bulgaria. Research interests are focused in computational electromagnetism, electromagnetic fields, numerical methods, finite element method, computer-aided design.