VARIATION OF DIELECTRIC AND SCATTERING PARAMETERS FOR TAMARINDUS INDICA TREE LEAVES WITH MOISTURE CONTENT AND MICROWAVE FREQUENCIES

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ABSTRACT

This study presents the data on complex dielectric constant, emissivity and scattering coefficient of Tamarindus indica tree species leaves at X-band microwave frequencies (9.63GHz, 10.63GHz and 11.63GHz). Wave guide cell method has been used for measuring dielectric constant and loss of tree leaves. The estimation of emissivity and scattering coefficient has been made using the measured values of dielectric constant. Emissivity of tree leaves is estimated by using emissivity model and scattering coefficient is estimated using perturbation model for slightly rough surface. For both,vertical and horizontal polarizations, at constant value of incident angle, emissivity of tree leaves is found to decrease significantly increase in the values of its gravimetric moisture content(MC%),while their scattering coefficient increases significantly with increase in the values of its moisture content(MC%). Also, the values of scattering coefficient and emissivity for tree leaves at same incident angle are greater for vertical polarization than for horizontal polarization. These reported results will be mainly useful for microwave remote sensing of vegetation canopy and also find uses in electronic communications.

***Keywords*: Complex permittivity, emissivity, microwave frequency, scattering coefficient, tree leaves.**

I. INTRODUCTION

The dielectric properties of vegetation samples, which are hygroscopic in general, vary predominantly with moisture content, but also they depend on the frequency of the applied electromagnetic field, the temperature of the materials, and on density and structure of the materials. Salinity and water content of plants determine the loss factor of that plant which also refers to the dielectric constant of it. Perfectly dried leaves behave like pure dielectric. The strength of interaction between microwaves and a material is determined by the dielectric constant and is an important determinant of emissivity of a material. The dielectric constant is a complex number. The real part of it determines the propagation characteristics of the energy as it passes through the material and the imaginary part determines the energy losses.

Dielectric behaviour of vegetation materials have reported by several investigators [1-4]. Their results have been reported dielectric parameters of plants as a function of moisture content at microwave frequencies. Emissive and scattering behaviour of tree species leaves have been experimentally studied at different microwave frequencies by using emissivity model [5-6]. The dielectric properties of Bamboo and Canna plants leaves at 9.8 GHz have been studied as a function of moisture content [7]. Experimental results on complex dielectric constant, emissivity and scattering coefficient for leaves of different tree species at microwave frequencies have been reported [5-15]. However, some of these investigations have pointed a scarcity of data on the dielectric and emissive and scattering properties relating to tropical vegetation/tree canopies [15].

In order to provide more experimental data relating to this area, we have carried out the experiments to measure complex dielectric constant for leaves of Tamarindus indica tree species at three different X-band microwave frequencies. These values can be used for designing the passive and active microwave sensors to be used for remote sensing of vegetation canopies and also in assigning the transmitter power in electronic communication systems.

II. MATERIALS AND METHODS

2.1 Preparation of the tree leaves samples

Samples of leaves of Tamarindus indica (Imli) has been used in our experiments. These tree species selected lie within the small area covering about 1 km^2 in the Dhule city. Dhule district comes under tropical zone and located in the northern region of Maharashtra state (India). Height of these tree species ranged between 8 to 20 meters. Initially, the newly plucked tree leaves are inserted into the solid dielectric cell and their dielectric constant is measured. Then the wet basis gravimetric moisture content (MC, %) of the tree leaves sample was gradually reduced by drying it in a hot air oven at 45^o to 50^o C. Moistures of leaves are varied from its natural to oven dry value.

2.2 Complex dielectric constant measurement

The waveguide cell method is used to determine the dielectric properties of the tree leaves samples. An automated X-band microwave set-up in the TE10 mode with Gunn source operating at frequencies 9.63 GHz, 10.63 GHz and 11.63 GHz PC-based slotted line control and data acquisition system is used for this purpose. It consists of Microcontroller (8051), ADC-12 Bit- MCP (3202) Visualbased software. The solid dielectric cell with this sample is connected to the opposite end of the source. The signal generated from the microwave source is allowed to incident on the tree leaves sample. The sample reflects part of the incident signal from its front surface. The reflected wave combined with incident wave to give a standing wave pattern. These standing wave patterns are then used in determining the values of shift in minima resulted due to before and after inserting the sample. The dielectric constant ε' and dielectric loss ε'' of the tree leaves are then determined from the following relations:

$$\varepsilon' = \frac{g_\varepsilon + (\lambda_{gs}/2a)^2}{1 + (\lambda_{gs}/2a)^2} \quad \ldots \quad (1)$$

$$\varepsilon'' = -\frac{\beta_\varepsilon}{1 + \left(\lambda_{gs}/2a\right)^2} \quad \ldots \quad (2)$$

Where, a = Inner width of rectangular waveguide.

λ_{gs} = wavelength in the air-filled guide.

g_{ε} = real part of the admittance;

β_{ε} = imaginary part of the admittance

From these measured values of dielectric constants at X-band frequencies (9.63GHz, 10.63GHz and 11.63GHz)for the tree leaves samples having different MC (%), the estimations of emissivity and scattering coefficient are made at different incident angles by using emissivity and perturbation models, respectively for vertical and horizontal polarizations.

2.3 Estimation of Emissivity from emissivity model

The basic expression for emissivity is

The emissivity $e_p(\theta)$ for vertical polarization (VV) can be written as

$$e_p(\theta) = 1 - r_p(\theta) = 1 - |R_p(\theta)| \quad \ldots \quad (3)$$

$$e_p(\theta) = 1 - \frac{\varepsilon' \cos\theta - \sqrt{\varepsilon' - \sin^2\theta}}{\varepsilon' \cos\theta + \sqrt{\varepsilon' - \sin^2\theta}} \quad \ldots \quad (4)$$

and the emissivity ep(θ) for horizontal polarization (HH) can be written as

$$e_p(\theta) = 1 - r_p(\theta) = 1 - |R_p(\theta)| \quad \ldots \quad (5)$$

$$e_p(\theta) = 1 - \frac{\cos\theta - \sqrt{\varepsilon' - \sin^2\theta}}{\cos\theta + \sqrt{\varepsilon' - \sin^2\theta}} \quad \ldots \quad (6)$$

θ = Angle of observation

$e_p(\theta)$ = Emissivity of the surface layer;

$r_p(\theta)$ = Reflection coefficient

$R_p(\theta)$ = Fresnel reflection coefficient

2.4 Estimations of scattering coefficient by using perturbation model

Estimations of scattering coefficient of Tamarindus indica (Imli) leaves have been made by using perturbation model, considering that the leaves have slightly rough surface. The perturbation method requires the surface standard deviation to be less than about 5% of the electromagnetic wavelength. In the present case, the wavelength lies between 4.28 cm to 3.13 cm. So the standard deviation should be less than 2.135 mm. In the present case, these values for Tamarindus indica(Imli) leaves are assigned around 0.5 mm, 0.4mm and 0.3 mm respectively for 9.63GHz, 10.63GHz and 11.63GHz and the corresponding correlation lengths for Tamarindus indica(Imli) leaves are around 6.0 mm, 5.0 mm and 4.4 mm respectively for 9.63GHz, 10.63GHz and 11.63GHz. In order to apply perturbation model, the necessary conditions to be satisfied are:

$K\sigma < 0.3$, and

$$\frac{\sqrt{2}}{l}\sigma < 0.3$$

Where, k = Wave number = $2\pi/\lambda$

σ = Surface standard deviation

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l = Surface correlation length

In the present case, $k\sigma = 0.1$ and $kl = 1.0$

The backscattering coefficient is given by

$$\sigma^{\circ}_{ppn}(\theta)=8K^4\sigma^2\cos^4\theta\times|\alpha_{pp}(\theta)|^2W(2K\sin\theta) \quad \ldots. \quad (7)$$

$p = v$ or h

where, $|\alpha_{hh}(\theta)|^2 = \Gamma_h(\theta)$ .... (8)

$$\alpha_{vv}(\theta) = (\acute{\varepsilon} - 1)\ \frac{[\sin^2\theta - \acute{\varepsilon}(1+\sin^2\theta)]}{[\acute{\varepsilon}\cos\theta + (\acute{\varepsilon} - \sin^2\theta)^{1/2}]^2} \quad \ldots. \quad (9)$$

$|\alpha_{hh}(\theta)|^2 = \Gamma_h(\theta)$ is the Fresnel reflection coefficient for horizontal polarization.

$$\alpha_{hh}(\theta) = \frac{\cos\theta - \sqrt{(\acute{\varepsilon} - \sin^2\theta)}}{\cos\theta + \sqrt{(\acute{\varepsilon} - \sin^2\theta)}} \quad \ldots. \quad (10)$$

and W (2Ksinθ) is the normalized roughness spectrum, which is the Bessel transform of the correlation function ρ(ξ), evaluated at the surface wave number of 2Ksinθ.

The normalized roughness = W (2Ksinθ), is given by the following equation

$$W(2K\sin\theta)=0.5l^2\exp[(kl\sin\theta)^2] \quad \ldots. \quad (11)$$

Eqs. (7) - (11), are used to estimate the scattering coefficient of tree leaves having various moisture content (MC %) for vertical and horizontal polarizations by knowing their values of dielectric constants.

III. RESULTS AND DISCUSSION

Our results on the variations of dielectric constant (ε') and dielectric loss (ε'') of leaves samples of Tamarindus indica tree species with different gravimetric moisture contents (wet basis) and also the variations of their emissivity and scattering coefficient for vertical and horizontal Polarizations (VV and HH) at different incident angles are summarized in "Figs.1-3". These experiments are performed at microwave frequencies 9.63 GHz, 10.63 GHz and 11.63 GHz and for MC variations from moistures of freshly plucked natural leaves to their oven-dry values.

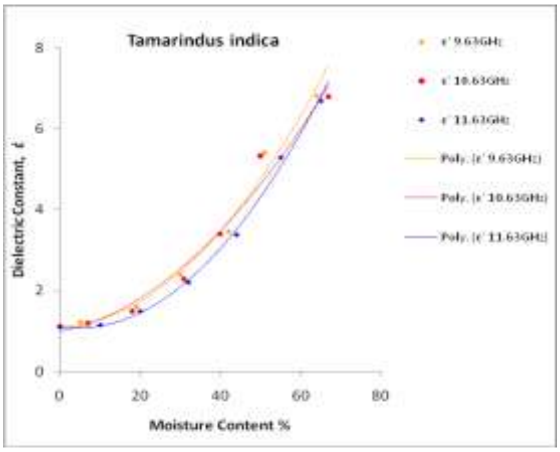

Fig.1 (a)

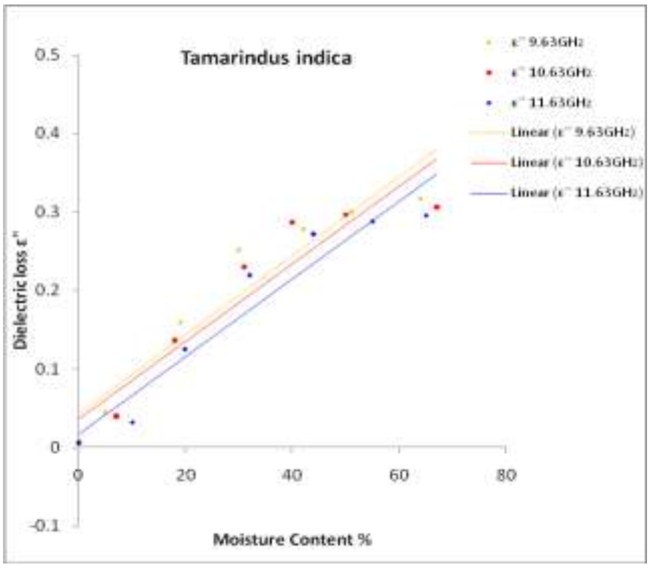

Fig.1 (b)

Fig.1(a)-(b): Variations of dielectric constant and loss of Tamarindus indica leaves with gravimetric moisture content at three different frequencies.

"Fig.1(a)-(b)" show the variations of dielectric constant and loss for Tamarindus indica (Imli) leaves samples with gravimetric moisture content at microwave frequencies 9.63 GHz, 10.63 GHz and 11.63 GHz respectively. The dielectric constant and loss of the leaves are found to increase with increase in MC (%) over the entire range studied. However, these variations with MC are relatively more nonlinear for (ε') than (ε'') and the general trends are almost similar for these the frequencies, except their relative magnitudes. Further, there is little decrease in dielectric constant and loss with increase in frequency.

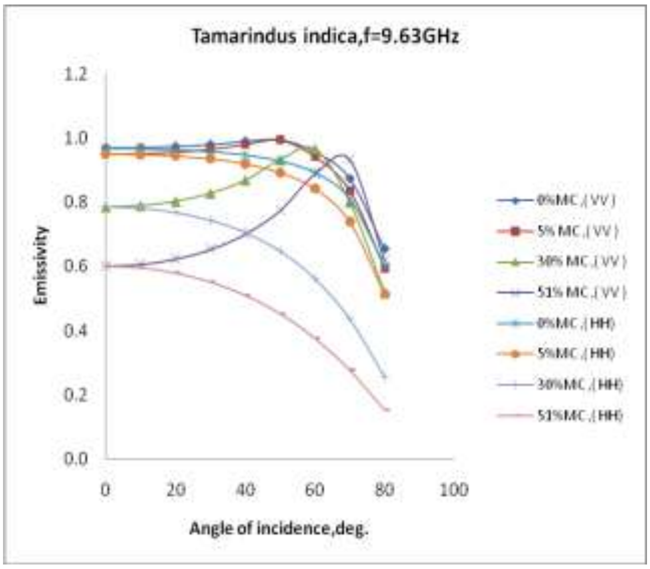

Fig.2 (a)

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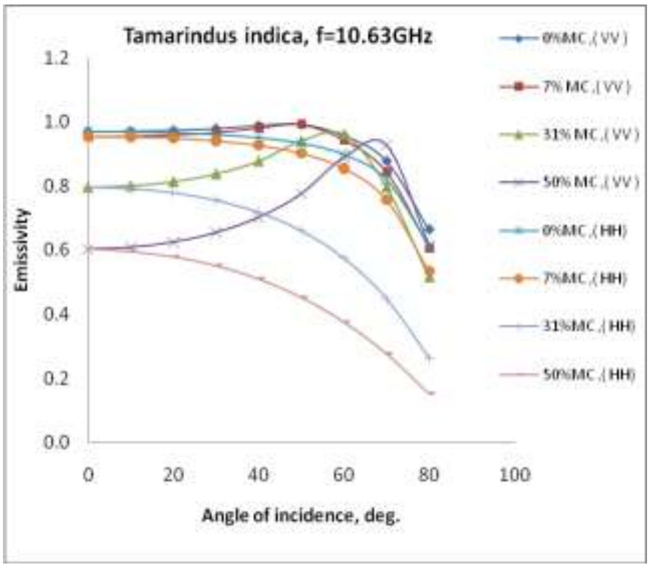

Fig.2(b)

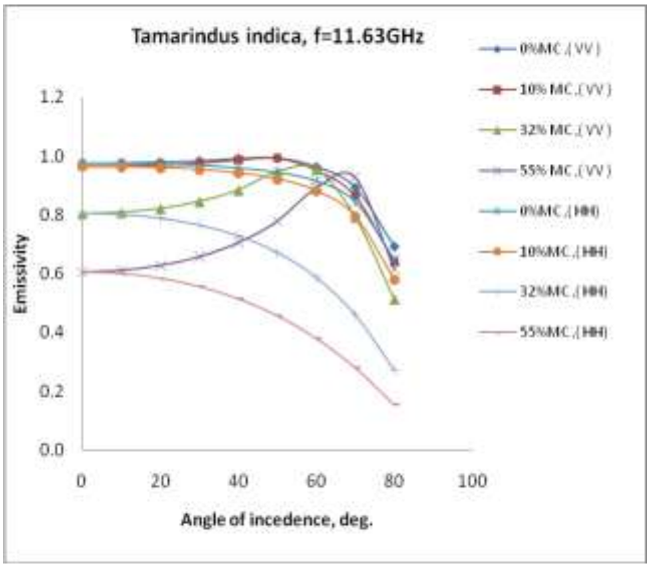

Fig.2 (c)

Fig.2(a)-(c): Variation of emissivity (Vertical and Horizantal Polarizations) for different wet basis gravimetric MC (%) with incident angles in degrees of Tamarindus indica leaves at 9.63 GHz, 10.63 GHz and 11.63 GHz.

"Fig.2 (a)-(c)" are plotted for emissivity against the angle of incidence. The graph suggests that for horizontal polarization emissivity reduces very fast as angle of incidence increases. The curve for horizontal polarization shows a decrease in emissivity at a slow rate initially up to 30^0, and above this angle the emissivity reduces faster as the angle of incidence increases. The curve for vertical polarization shows a gradual increase in emissivity initially, which becomes faster as the angle of incidence varies from 30^0 to 65^0. Beyond 65^0 angles there is change in the value of emissivity and the trend changes. Instead of increasing the emissivity decreases as shown in "Fig.2 (a)-(c)". Also show almost similar trends except little difference in their magnitudes for different X-band frequencies. Thus, results presented here show fairly good agreement with the experimental and theoretical studies of earlier investigators [2, 5, 6, 11-14].

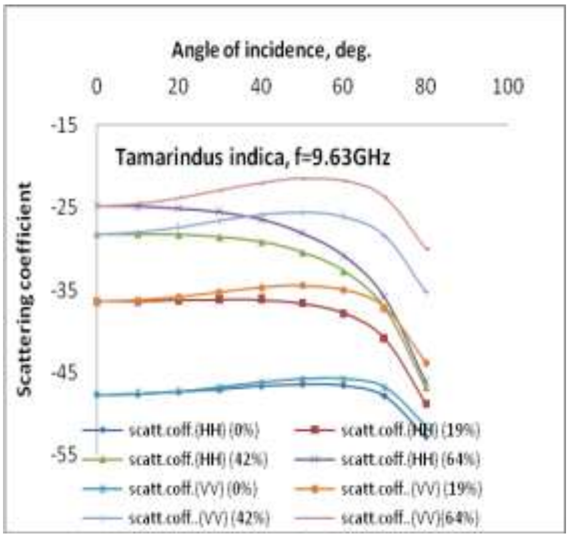

Fig.3 (a)

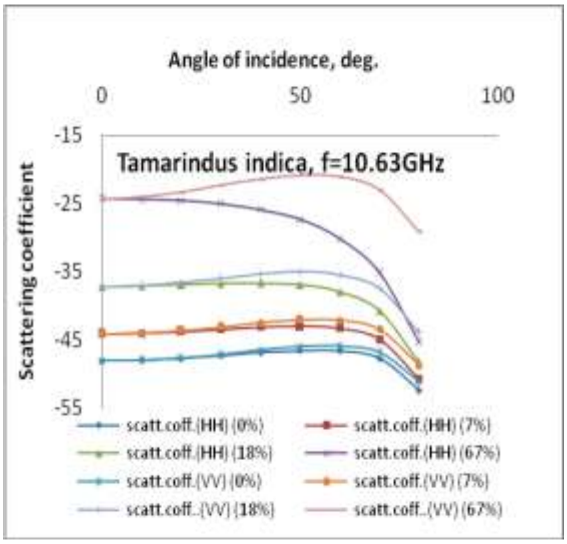

Fig.3(b)

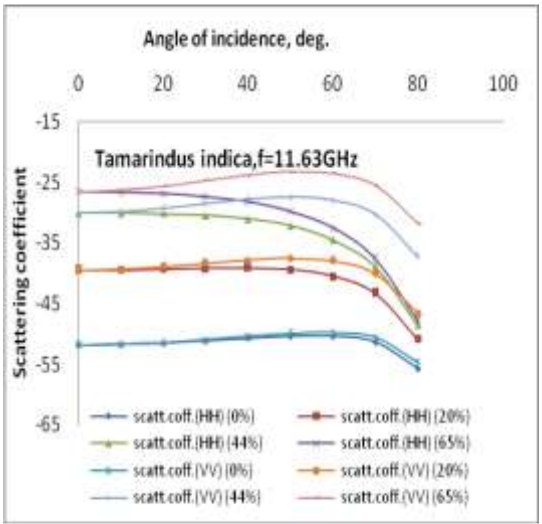

Fig.3 (c)

Fig.3(a)-(c): Variation of scattering coefficient (Vertical and Horizantal Polarizations) for different wet basis gravimetric MC (%) with incident angles in degrees of Tamarindus indica leaves at 9.63 GHz, 10.63 GHz and 11.63 GHz.

"Fig.3(a)-(c)"shows the variation of scattering coefficient for samples of leaves from Tamarindus indica (Imli) tree species having various moisture content(%) , with angle of incidence for horizontal and vertical polarizations, at X-band frequencies (9.63GHz, 10.63GHz and 11.63GHz). For horizontal polarization, the scattering coefficient decreases initially at a very slow rate on increasing the angle of incidence up to 30^0. After that, it decreases somewhat quickly up to 50^0 to 65^0 and drops down much faster from 70^0 to 80^0. For vertical polarization, we see that the value of scattering coefficient initially increases with increase in the incident angle and this increase continuous up to 60^0 incident angle, and beyond this angle, scattering coefficient decreases sharply. From the comparative study of the two polarizations, we see that the scattering coefficient for the vertical polarization is more as compared to the horizontal polarization and the value of scattering coefficient at 0^0 angle of incidence is almost same. Thus, we can say that the rate of decrease of scattering coefficient for the vertical polarization is comparatively slower than the horizontal polarization.

Further, in "Fig.3 (a)-(c)", at the constant value of incident angle for both vertical and horizontal polarizations, the scattering coefficient increases up on increase in the value of moisture content (%) over ranges studied. The results presented here also show fairly good agreement with the experimental and theoretical studies of earlier investigators [2, 5, 6, 11-14].

This study of emissivity and scattering coefficient of Tamarindus indica (Imli) leaves is very important from the point of view of microwave remote sensing for agricultural and forest areas. These parameters are required for designing passive and active sensors. Moisture dependent dielectric, emissive and scattering behaviour of tree leaves/vegetation will also be important in assigning transmitter power for electronic communication systems. Studies will also necessary to obtain the information about the status of crops in agriculture.

IV. CONCLUSIONS

- The dielectric constant and loss for Tamarindus indica (Imli) are found to increase with increase in its gravimetric MC (%) at microwave frequencies. However, most of these variations are nonlinear and also show little decrease with increase in microwave frequencies
- The estimated value of emissivity and scattering coefficient of Tamarindus indica (Imli) tree leaves depends upon their dielectric constant and surface roughness.
- For both, vertical and horizontal polarizations, at constant value of incident angle, emissivity of tree leaves is found to decrease significantly with increase in the values of its moisture content (%) while their scattering coefficient increases significantly with increase in the values of its moisture content (%) over the range studied.
- The values of scattering coefficient and emissivity for tree leaves at same incident angle are greater for vertical polarization than for horizontal polarization.

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