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A GENERALIZED DISPERSIVE ANALYSIS OF INTEGRATED CIRCUIT TRANSMISSION LINE STRUCTURES ON ANISOTROPIC SUBSTRATES

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Abstract

A spectral domain analysis of planar transmission lines on anisotropic layers is performed. The dielectric layers are assumed to be uniaxial anisotropic. The Hertz potentials and the Galerkin method are used to obtain the propagation characteristics for single and coupled microstrip lines on single and double layers and for bilateral fin-lines.

Introduction

The analysis of planar transmission lines is fundamental to the development of microwave integrated circuits. It has been observed that for better designs, the characterization of these lines should be performed taking into account that the propagating modes are hybrid modes [1] - [5] .

The effect of dielectric anisotropy on the characteristics of transmission lines has been investigated [1] - [6]. Quasi-static models [1],[6] (especially for strip transmission lines such as microstrips) and dynamic models [1] - [5] have been considered. This has been done because some dielectric materials used in MIC circuits show an anisotropic behavior, which may be natural or a result of the manufacturing process, and because the effect of dielectric anisotropy cannot be neglected at higher microwave frequencies.

A combination of Hertz potentials and the Galerkin method was used by Lee and Tripathi [2] in order to determine the impedance matrix functions for single microstrip lines on a uniaxial anisotropic layer, with three different orientations of the optical axis. No numerical results were obtained. In [3] this method was used in the analysis of microstrip lines on an arbitrary anisotropic layer (the optical axis was allowed to assume any orientation in the cross section of the microstrip line). The impedance matrix was determined and numerical results for the effective permittivities versus frequency for single and symmetric parallel-coupled microstrip lines on an anisotropic layer (optical axis normal to the ground plane) were obtained.
Agreement with the results from [4] was observed.

Theory

In this paper, the Hertz potentials and the Galerkin method are used in the analysis of several planar structures on anisotropic layers, such as single and coupled microstrip lines on single and double anisotropic layers and bilateral fin-lines.

The fields are assumed to have a harmonic time dependence of the type $\exp(j\omega t)$ and are obtained from the Hertz potentials oriented along the optical axis, ξ. Thus, at each dielectric anisotropic layer they are given by

$$\bar{\Pi}_h = \Pi_h \hat{\xi} \tag{1}$$

$$\bar{\Pi}_e = \Pi_e \hat{\xi} \tag{2}$$

and should satisfy the wave equation

$$\nabla^2 \bar{\Pi}_h + k_2^2 \bar{\Pi}_h = 0 \tag{3}$$

$$\nabla^2 \bar{\Pi}_e + k_1^2 \bar{\Pi}_e + \frac{\varepsilon_1 - \varepsilon_2}{\varepsilon_2} \frac{\partial^2}{\partial \xi^2} \bar{\Pi}_e = 0 \tag{4}$$

The expressions for the fields $\bar{e}$ and $\bar{h}$ in the anisotropic layer are

$$\bar{e} = -j\omega\mu_o \nabla \times \bar{\Pi}_h + k^2 \bar{\Pi}_e + \frac{\varepsilon_o}{\varepsilon_2} \nabla\nabla \cdot \bar{\Pi}_e \tag{5}$$

$$\bar{h} = \nabla \times \nabla \times \bar{\Pi}_h + j\omega\varepsilon_o \nabla \times \bar{\Pi}_e \tag{6}$$

In (1)-(6) ε_0, μ_0, and k_0 are parameters of free space, ω is the angular frequency and, referring to the crystal coordinate system (η, ξ, ζ), $\varepsilon_{\xi\xi} = \varepsilon_1$ and $\varepsilon_{\eta\eta} = \varepsilon_{\zeta\zeta} = \varepsilon_2$.

Using a Fourier transformation and imposing the appropriate boundary conditions the immitance functions were obtained for microstrip lines and bilateral fin-lines. For microstrip lines, single and coupled (symmetric/asymmetric) cases on single and double layers were studied.

Results and Conclusion

Curves of effective permittivities versus frequency are presented for all structures considered. Results obtained assuming the dielectric layers to be isotropic are also included for comparison purposes, in some cases.

As an example, curves for the even- and odd-mode effective permittivity versus frequency, obtained in this work for parallel coupled microstrip lines on double anisotropic layers (Fig. 1), are

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presented in Fig. 2. The quasi-static values published in [6] are in agreement with the lower frequency values of this work. Neverthless, as shown in Fig. 2, the strong dependence on frequency has to be considered if an equalization of phase velocities is desired. It should be observed that for frequencies above 5 GHz $H_2/H_1 = 1.0$ gives a better equalization than the quasi-static solution $H_2/H_1 = 1.777$. The results of this work for suspended microstrip lines are in agreement with the dynamic results presented in [4].

Fig. 4 shows the effective permittivity versus frequency for the dominant mode in bilateral fin-lines (Fig. 3). Three different orientations for the optical axis, ξ, are considered. The fin-line system (x, y, z) is shown in Fig. 3. Observe that $\varepsilon_{r1} = \varepsilon_1/\varepsilon_0$ and $\varepsilon_{r2} = \varepsilon_2/\varepsilon_0$. The results of this work are in close agreement with the results of Figs. 3 of [5].

The numerical results for the characteristic impedance obtained for single microstrip lines on anisotropic substrate are in good agreement with the results presented in [4].

The method used in this work is general and accurate. Changes in the boundary conditions would allow the investigation of other planar structures.

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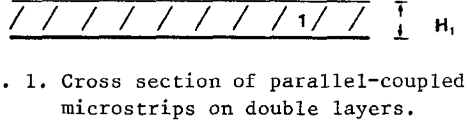

Fig. 1. Cross section of parallel-coupled microstrips on double layers.

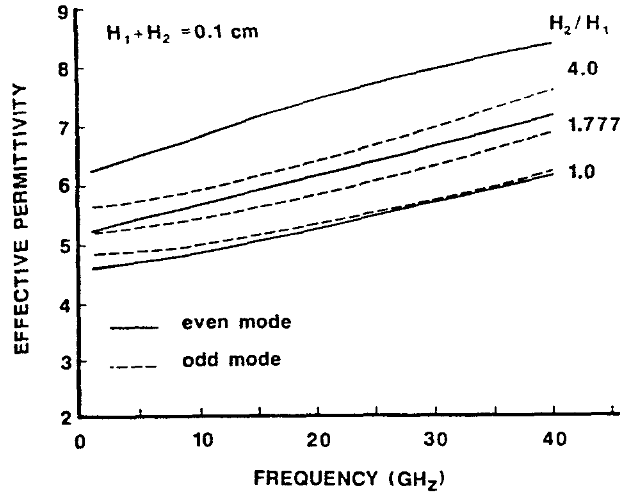

Fig.2. Frequency dependence of the even- and odd- mode effective permittivity of microstrips on double layers. Medium 1 is boron nitride and medium 2 is sapphire.

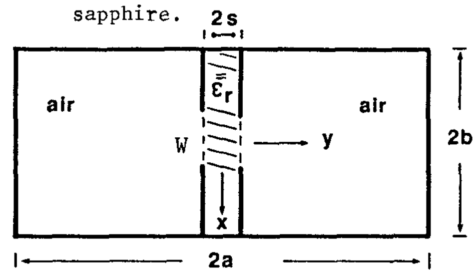

Fig. 3. Cross section of bilateral fin-lines.

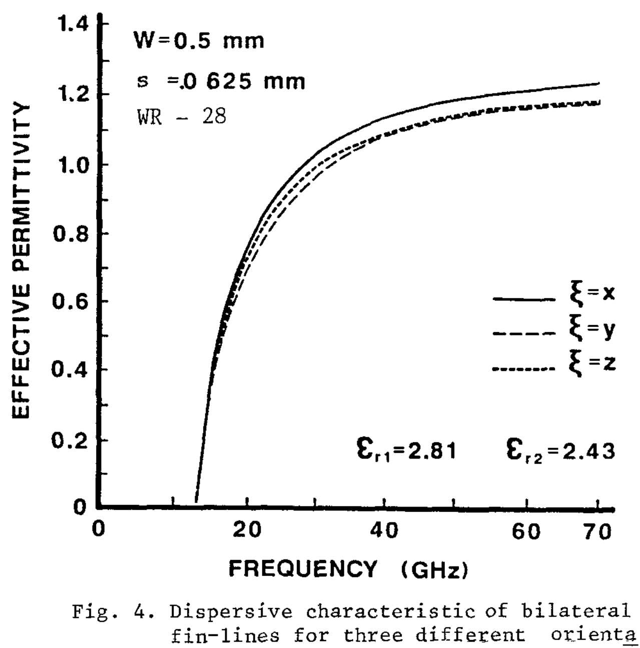

Fig. 4. Dispersive characteristic of bilateral fin-lines for three different orientations for the optical axis.