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Dielectric Measurement Techniques of Biological Tissue: A Review on Electrodes Perspective

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Abstract: The aim of this paper is to review the techniques that have been developed in biological tissue dielectric measurement. This manuscript may give a clear picture on the history, development of the technology and also the importance of dielectric measurement of biological tissue in biomedical engineering application especially in tumor detection. Enhancement of these measurement techniques could provide more chances to be integrated in the medical imaging system for more ease and accurate diagnosis system with high quality reconstructed images. With increasing numbers of researches in biological tissue, this review is hoped to be helpful to those who has interest in biological tissue dielectric measurement. *Copyright © 2012 IFSA.*

Keywords: Biological tissue, Dielectric, Measurement, Biomedical.

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1. Introduction

Tumor has been among the leading cause of death in the world and attacking people at all ages. Due to that reason, scientists all over the world have put full effort in detecting and providing solution to solve this cancer problem. Several methods have been introduced and one of them is dielectric measurement technique. Despite its popularity in medical applications, dielectric measurement technique also had been among the famous technique as non-invasive diagnostic in industrial process [1-3]. This technique could provide electrical or magnetic characteristics of the materials [4] which consist of capacitive, X (reactive) and resistive, R (resistance).

2. Dielectric Spectrum of Biological Tissue

In biological perspective, where this paper will look into, this resistive arises from cell extra and intracellular fluid meanwhile capacitance arises from cell membrane [5]. Dielectric properties of biological tissues are frequency dependent or dispersive. A significant change in dielectric properties over a frequency range, by convention, is called a dielectric dispersion which is divided into three regions that are α (below few kHz) – associated with ionic diffusion processes at the site of the cellular membrane , β (from tens of kHz to tens of MHz) – due mainly to the polarization of cellular membranes which act as a barriers to the flow of ions between intra and extra cellular media, while γ (in the microwave frequency region) – due to the polarization of water molecules [6, 7] as shown in Fig. 1. The knowledge on dielectric parameters of biological tissues had been the promising method in the medical diagnostics and imaging especially in tumor problems [8] since distributions of absorbed electromagnetic energy depends on the ratios of electrical conductivity between the different tissues involved [9].

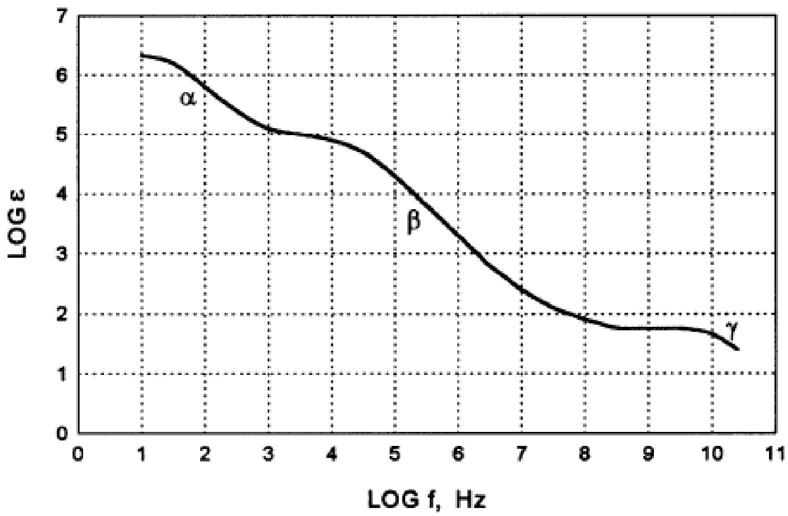

Fig. 1. Region of dielectric dispersion [10].

Since electrical impedance of human tissue contains both resistance and capacitance, it is complex and can be described by a serial representation

$$Z = R + jX, \quad (1)$$

where, Z is impedance; R, the resistance; and X, the reactance; or by a parallel representation

$$Y = G + j\omega C, \qquad (2)$$

where, Y = 1/Z is admittance; G, the conductance; C, the capacitance; and ω, the angular frequency [12].

3. Properties of Tumor Tissue

An abnormal mass of tissue that surrounded by one or more normal body tissues as in Fig. 2 is called a tumor which grows at the expense of healthy tissues. The normal and surrounding tissues had a significantly different electrical conductivity and permittivity from tumor tissue whereby tumor has higher value compare to normal tissue [10, 19].

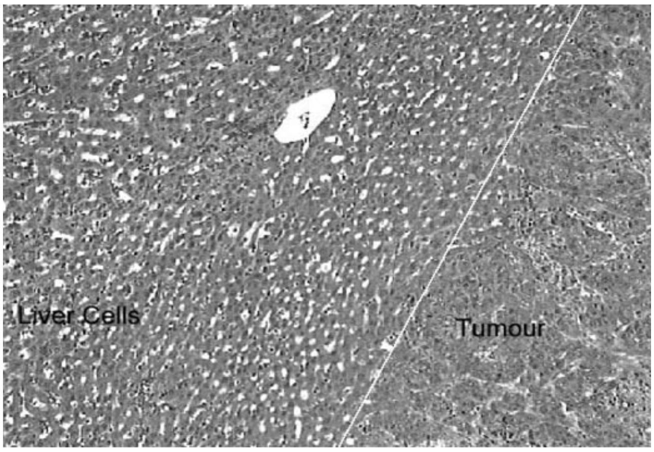

Fig. 2. Interface section at 10x between liver and tumor tissue [10].

Other than that, different development stages of tumor have also experimentally proven provided significant differences in the dielectric constant and conductivity of the tumor tissues [20]. On the other hand, different frequency used also produced different value of reading [21], however 100 MHz is the best suited frequency for differential detection and treatment of tumors [22].

4. Electrode Set-up

In dielectric measurement system of biological tissue, three different electrode setups are used to measure the electric properties of biological materials; two electrodes, three electrodes and four-electrodes method.

4.1. Two Electrodes Method

This method is suitable for alternating current measurements. It cannot be used as such for direct current measurements because of the electrode polarization that consequently gives incorrect results for the conductivity of the sample between the electrodes [10].

4.2. Three Electrodes Method

This so called novel three electrode shown in Fig. 3 has first reported in 1998 [11] with the advantages of cutting down the time consuming and suitable to be used in high conductivity fluids or semi-solid including biological tissues. This method has also been used in in-vivo breast cancer detection [12] as in Fig. 4.

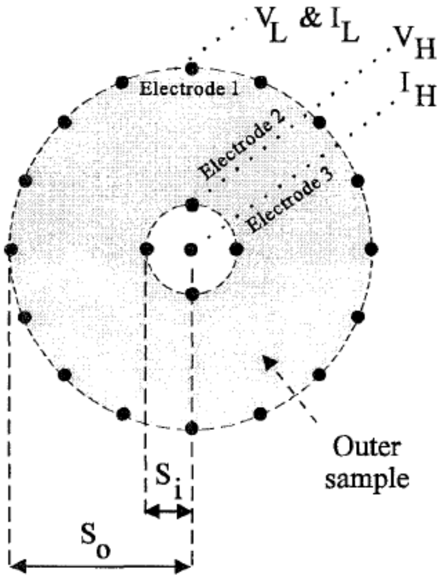

Fig. 3. Schematic design of three electrode system [11].

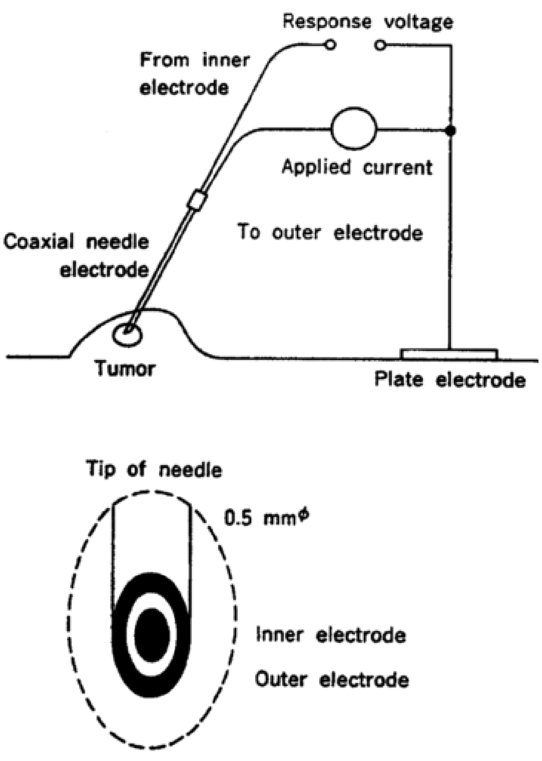

Fig. 4. In vivo impedance measurement using three electrodes method [12].

4.3. Four Electrodes Method

Four electrodes method as shown in Fig. 5 and Fig. 6, is available for direct and alternating current measurements. Two pairs of electrodes are used which is the outer for current and the inner electrodes for voltage. The current from the source passes through the sample. Voltage electrodes of known separation are placed in the sample between the current electrodes. One can determine the specific conductance of the sample between the inner electrodes by measuring the current as the voltage drop across a resistor in series with the sample and the voltage drop across the inner electrodes [10].

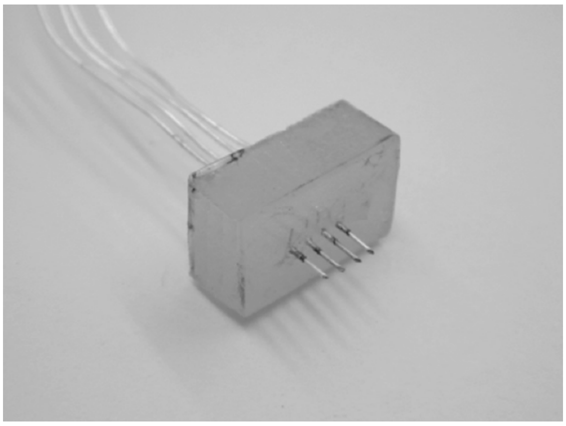

Fig. 5. The design of four-electrode plunge probe [13].

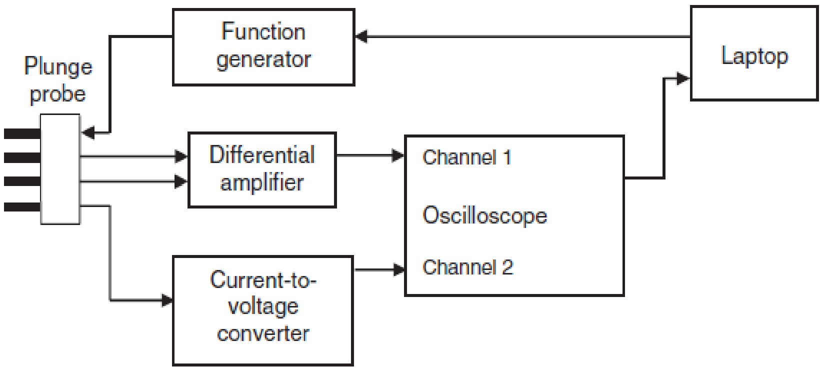

Fig. 6. Block diagram of conductivity measurement system [13].

5. Types of Used Probes

There are several types of probes that have been used in the research. Among the probes are waveguide probes, coaxial probes and pencil probes.

5.1. Waveguide Probe

This technique as in Fig. 7 is a non-destructive and non-invasive method based on reflection coefficient measurement attaching the material under test. The results of the measurement indicate that liquid dielectric with the low value of permittivity has significant influence on the cut-off frequency of waveguide with dominant mode propagation [14].

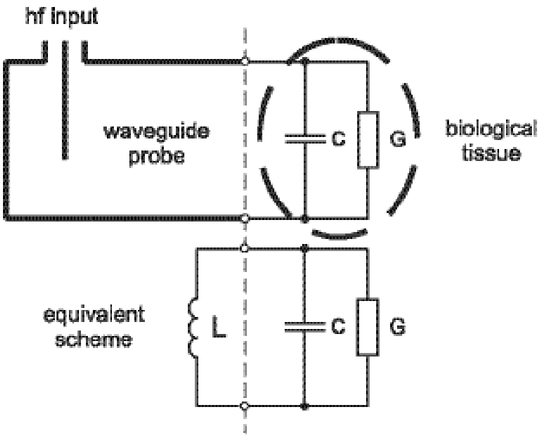

Fig. 7. Microwave waveguide probe [14].

5.2. Coaxial Probe

Open coaxial line shown in Fig. 8 is widely used as a sensor for nondestructive dielectric measurements on a wide range of frequency bands and in situ measurements of electrical properties of diverse types of materials. There are no manipulation pretreatment required to perform the coaxial probe technique. By using the coaxial probe, the measured dielectric properties also can be integrated directly with the surgical and pathology equipment such as needles [15] with the depth of the sense probe is approximately 1 to 3 mm [16] as in Fig. 9.

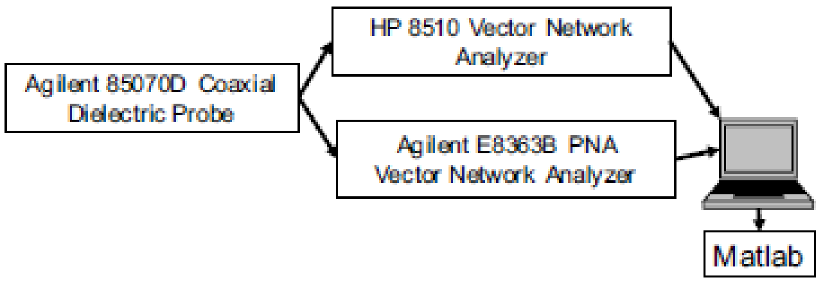

Fig. 8. Coaxial probe measurement system block diagram [17].

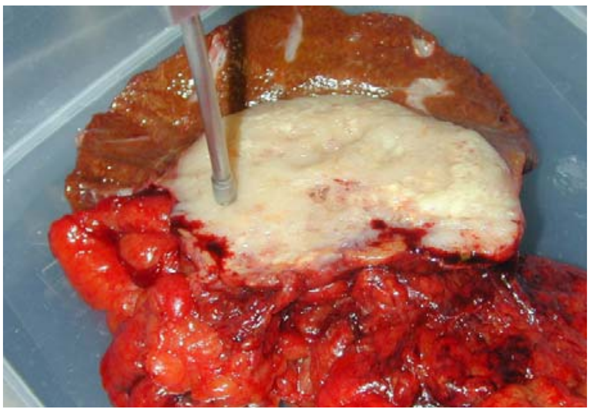

Fig. 9. Diagram of dielectric spectroscopy of an excised liver tumor (light-colored mass), using a precision open-ended coaxial probe [16].

There are a few of advantages in open ended coaxial probe technique which are it requires no machining of the sample and has an easy sample preparation. The dielectric properties of a large number of samples can be routinely measured in a short time after calibration. Besides that, the measurement using open ended coaxial probe also can be performed in a temperature controlled environment. However there are two disadvantages of this technique which is only reflection measurement are available and it can be affected by air gaps measurement of the tested specimen [4].

5.3. Pencil Probe

This technique employs a small-diameter, open-ended, semi-rigid coaxial line which has been machined at the open, radiating end to a conical termination, so that it resembles a pencil tip as in Fig. 10 and its circuit in Fig. 11. The multiple rationale for this choice are, it permits wideband measurements, subject to errors created by a variety of surface effects, prevents the generation of higher-order H-modes and it simplifies insertion into harder biological tissue types. Precise calibration of the probe depends on a proper choice of standards so that the radiation term can be accurately compensated. Permittivity measurements to within 2 % appear to be feasible over the microwave band [18].

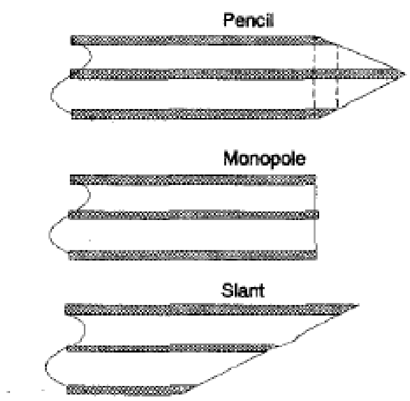

Fig. 10. Types of probes [18].

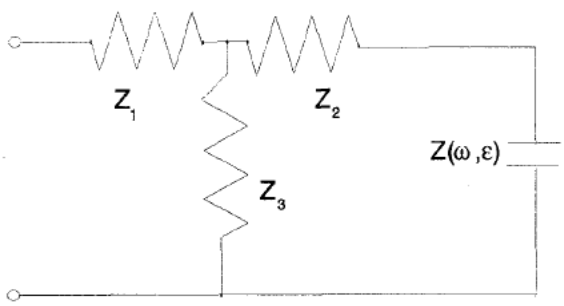

Fig. 11. Probes circuit [18].

6. Conclusion

Nowadays, the measurement of electrical properties had been an important method especially for noninvasive investigation on structure of the tissue and for monitoring the physiological changes in human organism properties. Unfortunately, the main problems still remain while encounter with bioimpedance measurement which is the reliability of the results obtain. However, the measurement of the differences or the changes in conductivity or relative permittivity still could lead for some useful application since the large differences data reported on dielectric properties of biological tissue.

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