EFFECT OF INHOMOGENEOUS DIELECTRIC LAYERS ON DISPERSION OF MICROSTRIP LINES USING MoL

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ABSTRACT : The analysis of microstrip lines coupled with dielectric waveguides is given in this paper using the method of Lines (MoL). Two configurations are investigated here, the first configuration consists of single microstrip line coupled with single dielectric waveguide. The second configuration consists of an asymmetric coupled microstrip lines coupled with single dielectric waveguide. The propagation constants are computed for both configurations as functions of the frequency. The effect of changing the position of the dielectric waveguide is studied at different frequencies. New results for the coupling between dielectric waveguides and asymmetric coupled microstrip lines are given.

I. FORMULATION OF THE PROBLEM

The problem of coupling the dielectric waveguides with microstrip lines using the method of lines is described in [1], [2]. The method of lines is adapted to the analysis of inhomogeneous dielectric layer. In this case, the wave field can be determined from two vector potentials Π_e and Π_h [1], [3]. Each vector potential has only one component in the x-direction. Thus the fields are given as [1]:

$$E = \frac{\nabla \times \nabla \times \Pi_e}{\varepsilon_r(x)} - jk_o \nabla \times \Pi_h \tag{1a}$$

and

$$\eta_o H = jk_o \nabla \times \Pi_e + \nabla \times \nabla \times \Pi_h \tag{1b}$$

where $k_o = \omega\sqrt{\mu_o \varepsilon_o}$ and $\eta_o = \sqrt{\mu_o / \varepsilon_o}$. The vector potentials are given by [1]:

$$\Pi_e = \psi_e \frac{\exp(-jk_z z)}{k_o^2} a_x \qquad \text{(LSM modes)} \tag{2a}$$

and

$$\Pi_h = \psi_h \frac{\exp(-jk_z z)}{k_o^2} a_x \qquad \text{(LSE modes)} \tag{2b}$$

where a_x is unit vector in the x-direction. The wave is assumed to propagate in the z-direction. The scalar potentials ψ_h and ψ_e must fulfill Helmholtz equation and the Sturm-Liouville differential equation [1], [4], respectively as:

$$\frac{\partial^2 \psi_h}{\partial x^2} + \frac{\partial^2 \psi_h}{\partial y^2} + \left(\varepsilon_r(x) k_o^2 - k_z^2\right)\psi_h = 0 \tag{3a}$$

and

$$\varepsilon_r(x) \frac{\partial}{\partial x}\left(\frac{1}{\varepsilon_r(x)} \frac{\partial \psi_e}{\partial x}\right) + \frac{\partial^2 \psi_e}{\partial y^2} + \left(\varepsilon_r(x) k_o^2 - k_z^2\right)\psi_e = 0 \tag{3b}$$

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The boundary conditions are:

$$\psi_h = 0, \ \frac{\partial \psi_e}{\partial x} = 0 \qquad \text{(Metallic Walls)} \qquad (4a)$$

$$\psi_e = 0, \ \frac{\partial \psi_h}{\partial x} = 0 \qquad \text{(Magnetic Walls)} \qquad (4b)$$

The above differential equations (3) are solved using the method of lines [1], [2] and [5]. In the method of lines, the field components in discretized form are determined on two systems of lines which are shifted away from each other by half the discretization distance. Moreover, the dielectric constants are discretized where there are two line systems given as:

$$\varepsilon_r(x) \rightarrow diag.(\varepsilon_r(x_e)) = [\varepsilon_e] \qquad (5a)$$

and

$$\varepsilon_r(x) \rightarrow diag.(\varepsilon_r(x_h)) = [\varepsilon_h] \qquad (5b)$$

For ε_h at interfaces where the dielectric constants change abruptly, the arithmetic average between the two dielectric constants is taken [1], [2]. After some algebraic manipulations [1], the characteristic equation is obtained in the spatial domain as

$$\begin{bmatrix} z_{11} & z_{12} \\ z_{21} & z_{22} \end{bmatrix}_{red.} \begin{bmatrix} jJ_{xm} \\ J_{zm} \end{bmatrix} \begin{matrix} \updownarrow elect.\ lines \\ \updownarrow mag.\ lines \end{matrix} = 0 \qquad (6)$$

in which the elements of the sub matrices Z_{11}, Z_{12}, Z_{21}, and Z_{22} are functions of the characteristics of the different dielectric layers, the frequency, and the propagation constant k_z. The quantities J_{xm} and J_{zm} are the current densities on the metallic strips. The elements of the system matrix are functions of the effective dielectric constants as $\varepsilon_{re}=(k_z/k_o)^2$. The eigenvalue ε_{re} is varied until the determinant of this system matrix vanishes. The current vector $[jJ^t_{xm}, J^t_{zm}]^t$ is determined as an eigenvector of system (6) for each eigenvalue ε_{re}. Thus all the electric and magnetic field components are calculated [1].

II. NUMERICAL EXAMPLES

In Fig. 1, the effective dielectric constant ε_{re} is plotted versus the frequency with the dielectric waveguide located at different positions (s/a)=0-11h, where h is the discretization distance. The dielectric constants are $\varepsilon_{r1}=\varepsilon_{r4}=1.0$, $\varepsilon_{r2}=16$, and $\varepsilon_{r3}=9.6$ (see Fig. 1a). The number of magnetic lines is N=29, the number of electric lines is N1=30, and the number of the electric lines on the strip is M=6. The results at f = 30Ghz are compared with the results of [2] to check the accuracy of the computer program. The numerical results of Fig. 1 show that the propagation constant increases with increasing the shift between the microstrip line and the waveguide up to a certain limit (s/a = 5h) and then it starts to decrease with the shift. In Fig. 2, the coupling between an asymmetric coupled microstrip lines with a single dielectric waveguide is shown. The effective dielectric constants of the dominant C and π modes are plotted versus the frequency at three different locations of the waveguide (case#1, 2 and 3), see Fig. 2a. The number of the magnetic lines is N=51, the number of the electric lines is N1=52, the number of the electric lines on the strips are M1=5, M2=10, and the number of the electric lines in the separation between the strips is M_s=3. The discretization distance is h=0.11428mm. A comparison between the results using MoL and the Spectral domain technique (Fig. 2 in [6]) is done to check the accuracy of the computer code. The results in Fig. 2b show that the effective dielectric constant of the π mode is larger than it for the C mode in configuration case # 1. On the other hand, the effective dielectric constant of the C mode is larger than it for the π mode in both configurations # 2 and #3.

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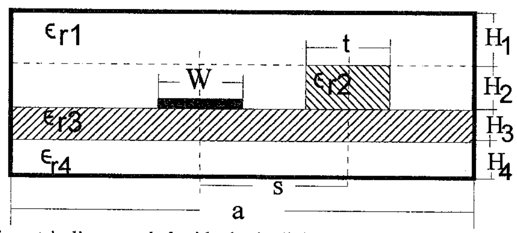

Fig. 1a, single microstrip line coupled with single dielectric waveguide, a=7.112 mm, W=1.6 mm, t=1.422 mm, H1=H2=H3=H4=0.729 mm, $\varepsilon_{r1}=\varepsilon_{r4}=1.0$, $\varepsilon_{r2}=16$, and $\varepsilon_{r3}=9.6$.

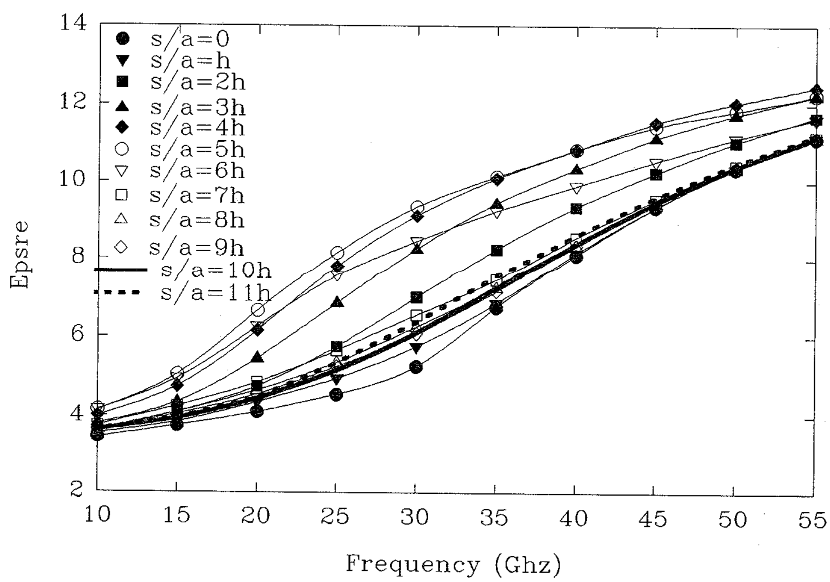

Fig. 1b The effective dielectric constant versus frequency.

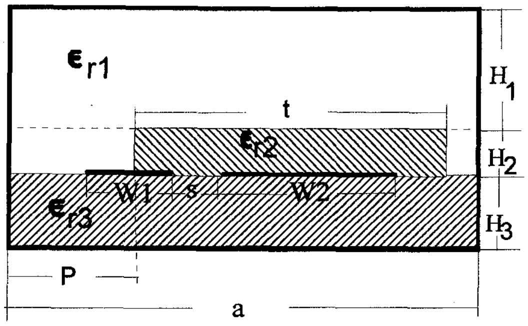

Fig. 2a, An asymmetric coupled microstrip lines coupled with single dielectric waveguide, a=5.828mm, H1=20mm, H2=H3=0.635mm, ε_{r1}=1.0, ε_{r2}=16, ε_{r3}=9.8, t=2.057mm, W1=0.6mm, W2=1.2mm, S=0.3mm, P=1.9428mm (case#1), P=2.857mm (case#2), and P=0.5714mm (case#3).

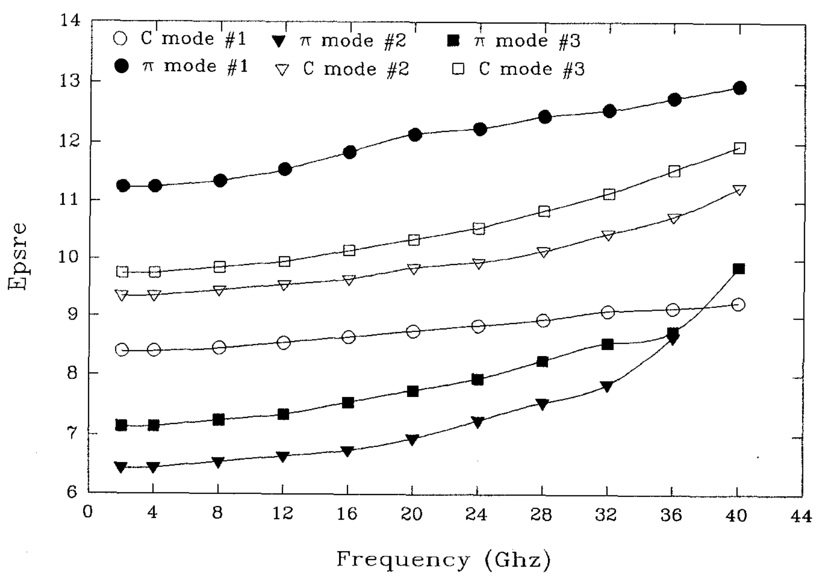

Fig. 2b The effective dielectric constant versus frequency.