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ANALYSIS OF DOUBLE-LAYERED FINLINES CONTAINING A MAGNETIZED FERRITE*

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ABSTRACT

The characteristics of propagation of the dominant mode in magnetized-ferrite-loaded double-layered finlines are studied. The analysis is based on Galerkin's method applied in the Fourier transform domain. Numerical results are presented for various values of structural and material parameters.

INTRODUCTION

Recently, several analytical methods for finlines consisting of ferrite have been investigated with a view to applications of such waveguide structures to nonreciprocal devices for millimeter-wave integrated-circuit techniques (1). Rigorous analyses based on the mode matching method (2), (3) or the spectral domain method (4), (5) have been presented. Although some of them claim to be applicable to the analysis of multilayered structures, no extensive results seem to have been published to date. From a practical point of view, multilayered structures should be suitable for integrated circuits.

This paper presents an analysis of ferrite-loaded double-layered finlines with a transversely magnetized ferrite. The analytical procedure is based on Galerkin's method applied in the Fourier transform domain. This method has been well established and successful in the analysis of a wide variety of waveguide structures for microwave and millimeter-wave circuits (6). Therefore, the detailed mathematical description will be omitted in the following and only the key steps are illustrated.

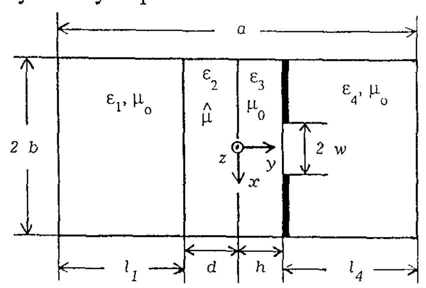

Fig. 1 Cross-sectional view of the ferrite-loaded double-layered finline.

WAVEGUIDE STRUCTURE AND ANALYTICAL METHOD

The waveguide structure under consideration is shown together with the coordinate system for the analysis in Fig. 1. When an external d.c. magnetic field is applied in the x direction, the tensor permeability of ferrite is expressed as

$$\hat{\mu} = \begin{bmatrix} \mu_o & 0 & 0 \\ 0 & \mu & -j\kappa \\ 0 & j\kappa & \mu \end{bmatrix}, \quad \left\{ \begin{array}{l} \dfrac{\mu}{\mu_o} = 1 - \dfrac{\gamma^2 H_o 4\pi Ms}{\omega^2 - (\gamma H_o)^2} \\ \dfrac{\kappa}{\mu_o} = \dfrac{\gamma 4\pi Ms\omega}{\omega^2 - (\gamma H_o)^2} \end{array} \right. \quad (1)$$

where μ_o, ω, H_o, $4\pi Ms$, and γ are the free-space permeability, the operating frequency, the applied d.c. magnetic field, the magnetization of the ferrite, and the gyro-magnetic ratio, respectively.

Following the standard procedure of the spectral domain approach, we obtain

$$\tilde{Y}_{xx}\tilde{E}_x + \tilde{Y}_{xz}\tilde{E}_z = \tilde{J}_x, \quad \tilde{Y}_{zx}\tilde{E}_x + \tilde{Y}_{zz}\tilde{E}_z = \tilde{J}_z \quad (2)$$

after applying all boundary conditions. $\tilde{E}_x$, $\tilde{E}_z$, and $\tilde{J}_x$, $\tilde{J}_z$ are the Fourier transforms of the tangential electric field components at the gap and the current components on the conductors. For instance,

$$\tilde{E}_x = \int_{-w}^{w} E_x(x)\, e^{j\alpha_n x}\, dx \quad , \text{at } y=h \quad (3)$$

where $\alpha_n = \pi n/b$. The matrix elements are known functions of α_n and the propagation constant β of the eigen mode, and the Green's functions Y_{xx}, etc. can be obtained by application of boundary conditions in the spectral domain.

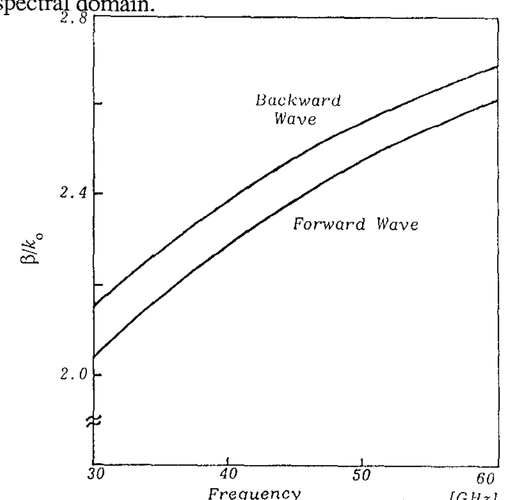

Fig. 2 Dispersion characteristics of the dominant mode propagating in the positive and negative z directions. $\varepsilon_{r1} = \varepsilon_{r4} = 1$, $\varepsilon_{r2} = \varepsilon_{r3} = 12.5$, $4\pi Ms = 5000$ [Ga], $H_o = 500$[Oe], $a = 4b = 4.7$[mm], $l_1 = l_4 = 2.1$[mm], $h = d = 0.25$[mm], $w = 0.5$[mm].

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Finally, Galerkin's procedure, in conjunction with Parseval's relation, yields the determinantal equation for the propagation constant (6).

NUMERICAL RESULTS

The accuracy of our solutions, for single-layered structures, have been checked and verified by comparing them with those in the literature (2). Fig. 2 shows the dispersion characteristics of the dominant mode propagating in the positive and negative z directions. With introduction of a dielectric layer, a larger nonreciprocity has been achieved than that documented in the literature (5).

The differential phase shift between the counterpropagating modes is shown in Fig. 3 as a function of thickness d of the dielectric spacer. The nonreciprocity does not seem to depend drastically on the intensity of the external magnetic field. This is because the resonance frequency is far below the operating frequency for these examples. Note that every curve reaches its peak at a certain value of h.

Finally, Fig. 4 shows curves for the differential phase shift as a function of finline location in the waveguide shield. There exists a maximum value as indicated in the literature (1). It is worthwhile to note that every curve takes its peak at approximately the same value of $l_1/a(\approx 0.06)$ and that they do not seem to depend strongly on the dielectric constant of the spacer. The curve for the case where $\varepsilon_3=3$ is truncated at $l_1/a\approx 0.03$ because one or both of the counterpropagating modes are cut off in the region below this value of l_1/a.

CONCLUSIONS

Nonreciprocal propagations in magnetized-ferrite-loaded double-layered finlines are analyzed. It is found that the dielectric layer introduced between the fin and the ferrite layer can improve the nonreciprocal phase shift characteristics. It is also found that an optimum condition exists for the parameters of the dielectric layer and the finline location in the waveguide shield.

REFERENCES

(1) A. Beyer and K. Solback, "A New Fin-Line Ferrite Isolator for Integrated Millimeter-Wave Circuits," IEEE TRANS. MICROWAVE THEORY TECH., Vol. MTT-29, No. 12, pp. 1344-1348:Dec. 1981.

(2) F.J.K. Lange, "Analysis of Shielded Strip- and Slot-Lines on a Ferrite Substrate Transversely Magnetized in the Plane of the Substrate," ARCH. ELEKTRON. UBERTRAGUNG., Vol. 36, No. 3, pp. 95-100:March 1982.

(3) G. Bock, "Dispersion Characteristics of Slot Line on a Ferrite Substrate by a Mode-Matching Technique," ELECTRON. LETT., Vol. 18, No. 12, pp. 536-537:March 1982.

(4) J. Mazur and K. Grabowski, "Spectral Domain Analysis of Multilayered Transmission Lines with Anisotropic Media," presented at URSI SYMP. ON EMW, Munich, 1980.

(5) Y. Hayashi and R. Mittra, "An Analytical Investigation of Finlines with Magnetized Ferrite Substrate," IEEE TRANS. MICROWAVE THEORY TECH., Vol. MTT-31, No. 6, pp. 495-498:June 1983.

(6) T. Itoh and R. Mittra, "Spectral-Domain Approach for Calculating the Dispersion Characteristics of Microstrip Lines," IEEE.TRANS. MICROWAVE THEORY TECH., Vol. MTT-21, No. 7, pp. 496-499:July 1973.

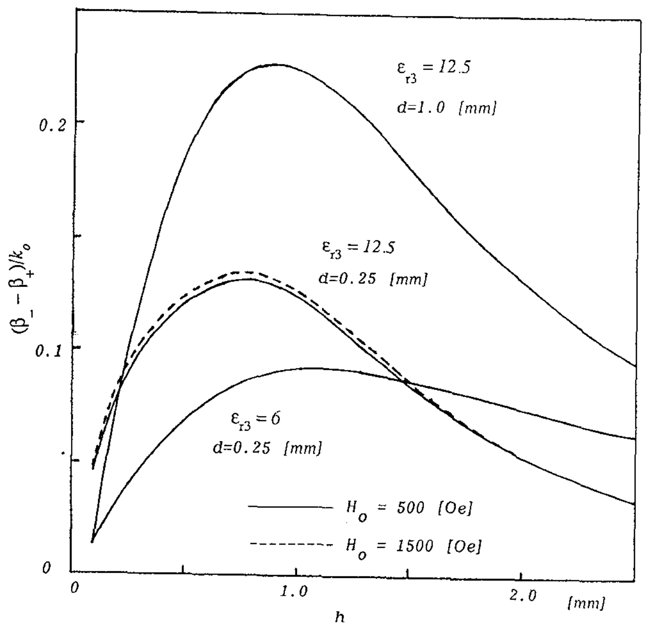

Fig. 3 Differential phase shift versus thickness h of the dielectric layer. $\varepsilon_{r1} = \varepsilon_{r4} = 1$, $\varepsilon_{r2} = 12.5$, $4\pi Ms = 5000$[Ga], $4b$=4.7[mm], w =0.5[mm], f=45[GHz].

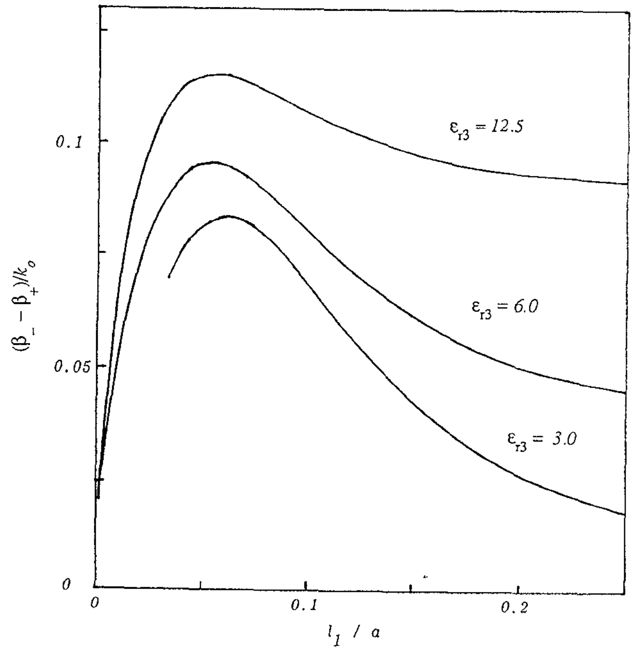

Fig. 4 Differential phase shift versus distance l_1/a from the shielding wall to the ferrite substrate. $\varepsilon_{r1} = \varepsilon_{r4} = 1$, $\varepsilon_{r2} = 12.5$, $4\pi M_s$=5000[Ga], H_o= 500[Oe]. $a = 4b = 4.7$[mm], h=d=0.25[mm], w = 0.5[mm], f=45[GHz].