

MEASUREMENT OF DIELECTRIC CONSTANT OF THIN LEAVES BY MOISTURE CONTENT AT 4 mm BAND

S. Helhel [†]

Department of Electrical and Electronics Engineering
Engineering Faculty
Akdeniz University
Antalya, Turkey

B. Colak

EMC Electronics Inc. Ltd. Coop.
Gebze, Kocaeli, Turkey

S. Özen

KEYTEK Electronics Inc. Ltd. Coop.
Antalya, Turkey

Abstract—A complex dielectric constant for poplar and monstera delicious's obtained by Ulaby at 10 GHz has been revised at 4 mm band. A measurement setup operating at 4 mm was established for making comparison between modeled and measured values. Results basically show that their electromagnetic transparency increases by drying as expected. While moisture content increases from 0% to 60%, transmitted power decreases from 95% down to 22%; reflection goes up to 50% and the absorption reaches from 1% to 20% for monstera leaf. A model developed for poplar responds much better than the model revised for monstera leaves.

Corresponding author: S. Helhel (selcukhelhel@akdeniz.edu.tr).

[†] Also with KEYTEK Electronics Inc. Ltd. Coop., Antalya, Turkey.

1. INTRODUCTION

Remote Sensing — RS is one of the fundamental techniques used for environmental, agricultural, and military purposes. For the last few decades, microwave radiometers have played an important role in monitoring the earth environment such as atmosphere, ocean, and soil. Rainfall, water vapor, and sea surface wind can be retrieved with the radiometer; especially vertical and horizontal electromagnetic fields of the target provide additional information for more accurate estimation. Its fundamental is based on understanding the linkage between electromagnetic and physical properties of the sample. These basic properties are important for radar response [1–3]. The success of RS applications need to understand electromagnetic behavior of vegetation canopy and model complex dielectric permittivity of them in general form or in singular form. Leaves are basic components of any vegetation canopy for developing efficient model such that some of them superposes the electromagnetic scatter from discrete leaves and branches to determine the total reflectivity of the vegetation canopy. That is why the dielectric properties of branch and leaf materials are important and well known to be strongly influenced by the gravimetric moisture content defined as the ratio between the mass of the moisture contained in the material and the total mass of the moist material. As the moisture content of branches shows significant diurnal and seasonal variations, their dielectric properties are also strongly time dependent [4]. At millimeter wave frequencies, the shape, surface roughness and orientations of the individual scatterers become more important to the overall reflectivity of the canopy; the leaf water content is also a very effective factor for determining the reflectivity. Plants are considered as a lose dielectrics. 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.

While ε_r is decreasing, scattering response begins to distort, since its imaginary part disappears [5]. Meanwhile, larger penetration depth gives us more information about the leaves. The physical optic parameters were obtained for X band before, and dielectric constants of tropical leaves were measured and calculated in the literature at X band. Sarabandi [6] and Senior [7] showed that a resistive sheet constitutes an effective model of a leaf.

Jong et al. [8] presented a model for the scattering of radio waves from the canopy of a single tree, and the canopy was modeled as a cylindrical volume containing randomly distributed and oriented cylinders, representing the branches, and thin disks, representing the leaves. His model parameters are based on volumetric moisture content

of leaves and branches. In order to be able to closely predict reflection and/or transmission properties of into lossy materials such as leaves, exact formulas are needed [9], and Chuah et al. [10] reported on the measured dielectric constants of leaves of two tropical crops, namely, rubber and oil palms at X-band.

W band radar systems have also been started to use for remote sensing and are the focus of scientists [11]. Motivation of this study is to determine and model the dielectric permittivity of a plant element (monstera leaves) to moisture content and make comparisons of those values with measurements of transmission, reflection and extinction cross-section of planar and strip shaped leaves versus their moisture concentration at 4 mm band. Comparison of calculated EM field using measured dielectric constant and EMF has also been presented in this study.

2. MEASUREMENT SETUP AND DIELECTRIC PERMITTIVITY OF LEAVES

Figure 1 represents the 4 mm measurement setup including a Gunn oscillator driven through an isolator to measurement volume in which sample leaf was inserted which is well known zebra type interferometer as in the previous study of Helhel et al. [12]. A piece of leaf sample is sandwiched between two waveguide sections. A modulated microwave is amplified and fed into the directional coupler. An attenuator was established between sample and isolator, for keeping system not to be burned. A detector sensed the transmitted complex power and reference signal to make a comparison. Phase and amplitude difference between those two signals were used to calculate power absorption, power transmission and power transmission values. Measurements were repeated for Teflon samples to prove our measurements before leaf measurements.

Chen [13,14] reported some practical problems which have to be taken into account while measuring reflection and transmission. One of those problems is the difficulty to ensure the sample is placed exactly at the waveguide flange, since a small position offset of the dielectric sample will give rise to some errors in calculating the dielectric constant. An explicit expression for the dielectric constant is obtained in terms of the transmission coefficient by simplifying the exact solution for transmission through a thin dielectric slab. Before each measurement, weight of leaves was measured and noted for calculating moisture content variation day by day. Parallel to weight measurements, thicknesses of modeled monstera leaves were also noted.

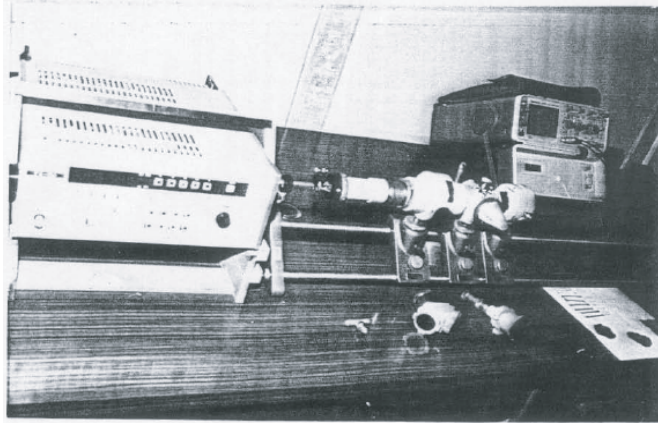


Figure 1. Measurement setup.

2.1. Dielectric Variation of Leaves

The scattering and extinction properties of individual scatterers are governed by its shape, size, and orientation and dielectric properties. A leaf can be modeled as an infinite planar layer, since 4 mm operating wavelength is about 10 times smaller than the smallest dimension of leaf. Leaf thickness τ (in mm) and complex relative permittivity ε are functions of moisture content of it. We know that for fresh leaves moisture content is about 55% of its total weight and saline. This property affects the dielectric characteristics that need to be defined, and a leaf can be modeled as a resistive strip whose resistivity defined by volumetric moisture content with the thickness of t and complex relative permittivity ε . The resistivity of a infinitesimally thin resistive sheet is given in [5] where k is the propagation constant and Z is free space impedance.

$$R = \frac{iZ}{k\tau(\varepsilon - 1)} \quad (1)$$

The relation between the moisture content Mg and physical parameters of a leaf should be defined experimentally. In X-band these were obtained in [1–3], where $\varepsilon = \varepsilon' - j\varepsilon''$ and

$$\begin{aligned} t &= 0.032Mg^2 + 0.091Mg + 0.075 \\ \varepsilon' &= 3.95 \exp(2.79Mg) - 2.25 \\ \varepsilon'' &= 2.69 \exp(2.15Mg) - 2.68 \end{aligned} \quad (2)$$

Since we are interested in the scattering in W (4 mm) band, it is necessary to obtain the new physical parameters which give

the dependency to the Mg of a leaf. We used 4 mm radar interferometer to obtain reflection, transmission and absorption parameters. Furthermore, the relation between the curves versus the moisture content and physical parameters was used to find the description of epsilon and t as a function of Mg. The exact solution of reflection and transmission coefficients is given below

$$R = \frac{(1 - N^2) \sin K_1 \tau \exp(-jk\tau \sin \phi)}{(1 + N^2) \sin K_1 \tau + 2jN \cos(K_1 \tau)} \quad (3a)$$

$$T = \frac{2jN \exp(-jk\tau \sin \phi)}{(1 + N^2) \sin K_1 \tau + 2jN \cos(K_1 \tau)} \quad (3b)$$

A leaf can be modeled as a resistive strip whose resistivity defined by volumetric moisture Mg content with the thickness of τ and complex relative permittivity ε , the resistivity of an infinitesimally thin resistive sheet given as below. For 4 mm band, it is necessary to obtain the new physical parameters represent the frequency dependency and Mg of a leaf. The relations between the curves versus the moisture content and physical parameters were used to find the description of ε and τ as a function of Mg and obtained physical parameters for poplar and monstera delicious's, and poplar leaves are calculated as below where $\tau = 0.204\text{Mg}^2 + 0.03\text{Mg} + 0.197$ is the thickness variation

$$\varepsilon_{\text{Poplar}} = (3.95e^{0.53\text{Mg}} - 2.25) + i(2.69e^{6.1\text{Mg}} - 2.68) \quad (4)$$

$$\varepsilon_{\text{monstera}} = (3.67e^{0.0736\text{Mg}} - 2.25) + i(3.19e^{0.841\text{Mg}} - 2.68) \quad (5)$$

3. EXPERIMENTAL RESULTS

Dielectric permittivity variation of leaves depending on moisture content has been measured and calculated in this section at 4 mm band, and the calculated values have been transferred to backscattering calculation section. Comparison has been made for leaf of thickness of $d = 0.07\text{mm}$ at 4 mm, and it is seen that both theoretical and experimental results are in good agreement.

At Figure 2 and Figure 3, T , R and A are standing for Transmission, Reflection and Absorption respectively. Figure 2 represents a theoretical and experimental response of transmission, reflection and absorption versus moisture content poplar leaves as well as Figure 3 representing for monstera leaves. Figure 3 represents revised theoretical response and measured data. Theoretical and experimental results track each other very well in shape. While moisture content increases from 0% to 60%, transmitted power decreases from 95% down to 22%. Parallel to this transmission

decreasing, reflection goes up to about 50%, and the absorption goes from 1% to up to 20%. Whole percentage need to be 100. Because measurements errors there is about 5% data missed that can be split to those three by equal distribution. That means, for the highest moisture content, transmitted power is 10%, reflected power is 50% and absorption power rate is 40%.

Three sets of samples were chosen for this experiment that each has different moisture contents and dielectric properties. Each set has 10 samples collected from same plant. Each set was formulated and combined to obtain one equation as below in Equation (6)

$$\varepsilon_{Sample\ 1} = (3.95 e^{0.07Mg} - 2.25) + i (3.766 e^{0.817Mg} - 2.68) \quad (6)$$

$$\varepsilon_{Sample\ 2} = (3.95 e^{0.0736Mg} - 2.25) + i (3.196 e^{0.899Mg} - 2.68) \quad (7)$$

$$\varepsilon_{Sample\ 3} = (3.16 e^{0.0736Mg} - 2.25) + i (2.716 e^{0.817Mg} - 2.68) \quad (8)$$

Superposing and evaluating above results, Equation (9) is obtained

$$\varepsilon = (3.67 e^{0.0736Mg} - 2.25) + i (3.196 e^{0.841Mg} - 2.68) \quad (9)$$

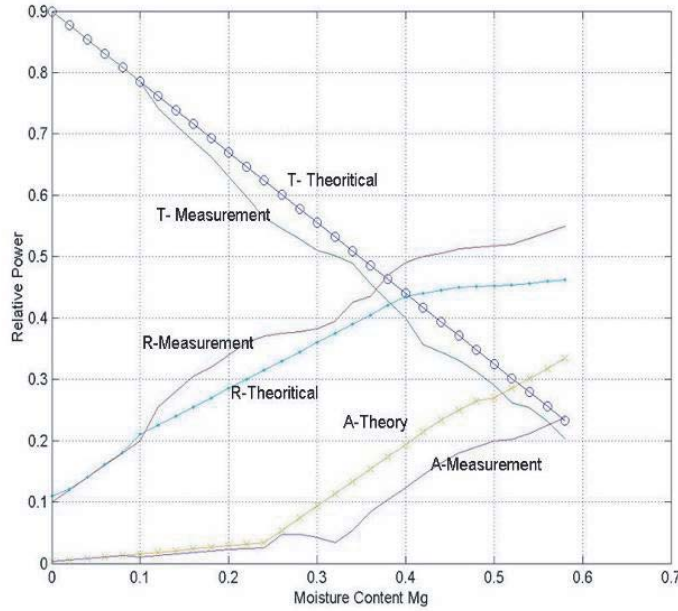


Figure 2. Experimental and theoretical results.

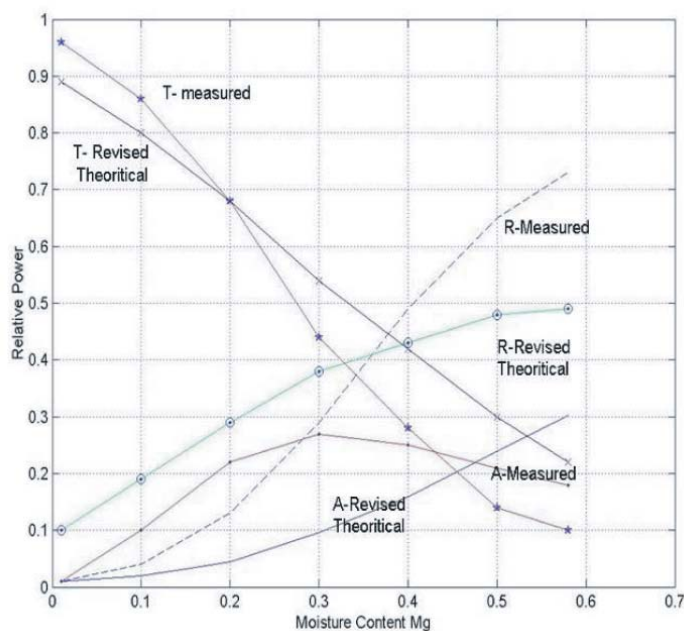


Figure 3. Experimental and modified theoretical results.

4. CONCLUSION

An empirical formula obtained by Ulaby [2] at 10 GHz has been revised for 4 mm band. Revised model was used to make theoretical calculations and compared with measurements. The measured dielectric constant of monstera shows very good agreement with theoretical calculations.

Increasing moisture content of leaves causes an increase in absorption and reflection coefficients, while optical transparency decreases. There is another discussion that the cell wall, cytoplasm, pigments and air cavities of leaves are the optical parameters affecting transmission, absorption, reflection and scattering, and those parameters are changing by drying. These results refer to the seasonal changes in transmission, and it is important for radio link design engineers while they are making optical link budget calculations.

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