DETERMINATION OF THE COMPLEX PERMITIVITY OF MATERIALS USING A PARTIALLY FILLED WAVE GUIDE

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ABSTRACTS

A transmission line method for measuring the complex permitivity of bulk materials in the microwave region is presented. The method makes use of the complex propagation constant determined from mutiline TRL calibration for the partially filled wave-guide. In this method samples of two different lengths, and the port extension technique to extend the calibration plane of the VNA to the surface of the samples inside the wave-guide are used. The measurements were made in a X-band wave-guide partially filled with the Teflon blocks. From the measured Scattering parameters of the partially filled wave-guide with samples of two different lengths the dielectric constant and dielectric loss of the samples at different frequencies are determined.

1 INTRODUCTION

The study of the dielectric properties of materials is motivated by the continuously increasing number of applications involving electromagnetic fields and their interaction with matter. Microwave industrial and communication applications requires the knowledge of the permitivity of the involved materials. The choice of the measurement approach is mostly determined by the shape, consistency and extension of the material to be characterized. The transmission /reflection method is commonly used to measure the broadband complex permitivity of the dielectric materials [1]. In this technique the sample is inserted in a wave-guide or coaxial transmission line. The complex permitivity of the sample is determined using iterative algorithms from the calibrated scattering parameter measurements. The complex permitivity of the samples were also being determined using multiline TRL algorithm from the uncalibrated scattering parameter measurement [2]. In this method, two waveguides of different lengths are filled completely with a dielectric material. The waveguides must have identical cross sections but different lengths. The complex propagation constant can be determined from the measured scattering parameters for the wave guide transmission lines using the multiline Calibration algorithm [3]. We propose a method that uses Scattering parameters measured for the partially filed wave guide with the dielectric samples of two different lengths. The Scattering parameters were measured after extending the calibration plane of the VNA to the sample surfaces. After extending the calibration plane the partially filled wave guide with dielectric samples of length L_1 and L_2 is assumed as two wave guides of length L_1 and L_2 completely filled with dielectric materials. Now the mutiline calibration algorithm for the completely filled transmission lines can be applied to find out the complex propagation constant for the materials.

2 THEORY

We use the multiline [3] method for determining the propagation constant from the measured Scattering parameters for the wave guide with the dielectric samples of two different lengths. Using the measured Scattering parameters for one of the samples form the cascade matrix as defined below

$$M_i = \frac{1}{S_{21_i}} \begin{bmatrix} \left(S_{12_i} S_{21_i} - S_{11_i} S_{22_i}\right) & S_{11_i} \\ -S_{22_i} & 1 \end{bmatrix} \tag{1}$$

Similarly from the measured Scattering parameters from the other sample form the cascade matrix M_j as defined above.

The cascade matrix for an ideal transmission line of length l is defined as

$$T = \begin{bmatrix} e^{-\gamma l} & 0 \\ 0 & e^{\gamma l} \end{bmatrix} \tag{2}$$

where γ is the propagation constant and l is the length of the transmission line .The measured cascade matrices of two transmission lines 1 and 2 of differing lengths can be combined to form an eigen value equation.

$$M_{ij} X = X T_{ij} \tag{3}$$

where

$$M_{ij} = M_j [M_i]^{-1} \tag{4}$$

and

$$T_{ij} = T_j [T_i]^{-1} \tag{5}$$

Here the matrix M_{ij} is a two by two matrix whose eigen values are represented by λ_{1M} and λ_{2M} where λ_{1M} and $\lambda_{2\,M}$ are defined as

$$\lambda_{1M}, \lambda_{2M} = \frac{(M_{11} + M_{22}) \pm \sqrt{(M_{11} - M_{22})^2 + 4M_{12}M_{21}}}{2} \tag{6}$$

Here M_{11},M_{22},M_{12} and M_{21} are the elements of the matrix M_{ij}
The two eigenvalues λ_{1T} and λ_{1T} of T_{ij} are

$$\lambda_{1T}, \lambda_{2T} = e^{\pm\gamma(l_2 - l_1)} \tag{7}$$

Combining equation (6) and (7) to solve for the propagation constant

$$\gamma = \frac{\ln(\lambda)}{l_1 - l_2} \tag{8}$$

where λ is the average of the two eigen values

$$\lambda = \frac{1}{2}\left[\lambda_{1M} + \frac{1}{\lambda_{2M}}\right] \tag{9}$$

The complex propagation constant γ can be expressed in terms of its real and imaginary parts as shown below

$$\gamma(a) = \alpha(a) + j\beta(a) \tag{10}$$

where α is the attenuation factor and β is the phase factor. For a TE_{10} mode rectangular wave guide, we can relate the real part of the sample permitivity ε^1_s to the phase constant β[4] by

$$\varepsilon_s^{'} = \frac{\beta^2 + \left(\frac{\pi}{a}\right)^2}{\omega^2 \mu_0 \varepsilon_0} \tag{11}$$

where a is the longer width of the wave guide, ω is the angular frequency μ_0 and ε_0 are the free space permeability and permitivity.
If we neglect the conductive losses in the metal waveguide we can relate the imaginary part of the sample permitivity ε_s" to the attenuation constant α [4] by

$$\varepsilon_s^{''} = \frac{2\alpha\varepsilon_s^{'}}{k}\sqrt{1-\left(\frac{\lambda}{2a}\right)^2} \tag{12}$$

where

$$\lambda = \frac{2\pi}{k} \tag{13}$$

and

$$k = \omega\sqrt{\mu_0\varepsilon_0\varepsilon_s^{'}} \tag{14}$$

That means the Scattering parameter measurements from the partially filled waveguides after extending the calibration plane to the sample surface can be used to determine the dielectric permitivity of the materials. The calibration plane is extended by manually feeding the phase factor and electrical delay equivalent to the sample distance to the calibration plane.

3 MEASUREMENT AND VERIFICATION

Two teflon pieces of length 1cm and 2cm were machined exactly in order to fill the cross section of an X- band wave-guide of length 7.6cm.The wave guide sample holder is connected to the Agilent 8722ES VNA through a coaxial to wave guide adapter after a full two port calibration with the coaxial to wave guide adapters. The sample holder with the sample is then connected to these adapters; the calibration plane from the adapter surface is extended to the sample surfaces by manually feeding the phase factor equivalent to the distance of the sample form the calibration plane. The complex propagation constant is determined from the measured scattering parameters and the dielectric parameter of the samples were calculated using equation (11) and (12). For comparison the complex permitivity of both samples using the Reflection/Transmission epsilon fast model of material measurement software® of Agilent Technologies as well as the nicolson rose method were measured. Figure1 (a) and (b) present the real and imaginary part of the sample permitivity for these three methods. The dielectric constant obtained by these methods is found to be almost equal. The dielectric constant obtained by the present method is found to be little higher compared to the other one. The reasons for this divergence in dielectric constant is under further investigations. For this purpose the dielectric constant of the samples has to determine by Von hippels method as well as TRL multiline method by completely filling the wave-guide. The air gap between the sample and sample holder is trying to arrest completely by applying little quantity of silver paste on the edges of the sample. This method is found to be efficient for determining the dielectric properties of ferroelectric materials also.

CONCLUSIONS

In conclusion it is shown that the port extension techniques and the muliline calibration algorithm could be effectively applied to determine the propagation constants for partially filled wave-guides and hence it is possible to extract the dilectric parameters of the samples accurately. We are trying to extend this method to high K dielectric materials as well as ferro electric materials to find out their dielectric properties as a function of frequency and temperature.

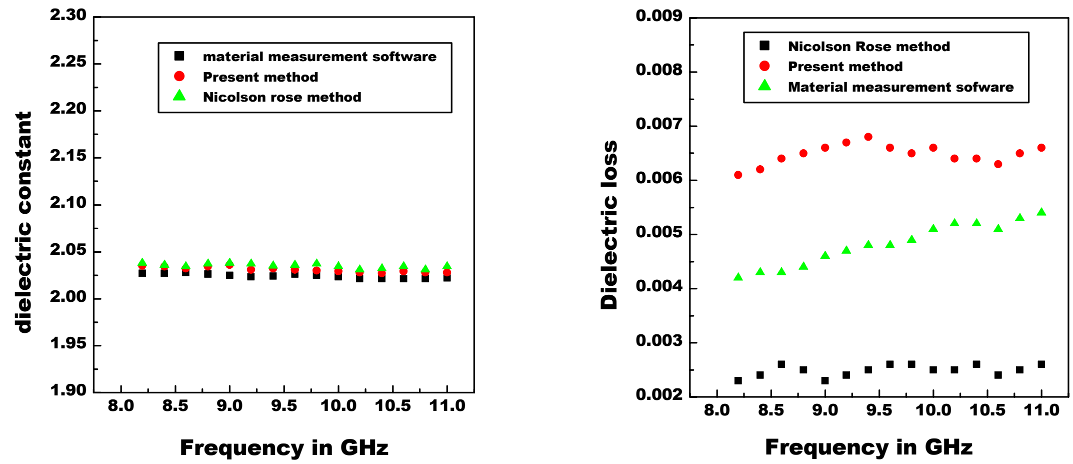

Fig1 (a) (b)

Fig1 (a) and (b)shows the variation of dielectric constant and dielectric loss for Teflon with frequency.

(The present method is compared with the measured values using the “Reflection/Transmission epsilon fast model” of the material measurement software from Agilent Technologies Inc as well as the nicolson rose method)

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