ASYMMETRICAL COPLANAR WAVEGUIDE WITH FINITE METALLIZATION THICKNESS CONTAINING ANISOTROPIC MEDIA

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ABSTRACT

The spectral-domain approach (SDA) is extended to analyze the metallization thickness effect in the asymmetrical coplanar waveguide (ACPW) with an anisotropic substrate. Numerical computations are carried out for ACPW with a uniaxially anisotropic substrate and for a magnetized ferrite substrate. The paper demonstrates the metallization effect and the nonreciprocal properties in ACPW for the first time.

I. INTRODUCTION

Coplanar waveguides (CPW) with an anisotropic substrate have been investigated for use in microwave and millimeter-wave integrated circuits[1]-[4]. A number of theoretical analyses for CPW have been reported based on the quasi-static approach[2],[3] and frequency-dependent hybrid-mode approach[2],[4]. However, most of these efforts have been based on the assumption that the metallization thickness is zero, and have treated the symmetrical CPW. Metallization thickness effect of CPW's, in general, is larger than that of strip lines because of the field configurations[3],[5],[6]. The effects have been investigated by one of the authors for the symmetrical CPW with isotropic[2] and/or uniaxially anisotropic media[3]. The asymmetrical version of the coplanar waveguide (ACPW) has been introduced to take advantage of the additional flexibility offered by the asymmetric configuration in the design of integrated circuits[7],[8]. However, there is no analytical method applicable to ACPW with finite metallization thickness.

In this paper we extend the spectral-domain approach (SDA)[9],[10] to analyze the asymmetrical coplanar waveguide (ACPW) with anisotropic media, taking the finite metallization thickness into consideration. Numerical computations are carried out for ACPW with an anisotropic substrate made of uniaxially anisotropic media and magnetized ferrites. The effect of the metallization is presented.

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II. ANALYTICAL FORMALISM OF ELECTROMAGNETIC FIELDS

Fig.1 shows the cross-section of an asymmetrical coplanar waveguide(ACPW) . The structure consists of printed conductors of finite thickness on an anisotropic substrate. The substrate is assumed to be lossless, but an anisotropic medium. Anisotropic media of practical importance are uniaxially or biaxially anisotropic dielectrics, e.g. sapphire, and the magnetized ferrites. When the substrate is made of an anisotropic dielectric of this type, the permittivity tensor is expressed as

$$\overline{\overline{\varepsilon}} = \varepsilon_0 \begin{bmatrix} \varepsilon_1 & 0 & 0 \\ 0 & \varepsilon_2 & 0 \\ 0 & 0 & \varepsilon_3 \end{bmatrix}$$

When the medium is the ferrite and is magnetized in the x direction, the permeability tensor is expressed as[9]

$$\overline{\overline{\mu}} = \mu_0 \begin{bmatrix} 1 & 0 & 0 \\ 0 & \mu_r & j\kappa \\ 0 & -j\kappa & \mu_r \end{bmatrix}$$

where μ_r and κ are dependent on the operating frequency ω, the applied dc magnetic field H_0, and magnetization of the ferrite $4\pi M_s$.

$$\mu_r = 1 - \frac{\gamma^2 H_0 4\pi M_s}{\omega^2 - (\gamma H_0)^2}$$

$$\kappa = \frac{\gamma\, 4\pi M_s \omega}{\omega^2 - (\gamma H_0)^2}$$

Electromagnetic fields in the aperture region ($t > y > 0$) are expressed by the Fourier series representation with respect to the x-direction, viz.,

$$E_{xi}(x,y,z) = \frac{1}{\sqrt{2W_i}} \sum_{n=-\infty}^{\infty} \tilde{E}_{xi}(y)\, e^{-j\alpha_{in}(x-x_i)}\, e^{-j\beta z}$$

$$i = 1,2$$

where β is the phase constant, x_i represents the center of the i-th aperture and Fourier variables α_{in} in the aperture region are determined so that the boundary conditions at the side wall are satisfied,

$$\alpha_{in} = \frac{n\pi}{W_i}$$

Fields in the other regions are expressed by the Fourier integral representation in the x-direction, e.g.,

$$E_x(x,y,z) = \frac{1}{\sqrt{2\Pi}} \int_{-\infty}^{\infty} \tilde{E}_x(y)\, e^{-j\alpha x} d\alpha\, e^{-j\beta z}$$

Applying the continuity conditions at the interfaces and introducing the aperture fields at y = t, $e_i^U(x)$, and at y = 0, $e_i^L(x)$ (Fig.2), the transverse (to y) components of magnetic fields $H_t(x,y,z)$ in the subregions can be related to the aperture fields $e_i^U(x)$ and $e_i^L(x)$;

$$H_t(x,y,z) = \sum_i \int_{x'} \{ \overline{\overline{Y}}_{Ui}(x,y|x')e_i^U(x') + \overline{\overline{Y}}_{Li}(x,y|x')e_i^L(x') \}\, dx'\, e^{-j\beta z}$$

where the $\overline{\overline{Y}}$'s are the dyadic Green's functions.

Finally, applying the continuity conditions of the magnetic fields at the aperture planes y = t and 0 to the expression of $H_t(x,y,z)$, we obtain the integral equations for the aperture fields $e_i^U(x)$, $e_i^L(x)$ and implicitly the propagation constant β. Then, applying Galerkin's procedure[2],[4]-[7],[9],[10] to the integral equations, we obtain the determinantal equation for β .

III. NUMERICAL EXAMPLES

Fig.3 shows the frequency-dependent characteristics of the dominant π-modes of the ACPW with an anisotropic sapphire substrate. The figure includes the numerical results for the special cases with zero metallization thickness (t = 0)[2],[7] and the quasistatic values of the CPW's with zero[2],[8] and finite metallization thickness[3] for comparison. Frequency dependent hybrid-mode values converge to the corresponding quasistatic values in the lower frequency range for all cases.

Fig.4 shows the dispersion characteristics of the ACPW with the magnetized ferrite with zero and finite metallization thickness. The nonreciprocal properties as well as the metallization thickness effect are demonstrated in the figure. The metallization thickness effect in the forward waves is larger than that in the backward waves because of the difference of the field distribution between the forward and backward waves, which increases the nonreciprocity slightly in this configuration.

IV. CONCLUSIONS

The spectral-domain approach (SDA) is extended in the present paper to analyze the asymmetrical coplanar waveguide (ACPW) with a finite metallization thickness on an anisotropic substrate. The metallization thickness effect in ACPW and the nonreciprocal properties in ACPW are presented in the numerical results for the first time. The present method can be readily extended for the cases with multilayered anisotropic media[9],[11]. The numerical data for such cases will be reported in near future.

ACKNOWLEDGEMENT

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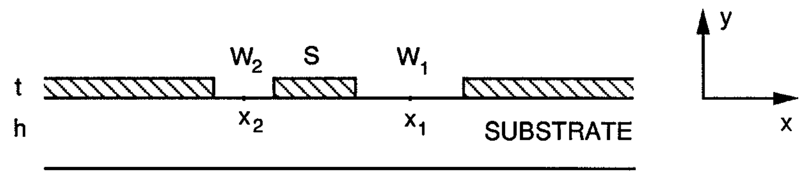

Fig.1 Asymmetrical coplanar waveguide

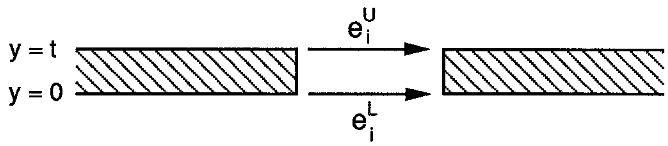

Fig.2 Aperture fields

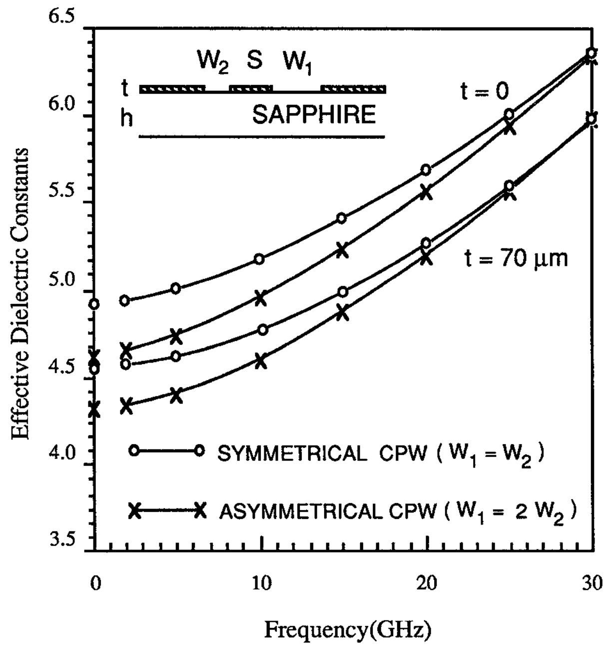

Fig.3 Dispersion characteristics of ACPW with an anisotropic sapphire substrate.

$h = 1$ mm , $W_2 = 1$ mm , $S = 0.5$ mm

$\varepsilon_1 = \varepsilon_3 = 9.4$, $\varepsilon_2 = 11.6$

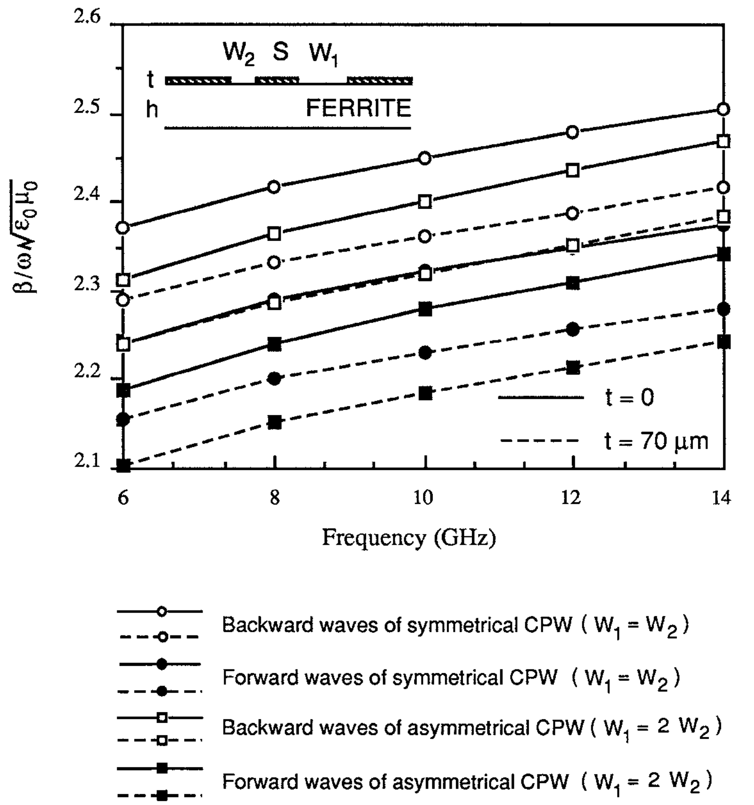

Fig.4 Dispersion characteristics of ACPW with magnetized ferrite

$h = 1$ mm, $W_2 = 1$ mm, $S = 0.5$ mm

$\varepsilon_F = 11.6$, $M_s = 1800$ A/cm, $H_0 = 300$ A/cm