Dielectric Behavior of Biomaterials at Different Frequencies on Room Temperature

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Abstract. Propagation of electromagnetic (EM) waves in radiofrequency (RF) and microwave systems is described mathematically by Maxwell’s equations with corresponding boundary conditions. Dielectric properties of lossless and lossy materials influence EM field distribution. For a better understanding of the physical processes associated with various RF and microwave devices, it is necessary to know the dielectric properties of media that interact with EM waves. For telecommunication and radar devices, variations of complex dielectric permittivity (referring to the dielectric property) over a wide frequency range are important. For RF and microwave applicators intended for thermal treatments of different materials at ISM (industrial, scientific, medical) frequencies, one needs to study temperature and moisture content dependencies of the Permittivity of the treated materials. Many techniques have been developed for the measurement of materials. In the present paper authors used Bones and scales of Fish taken from Narmada River (Rajghat Dist. Barwani) as biomaterials. Dielectric properties of Biomaterials with the frequency range from 1Hz to 10 MHz at room temperature with low water content were measured by in-situ performance dielectric kit. Analysis has been done by Alpha high performance impedance analyzer and LCR meters. The experimental work were carried out in Inter University Consortium UGC-DAE, CSR center Indore MP. Measured value indicates the dielectric constant (ε') dielectric loss (ε") decreases with increasing frequency while conductivity (σ) increases with frequency increased.

Key words: dielectric constant, dielectric loss, conductivity, biomaterials (Bones and Scales)

1 Introduction

The behavior of a dielectric material in the presence of an electromagnetic field is entirely different from that in presence of a direct current field. In order to understand the behavior of dielectric materials under the action of electromagnetic fields, one has to investigate its interaction in such electromagnetic field. In the presence of an alternative electric field, the dielectric materials get polarized along the field direction. The degree of polarization depends on the applied electromagnetic power and the nature of the material itself [1]. The static dielectric constant and dipole moment values are a measure of the polarization of the material at low frequencies. However, in the presence of a high frequency field, there exist a time lag in the attainment of equilibrium in a system with changing field and hence an anomalous dispersion (dielectric constant decrease within increase in frequency) takes place [2, 3]. The different biomaterials (Bones and Scales) sample in low water (Dry) content gives
rise to a large variation in the dielectric constant. Thus, knowledge of the variation of the dielectric constant of the biomaterials (*Bones and Scales*) at different frequency for the room temperature. Porosity of the Bones and Scales greatly helps to judge the moisture movement within the biomaterial. Macro pores allow readily movement of air and water. It does not hold water under normal condition. The porosity of soil is easily changed. The dielectric properties of most materials vary with several different factors. In hygroscopic materials such as agricultural products, the amount of water in the materials is generally a dominant factor. The dielectric properties also depend on the frequency of the applied alternating electric field, the temperature of the materials, and on the density and structure of the materials. In granular or particulate materials, the bulk density of the air-particle mixture is another factor that influences their dielectric properties. The dielectric properties of materials are dependent on their chemical composition and particularly molecules in the materials [4]. Researchers have tested different techniques of using the dielectric properties of biomaterials to estimate water content. These studies include transmission line techniques such as waveguide (coaxial and free-space), impedance and cavity methods [5]. Dielectric properties are, by definition, a measure of the polarizability of a material when subjected to an electric field [6]. For lossy materials, the relative complex permittivity, \( \varepsilon = \varepsilon' + j\varepsilon'' \), represents the dielectric properties. The dielectric constant \( \varepsilon' \), describes the materials ability to store energy, the dielectric loss factor \( \varepsilon'' \), describes the materials ability to dissipate the electric field energy, and \( j \) is the imaginary root of -1 [8]. The dielectric properties of many materials depend on frequency, moisture content, bulk density, temperature, chemical composition, and the permanent dipole moments association with water and other constituent molecules. With the exception of some extremely low-loss materials, that is, materials that absorb essentially no energy from RF and microwave fields, the dielectric properties vary considerably with the frequency of the applied electric fields. An important phenomenon contributing to the frequency dependence of the dielectric properties is the polarization arising from orientation with the imposed electric field of molecules which have permanent dipole moments. However water in biomaterials exists both as liquid water and as water bound to the inner structure of the biomaterial. The dielectric properties of bound water lie somewhere between those of ice and those of liquid water depending on how tightly the water is bound. Therefore, testing of biomaterials has been conducted comparing potential difference measurements of elements with knows permittivity to the test material or by correlating the transmission potential difference between two or more quantities of same material with the water content.

### 2 Experiment details

Ribbons Dielectric properties of biomaterials (*Bones and Scales*) with low water content have been measured by performance dielectric probe kit. This performance dielectric probe kit is based on non-destructive method. To quickly and accurately estimate plant biomaterials in situ may provide producers with essential information for making this production. The power source for this method is impedance analyzer and LCR meters with high frequency resolution [9]. The measurement made by simply immersing the probe into the *Bones and Scales* sample. There is no requirement of special fixtures and connectors. The complete system is based on impedance analyzer. This measures the materials response to RF and microwave energy. The samples were performed by different biomaterials (*Bones and Scales*) in low water content. The two different fish species (*cyprinid* and *cyprinus carpio*) of biomaterial (*Bones and Scales*) were taken from Narmada river Rajghat distt. Barwani (M.P.). First Bones and Scales body tissues remove from fish body. The remove biomaterials dried within 7 days in sunlight heat and preservations. The dried body tissues sample low water content (Dry).The samples prepare proper shape and size at different frequency ranges. The experimental works carried out done in inter university consortium UGC-DAE Indore (M.P.). The mathematical formulation developed by Debye to describe this process for pure polar materials can be expressed as

\[
\varepsilon = \varepsilon_0 + \varepsilon_\infty / 1 + i\omega\tau
\]

where \( \varepsilon_\infty \) represents the dielectric constant at frequencies so high that molecular orientation does not have time to contribute to the polarization, \( \varepsilon_0 \) represents the static dielectric constant, that is, the value at zero frequency (dc value), and \( \tau \) is the relaxation time, the period associated with the time for the dipoles to revert to random orientation when the electric field is removed.
3 Results and discussions

The experimental results show the effect of frequency variation on dielectric properties of biomaterials with low water content. The biomaterials give the effective response with different frequencies (1 Hz to 10 MHz at room temperature (Table 1). Their frequency dependence study has been qualitatively explained. The value of dielectric constant, dielectric loss and conductivity of low water content and biomaterials are measured and plotted in Figure 1, Figure 2, and Figure 3. By measurements, it is observed that there is a variation in the dielectric constant of different biomaterials at room temperature. The value of dielectric constant ($\varepsilon'$) and dielectric loss ($\varepsilon''$) decreases with increasing frequency while the value of conductivity ($\sigma$) increases with frequency increases. Such behaviour may be in light of the model of multiple conductive relaxation modes.

### Table 1

| S.N. | Frequency (Hz) | Biomaterials  | Dielectric constant ($\varepsilon'$) | Dielectric loss ($\varepsilon''$) | Conductivity $\sigma$ (S/m) |
|------|----------------|---------------|-------------------------------------|----------------------------------|-------------------------------|
| 1    | 1 Hz           | Bone catla    | 99.9                                | 14.01                            | 8.08x10^{11}                 |
| 2    | 1 Hz           | Bone common   | 30.3                                | 294.0                            | 7.86x10^{-12}                |
| 3    | 1 Hz           | Spine catla   | 147.0                               | 145.0                            | 1.63x10^{-10}                |
| 4    | 1 Hz           | Scale catla   | 34.03                               | 52.04                            | 2.91x10^{-11}                |
| 5    | 1 Hz           | Scale common  | 9.05                                | 7.82                             | 4.35x10^{-12}                |
| 6    | 100 Hz         | Bone catla    | 34.7                                | 293.0                            | 8.05x10^{-10}                |
| 7    | 100 Hz         | Bone common   | 12.7                                | 16.6                             | 2.48x10^{-10}                |
| 8    | 100 Hz         | Spine catla   | 36.9                                | 9.49                             | 9.24x10^{-10}                |
| 9    | 100 Hz         | Scale catla   | 8.82                                | 3.12                             | 2.65x10^{-10}                |
| 10   | 100 Hz         | Scale common  | 4.74                                | -6.55                            | 5.56x10^{-11}                |
| 11   | 10 KHz         | Bone catla    | 13.2                                | -3.34                            | 1.78x10^{-7}                 |
| 12   | 10 KHz         | Bone common   | 8.04                                | 1.44                             | 2.90x10^{-8}                 |
| 13   | 10 KHz         | Spine catla   | 16.7                                | 2.05                             | 7.98x10^{-8}                 |
| 14   | 10 KHz         | Scale catla   | 5.21                                | -1.82                            | 1.58x10^{-8}                 |
| 15   | 10 KHz         | Scale common  | 3.85                                | -82.8                            | 7.19x10^{-9}                 |
| 16   | 10 KHz         | Bone catla    | 11.04                               | -2.09                            | 7.68x10^{-7}                 |
| 17   | 10 KHz         | Bone common   | 7.76                                | -9.73                            | 1.46x10^{-7}                 |
| 18   | 10 KHz         | Spine catla   | 15.5                                | 1.10                             | 3.26x10^{-7}                 |
| 19   | 10 KHz         | Scale catla   | 5.07                                | -11.6                            | 8.07x10^{-8}                 |
| 20   | 10 KHz         | Scale common  | 3.79                                | -665                             | 4.62x10^{-8}                 |
| 21   | 10 MHz         | Bone catla    | 10.05                               | -435                             | 2.41x10^{-6}                 |
| 22   | 10 MHz         | Bone common   | 7.56                                | -93.07                           | 2.42x10^{-8}                 |
| 23   | 10 MHz         | Spine catla   | 14.04                               | -43.03                           | 1.81x10^{-6}                 |
| 24   | 10 MHz         | Scale catla   | 4.96                                | -131                             | 7.29x10^{-8}                 |
| 25   | 10 MHz         | Scale common  | 3.71                                | -528                             | 2.94x10^{-8}                 |
4 Conclusions

The dielectric properties of biomaterials different frequency ranges good results are obtained for the dielectric constant and dielectric loss. The dielectric properties of the bulk materials in the form of biomaterials with low water content are useful in understanding the effect of biological tissues as biomaterials. The results such studies are important for an understanding of the fundamental nature of the response of the particularly biomaterials to the high frequency electromagnetic fields.

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