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European Journal of Applied Engineering and Scientific Research, 2013, 2 (2):28-32
(http://scholarsresearchlibrary.com/archive.html)

ISSN: 2278 – 0041

Studies on microwave perturbation and permittivity of leaf stem material

Pradeep Kamble[1], Vijaya Puri*

[1]Department of Physics, New college, Kolhapur. India
**Thick and thin film device lab, Department of Physics, Shivaji University. Kolhapur. India.*

ABSTRACT

Wave guide reflectometer and voltage standing wave ratio (VSWR) methods have been used to study the X band (8-12 GHz) microwave perturbation and permittivity of leaf stem material of Ficus Bengalanesis. The effect of moisture content has been investigated on the stem taken from two places in the branch. The transmittance of the waveguide decreases and reflectance increases due to the stem. The perturbations in the reflection mode are highly frequency dependent. The real permittivity ε' of the stem has a value of ~ 80 and ε" is ~ 180 at ~ 10 GHz. Beyond 10 GHz the dielectric constant shows frequency dependent variations. The permittivity decreases with decrease in moisture content in the stem. The microwave impedance shows both capacitive and inductive reactance varying randomly with frequency and moisture content.

Key Words: *Permittivity, microwave, leaf stem, perturbation, transmittance, reflectance*

INTRODUCTION

The dielectric properties of the leaf vegetation material due to presence of water in varying quantities can be detected using microwave methods [1,2]. Leafy vegetation forms a major constituent of the agricultural sector. Most of the high frequency studies available on agriculture related biomaterials are on seeds and grains [3-7] wherein the moisture content has been measured. Dielectric data of moist granular materials is very limited [3,8-9] and data on leafy vegetation material is still lesser [10,11]. To the authors knowledge there are no studies on the stem part of the leafy vegetation material.

The water and nutrient bearing part to the leaf is the stem. The density of the stem varies from place to place due to which the water content also varies. In this work the X band microwave permittivity and perturbation effects of the stem of Ficus Bengalanesis are reported. The wave guide transmission, reflection and voltage standing wave ratio (VSWR) has been used for the measurements. The effect of moisture content on the properties is also reported.

MATERIALS AND METHODS

The leafy stem material was from Ficus Bengalanesis a very common tree available in various parts of India. The stem from one of the branches at the top was chosen for the experiment. These stems were chosen because at the top new leaves starts sprouting. Two portions 2.2 cm long and diameter 0.8 cm were cut from two regions of the stem. The region of the stem corresponding to the topmost end was termed S1 and 4" below was termed S2. The size of the stem was such that it completely filled the slot of the waveguide.

The wave guide reflectometer method as shown in figure 1(a) was used for perturbation measurements and the slotted section as shown in figure 1(b) was used for permittivity measurements. The input microwave power was in the frequency range 8-12 GHz was given through a system of Gunn oscillator, isolator, attenuator, directional coupler and the output measured by diode detectors. A special sample holder of bakelite was made for holding the stem such that the axis of stem was perpendicular to the E field in the waveguide.

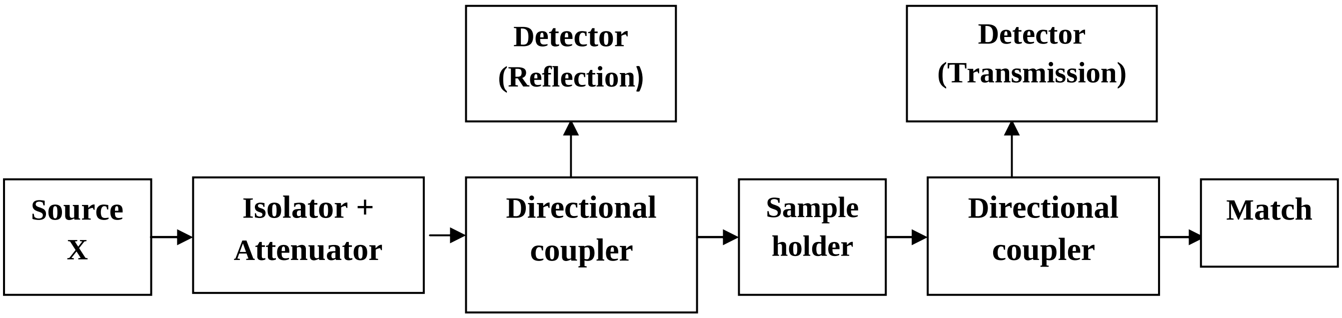

Fig.1 (a). Schematic of the microwave reflectometer measurement set up.

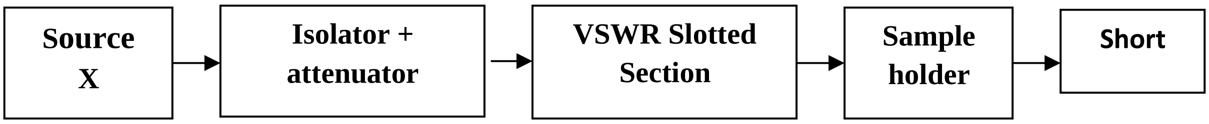

Fig.1 (b) . Schematic of the microwave VSWR measurement set up

The permittivity was measured using double minima method [12]. Initially the slotted section was calibrated with short as the load. The positions of the minima of the standing wave were obtained. The sample holder with the stem material was placed before the short and again the positions of the minima and the reflection coefficients were measured. Using Smith chart [12], the phase shift was measured. From the attenuation and phase shift the complex permittivity of the stem was calculated using the following equations [6].

$$\varepsilon' = \{1+ (\Delta\Phi\lambda_0/360d)\} \text{ and } \varepsilon'' = (\Delta A\ \lambda_0\ \varepsilon^{1/2})/\ (8.686\pi d)$$

where $\Delta\Phi$ is the phase difference with and without sample, ΔA the difference in attenuation with and without sample, d is the thickness of the sample

The effect of moisture content in the stem was also investigated. The moisture content on wet basis was measured gravimetrically. The percentage moisture was found using the following equation

$MC\ \% = (M_w/M_w+ M_d)\ X\ 100$ where M_w is the weight of water and M_d is the weight of dry material.

Initially the fresh stem was studied and it was kept for drying naturally for 24 Hrs at room temperature. After every drying period the weight was measured and microwave studies done. The results reported are after removing the effect of sample holder.

RESULTS AND DISCUSSION

The perturbation in transmittance and reflectance as measured from reflectometer method is shown in figures 2 and 3 respectively.

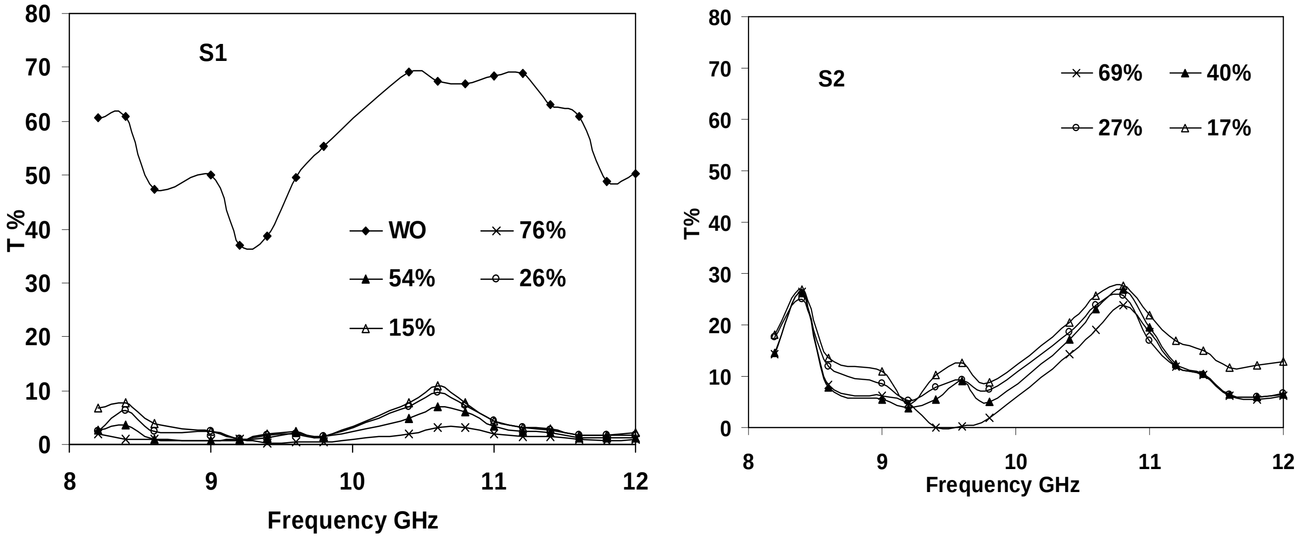

Fig. 2. Perturbation in transmission due to stem

The transmittance and reflectance without sample (WO) has also been plotted for reference.

The transmittance was ~60% and reflectance ~2.5% of the system without the sample. The effect of the stem is to decrease the transmittance and increase the reflectance. The fresh stem from the top of branch (S1) had ~76% MC whereas S2 had ~69% MC. The initial rate of decrease of moisture content after 24Hrs drying of S2 was larger as compared to S1.

In the transmission mode a peaking tendency is observed whereas in the reflection mode large dispersion is obtained. The introduction of S1 in the path produces larger reduction in transmission than S2.

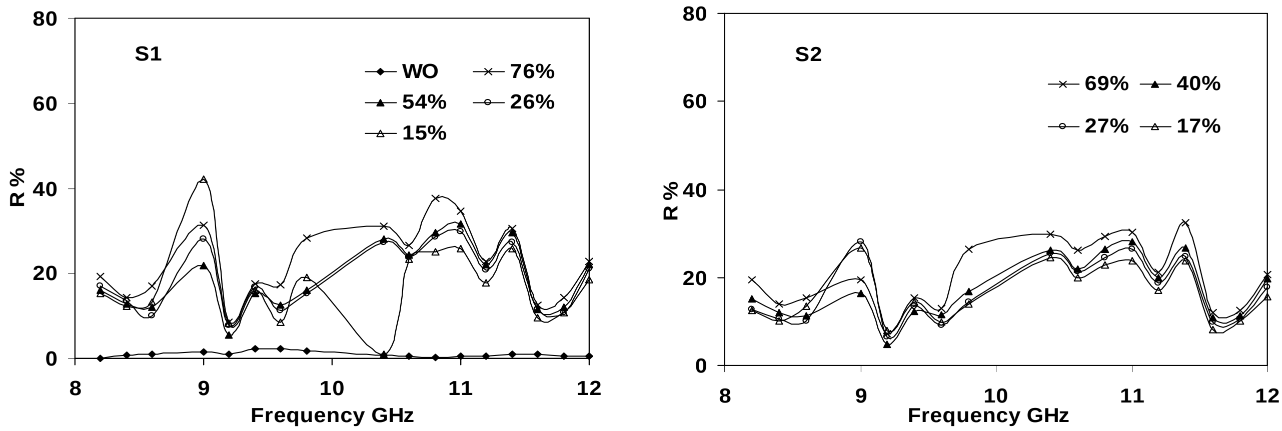

Fig.3. Perturbation in reflection due to stem

As the moisture content decreases transmittance increases and reflectance decreases. An interesting result obtained is that between 10-11 GHz the transmittance and reflectance both are high.

Figure 4 depicts the variation of ε' and figure 5 that of ε'' as a function of frequency. From the figures it is seen that the dielectric constant ε' lies in the range 20-40 in the frequency range 8-9.5 GHz and 10.5-12 GHz. In the frequency range 9.5-10.5 GHz the ε' curve shows peaking tendency with a maximum ε' of ~75-80 at 10 GHz. The dielectric loss factor ε" curve also shows a peak value of ~ 180 at 10 GHz. At other frequencies below 9.5 GHz ε" is ~ 30-90 and shows oscillatory behaviour beyond 10.5 GHz. As moisture content decreases both ε' and ε" decreases.

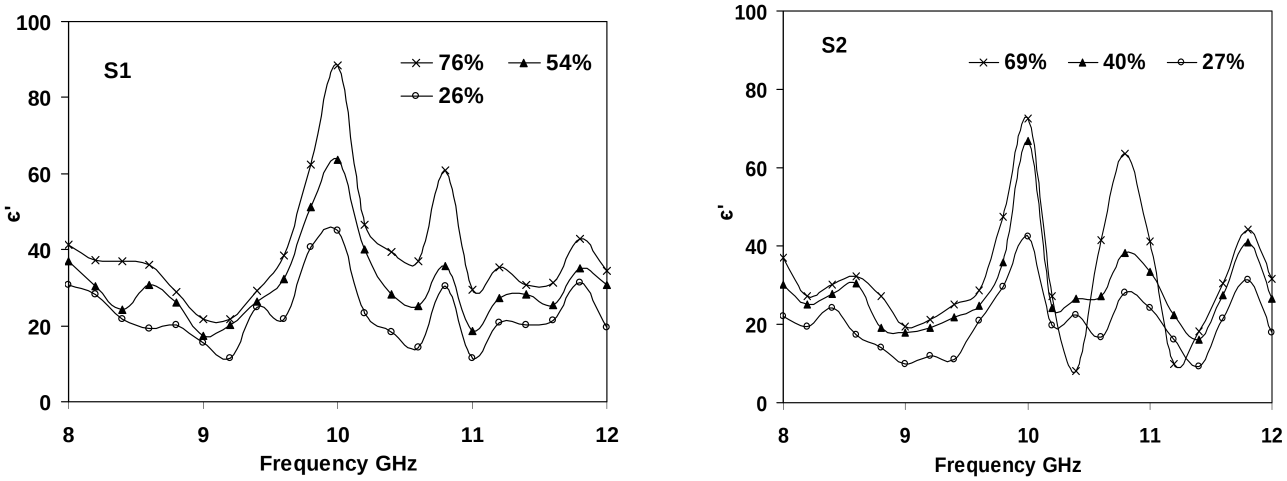

Fig. 4. Real permittivity ε' as a function of frequency and moisture content

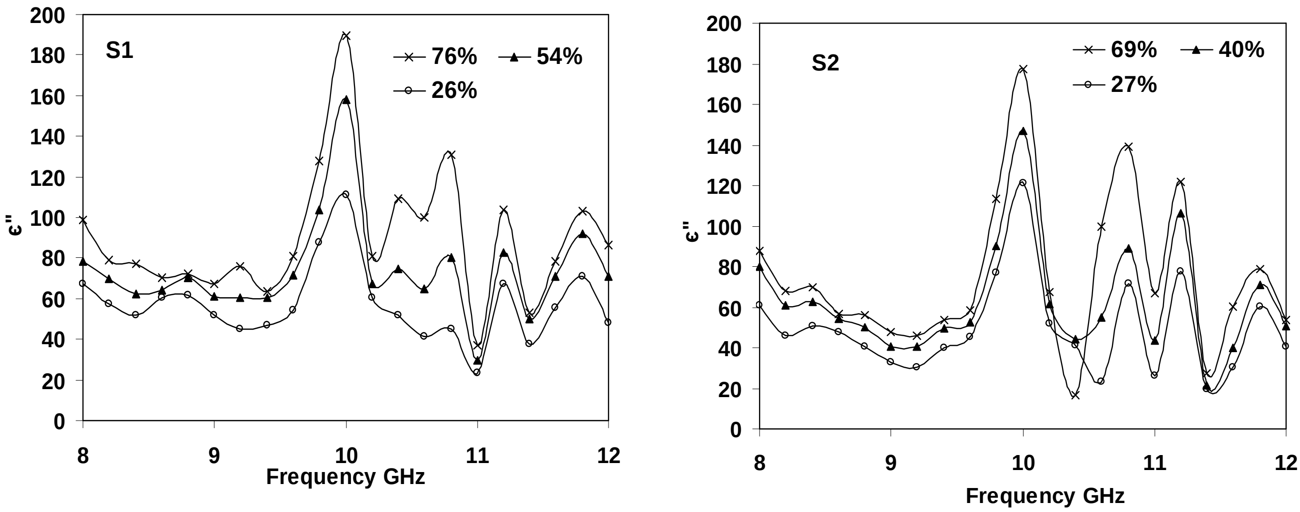

Fig.5. Moisture dependent dielectric loss

The real and imaginary part of stem impedance as calculated from VSWR measurements is tabulated in table 1. The microwave impedance is given by Z= R + jX

where X can be +ve or –ve.

Table I. Data of microwave impedance of stem as measured by VSWR method.

Microwave Impedance						
Type of stem →	S1 Moisture content			S2 Moisture content		
Frequency GHz ↓	76 %	54 %	26 %	69 %	40 %	27 %
8.2	31 + j17	30 – j19	35 – j22	33 + j17	34 + j21	63 – j40
8.6	34 + j11	33 – j4	40 – j3	37 – j31	30 – j26	19 + j17
9.0	45 - j39	61 – j33	70 + j37	17 – j15	21 – j15	21 – j17
9.6	14 - j10	20 + j19	24 + j19	27 + j21	16 – j11	56 + j7
10.0	37 + j28	29 + j17	50 – j10	26 – j17	29 + j17	60 – j35
10.6	27 + j21	30 – j21	35 + j22	14 – j10	27 – j15	12 – j8
11.0	17 - j13	21 – j15	14 + j10	24 – j16	61 – j33	17 + j9
11.6	37 - j31	50 –j37	63 – j40	34 + j11	35 – j16	35 – j22
12.0	33 + j17	36 – j27	47 – j13	31 + j17	36 – j27	35 + j5

From the table it is seen that in general for higher moisture content the real impedance is less than 50Ω, the characteristic impedance of the system and the reactance shows both capacitive (-ve) and inductive (+ve) effects. There is systematic change from capacitive to inductive due to frequency or moisture content.
The stem is the major carrier of water and other minerals to the various parts of the plant. The structure of the stem bearing the leaves is such that the topmost portion is denser than the lower portions. The water content is more in S1 than in S2. The stem is a heterogeneous material consisting of materials with different dielectric behaviors.
When stem is kept in the path of microwaves in the waveguide, the electromagnetic waves are perturbed due to the properties of the stem. These perturbations are seen as changes in transmission and reflection. In the transmission mode microwave passes through the entire material, whereas in reflection mode only the surface is involved. S1 is more densely packed than S2 which is more fibrous and hollow due to which the transmittance is larger due to S2 and reflectance higher due to S1.

In almost all vegetation related biomaterials water is the most dominant factor dictating the dielectric behaviour at microwave frequencies. If it were only moisture effects it is expected that as the moisture content decreases, the dielectric loss factor ε" should decrease. Since at many frequencies ε" increases it seems that the effects other than only moisture content also play a role.

The impedance also indicates the measure of perturbation. The waveguide system has a characteristic impedance of 50 Ω. Any perturbation in the form of unmatched load (stem) changes the VSWR from 1. The amount of deviation from 50Ω indicates the lossy nature of the material.

CONCLUSION

Moisture dependent microwave perturbation and permittivity has been measured for vegetation biomaterial the stem of Ficus Bengalanesis. Since the complex permittivity and impedance are intrinsic properties, they can be extracted from the reflection and transmission measurements. The permittivity decreases with decrease in moisture content in the stem. The microwave impedance shows both capacitive and inductive reactance varying randomly with frequency and moisture content.

The amount of the biomaterial required for these measurements being very small the VSWR technique can be used as moisture sensor or also as dielectric sensor for various solid biomaterials materials.

Acknowledgement
One of the authors Vijaya Puri gratefully acknowledges the UGC India for Award of Research Scientist 'C'. P.D. Kamble is thankful to the Management, and Principal New college Kolhapur.. The authors acknowledge UGC-SAP, DST-PURSE and DST-FIST.

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