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Research Paper :

New method for the determination of dielectric constant at microwave frequency using double ridge wave-guide

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ABSTRACT

This paper deals with introduction of the method of measurement of dielectric constant at microwave frequency. The variation of cutoff frequency of Step Ridge wave-guide was taken as a parameter for calibration of dielectric constant and a new method of dielectric constant is suggested. By placing the material sample at various locations, theoretically the changes in cutoff frequency of fundamental and first overtone are worked out and the location of maximum change was selected for further calculations. Using Finite Element Method (FEM) and sample of different dielectric constant located at the selected place, the variations in cutoff frequencies were calculated. Using these variations, a calibration curve was established and a new method of measurement of dielectric constant was suggested.

Key words : Dielectric constant measurement, FEM, Double Ridge Wave guide.

Many times physical quantities are measured indirectly using their effect on some other properties. Dielectric constant measurement is also an indirect measurement in which dielectric constant is measured from the changes its makes in various properties like resonance frequency of resonator(Andrade *et al.*, 1981), impedance of transmission line, VSWR in slot line (Van, 1935), S-parameter of a device (Abdulnour *et al.*, 1995; Tian and Tinga, 1994), refection coefficient in coaxial cable (Wong, 1998). How ever the use of cut off frequency for such measurement has not been made so far. Hence we proposed to introduce the possibility of establishing a method of dielectric measurement based on the cut off frequency variation of a double ridge wave-guide. To justify the validity of the method we have worked out cutoff frequency for various e values using Finite Element Method. It is shown that the cut off frequency variation with e is smooth and can be used as calibration curve for e measurement.

METHODOLOGY

Consider double ridge wave-guide (H-Shaped). Let the walls of wave-guide be perfectly conducting. The problem is analyzed for the air medium and dielectric medium. The Double Ridge wave guide (DRW) is as shown in Fig. 1. The dimension of DRW are a and b while h is the length of ridge and w be the width, symmetric ridges are used.In the process of calibration we firstly, find the cut off frequencies for different modes by placing the dielectric material sample at different locations in a double ridge wave-guide along the line. Then decide which location gives maximum change in which property. At the location of maximum change different dielectric constant value samples are placed and the value of property are evaluated by FEM .The choice of the ridge wave guide property, its variation calibration with dielectric constant enable us to suggest a new method for measuring dielectric constant .The use of FEM in establishing the method of characterization of permittivity of dielectric material has made by Deshpande and Reddy (1997) and Robertcoccioli *et al.* (1997), respectively.

Mathematical formulation :

The electric and magnetic fields, inside the wave guide will satisfy the Maxwell's equations and assuming the time dependence of the fields; as $e^{j\omega t}$ the Maxwell's equation are written as:

ď x E = - jμ«$_0$H (1)

ď x H = jμ£$_0$£ E (2)

The magnetic field vector formulation (Koshiba *et al.*, 1985) is used for the solution of the problem. Therefore, Maxwell's equation (2) is expressed as

£$^{-1}$ (ď x H) = jμ£$_0$E (3)

Taking the curl of equation (3) and using equation (1), equation (3) can be written as

ď x (£$^{-1}$ ď x H) = k$_0^2$H (4)

where, $k_0^2 = \omega^2 \mu_0 \varepsilon_0$

Here, ω is the angular frequency, ε_0 and μ_0 are the permittivity and permeability of free space and ε is the relative permeability of the medium, inside the wave-guide. For air medium the value of $\varepsilon = 1$.

The magnetic field H must satisfy the suitable boundary condition at the conducting boundaries, the normal component of the magnetic field is zero on conductor boundaries.

$$H.n \,\Big|_{boundary} = 0$$

Fem formulation:

To develop a functional for FEM formulation of the given problem, the equation (4) is multiplied by an arbitory test function $\vec{V}$ and then integrated it over the domain of the problem. This leads to an expression for functional as:

$$\Pi = \int_\Omega \vec{V} \cdot \nabla \times \{\varepsilon^{-1} \nabla \times \vec{H}\} d\Omega - \int_\Omega \vec{V} \cdot k_0^2 \vec{H} \, d\Omega \qquad (5)$$

Using vector identity for the first term in equation (5) and converting volume integral into surface integral, we get,

$$\Pi = \int_\Gamma \vec{n} \cdot [\varepsilon^{-1} \nabla \times \vec{H} \times \vec{V}] d\Gamma + \int_\Omega [\varepsilon^{-1} \nabla \times \vec{H}] \cdot [\nabla \times \vec{V}] d\Gamma - \int_\Omega \vec{V} \cdot k_0^2 \vec{H} d\Omega \qquad (6)$$

which further can be transfer to

$$\Pi = \int_\Gamma \vec{V} \cdot \{\vec{n} \times [\varepsilon^{-1} \nabla \times \vec{H} \times \vec{V}]\} d\Gamma + \int_\Omega [\varepsilon^{-1} \nabla \times \vec{H}] \cdot [\nabla \times \vec{V}] d\Gamma - \int_\Omega \vec{V} \cdot k_0^2 \vec{H} d\Omega \qquad (7)$$

The coefficient of boundary integral constitutes the natural boundary condition .So it is included in the formulation. Since tangential component of E is continuous at the boundary, the first term in equation (7) will be zero. Using Galerkin's criteria as $\vec{V} = H^*$(complex conjugate of H),the functional Π will become bilinear and symmetric. The bilinear terms are multiplied by 1/2 , we get functional

$$\Pi = \frac{1}{2} \int \{[\nabla \times \vec{H}] \cdot [\varepsilon^{-1} \nabla \times \vec{H}] - k_0^2 \vec{H}^* \cdot \vec{H}\} d\Omega \qquad (8)$$

The domain of the cross section of a wave-guide is divided in to rectangular elements with Four nodes. The functional over each element is taken in the form of derivative form of mapping function and hence function is given in the form of S_e, Te form :

$$\Pi = \sum [\{H^e\}^T [S^e] \{H^e\} - K_0^2 \{H^e\}^T [T^e] \{H^e\}]$$

where S^e and T^e are the matrix, Therefore,

$\Pi = \{H\}^T [S] \{H\} - K_0^2 \{H\}^T [T] \{H\}$,. The H value can obtained by minimization of Π *i.e.* using the the condition

$\frac{\partial \Pi}{\partial \{H\}} = 0$ leads to the following matrix equation.

$$[S]\{H\} - K_0^2 [T]\{H\} = 0 \qquad (9)$$

Equation (9) is the matrix equation to be solved for eigen values K_0^2

RESULTS AND DISCUSSION

Here, for the measurement of dielectric constant Double Ridge Wave guide with ridge on two sides like H shaped was used. The wave-guide dimensions were a = 7.2cm, b= 3.3cm.and has ridge of length 2.4 cm.and height 0.66 cm. The dielectric sample was of size height 0.33 cm and width 0.60 cm. The cross sectional wave-guide was divide in to 416 rectangular elements. It was suppose to have 1407 number of nodes and unknown component out of these 116 number of unknown will be specified by the boundary conditions, hence the matrix eigen equation will contain matrices of the size 1294x1294.The time required to run the programme is up to 40 sec.

Firstly for the empty ridge wave guide, cut off wave numbers for fundamental and first harmonic modes were obtained by using the FEM software for H- formulation of electromagnetic propagation problems. The dielectric sample material of $\varepsilon = 5$ was placed at the position indicated by Fig. 1. With the label "1", again the FEM programme was run to find the cut off number for fundamental and harmonic, the same procedure was repeated for different location and the mode for which higher changes were indicated, and were selected as the best location for measurements. The results are indicated in Table 1. At the selected location samples with differ dielectric constant are placed and the cut off wave number for each sample are obtained by analyzing with FEM software. These results are indicated in Table 2. It was observed that the changes due to dielectric constant of material for cut off fundamental mode are small, where

Table 1 : Variation of cut off frequency due to different locations of dielectric sample

Location no. of dielectric	Fundamental mode cut off (GHz)		Change in frequency due to dielectric (GHz)	
	I mode	II mode	I	II
0	1.9553	4.1254	0	0
1	0.7690	1.9850	1.4730	1.6355
2	0.7788	1.9798	1.4632	1.6407
3	0.7780	1.9699	1.1773	1.6506
4	0.7689	1.9689	1.1864	2.1565
5	0.7788	1.9798	1.4632	1.6407
6	0.7780	1.9699	1.1773	1.6506
7	0.7778	1.9789	1.4642	1.6416
8	0.7870	1.9899	1.4550	1.6306
9	0.7699	1.9698	1.4721	1.6507
10	0.7778	1.9789	1.4642	1.6416
11	0.7870	1.9899	1.4550	1.6306
12	0.7699	1.9698	1.4721	1.6507

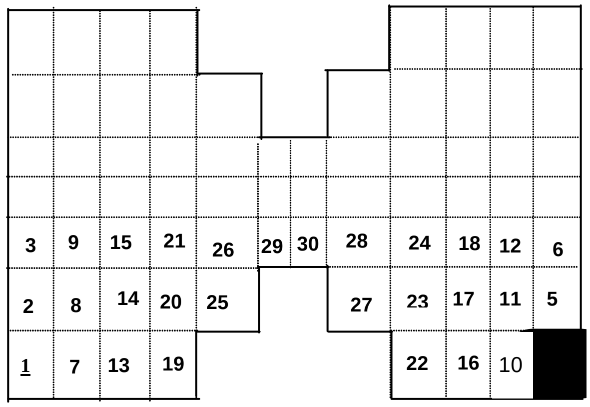

Fig. 1 : Number indicates the location number

Table 2 : Variation of cut-off frequency due to dielectric sample

Values of dielectric constant	Change in frequency due to dielectric (GHz)		Change in cut off frequency (GHz)	
	I mode	II mode	I	II
1	1.8559	4.4434	0	0
1.5	1.4997	3.6051	0.3562	0.8383
2	1.3119	3.1359	0.544	1.3075
2.5	1.0838	2.7156	0.7721	1.7278
3	0.9893	2.4791	0.8666	1.9643
4	0.8566	2.1471	0.9993	2.2963
5	0.8566	2.1471	0.9993	2.2963
6	0.7689	1.9689	1.0870	2.4745
7	0.6992	1.7532	1.1567	2.6902
8	0.6472	1.6232	1.2087	2.8202
9	0.6053	1.5184	1.2506	2.9250
10	0.5705	1.4315	1.2854	3.0119

as the changes for cut off of first harmonic mode were appreciable for their measurements and hence first harmonic mode changes can be used as parameter to calibrate for ε. Calibration curve in Fig. 2 can be used

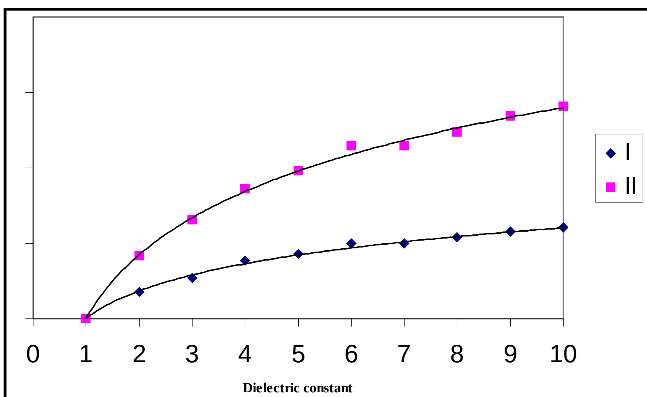

Fig. 2 : Calibration curve

for findinge of a material corresponding first harmonic mode change was observed. These ascertain the usefulness of the new procedure for dielectric constant (ε) measurement.

Conclusion:

Calibration curve can be used for introducing a new method. for the measurement of permittivity (ε). Using the above information, a new method suggested may have the following three steps.

– Experimental determination of calibration curve of cut off frequency with ε.

– Finding the cut off frequency for sample material.

– Obtaining ε (permittivity) of specimen by interpolation using calibration curve.

Thus, by using FEM technique, a new method of Dielectric Constant Measurement based on the property of cut off frequency of H-Shaped ridge waveguide is suggested.

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