Microwave Dielectric Properties and Emissivity Estimation of Freshly Cut Banana Leaves at 5 GHz

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Abstract: This paper contains experimental measurements of complex dielectric properties of freshly cut banana leaves at 5 GHz; the central frequency of the Microwave C-band. These measurements were carried out for different gravimetric moisture contents of the banana leaves at room temperature. The Von Hipple method is used to measure complex dielectric properties using an automated C-Band microwave bench set up. The least square fitting technique is used to calculate dielectric constant ε′, dielectric loss ε″ and errors in the measurements. Emissivity and Brightness Temperature are theoretically estimated from measured dielectric properties at different angles of incidence for dry and moist banana leaves using Fresnel equations. These parameters are significance to microwave remote sensing of vegetation especially for banana canopy.

Keywords: Dielectric Properties, Microwaves, Banana Vegetation, Von Hipple Method, Emissivity.

1. Introduction

For applications of microwave remote sensing to earth resources, interpretation of remotely sensed data plays a very important role. The interpretation of such data mainly involves the complex dielectric properties and orientation of the object under investigation. Microwave remote sensing is used for various agricultural applications like discrimination of crops, monitoring of crop growth, biomass estimation, monitoring of moisture of vegetation etc. (Ramana, Seshasai, and Srikant, 2014; Pampaloni and Paloscia, 1984). The dielectric property is fundamental property of material which helps to understand the interaction between electromagnetic energy (microwave) and the material. The dielectric constant is a complex quantity. The real part gives propagation characteristics of microwave energy passing through a material medium. The imaginary part is energy loss or dissipation. Both are related by following expression

\[ \varepsilon^* = \varepsilon' - j\varepsilon'' \] (1)

Where

ε′ – Dielectric constant (real part)
ε″ – Dielectric loss (imaginary part)

The complex dielectric properties depend on several physical parameters like size, shape, salinity, frequency of incident radiation, temperature etc. The dielectric properties control scattering and emission of vegetation (Ulaby, 1984). The emission properties depend on type of vegetation and incident frequency (Calla OPN). The laboratory validation of dielectric properties is important for interpretation of data pertaining to microwave remote sensing (Kurtadikar, Popalghat, and Mehrotra, 2013). Thus there is requirement to investigate the dielectric properties of types of vegetation at microwave frequency.

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The reports are available for dielectric properties of vegetation (Ulaby, and Jedlicka., 1984, Ulaby, and EL-Rayes, 1987). Vegetation is highly a heterogeneous medium due to distributed orientation which consists of leaves, stalk, fruits and branches. Most of the covered parts of the vegetation canopy are leaf. Leaves give energy to the plants through the process of photosynthesis. Water content is an essential component in leaf material which works as a solvent and transportation agent for minerals nutrients and other dissolved salts in plants (Ferguson, 1959). The complex dielectric properties of leaves are strongly affected by water inside it. Water in leaves can be divided in to free and bound water. Free water is not tightly bind to its surrounding constituents and freely moves through the leaves and act as solvent. While bound water is bind to its surrounding constituents causing inability to move in leaves.

Banana is an herbaceous plant (i.e. not woody) from the “musaceae” family. It grows in tropical and sub tropical environment. Banana leaves are large, flexible, and waterproof. Banana plant is isohydric in behavior. It evenly maintains constant water potential during the day at value which does not depend on soil water status until plants closed to death. Leaf water content can change its dielectric properties significantly affects backscatter. Thus change in water content in leaf of banana may changes its dielectric properties and hence affects the emission and backscatter (only due to leaves) from canopy. This motivates author to investigate dielectric properties of banana leaves with respect to moisture change in it. In the present work authors have measured dielectric properties of freshly cut banana leaves (containing natural moisture) and of different moisture content (due to natural evaporation over time) including dry (oven dried 0% moisture). The emissivity is estimated from measured dielectric properties at different angle of incidence for moist and dry banana leaves by using Fresnel’s equations. Brightness Temperature related to physical temperature is theoretically calculated for banana leaves. These parameters are significant for microwave remote sensing of banana vegetation especially in agriculture applications.

The effect of vegetation cover produces the attenuation of microwave energy emitted and affects microwave radiometric sensitivity to the soil moisture (Ulaby, Razani, and Dobson, 1983). This effect depends on the type of vegetation and wavelength of observations (Jackson and Schmugge, 1991). Present study may be useful to understand the attenuation of microwave radiation due to banana vegetation cover which affects the sensitivity of microwave remote sensing of soil moisture. Dielectric properties of the earth resources; Soil (Agrawal, Kurtadikar, and Murugkar, 2004; Kulkarni, Agrawal , and Kurtadikar, 2007), Ices (Kurtadikar, 2008), Sea Water (Joshi and Kurtadikar, 2013), Saline soil (Deshpande et al. 2015), and Algae –Aquatic Vegetation (Itolikar, and Kurtadikar, 2015) were studied and reported by the MW group of this laboratory by using the same method and the same C-Band microwave bench set up provided by Indian Space Research Organization (ISRO) under a “RESPOND” project to the PI, (M. L. Kurtadikar) and is used for present work as well.

2. Methodology and Material

2.1 Sampling

Leaves of fresh banana crops from height around 130 cm were cut from the location, Eight to ten kilometer away from Jalna city, Marathwada Region, Maharashtra State, India. A freshly cut banana leaf starts shrinking and loses moisture content over a period. To avoid the loss of moisture, the leaves were covered in a polythene bag and transported to the laboratory. The leaves were cut in to the rectangular size of cross-
section of the waveguide cell. Bunch of such cut sized leaves were inserted in to the waveguide cell with a compactness to achieve the homogeneity of the material medium which is prime requirement for the method used in this work. The equal and constant compactness was maintained by fitting the sample of banana leaves in the cell between reflector (rear end of the cell) and the mica window (front end of the cell). The reflector is movable and can slide inside the cell to push the sample towards mica window. The sampling and the measurements were done for freshly cut banana leaves with natural moisture content (81.80%) and for 79.77%, 71.87%, 39.52, 00. 00% (oven dry). Moisture of leaves decreased when it cut from plant. Due to the time passed of transportation and sampling of leaves to track actual natural moisture of leaves is very difficult for laboratory measurement. The natural moisture content of banana leaves (81.80%) mentioned above is including the consideration of this barrier. The moisture of the leaves was changed due to natural evaporation over a period. It is observed for banana leaves the moisture is reduced around 2 to 3 % per day when it is placed in air tight plastic box. Finally sample is placed at 70°C in oven until get completely dried and referred as dry weight of sample. The moistures of the banana samples were measured gravimetrically on the weight basis given in equation (2).

\[
\text{% Moisture Content} = \frac{W_s - W_d}{W_s} \times 100
\]

(2)

where,

Ws- Weight of sample; Wd-Wight of dry sample; (Ws-Wd)- Weight of moisture content

2.2 Experimental details

2.2.1 Modification and fabrication of sample cell for leaves sample

A solid dielectric cell with a movable reflector for compaction of vegetation leaves is fabricated. It consists of movable rectangular reflector which is fitted on rear end of waveguide cell. The dimensions of reflector are just smaller than that of the inner dimensions of the wave guide so that it can easily slide inside the wave guide cell. A long screw is connected to rear side of solid reflector and is externally connected to a micrometer screw gauge. By rotating the micrometer screw gauge, thickness of sample inside the cell is measured. Sample is fitted between reflector and mica sheet by giving appropriate rotations to the screw for homogeneity and constant compactness of sample inside the cell. These modifications and fabrication were carried out at a workshop of government Industrial Training Institute, Aurangabad (MS), India. Refer figure

![Modified dielectric cell with movable reflector for vegetation leaves](image)
2.2.2 Experimental set up

![Block diagram of Microwave C-band Bench Set Up](image)

There are several methods of dielectric measurement of vegetation (Udo, 2010). In present work, the dielectric properties of dry and moist banana leaves were measured using Von Hippel method for which automated C-Band microwave bench setup is used (Von Hippel, 1954). This method is frequency domain so measurements can be done with a signal frequency at a time (in this case 5 GHz.) is the disadvantage of this measurement method. However it is reasonably accurate method. The block diagram of the setup is shown in (Figure 2). It consists of a low power microwave source VTO, isolator, coaxial-waveguide adapter, attenuator, SS tuner, slotted section and solid dielectric cell with movable reflector.

Microwaves generated by VTO are propagated through passive components of rectangular waveguide in to the dielectric cell with perfect reflector at the closed rear end. MW source is tuned to give 5 GHz frequency by applying tuning voltage of 7 volts. Attenuator is used to keep the desired power in waveguide assembly of the bench. A slotted section with a tunable probe containing 1N23 detector with the square law characteristics has been used to measure power (current) along the slotted line. The detector is connected to a micro ammeter and to the PC to read and record the measured power. The probe sits on slot line such that the tip of the tunable probe is slightly penetrated and it can be moved forwarded and backward along the slot line section to sense the electromagnetic field in the wave guide. The bench is tuned to get a symmetrical standing wave pattern in slot line. The tuning of the bench is possible by critical adjustments of probe detector and S.S. Tuner. A symmetrical standing wave pattern with empty dielectric cell is obtained. The dielectric sample under consideration (sampled banana leaves) is inserted in the dielectric cell with a constant compaction (for homogeneity of the medium). The probe is transverse along the slot line at equal intervals and power (current) is recorded with respect to the corresponding probe positions. This data is acquired and stored in a file using microcontroller interface system. This data makes use of α and β as fitting parameters, where α = attenuation factor, β=phase shift constant. The data is stored for banana leaves samples of different thickness. The guided wavelength $\lambda_g$ is measured from the minima of the standing wave pattern.

$$\beta = \frac{2\pi}{\lambda_g}$$  \hspace{1cm} (3)

The free space wavelength, $\lambda_0$ is determined using the relation refer equation (4)

$$\frac{1}{\lambda_0^2} = \frac{1}{\lambda_g^2} + \frac{1}{\lambda_C^2}$$  \hspace{1cm} (4)
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Where, \( \lambda_c = 2 \times a = 2 \times 4.73 = 9.46 \text{ cm} \), ‘a’ being the broader side of the C-band rectangular wave-guide. The real and imaginary parts of the complex dielectric constant are calculated using the relations given in equation (5) and (6)

\[
\begin{align*}
\varepsilon' &= \lambda_0^2 \left( \frac{1}{\lambda_c^2} + \frac{(\alpha^2 - \beta^2)}{4\pi^2} \right) \\
\varepsilon'' &= \frac{\lambda_0 \alpha \beta}{2\pi^2}
\end{align*}
\]

Where, \( \lambda_c \) is the wavelength in the C-band, \( \alpha \) and \( \beta \) are the propagation constants along the two principal axes of the waveguide.

A source code for computing the dielectric constant has been developed. The number of data files, for different thicknesses (in this case measured for three thicknesses) of the samples are combined to get single input data file, which can be used, in the source code for calculating dielectric constant( \( \varepsilon' \) ) and loss(\( \varepsilon'' \)) with errors in the measurements as \( \Delta \varepsilon' \) and \( \Delta \varepsilon'' \). These values are tabulated in Table1.

### 2.2.3 Estimation of Emissivity

The emissivity is expressed as given in equation (7).

\[
e_s(p) = (1 - R_s(p))
\]

Where \( R_s(p) \) is the smooth-surface reflectivity. For a homogeneous leaves sample with a smooth surface, the reflectivity at vertical and horizontal polarizations, \( R_sV \) and \( R_sH \), are given by the Fresnel expressions given by equations 8 and 9.

\[
R_sV = \left| \frac{K \cos u - \sqrt{K - \sin^2 u}}{K \cos u + \sqrt{K - \sin^2 u}} \right|^2
\]

\[
R_sH = \left| \frac{\cos u - \sqrt{K - \sin^2 u}}{\cos u + \sqrt{K - \sin^2 u}} \right|^2
\]

Where ‘u’ is the incidence angle and ‘K’ is the absolute value of the dielectric constant of banana leaves, which is a measure of the response of the leaves to an electromagnetic wave and is largely determined by moisture content of the leaves. Emissivity of banana leaves for different moisture content, for different angles of incidence is calculated using Fresnel equations.

### 2.2.4 Brightness Temperature

Passive microwave remote sensing is based on the measurement of thermal radiation in the centimeter wave band of the electromagnetic spectrum \( T_b \). This radiation is determined largely by the physical temperature and the emissivity of the radiating body and can be approximated by using equation 10.

\[
T_b(p) \approx e_s(p) T
\]

Where \( T_b \) observed brightness temperature; \( T \) physical temperature of the emitting layer; \( p \) refers to vertical or horizontal polarization; \( e_s \)- smooth-surface emissivity.
3. Results and Discussion

Dielectric properties of banana leaves are studied at 5GHz frequency, at room temperature. Complex dielectric constant and loss of freshly cut banana leaves of natural moisture content (81.80%) is measured. Then change in moisture content is measured gravimetrically on weight basis. Measurements are done for 81.80%, 79.77%, 71.87, 39.52, 0.0% (dry) moistures contents of banana leaves. Figure 3 shows the variation of dielectric constant (real part) with respect to moisture content (%) for banana leaves. The trend is nonlinear (Figure 4) shows the variation of dielectric loss (Imaginary Part) with respect to moisture content (%) for banana leaves. Similar to dielectric constant the trend for dielectric loss is also nonlinear in nature. Figure 5 shows variation in the estimated emissivity with angle of incidence for different moisture contents in banana leaves, 81.80%, 79.77%, 71.87%, 39.52% and 0.0% (dry) from measured dielectrics. At normal incidence (zero Angle of incidence). Estimated emissivity ranges from 0.48 to 0.80 for normal incidence. The curves for horizontal polarization show decrease of emissivity with increases in angle of incidence for banana leaves. The rate of decrease of emissivity value is very slow initially up to 200, after then it is comparatively rapid. The curves for vertical polarization show increase of emissivity initially at slow rate and after angle of incidence is 300, the rate become more up to angle of incidence from 700 to 850 beyond which the emissivity trend for vertical polarization is reversed and found to be decreasing.

This change of emissivity in range of angle of incidence from 70° to 85° varies with moisture content of the banana leaves. Figure 6 shows Brightness Temperature related to physical temperature, in this case room temperature (30°C), as a function of angle of incidence for different moisture content in banana leaves, 81.80%, 79.77%, 71.87%, 39.52 and 0.0% (dry). At normal incidence, the value of Brightness Temperature ranges from 140 to 250. The curves for horizontal polarization show decrease of Brightness Temperature with increases in angle of incidence for banana leaves. The rate of decrease of Brightness Temperature value is very slow initially up to 20°, after then it is comparatively rapid. The curves for vertical polarization show increase of Brightness Temperature initially with slow rate and after angle of incidence is 30°, the rate become fast up to angle of incidence from 70° to 85° and the trend is reversed beyond this region; the values start decreasing. This change of Brightness Temperature in range of angle of incidence from 70° to 85° varies with moisture content of the banana leaves.
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**Figure 4:** Dielectric Loss of Banana Leaves as Function of Moisture Content (%)

**Figure 5:** Emissivity of Banana Leaves at different angle of incidence for dry and moist samples

**Figure 6:** Brightness Temperature of Banana Leaves at different angle of incidence for dry and moist samples
5. Conclusion

The work reported in the present paper gives the moisture dependence of dielectric properties of banana leaves at microwave frequency of 5 GHz. Emissivity is estimated and Brightness Temperature is theoretically calculated from measured dielectric properties of banana leaves. These parameters are important for interpretation of microwave remotely sensed data especially for agricultural applications. This study generates the laboratory dielectric properties database for banana vegetation and provides fundamental information for remote sensing which can be useful for designing of active and passive microwave sensors. It may be useful for study of attenuation of microwave radiation due to banana vegetation cover which affects the sensitivity of microwave remote sensing of soil moisture.

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