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Ag thick film microstripline as nondestructive dielectric and moisture sensor for soybean

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Abstract

A cost effective miniaturized Ag thick film microstripline 1in x 1in was used as a nondestructive dielectric and moisture sensor for soybean. The in-touch overlay method provides ease of loading and unloading. The perturbation obtained in the transmittance and reflectance of thick film microstripline due to the Soybean overlay has been used to obtain the permittivity. The changes in the moisture content in the seed produces frequency dependent changes in the characteristics of microstripline. As the moisture content increases the dielectric constant and dielectric loss increases. Microwave conductivity decreases with moisture content. A simple relationship between dielectric properties and bulk density is indentified, and a new density-independent function for moisture content prediction is proposed. Explicit calibration equations for moisture prediction at different frequencies and moisture contents are provided.

Key words: Moisture sensor; Microstripline; Permittivity; conductivity; soybean; microwave.

Introduction

Among the various oil seeds Soybean is very useful due to its high nutritional value. The permittivity of these materials is of vital importance in understanding their behavior when exposed to moisture and also electromagnetic fields. Moisture content determines the quality and shelf life of these materials. Oil seeds form a major constituent of the agricultural and food sector. The dielectric properties of the seeds are correlated with the moisture content. The presence of water in varying quantities can be detected using microwave methods [1,2].The resonant cavity perturbation method has been used to study nuts, seeds grains etc [3,4]. Free space measurements have been used more than any other methods [2,4,5]. The microstrip component being in planar form can offer an alternative miniaturized device for granular materials of uneven shape and size like oil seeds and cereal grains.

The use of thin film resonant microstrip component the ring resonator for moisture content measurement in grains has been reported [6-8]. Compared to thin film fabrication, thick film technology provides a cost effective mode of miniaturization. The perturbation of thick film microstripline components using various overlays has been studied by the authors group [9-12]. The simple microstripline is a non resonant component. The changes in the transmission and reflection of this component due to changes in the medium above the component can be used to characterize the material placed above it. A dielectric material overlaid on a microstripline perturbs its fringing field. This method is nondestructive and is useful irrespective of the size and shape of the overlaid material.

The main objective of this work was to use the overlay method on the simple miniaturized Ag thick film microstripline which is a non resonant component to predict the permittivity and moisture content of soybean seed when used as overlay. In this work soybean seed was chosen because of its excellent source of proteins and carbohydrates. The seed was kept as in touch overlay at the centre of the microstripline and change in the transmittance and reflectance at different moisture contents is reported. The microwave conductivity, dielectric constant and dielectric loss of soybean due to moisture content is also reported. The investigations are conducted in the Ku-Band (13-18 GHz). To the authors knowledge using Ag thick film microstripline the dielectric characterization and prediction of moisture content of bio vegetation has been reported for the first time.

Materials and Methods

The Ag thick film microstripline (figure1(a)) was delineated by screen printing silver on 96% alumina (Kyocera, Japan) substrate and fired at 700^0C by conventional thick film firing cycle. The width of thick film microstripline was 25mil. The microwave transmittance (S21) and reflectance (S11) 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. In this technique, the change in transmission and reflection of the microstripline with a single seed with different moisture contents kept at the centre the microstripline were measured. Figure 1shows the microstripline with overlaid soybean seed. The investigations were done for fresh seeds, fully soaked for 24 hours and dried naturally up to 144hrs. The moisture content was measured on wet basis using gravimetric method.

The 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. The thermocol block did not change the characteristics of microstripline when placed over them. Three identical thick film microstriplines were investigated and six seed samples with same moisture content were used as overlay. All soybean seeds had spherical shape and the sample to sample variation in thickness was ~ 0.01cm and variation in length was ~0.015 cm. The seed to seed variations were of the order of ~ 0.020 in transmittance and ~ 0.016 in reflectance. The as obtained seeds had a moisture content of 7.68%. These were soaked in distilled water for 28hrs for maximum moisture absorption as confirmed by no further weight increase of the soybean as measured by microbalance (K-16Micro, accuracy 0.001 mg). Eight moisture levels from 4.68% to 60.43% were measured for all the six soybean seeds. Due to moisture the thickness of the soybean varied from 0.46-0.61cm, length from 0.5-0.7cm and bulk density from 0.71-0.85g/cm^3. All the measurements were conducted at room temperature (27^0C) .

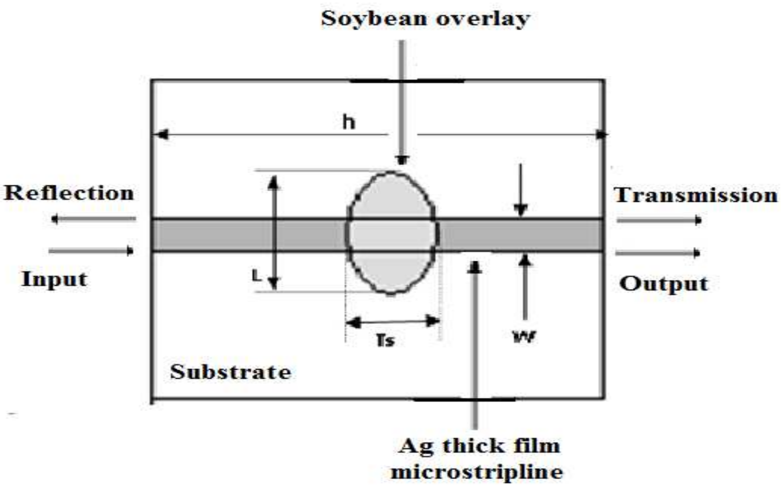

Fig.1: The schematic of Ag thick film microstripline with soybean overlay

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 soybean; Ts, thickness of the soybean.

Results and Discussion

Figure 2 shows the perturbation in transmission and reflection due to seed overlay and without the seed overlay on Ag thick film microstripline in the frequency range 13-18GHz. 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. Due to the moisture laden soybean overlay the average (average of six seeds) transmittance decreases and reflectance increases.

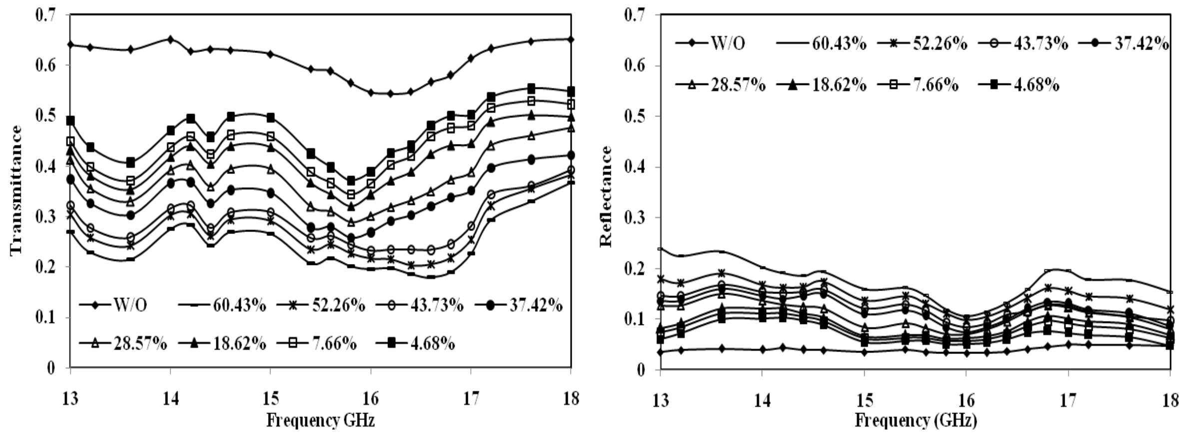

Fig.2. Perturbation in transmission and reflection due to seed overlay
W/O –Without overlay,% - Moisture content %

Figure 3 shows the reflectance as a function of moisture content for different frequencies. 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 for 13GHz and 15 GHz indicating better moisture sensitivity.

From the reflection coefficient, the dielectric constant was calculated using the equation according to Gouker et al [13]. Using the data of change in transmittance of the microstripline due to seed overlay the dielectric loss (ε”) was calculated using the equation by Kim et al [14].

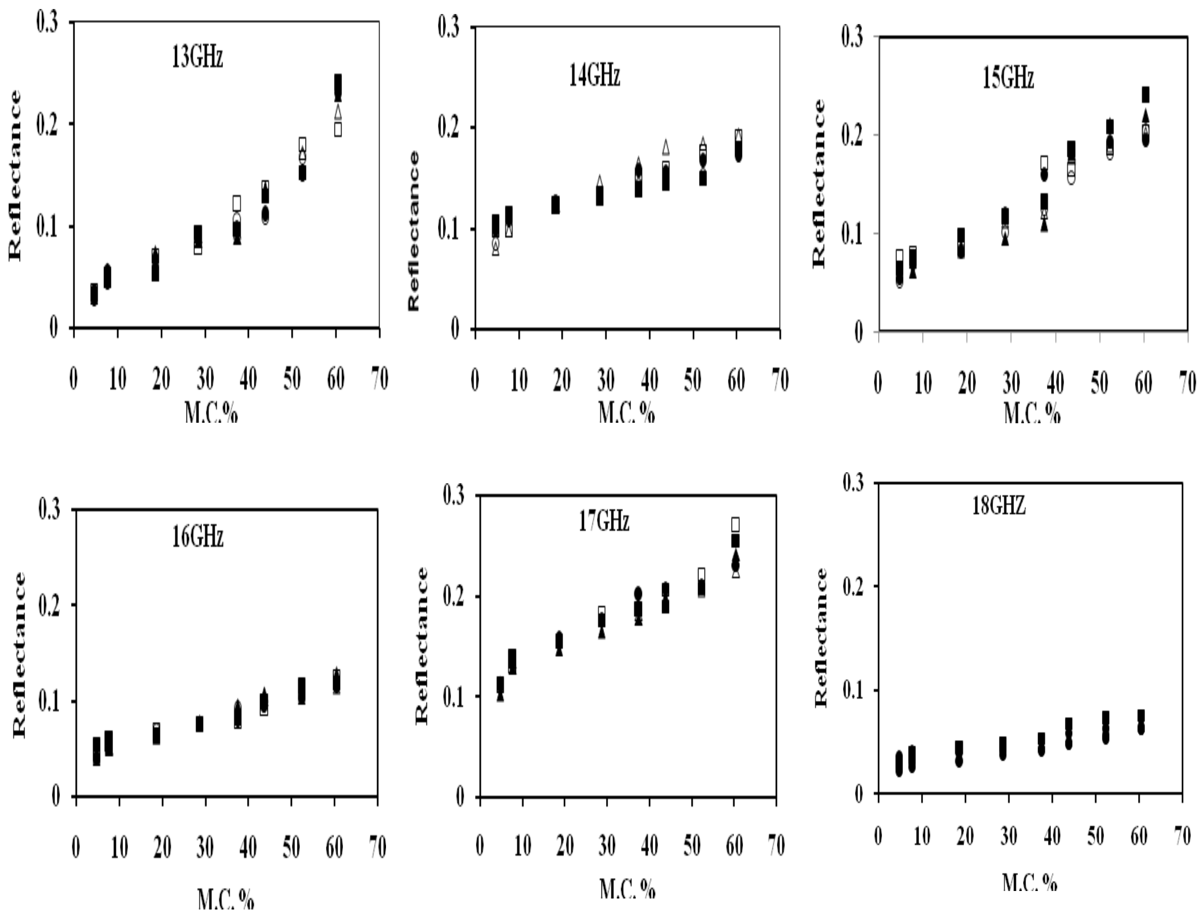

Fig.3. Reflectance as a function of moisture content for various frequencies

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 all six seeds data is plotted and for 14 -17 GHz only one seed data 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 soybean seed exhibit low dielectric constant. The dielectric constant (έ) of the seed varies from 2 to 8 and dielectric loss (ε”) ~ 0.1 to 2. These values are similar to those obtained by other workers using other techniques [4].

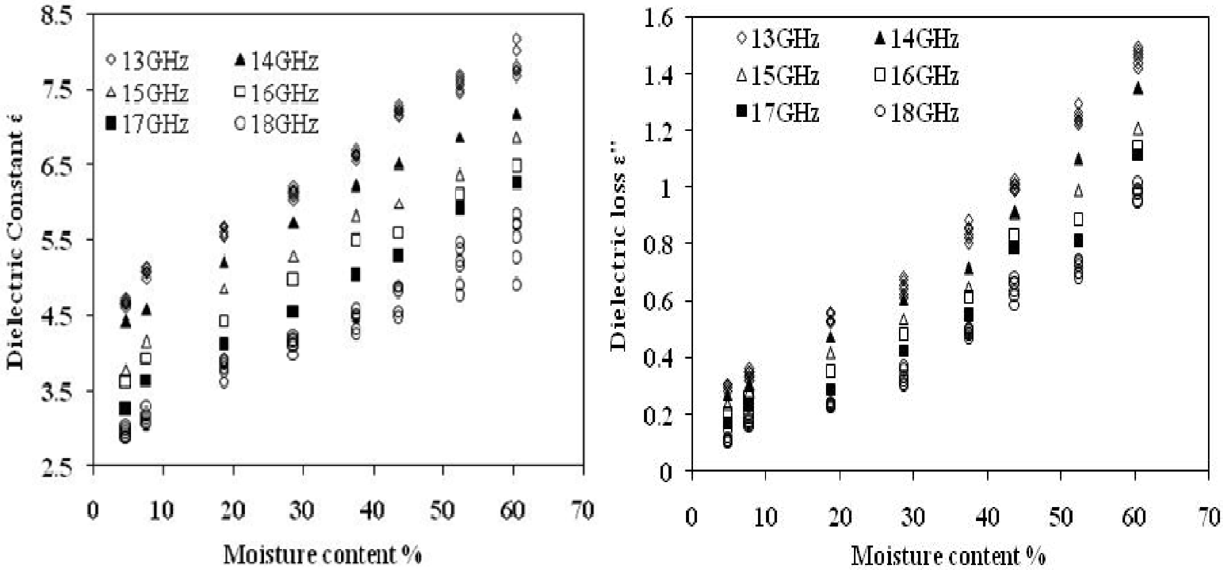

Fig.4. Dielectric constant (έ) and Dielectric Loss (ε”) as a function of moisture content (%) for Soybean seed at different frequencies

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 a single moisture content for a particular frequency.

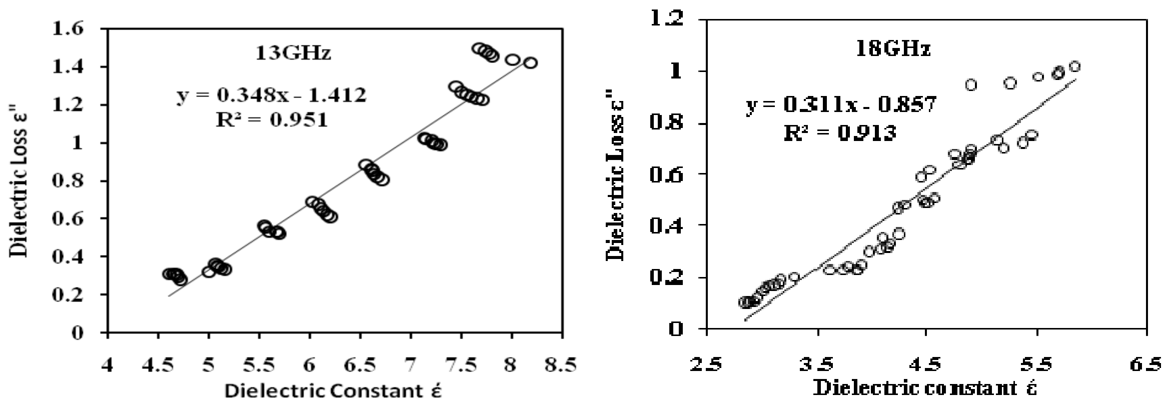

Fig. 5 Variation of dielectric loss with dielectric constant

Figure 5 shows the dielectric loss (ε”) as a function of the dielectric constant (έ) for soybean seeds at 13 and 18 GHz for different 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 soya bean seed. 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 (%).

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 [15]. The equation governing the various parameters is

$$\psi = \sqrt{\frac{\varepsilon''}{\varepsilon'\left(a_f\varepsilon' - \varepsilon''\right)}} \tag{1}$$

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 0.456 and 0.377at 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 and 18 GHz for soybean seeds.

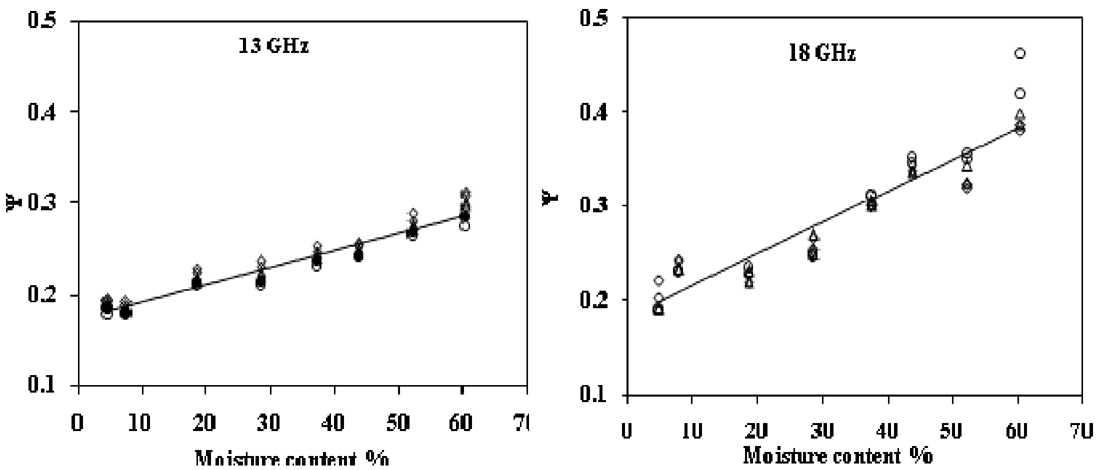

Fig. 6 Moisture dependence of calibration function (ψ) for soybean (six seeds)

Linear fitting provides the frequency-dependent coefficient; intercept and coefficient of correlation are tabulated in table 1. Consequently, a single calibration equation can be established and used for moisture content determination for soybean 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, $\Psi = 0.002M + 0.180$ $r^2 = 0.963$ (2)
For 18 GHz, $\Psi = 0.002M + 0.201$ $r^2 = 0.899$ (3)

From equation (1), (2) and (3) the universal moisture calibration equation is determined as
For 13 GHz, $M = 479.2\Psi - 85.41$ (4)
For 18 GHz, $M = 327.7\Psi - 62.79$ (5)

In figure 7 (a) and (b), the moisture content predicted in each seed by equation (4) and (5) versus the actual moisture content for two different frequencies are plotted. The data points lie along the straight line that corresponds to the ideal relationship.

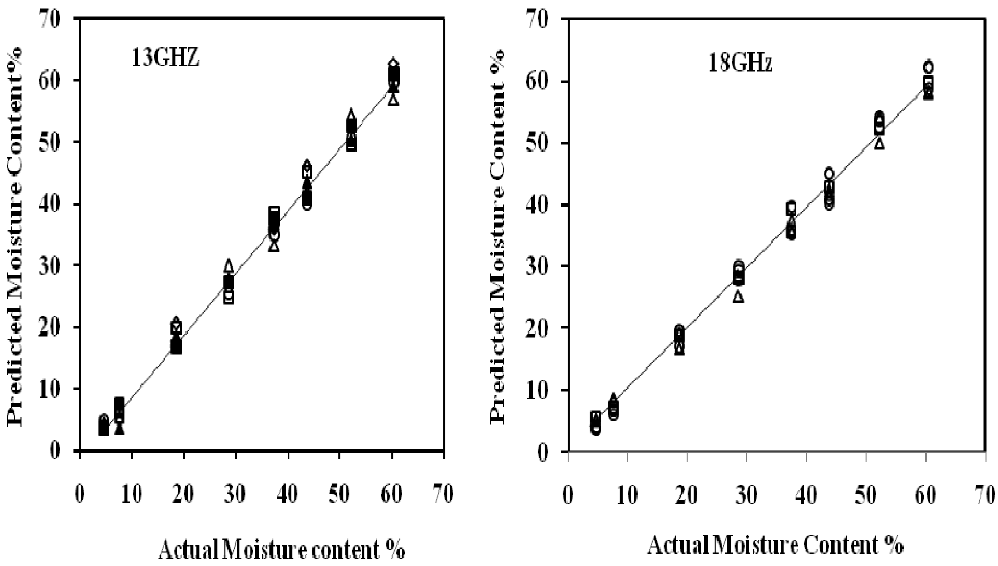

Fig. 7 Predicted moisture content versus actual moisture content for soybean seed

Effectiveness of equation (4) and (5) in determining moisture content in soybeans can be evaluated by calculating the standard error of performance (SEP) [2] which is given by,

$$SEP = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(\Delta M_i - M)^2} \qquad (7)$$

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 values of SEP is also given in table 1. 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.

Table 1: Data of a_f, intercept (k), correlation coefficient (R^2) and SEP (%) of linear regression (M.C.-Moisture content)

Frequency (GHz)		13	14	15	15	17	18
a_f		0.530	0.637	0.448	0.465	0.414	0.425
k		-3.231	-3.820	-0.252	-2.212	-1.763	-1.675
R^2		0.797	0.840	0.782	0.759	0.722	0.725
SEP, %	**60.43% M.C.**	0.21	0.32	0.32	0.47	0.49	0.54
	4.68% M.C.	0.10	0.16	0.27	0.30	0.43	0.47

Granular materials are complex random dense media consisting of mixtures of components with various dielectric behaviors. Since the soybean 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.

Our results are comparable to those obtained by other workers using free space technique of measurement, indicating that overlay technique on a non resonant microstripline can be used to fabricate a dielectric and moisture sensor for granular bio materials.

Conclusions

Ag thick film microstripline has been used to predict the permittivity and moisture content of moisture laden soya bean. 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 soyabean seed that is easy to use. 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. It can be of potential use in many applications, particularly for on-line configurations for monitoring and control of such entities. 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.

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