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Microwave permittivity and moisture prediction of sunflower seeds using non resonant Ag thick film microstripline as a sensor

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ABSTRACT

In this paper the studies in the Ku band (13-18 GHz) of non resonant Ag thick film microstripline overlaid with moisture laden sunflower (Helianthus Annuus) seed is reported. The perturbation obtained in the transmittance and reflectance of the thick film microstripline due to the sunflower overlay has been used to obtain permittivity. Using the amplitude data the permittivity and moisture content of moisture laden sunflower seed has been predicted by overlay technique. As moisture content increases microwave dielectric constant, dielectric loss and conductivity of sunflower seed increases. Ag thick film microstripline is sensitive to very low moisture content in the overlay material. From the permittivity, the calibration factor for moisture sensing has been found and the moisture content in the sunflower seed has been predicted. The predicted moisture content and actual moisture content of the sunflower seed are almost identical.

Key Words: Microstripline, sunflower seed, moisture content, permittivity, microwave.

INTRODUCTION

Agricultural biomaterials are basically materials consisting of organic and inorganic inclusions along with water. In the microwave region of the electromagnetic spectrum, dielectric properties of the moist granular materials depends on frequency, moisture content, bulk density and temperature [1,2]. Oil seeds form a major constituent of the agricultural and food sector. The dielectric properties of the grains due to the presence of water in varying quantities can be detected using microwave methods [3]. Various microwave techniques [4-10] have been used to study the moisture content (MC %). The authors in reference [8-10] have used a thin film resonating component to predict moisture content.

The simple miniaturized microstripline is a non resonant component. In the previous papers [11,12] we had reported the use of Ag thick film Microstripline for predicting the moisture content of soybean and groundnut seed. In this paper, the overlay technique has been used on the same non resonant Ag thick film microstripline to predict the moisture content of sunflower seeds (*Hellanthus Annuus)* using the Ku band microwave permittivity. The sunflower seeds are smaller in size than the soybean and groundnut and also it has more oil content due to which the equilibrium moisture content is lesser than the other two seeds. Though the methodology used is similar to that reported in our previous papers [11,12], this work proves the efficacy of the overlay method for moisture prediction even for very small samples and high oil content. To the authors knowledge there are no reports on the use of non-resonant Ag thick film microstripline to predict moisture content and permittivity of sunflower seeds.

MATERIALS AND METHODS

The width of thick film microstripline was 25mil. The Ag thick film microstripline (figure1) was delineated by screen printing silver on 96% alumina (Kyocera, Japan) substrate and fired at 700^0C by conventional thick film firing cycle in the three zone furnace. The microwave transmittance (S_{21}) and reflectance (S_{11}) measurements were made point by point in the frequency range 13-18 GHz with the help of microwave bench consisting of Gunn source, isolator, attenuator, directional coupler and detector.

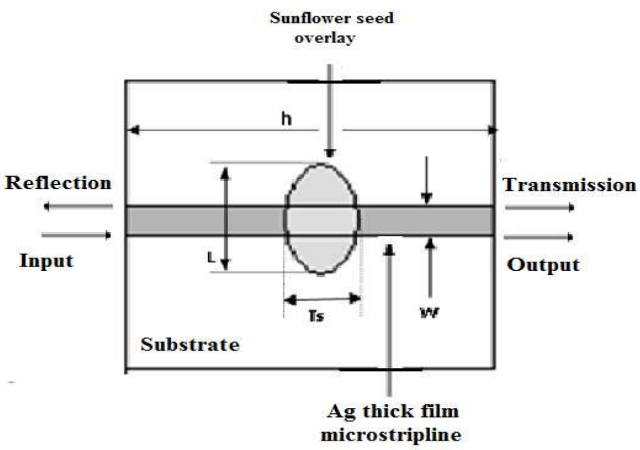

Fig.1: The schematic of Ag thick film microstripline with sunflower seed overlay [11,12] The geometry of microstripline showing a cross section (not to the scale): w, width of the microstripline= 0.0635cm; h, length of substrate = 2.54cm; L, length of sunflower seed;

Ts, **thickness of the seed**.

In this technique, the change in transmission and reflection of the microstripline with a single sunflower seed with different moisture contents kept at the center the microstripline were measured. Fig.1 shows the schematic of the microstripline with sunflower overlay. The investigations were done for as it is seeds, fully soaked for 24 hours and dried naturally upto 144 hrs. The moisture content was measured on wet basis using gravimetric method.

The sunflower seed was held in place with pressure block of thermocol on it to ensure better contact between circuit and seed and to avoid air gap. For this thermocol block was used. The thermocol block did not change the characteristics of microstripline when placed over them. Three identical thick film microstriplines were investigated and six sunflower seeds with same moisture content were used as overlay. All sunflower seeds had ellipsoidal shape and the sample to sample variation in thickness was ~ 0.006cm and variation in length was ~0.008 cm. The seed to seed variations were of the order of ~ 0.02 in transmittance. Due to excellent source of dietary fiber, protein and rich in cholesterol lowering phytosterols sunflower seed was chosen. The as obtained seed had a moisture content of 4.22%. These were soaked in distilled water for 24 hrs for maximum moisture absorption as confirmed by no further weight increase of the seed as measured by microbalance (K-16Micro, accuracy 0.001 mg). Eight moisture levels from 4.22% to 34.78% were measured for all the six sunflower seeds. Due to moisture the thickness of the seed varied from 0.46-0.58cm, length from 1.22-1.46cm and bulk density from 0.18-0.24g/cm^3. All the measurements were conducted at room temperature (27^{0}C).

RESULTS AND DISCUSSIONS

Since overlay technique was used for permittivity measurement and moisture detection, the characteristics of the Ag thick film microstripline without overlay was studied. The transmittance of the thick film microstripline is between 0.6 and 0.7 and reflectance is between 0.03 and 0.05 for the microstripline without overlay with almost no dispersion.

The perturbation in transmission and reflection due to sunflower overlay and without the overlay on Ag thick film microstripline in the frequency range 13-18GHz is shown in Fig. 2 with error bars indicating ± one standard deviation from mean value.

Due to the moisture laden sunflower overlay the average (average of six seeds) transmittance decreases and reflectance increases.

Figure 3 shows the reflectance as a function of moisture content only for 13GHz, 15GHz and 18GHz frequencies. From the figure, it is seen that the vertical spread of the data points indicates the seed to seed variations. Frequency dependent reflectance is obtained indicating scope for choice of frequency with maximum variations. The slope of the reflectance curve appears to be larger only for 13GHz and 15GHz indicating better moisture sensitivity while as 18GHz indicating lower moisture sensitivity.

From the reflection coefficient, the dielectric constant was calculated using the curve fit equation suggested by Gouker et al. [13]. Using the data of change in transmittance of the microstripline due to sunflower overlay the dielectric loss (ε”) was calculated using the expression by Kim et al. [4].

The graph of dielectric constant (έ) and dielectric loss (ε”) vs. moisture content (%) is shown in Figure 4. From this figure, it is seen that as moisture content (%) increases dielectric constant (έ) and dielectric loss (ε”) also increases. Only for 13 and 18 GHz frequency data of all the six seeds are plotted and for 14 -17 GHz only data of one seed is plotted. The vertical spread of the data points is due to the variation of frequency. The dielectric loss shows behavior similar to dielectric constant. The sunflower seed exhibit low dielectric constant. The dielectric constant (έ) of the seed varies from 2 to 6 and dielectric loss (ε”) ~ 0.04 to 1.2.

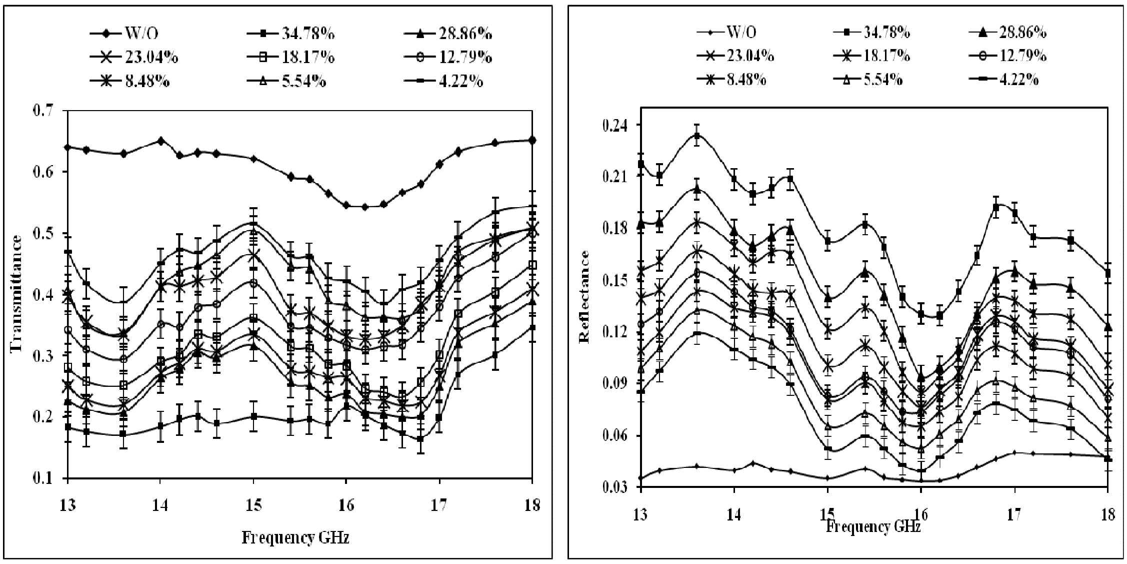

Fig.2. Perturbation in transmission and reflection due to sunflower overlay with error bars W/O –Without overlay, % - Moisture content %

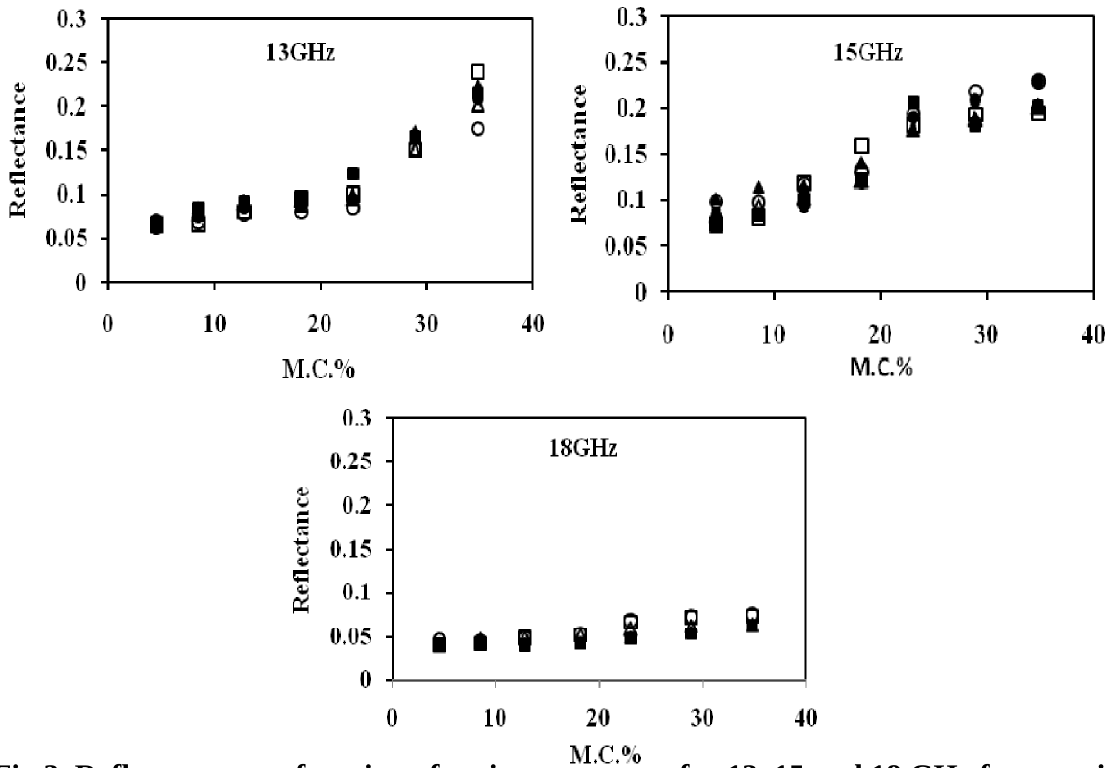

Fig.3. Reflectance as a function of moisture content for 13, 15 and 18 GHz frequencies. M.C. % - Moisture Content

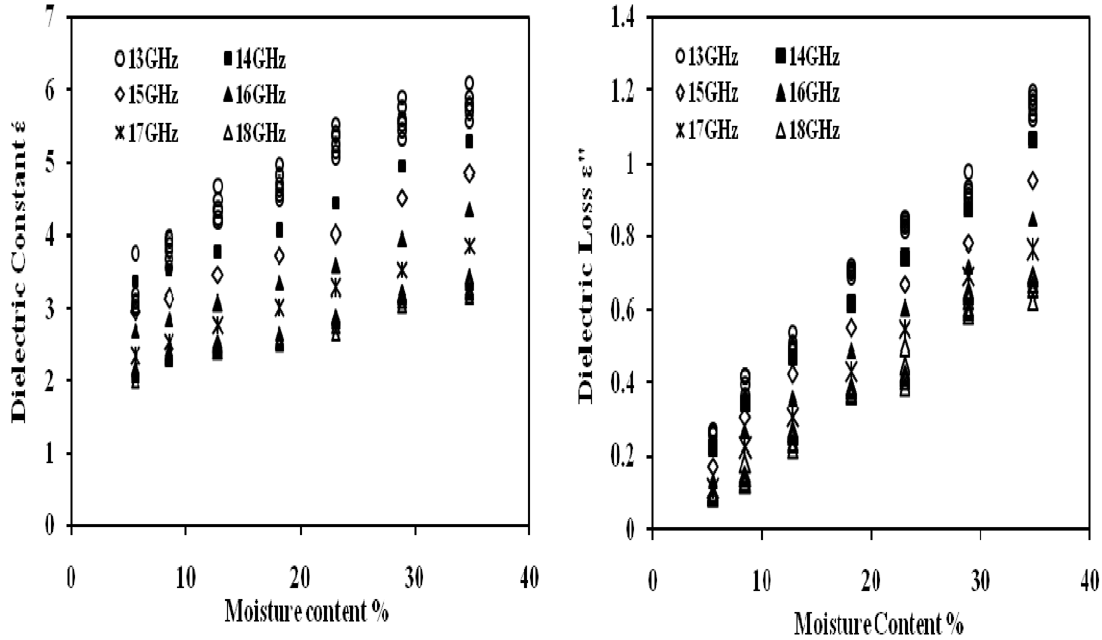

Fig.4. Dielectric constant (ɛ́) and Dielectric loss (ɛ”) as a function of moisture content (%) for Sunflower at different frequencies.

Table 1: Data of microwave conductivity(S/cm) for different frequencies and moisture contents

Microwave conductivity(S/cm)								
Moisture content %→ Frequency GHz ↓	**34.78**	**28.86**	**23.04**	**18.17**	**12.79**	**8.48**	**5.54**	**4.22**
13	0.86	0.70	0.60	0.51	0.38	0.28	0.19	0.13
14	0.83	0.68	0.57	0.48	0.36	0.26	0.18	0.10
15	0.79	0.65	0.55	0.45	0.35	0.25	0.14	0.08
16	0.75	0.64	0.53	0.43	0.31	0.23	0.12	0.07
17	0.72	0.62	0.51	0.40	0.29	0.21	0.10	0.05
18	0.68	0.61	0.49	0.38	0.26	0.18	0.09	0.04

The microwave conductivity of sunflower seed was calculated using the dielectric loss.

$$\sigma = \omega\, \varepsilon''\, \varepsilon_o \qquad (1)$$

Where $\omega = 2\pi f$ here f is frequency in GHz.

ε_o= permittivity of free space = 8.85 x 10^{-12} SI unit
And ε"= dielectric loss

The microwave conductivity value obtained by this method varies from 0.04 to 0.86 S/cm. As frequency increases conductivity decreases while as moisture content increases conductivity also increases. The microwave conductivity due to sunflower seed overlay for all frequencies and moisture contents (%) is tabulated in Table 1.

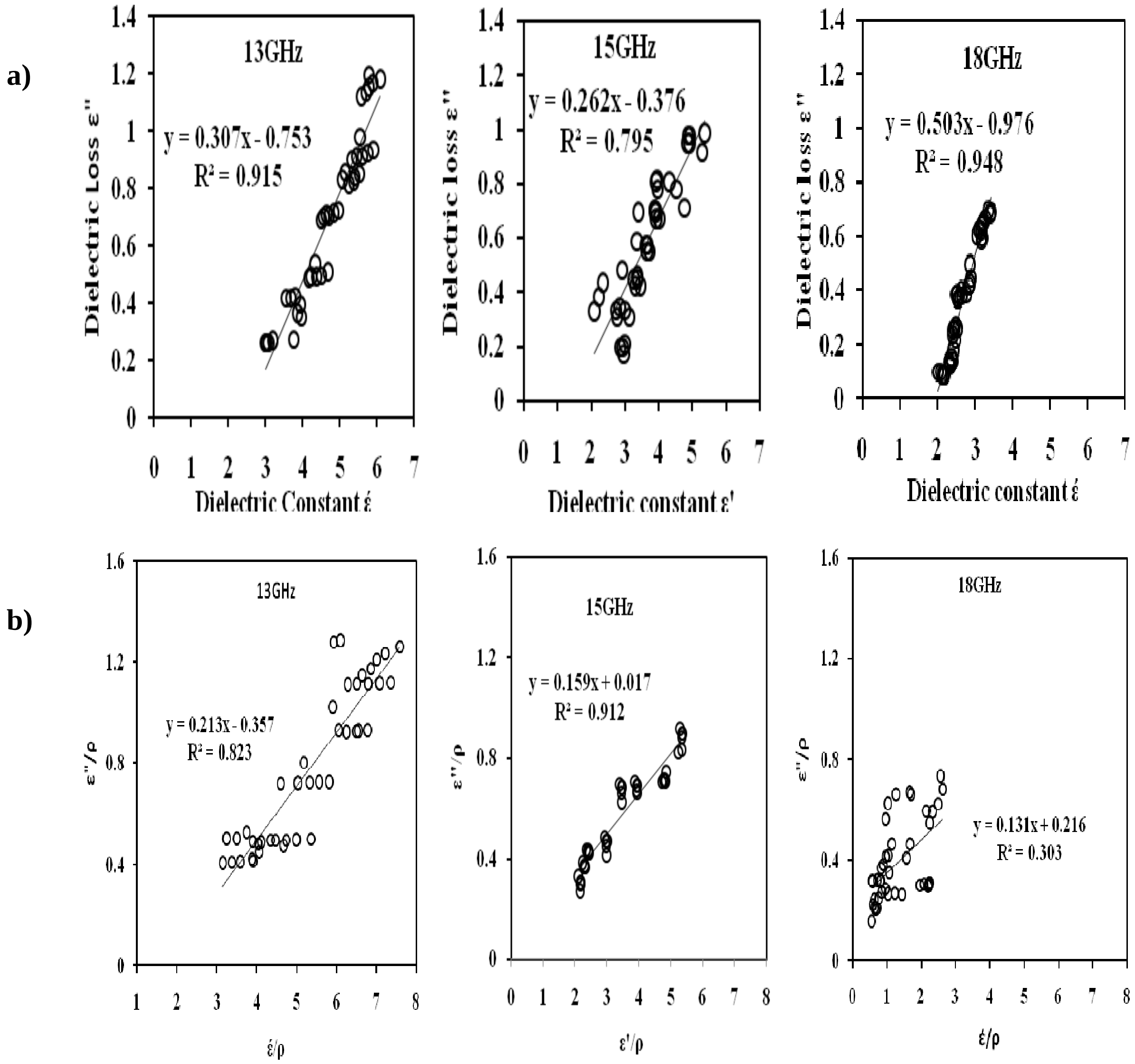

Fig. 5. Variation of dielectric loss with dielectric constant (a) Dielectric loss (ε") as a function of dielectric constant (έ) and (b). Dielectric loss divided by bulk density (ε"/ρ) as a function of dielectric constant divided by bulk density (έ/ρ) at 13,15 and 18GHz frequency.

Though moisture content is a major component in the wave-material interaction at microwave frequencies the densities also play a definite role. For moisture content prediction, compensation has to be done for the density effects. A calibration equation has to be used to provide single moisture content for a particular frequency.

Figure 5 (a) shows the dielectric loss (ε”) as a function of the dielectric constant (έ) for sunflower seeds at 13, 15 and 18 GHz for different moisture contents. From the figure, it is seen that both dielectric constant and dielectric loss show a slight decrease with increasing frequency while as moisture content increases dielectric constant and dielectric loss also increases.
The vertical spread of the data points is due to the variation of moisture contents (%). A cluster of data points is obtained in the complex plane. This gives the distribution of the electric field energy between dissipated and stored energy within the sunflower seed.

When the complex permittivity is normalized to bulk density and plotted, the slope of the straight line is the coefficient a_f which is dependent on the frequency alone [6,14]. The equation governing the various parameters is,

$$\psi = \sqrt{\frac{\varepsilon''}{\varepsilon'\left(a_f\varepsilon' - \varepsilon''\right)}} \qquad (2)$$

Figure 5(b) shows the loss factor (ε”) divided by bulk density as a function of the dielectric constant (έ) divided by bulk density for sunflower seeds of different moisture contents at three different frequencies (13, 15and 18 GHz) where the points are located along a straight line.
From the figure, it is seen that the slope decreases as frequency increases. The X-axis intercept is characteristic of the material and represents the normalized dielectric constant of dry sample. As moisture content increases, the mobility of the water molecules increases, making their contribution to the polarization of the medium higher and increasing the losses at the same time.

At 13 GHz, a_f is 0.213, at 15 GHz 0.159 and 0.131 at 18 GHz. For a_f determination, measurements at one frequency and one moisture content are sufficient. After obtaining ε’ and ε”, the calibration permittivity function ψ is computed for each sample at different frequencies and moisture content. Figure 6 shows the variation of ψ as a function of moisture content at 13, 15 and 18 GHz for sunflower seeds.

Linear fitting provides the frequency-dependent coefficient, intercept and coefficient of correlation which are tabulated in Table 2. Consequently, a single calibration equation can be established and used for moisture content determination for sunflower from the measurement of their dielectric properties at microwave frequencies. The following linear fitting is used to correlate ψ with moisture content:

For 13 GHz,	$\Psi = 0.002M + 0.347$	$r^2 = 0.860$	(3)
For 15 GHz,	$\Psi = 0.002M + 0.380$	$r^2 = 0.902$	(4)
For 18 GHz,	$\Psi = 0.003M + 0.405$	$r^2 = 0.854$	(5)

From equation (3) and (4) the universal moisture calibration equation is determined as

For 13 GHz, $M = 291.7\Psi - 98.74$ (6)

For 15 GHz, $M = 260.4\Psi - 92.07$ (7)

For 18 GHz, $M = 221.2\Psi - 79.97$ (8)

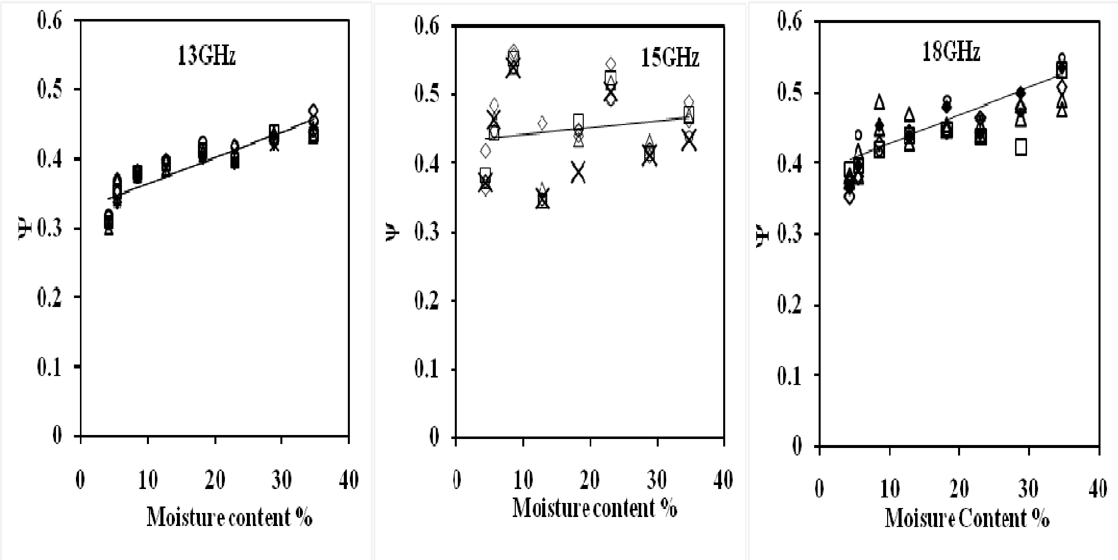

Fig. 6 Moisture dependence of calibration function (ψ) for sunflower seeds (six seeds) at 13 GHz, 15 GHz and 18 GHz frequency

In figure 7 the moisture content predicted in each sunflower seed by equation (6),(7) and (8) versus the actual moisture content for three different frequencies are plotted. The data points lie along the straight line that corresponds to the ideal relationship.

Effectiveness of equation (6), (7) and (8) in determining moisture content in sunflower seeds can be evaluated by calculating the standard error of performance (SEP) which is given by, (SEP) given by Trabelsi et al [6,14].

$$SEP = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(\Delta M_i - M)^2} \quad (9)$$

Where, N is the number of samples.

$\Delta M_i =$ difference between the predicted and actual value of moisture content.

And $$M = (1/N)\sum_{i=1}^{N} \Delta Mi$$

The value of SEP is given in Table 2. From the table it is seen that as moisture content increases SEP increases and also it increases with frequency. This might be related to the scattering effects and losses occurring in the microstripline. The reflection coefficient has been used for dielectric constant calculations and since Ag thick film microstripline has been used as the device for determination of the various parameters, the inherent losses in the component adds to the measurement errors.

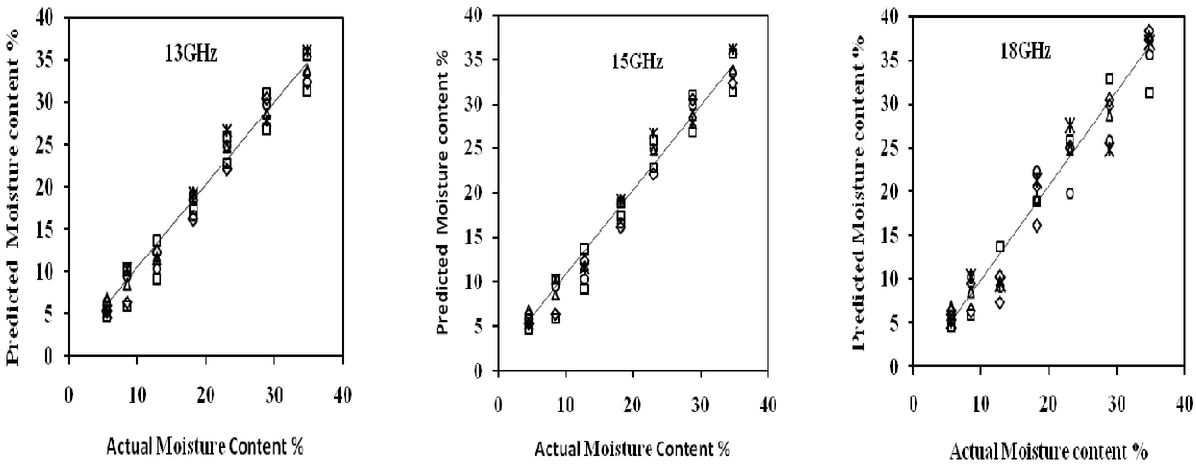

Fig.7 Predicted moisture content versus actual moisture content for sunflower seed at 13 GHz, 15GHz and 18GHz

The basic microstripline is an open structure which is capable of supporting an infinite number of modes. Usually designing is done to allow propagation by fundamental mode only. The designing of the microstripline has been made with alumina as substrate and air as dielectric on top. Owing to overlay the parameters on the top changes. Granular biomaterials like as oilseeds are complex random dense media consisting of mixtures of components with various dielectric behaviours. Since the sunflower seed is kept as overlay the microwaves in the form of fringing field on the microstripline interacts with only part of seed and not with the absolute water content of the seed. When the seed is used as overlay there is a possibility of air gaps present below the overlay. The overlay material does not conform to the conductor contour. The size of the overlay is also smaller than the length of the circuit. Since the seed is placed at the center of the microstripline the electromagnetic waves suddenly meet a partially perturbed situation with a different dielectric constant.

Table 2: Frequency dependent coefficient (a_f), intercept (k), correlation coefficient (R^2) and Standard Error of Performance (%) (M.C.-Moisture content)

Frequency (GHz)		**13**	**14**	**15**	**16**	**17**	**18**
a_f		0.213	0.209	0.159	0.164	0.182	0.131
k		-0.357	-0.193	0.017	0.112	0.171	0.216
R^2		0.823	0.949	0.912	0.719	0.711	0.303
SEP, %	**34.78% M.C.**	0.23	0.27	0.29	0.35	0.38	0.42
	4.22% M.C.	0.13	0.17	0.23	0.28	0.34	0.37

Since major contribution to the reflected energy from a biomaterial comes from the moisture, the microwave transmission and reflection data obtained will help in identifying the biomaterial features.

CONCLUSION

Our results indicate that overlay technique on a non resonant microstripline can be used to fabricate a nondestructive dielectric and moisture sensor for granular bio materials as small as a sunflower seed. The perturbation causes changes in electrical parameters which are governed by the dielectric constant and size of overlay. Due to shape of seed partial overlay and moisture dependent effects are observed in the microstripline. The thick film component along with overlay can be cost effective dielectric and moisture sensor especially for biomaterials, since any size and shape of the overlay can be used. Ag thick film microstripline has been successfully used to predict the moisture dependent dielectric constant, loss factor and conductivity of sunflower seeds. The permittivity of seeds increases with increase in moisture. The calibration function (Ψ) has been expressed in terms of two components of the relative complex permittivity (έ and ε”) which are intrinsic electrical properties of the material. It also takes into account the energy distribution and integrates effects on frequency and moisture content. A non resonant cost effective miniaturized microwave component can be used as a non destructive sensor for measuring dielectric constant and moisture content in individual sunflower seed that is easy to use. It can be of potential use in many applications, particularly for on-line configurations for monitoring and control of such entities.

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