Estimation of emissivity and scattering coefficient of the constituents of vegetation at microwave frequencies

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A vegetation canopy is a dielectric mixture consisting of discrete dielectric inclusions (leaves, stalks and fruits) distributed in a host material (air). The scattering and emission behaviour of vegetation canopy made up of neem-like trees has been studied. The estimation of emissivity, brightness temperature and scattering coefficient has been made using the measured values of dielectric constant. The measurement of dielectric constant of neem leaves has been carried out using waveguide cell method in the frequency range of X-band (8.2 GHz - 12.4 GHz) at 9.035 GHz. The estimations of emissivity, brightness temperature and scattering coefficient are made for incidence angles varying from 0° to 80° for both horizontal and vertical polarization. The results of emissivity and scattering coefficient so obtained have been presented.

Keywords: Emissivity, Scattering coefficient, Canopy, Microwave frequency, Dielectric constant

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1 Introduction

In the microwave remote sensing of land, the features that are considered are soil, vegetation and other terrain elements. The study of soil at microwave frequencies has been done extensively and reported1-3. The study of bare soil and also that covered with vegetation canopy4 is important for obtaining the electrical parameters for the microwave sensors to be designed for microwave remote sensing. The vegetation canopy consisting of wheat, soyabean, etc. has been studied at great length. In desert areas, the vegetation canopy at different locations consists of neem trees, which are found in large numbers in arid climate zone, and so the study of electrical properties of neem tree is required when one is to study the desert terrain using microwave remote sensing techniques. Neem is an evergreen tree found in warm, tropical lowlands having rainfall between 30 cm and 100 cm. Neem has emerged as a single plant species possessing both pesticidal and medicinal properties. The roots absorb the moisture from the underlying soil and transport it to the various parts of the tree by capillary action.

Here, the measurement of the storage factor of the dielectric constant of the vegetation (neem leaves) at a frequency in the microwave range, estimation of emissivity using emissivity model and estimation of scattering coefficient using the perturbation model have been presented.

2 Measurement of dielectric constant

There are basically four methods5 for measurement of dielectric constant, viz. transmission line method, cavity method, free space method and waveguide cell method. In this paper, the data of dielectric constant, which is already measured6 using waveguide cell method have been used for estimation of emissivity and estimation of scattering coefficient. The dielectric constant was measured for different leaf thickness at X-band frequency (9.035 GHz) in the laboratory.

3 Microwave emission models

Various theoretical models4,7 are available for estimating the microwave emissions from different types of surfaces. These models include zero-order non-coherent model, radiative transfer model, first order non-coherent radiative transfer model, coherent model and emissivity model7. The emissivity and brightness temperature of neem leaves have been estimated using the available data of dielectric constant and using emissivity model7 applicable for emission from a range close to the surface.

4 Estimation of emissivity from emissivity model

This model is the simplest to use with reasonable accuracy for the radiation within a range close to the surface.

In this model, the brightness temperature is given by
\[ T_B = e_p(\theta) T + r_p(\theta) T_{sky} \]  

where,

- \( e_p(\theta) = \) Emissivity of the surface layer
- \( p = v \) or \( h \), i.e. polarization either vertical or horizontal
- \( r_p(\theta) = \) Reflection coefficient
- \( T = \) Surface temperature
- \( T_{sky} = \) Brightness temperature equivalent of the sky.

The emissivity \( e_p(\theta) \) can be written as

\[ e_p(\theta) = 1 - r_p(\theta) \]  
\[ r_p(\theta) = |R_p(\theta)| \]  

where, \( R_p(\theta) \) is the Fresnel reflection coefficient and is given as

\[ R_p(\theta) = \frac{\cos \theta - \sqrt{\varepsilon - \sin^2 \theta}}{\cos \theta + \sqrt{\varepsilon - \sin^2 \theta}} \]  

The above equation is for horizontal polarization and the equation for vertical polarization is given as

\[ R_p(\theta) = \frac{\varepsilon \cos \theta - \sqrt{\varepsilon - \sin^2 \theta}}{\varepsilon \cos \theta + \sqrt{\varepsilon - \sin^2 \theta}} \]  

where,

- \( \theta = \) Angle of observation
- \( \varepsilon = \) Dielectric constant

The emissivity can be calculated using Eqs (2)-(5) and then the brightness temperature can be calculated using Eq. (1).

**5 Backscattering behaviour of surfaces**

A given surface may appear very rough to an optical wave, but the same surface may appear to be very smooth to microwaves. The reason for this statement is that the degree of roughness of random surface is the characteristics of statistical parameters that are measured in units of wavelength. The standard deviation of the surface (r.m.s) height variation and the surface correlation length are the two fundamental parameters that are used to characterize surface roughness. Microwave backscattering of a surface depends on its roughness and dielectric constant of the material.

**6 Scattering models for soil surface**

For the estimation of scattering coefficient of a surface one may use one of the theoretical models, viz. physical optics model, geometric optics model, and perturbation model. The estimation of scattering coefficient of neem leaves has been done using perturbation model, considering them as slightly rough surface.

**7 Computation of scattering coefficient**

The perturbation method requires the surface standard deviation to be less than about 5% of the electromagnetic wavelength.

In the present case, the wavelength is 3.3 cm. So the standard deviation should be less than 1.6 mm. In case of neem leaves it is around 0.5 mm. The correlation length in the case of neem leaves is around 5 mm. Thus, mathematically the conditions for perturbation model to be satisfied are:

\[ k \sigma < 0.3 \]

and

\[ \frac{\sqrt{2} \sigma}{\ell} < 0.3 \]

where,

- \( k = \) Wave number = \( 2\pi/\lambda \)
- \( \sigma = \) Surface standard deviation
- \( \ell = \) Surface correlation length

In the present case

\[ k \sigma = 0.1 \]

and

\[ k \ell = 1.0 \]

The backscattering coefficient is given by

\[ \sigma^b_{\text{ppn}}(\theta) = 8K^4\sigma^2\cos^4\theta \times |\alpha_{pp}(\theta)|^2 W(2K\sin \theta) \]  

where, \(|\alpha_{nn}(\theta)|^2 = \Gamma_n(\theta)\) \(\) and \(\alpha_{vv}(\theta) = \frac{(\varepsilon_v - 1) \sin^2 \theta - \varepsilon_v (1 + \sin^2 \theta)}{[\varepsilon_v \cos \theta + (\varepsilon_v - \sin^2 \theta)^{1/2}]^2} \)
where
\[ \varepsilon_s = \text{Dielectric constant of surface} \]
\[ \alpha_{th}(\theta) = \Gamma_3(\theta) \text{ is the Fresnel reflection coefficient for horizontal polarization which is given by} \]
\[ \alpha_{th}(\theta) = \frac{\cos \theta - \sqrt{(\varepsilon_s - \sin^2 \theta)}}{\cos \theta + \sqrt{(\varepsilon_s - \sin^2 \theta)}} \quad \ldots (9) \]
and
\[ W(2K\sin \theta) \text{ is the normalized roughness spectrum, which is the Bessel transform of the correlation function } \rho(\xi), \text{ evaluated at the surface wave number of } 2K\sin \theta. \]

The normalized roughness \( W(2K\sin \theta) \) is given by the following equation
\[ W(2K\sin \theta) = 0.5 l^2 \exp \left[ (kl\sin \theta)^2 \right] \quad \ldots (10) \]

8 Results and discussion

The estimated emissivity, brightness temperature and scattering coefficient have been plotted in Figs 1-4 for the variable thickness of leaves (by having more number of leaves), angle of incidence (0°-80°) and both horizontal and vertical polarization.

From Fig. 1, where the graph is plotted between emissivity and the thickness of leaves (in cm), the following observations have been made.

(i) Initially, for less number of leaves the dielectric constant is relatively high and so the corresponding emissivity is very low.

(ii) As the dielectric constant decreases with increase in thickness (increase in number of leaves), the value of emissivity increases at a very fast rate showing a steep rise in the curve. Then suddenly, it drops down with the sudden increase in the dielectric constant (anomalous behaviour).

(iii) On further increasing the thickness the emissivity shows the exponential behaviour and increases with a steady rate.

From Fig. 2, where the graph is plotted between emissivity and angle of incidence, the following observations have been made.

(i) The curve for horizontal polarization shows a decrease in emissivity at a slow rate initially up to 30°, and above this angle the curve becomes faster as the angle of incidence increases.

(ii) The curve for vertical polarization shows a gradual increase in emissivity initially, which becomes faster as the angle of incidence varies from 30° to 70°. At 74° angle, there is a change in the value of emissivity and the trend changes. The trend of the emissivity curve changes for vertical polarization at 74°. Instead of increasing, the emissivity decreases as shown in Fig. 2. The changeover is taking place above 70° and at an angle of 74°, which is the Brewster angle. Theoretically, the Brewster’s angle is given by the following relation
\[ \tan \theta = \sqrt{12.3} \]
\[ \theta = 74° \]

From Fig. 3, where the scattering coefficient is plotted against the leaf thickness (number of leaves), the following observations are made.

(i) The value of scattering coefficient decreases at a very fast rate showing a steep slope initially up to thickness of 0.13 cm.

(ii) After that, it suddenly increases with the increase in dielectric constant and decrease of scattering coefficient.

Beyond this level, the scattering coefficient decreases at an approximately constant rate showing linear nature.
From Fig. 4, where the graph has been plotted for scattering coefficient and the angle of incidence, the following observations have been made.

(i) For horizontal polarization, the scattering coefficient decreases initially at a very slow rate on increasing the angle of incidence up to $20^\circ$. After that, it decreases somewhat quickly up to $60^\circ$ and drops down much faster from $70^\circ$ to $80^\circ$.

(ii) For vertical polarization, we see that the value of scattering coefficient remains almost constant between the angles of incidence $0^\circ$ and $20^\circ$ and decreases at extremely slow rate up to $50^\circ$. After that, it drops down quickly from $60^\circ$ to $80^\circ$.

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 $0^\circ$ 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.

9 Summary and conclusion

From the results obtained, it can be concluded that the estimated values of emissivity and scattering coefficients of neem leaves depend upon their dielectric constant and surface roughness.

It can be said that it will be desirable to use vertical polarization for study of emissivity and scattering coefficient for microwave remote sensing of vegetation canopies.

This study gives input with regard to the electrical properties of a constituent of neem tree. This study of emissivity and scattering coefficient of neem tree leaves is very important from the point of view of microwave remote sensing as these parameters are required for designing passive and active sensors. This input of emissivity and scattering coefficient is also useful from the point of view of data base generation with regard to neem leaves. This tree is in abundance in Rajasthan and so the study has been initiated and will be useful for microwave remote sensing of vegetation canopies in arid zone.

References