

Microwave Dielectric Studies On Biological Tissues

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Abstract –In this communication a comprehensive study of the dielectric properties of biological lossy dielectric at microwave frequencies is presented. Present paper concern with the theoretical and experimental investigation to study the dielectric properties of biological soft tissues using ‘two point method’ on X-band microwave bench.

Key words– Biological lossy dielectric, microwave frequency, dielectric properties, two point method.

1. Introduction

A living body is made up of a complex structure of biological tissue (lossy dielectric) with very dissimilar electric properties (dielectric permittivity and conductivity). These properties are, to a great extent, responsible for the interaction of electro magnetic fields with molecules and biological super molecular structures. Information about the dielectric properties of biological systems is essential to RF dosimetry. Measurements of tissue dielectric properties is important as it provides information necessary for calculating RF power absorption by biological models and for constructing tissue — equivalent models. Also, many biophysical interaction mechanisms of EM fields with biological systems can be inferred from the characteristic behavior of tissue permittivity as a function of frequency [1-3]. The proper knowledge of the dielectric properties of the biological systems is essential either to determine safe levels for the personnel exposure to electro magnetic radiation or to effectively employ electromagnetic radiation in beneficial biomedical application [4]. Thus, the measurement of dielectric properties of biological tissues would play a significant role in any well founded effort containing tissue interaction with electromagnetic energy. It is well recognized that radio frequency and microwave energy can be effectively used in the treatment of many diseases. It must be considered that the dielectric properties of the tissues will determine the absorption and propagation of electromagnetic energy through the tissues. So from the knowledge of dielectric constant, tissue properties can be characterized in the microwave frequency range. Dielectric constant is one of the important parameter to predict the nature of biological tissue at microwave frequency range [5]. In view of the above, an attempt is made to study the dielectric properties of biological tissues at microwave frequencies.

2. Theory of lossy dielectrics at microwave frequency

At frequencies below 100 MHz, methods based on the impedance bridge are satisfactory for measuring the electrical properties of tissue samples. However, above 300 MHz complex permittivity measurements are not straightforward and the results are subject to great error. In this frequency range a distributed – circuit approach rather than a lumped – circuit approach is required because the sample size is usually a considerable fraction of a wave length [6,7].

Lossy dielectric is one which is partly conductive and partly polarisable, when placed in an external electric field [8]. Biological tissue is a complex lossy dielectric whose values of dielectric constant and dielectric loss are high. Lossy dielectrics are characterized by $\tan \delta > 0.1$. They may or may not exhibit DC electrical conductivity. Dielectric properties usually vary with frequency. In general, the lower the specific DC resistivity, the greater is the frequency sensitivity. A frequency response is advantageous in many applications of lossy dielectrics in increasing ϵ' and ϵ'' with decreasing frequency. The arrangement of constituent atoms and molecules in the dielectric material is changed as a reaction to an external electric field. The response of the dielectric to the field also depends on frequency. For this reason, the relative permittivity is a complex number.

$$\epsilon_c = \epsilon' - j\epsilon''$$

Where ϵ' = Dielectric permittivity a measure of how an electric field is stored in the material.

ϵ'' = loss, which accounts for frequency dependence.

The complex propagation coefficient for electromagnetic waves inside a inhomogeneous sample can be written as $\gamma = \alpha + j\beta$ where α is attenuation co-efficient and β is phase constant. Complex propagation coefficient γ is a function of the complex relative permittivity.

2.1. Two Point method

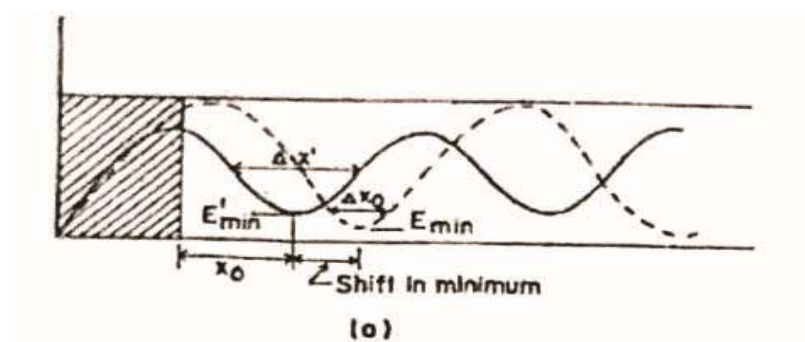
There are many ways in which dielectric measurements may be made at microwave frequencies [9-12].

For liquids it is easy to obtain sample length in multiples of half wavelengths but is difficult to do that in case of solids. However, for such samples which are reducible to wave guide dimensions, two point method is used as an alternative.

Consider a solid sample of length l_ϵ loaded in a rectangular wave guide against short circuit that touches it well. In Fig. 1(a-c), D and D_R are respectively the positions of first voltage minimum of the standing wave pattern when wave guide is loaded and unloaded with the dielectric. The respective distances from the short circuit will be $(l + l_\epsilon)$ and $(l_R + l_\epsilon)$. Now looking from A towards right and left, the impedances are equal, so

$$Z_0 \tan \beta l = -Z_\epsilon \tan \beta_\epsilon l_\epsilon \quad \dots\dots\dots (1)$$

Where Z_0 and Z_ϵ are respectively the characteristic impedance of empty and dielectric-filled wave guides and β and β_ϵ are



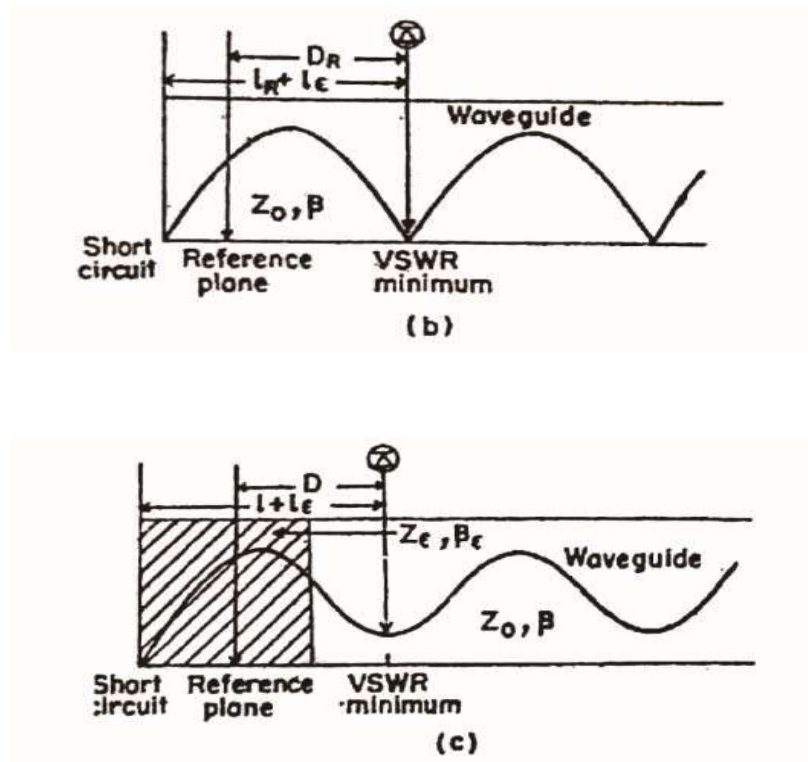


Fig.1.(a-c) Illustration of two point method for measuring dielectric constant (a) double minimum width, (b) position of minimum with shorted waveguide without dielectric, (c) position of minimum with shorted waveguide with dielectric.

respective propagation constants. Similarly from Fig.1(b), we have

$$Z_0 \tan \beta(l_R + l_\epsilon) = 0 \quad \dots\dots (2)$$

Now, consider the expression.

$$\tan \beta(D_R - D + l_\epsilon) = \tan \beta \{ (l_R + l_\epsilon) - l \}$$

Expanding the tangent sum angle and making use of Equation (2)

$$Z_0 \tan \{ \beta(D_R - D + l_\epsilon) \} = Z_\epsilon \tan \beta_\epsilon l_\epsilon \quad \dots\dots (3)$$

Again recalling the relation

$$\frac{\tan \{ \beta(D_R - D + l_\epsilon) \}}{\beta l_\epsilon} = \frac{\tan \beta_\epsilon l_\epsilon}{\beta_\epsilon l_\epsilon} \quad \dots\dots (4)$$

Equation (4) suggests a method for measuring dielectric constant. Quantities on the LHS are all experimentally measurable ($\beta = \frac{2\pi}{\lambda_g}$). Equation (4) has been recast for lossy (complex) dielectrics. In lossy cases we determine voltage standing wave ratio and compute reflection coefficient in complex form. The phase difference in the waves travelling in the guide with and without dielectric is

$$\phi = 2\beta(\Delta_x - l_\epsilon)$$

Δ_x is the shift in minimum

$\beta = (2\pi/\lambda_g)$ is the propagation constant

l_ϵ is the length of the dielectric

Now, reflection coefficient is given by

$$|\Gamma| = \frac{S-1}{S+1}, \text{ where } S \text{ is } VSWR = \frac{E_{max}}{E_{min}}$$

If we define

$$C = \frac{1}{j\beta l_\epsilon} \frac{1-|\Gamma|e^{j\theta}}{1+|\Gamma|e^{j\theta}}$$

$$= \frac{\tan X \angle \theta}{X \angle \theta}$$

It is complex transcendental equation the solutions X and θ are obtained from von hippel charts (Fig.2). then admittance is given by

$$Y_\epsilon = \left(\frac{X}{\beta l_\epsilon}\right)^2 \angle 2(\theta - 90^\circ) = G_\epsilon + js_\epsilon \text{ (say)}$$

G_ϵ and s_ϵ are related to ϵ' and ϵ'' as

$$\epsilon = \frac{G_\epsilon + \left(\frac{\lambda g}{2a}\right)^2}{1 + \left(\frac{\lambda g}{2a}\right)^2} \quad \dots\dots\dots (5)$$

And

$$\epsilon = \frac{-s_\epsilon}{1 + \left(\frac{\lambda g}{2a}\right)^2} \quad \dots\dots\dots (6)$$

However, it is well to note that quantities

Ψ, θ and $\left(\frac{x}{\beta l_\epsilon}\right)^2$ fall into ranges

$$0 < \Psi < 180^\circ, 45 < \theta < 90^\circ, \left(\frac{x}{\beta l_\epsilon}\right)^2 > 1$$

Proper values of $X \angle \theta$ is that value which yields the same value of Y_ϵ for the two samples. The effective conductivity of the medium.

$$\sigma = \omega \epsilon_0 \epsilon'' \quad \dots\dots\dots (7)$$

$$\omega = 2\pi v$$

$$v = \text{Frequency in GHz}$$

$$\epsilon_0 = \text{Permittivity of Free space}$$

$$= 8.85 \times 10^{-12} \text{ F/m}$$

$$\epsilon'' = \text{Dielectric loss}$$

$$\text{Loss tangent, } \tan \delta = \frac{\epsilon'}{\epsilon''} \quad \dots\dots\dots (8)$$

Energy is absorbed as the field is transmitted or coupled in to the material, which is assumed to be a lossy dielectric as all biological media are. Attenuation occurs as energy is absorbed i.e., the amplitude of the wave decreases. It is characterized by appropriate constants that depend on the dielectric properties of the media. Attenuation per unit length is the attenuation coefficient defined by the expression.

$$\alpha = \frac{\omega}{c} \left[\frac{(\epsilon'^2 + \epsilon''^2)^{1/2} - \epsilon'}{2} \right]^{1/2} \dots\dots\dots (9)$$

Where

ω = Angular frequency = $2\pi\nu$

C = Velocity of light

ν = Frequency in GHz

ϵ' = Dielectric constant

ϵ'' = Dielectric loss

$$\% \text{ of power reflected} = \Gamma^2 \times 100 \dots\dots\dots (10)$$

$$\% \text{ of power absorbed} = (1 - \Gamma^2) \times 100 \dots\dots\dots (11)$$

3. Material and methods

3.1. sample collection and preparation

The biological soft tissues are collected from local market. The samples are collected within 6hrs of slaughtering. The fresh excised tissues of different divisions are taken for experimentation. The fresh excised tissues that are under study of different individuals are cut into a rectangular wave guide dimensions (2.2cm x 0.95cm) of different lengths. The cross sectional area of all samples is equal. In microwave dielectric measurement of a tissues, where transcendental equations are applied, the sample thickness should be about one quarter of a wave length of the radiation ($\lambda_g/4$) contained in the sample[13] In order to ensure no loss of water content, the samples were kept in Petri dishes and closed [14].

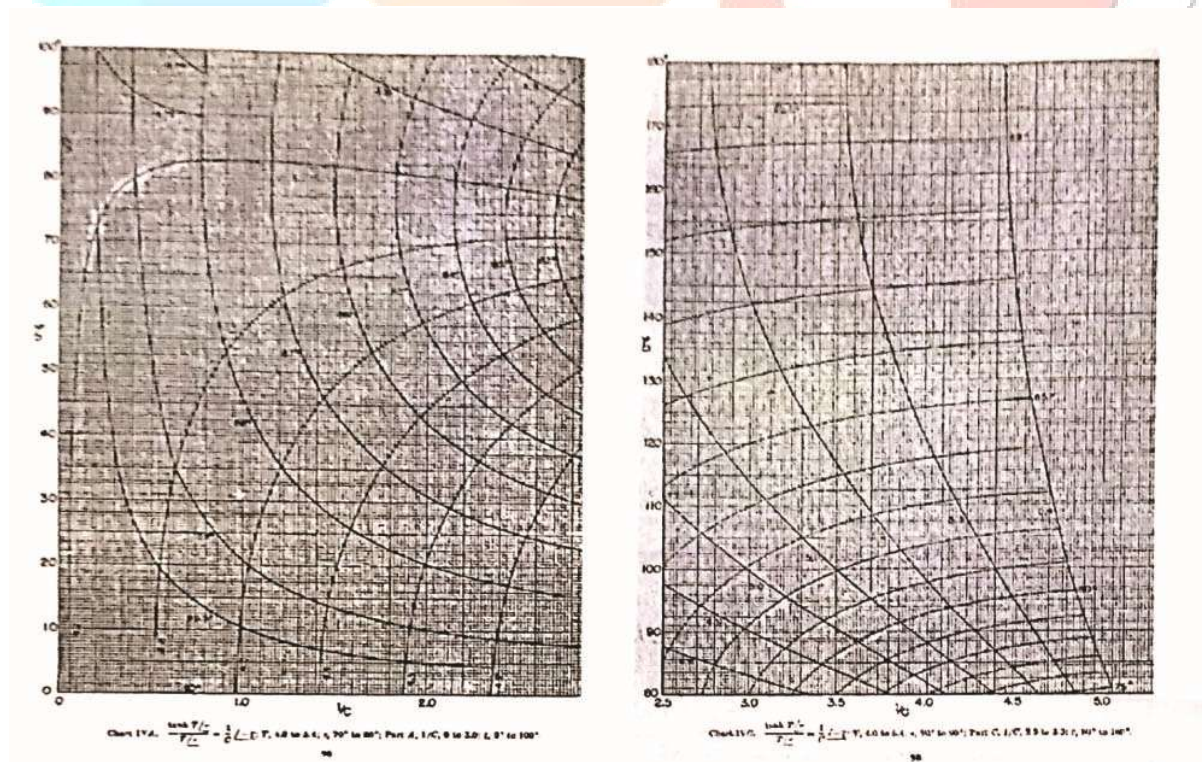


Fig.2 Vonnipp Charts

The thickness of the sample should match the wave guide dimensions. Every care is taken to see that there is no air gap in the sample. The sample of the tissue is so flexible, that it takes the shape of the wave guide.

3.2. Experimental Setup.

Fig. 3 shows a block diagram of experimental set-up for measuring dielectric parameters of a biological soft tissue at microwave frequency. Microwave bench and wave guide is shown in Fig. 4.

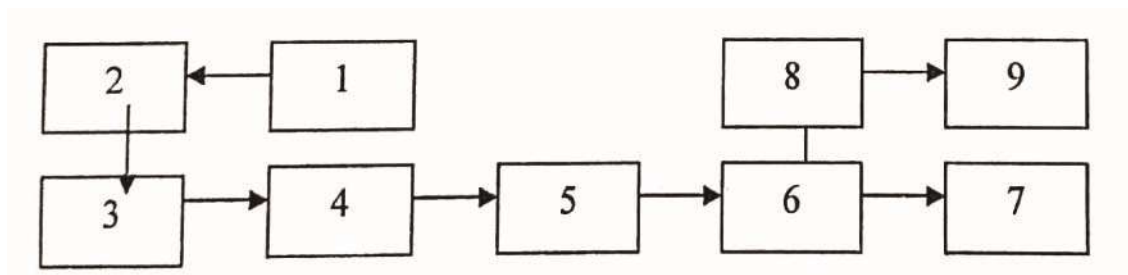
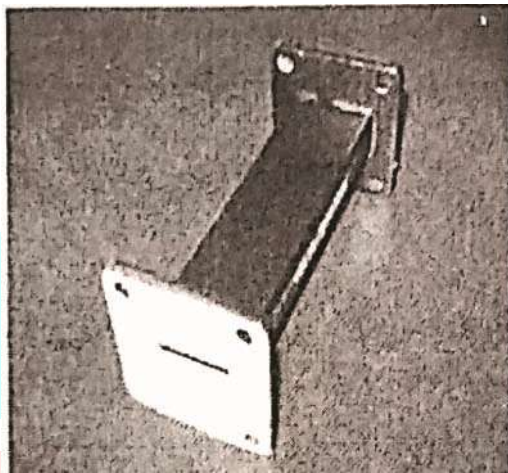
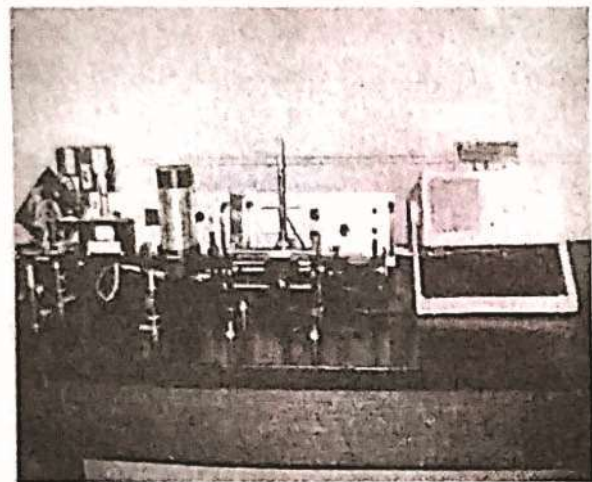


Fig 3. Block diagram of X-band Microwave Bench

1.Klystron power supply, 2. Reflex Klystron, 3. Isolator, 4.Attenuator, 5. Frequency meter, 6.Slotted Section, 7.Short circuited wave guide, 8. Tunable detector, 9. VSWR meter



Wave guide



Microwave Bench

Fig. 4. Microwave setup

3.3 Experimental Procedure

Two point method is employed for the measurement of dielectric parameters of biological soft tissues at microwave frequency (X – band). A rectangular wave guide is used. Reflex Klystron is the source of microwave power. Klystron is set into operation by applying beam voltage, repeller voltage and beam current through Klystron power supply. To avoid damaging of the Klystron, repeller voltage is applied before beam voltage. The frequency of operation is measured by means of drum type frequency meter. It is measured by rotating frequency meter and observing resonance dip in cathode ray oscilloscope. The frequency of operation varies with respect to repeller voltage. The attenuator should be kept a minimum attenuation position for microwave transmission. With the air inside, the wave guide is short-circuited. A stationery wave is formed inside the wave guide. The voltage of the maxima and minima of a stationery wave is detected by a diode and measured by VSWR meter. With air inside the waveguide, the plunger is moved along the slotted section and the position of first voltage minimum (D_R) is noted on the scale by observing in VSWR meter. The least count of the Vernier Scale of the slotted section is 0.01 cm. The positions of first, second and third minima are noted on the scale with air in the wave guide. The difference of the positions of first and second minima or second and third minima gives the half of the wave length of stationery wave. After noting down the value of D_R and λ_g , the sample of definite length is introduced into

the wave guide and short-circuited. The position of the first voltage minimum (D) is noted by observing VSWR meter. By moving a plunger on the slotted section, voltage standing wave ratio (S) of the sample is measured by VSWR meter. The experiment is repeated for different lengths of the sample of different individuals. The electro magnetic field at any point of a transmission line is considered as the sum of two travelling waves. The wave from the generator incident on the load is reflected towards the generator due to mismatch. The reflected wave will combine with the forward waves to give a standing wave pattern. The maximum field strength is found when two waves add in phase and the minimum occurs when the two add in opposite phase. The ratio of the amplitude of the maximum to the minimum field strength of the wave is called voltage standing wave ratio.

$$VSWR = \frac{E_{max}}{E_{min}}$$

The ratio of E_{max} and E_{min} are calibrated in VSWR meter.

VSWR lies between 1 and ∞ . Measurement of high VSWR ($S > 10$) is done by double the minimum method using the formula,

$$VSWR = \frac{\lambda_g}{\pi(X_1 - X_2)} \text{ where } X_1 \text{ and } X_2 \text{ are the positions of the probe for full scale deflection.}$$

3.4. Calculation of dielectric parameters of tissues

A pair of different lengths of the tissue of an individual is taken as a single entity. A pair of different lengths of the tissue of different individuals is considered to calculate mean value of dielectric parameters

A sample whose length is less than $\lambda_g/4$ is inserted into the wave guide and is short circuited. The position of the first voltage minimum with the sample in the wave guide is noted. Voltage standing wave ratio is measured by VSWR meter. The value of l_e , D, D_R and S are the observed parameters of the tissue. A complex transcendental equation is computed using Math lab Software Programme. The value of C, ψ are known from computation. The complex transcendental equation is solved by knowing the values of X and θ . Corresponding to $C\angle -\psi$ and $\frac{1}{c}\angle -\psi$ from Von-hipple charts for a pair of lengths of the sample.

The admittance corresponding to X and θ of $C\angle -\psi$ and $\frac{1}{c}\angle -\psi$ of a pair of lengths is computed. For a given pair of lengths of the sample, the admittance corresponding to either $C\angle -\psi$ or $\frac{1}{c}\angle -\psi$ will coincide approximately. The mean value of admittance for a pair of lengths of the sample is calculated. The dielectric properties such as dielectric constant, dielectric loss, conductivity, attenuation coefficient, percentage of power reflected and percentage of power absorbed are calculated from equations (5 -11).

4. Conclusions

Two point method can be very useful for measuring the complex dielectric permittivity of biological tissues at microwave frequencies. The study presented in this paper may aids for extensive research on tissue properties.

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