EFFECT OF THE MAGNETIC ANISOTROPY ON THE CHARACTERISTICS OF MICROSTRIP ANTENNAS WITH SEVERAL LAYERS

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Abstract - The main objective of this work is to show how the properties of a ferrimagnetic material change the characteristics of a microstrip patch with several layers. Particularly, it is investigated how the resonant frequency and the radiation pattern are changed by varying the ferrimagnetic layer thickness or the magnitude and/or direction of the external applied magnetic field. The analysis is carried on by using Hertz potentials and Galerkin method.

I. INTRODUCTION

The development of microstrip structures using ferrites has been considered by several authors [2]-[6]. The basic idea is to take advantage of tuning possibilities, which are provided by varying the magnitude / directions of the external magnetic field.

It was observed that, a special attention has been dedicated to the study of microstrip antennas and resonators on anisotropic dielectric [1] and ferrimagnetic [2]-[4] substrates. The effect of dielectric and magnetic anisotropies on the resonant frequency, quality factor, bandwidth and radiation patterns of a single layer microstrip patch were reported.

In this work, Hertz vector potentials, in the spectral domain, and the moment method were used to analyze the behavior of the resonant frequency for a microstrip resonator on a two-layer substrate, where the grounded one is ferrite and the other one is an isotropic dielectric substrate.

Microstrip antennas / resonators are built by considering a conducting patch which lies on a substrate mounted on a ground plane. Several materials suitable for microwave applications may show some kind of anisotropy, either electric or magnetic. The microstrip antennas structures obtained by using anisotropic substrate have been studied since the 70's and some advantages have been reported, specially when this patch is compared to conventional antennas. Among these advantages are low cost, small dimensions and light weight. Of course, there are some disadvantages like the small bandwidth, high losses and low power handling capabilities.

II. THEORY

Fig. 1 shows the structure considered in this work. It is obtained by letting a conducting patch on a two-layer substrate, which is mounted on a ground plane. Furthermore, the ground layer (region 1) is ferrite and the top one (region 2) is filled with an isotropic dielectric material.

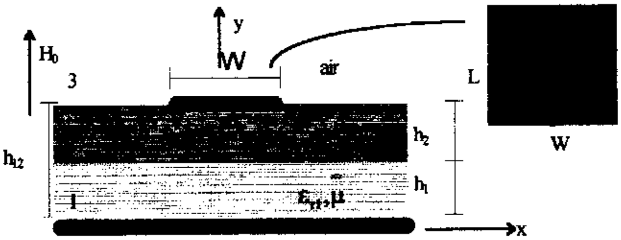

Fig. 1 : Geometry of a microstrip patch on a two-layer ferrimagnetic substrate.

The analysis is carried on by assuming that an external magnetic field, H_0, is applied along the y direction in Fig. 1. For region 1, filled with a ferrimagnetic material, the tensor permeability is then given by

$$\overset{=}{\mu} = \mu_0 \cdot \begin{bmatrix} \mu_r & 0 & -jk_r \\ 0 & 1 & 0 \\ jk_r & 0 & \mu_r \end{bmatrix} \tag{1}$$

where

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

and

$$k_r = \frac{\gamma 4\pi M_s f}{f^2 - (\gamma H_0)^2} \tag{3}$$

In (1) to (3), γ is the gyromagnetic ratio, $4\pi M_s$ is the magnetization saturation and f is the operation frequency.

The electric, $\overline{\Pi}_e$, and magnetic, $\overline{\Pi}_h$, Hertz vector potentials are assumed to be in the same direction as $\overline{H}_0$, giving

$$\overline{\Pi}_e = \Pi_e \hat{a}_y \tag{4}$$

$$\overline{\Pi}_h = \Pi_h \hat{a}_y \tag{5}$$

The expressions for the electric and magnetic fields, as functions of $\overline{\Pi}_e$ and $\overline{\Pi}_h$, are obtained from Maxwell's equations as

$$\overline{E}_1 = -j\omega\mu_0\mu_r \nabla \times \overline{\Pi}_{h1} + \omega^2 \varepsilon_{r1}\varepsilon_0\mu_0\left(\frac{\mu_r^2 - k_r^2}{\mu_r^2}\right)\overline{\Pi}_{e1} + \frac{1}{\mu_r}\nabla\nabla \cdot \overline{\Pi}_{e1} \tag{6}$$

$$\overline{H}_1 = j\omega\varepsilon_{r1}\varepsilon_0\mu_0\left(\frac{\mu_r^2 - k_r^2}{\mu_r^2}\right)(\overline{\overline{\mu}})^{-1}\nabla \times \overline{\Pi}_{e1} + \omega^2\varepsilon_{r1}\varepsilon_0\mu_0\mu_r\overline{\Pi}_{h1} + \nabla\nabla \cdot \overline{\Pi}_{h1} \tag{7}$$

and should satisfy the wave equations given below

$$\nabla^2 \overline{\Pi}_{e1} + \omega^2\varepsilon_{r1}\varepsilon_0\mu_0\left(\frac{\mu_r^2 - k_r^2}{\mu_r}\right)\overline{\Pi}_{e1} = 0 \tag{8}$$

$$\nabla^2 \overline{\Pi}_{h1} + \omega^2\varepsilon_{r1}\varepsilon_0\mu_0\overline{\Pi}_{h1} - \left(\frac{\mu_r - 1}{\mu_r}\right)\frac{\partial^2 \overline{\Pi}_{h1}}{\partial y^2} = 0 \tag{9}$$

In the Fourier domain [1], the wave equations are obtained as

$$\frac{\partial^2 \widetilde{\Pi}_{e1}}{\partial y^2} - \gamma_e^2 \widetilde{\Pi}_{e1} = 0 \tag{10}$$

and

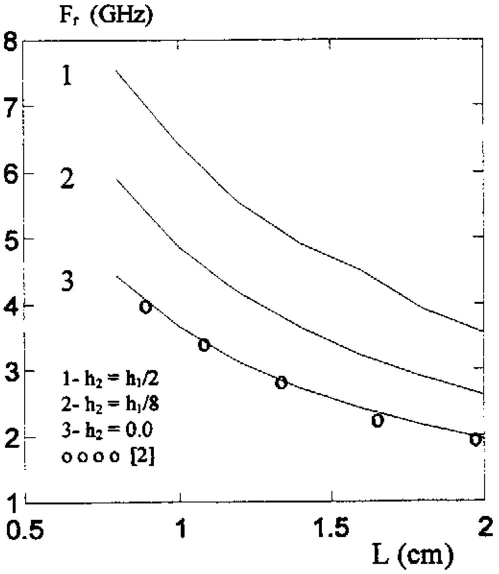

Fig. 2 : Resonant frequency versus patch length: w = 0.4 cm, h_1 = 0.127 cm, ε_{r1} = 15.2, ε_{r2} = 2.35, H_0 = 5024 Oe, $4\pi M_s$=1200 G.

$$\frac{\partial^2 \widetilde{\Pi}_{h1}}{\partial y^2} - \gamma_h^2 \widetilde{\Pi}_{h1} = 0 \tag{11}$$

where

$$\gamma_e^2 = \alpha^2 + \beta^2 - \omega^2\varepsilon_{r1}\varepsilon_0\mu_0\left(\frac{\mu_r^2 - k_r^2}{\mu_r}\right) \tag{12}$$

$$\gamma_e^2 = \mu_r(\alpha^2 + \beta^2) - \omega^2\varepsilon_{r1}\varepsilon_0\mu_0\mu_r \tag{13}$$

For dielectric regions 2 (isotropic) and 3 (air), the electric and magnetic fields are obtained from (4) to (13) by imposing $\mu_r = 1$ and $k_r = 0$ and replacing ε_{r1} by ε_{r2} (for region 2) or by ε_{r3} = 1 (for region 3).

After some algebraic manipulations, the transformed electric field components, $\widetilde{E}_x$ and $\widetilde{E}_z$, at the interface y = h_{12} (Fig. 1), are expressed as functions of the transformed surface current density components, $\widetilde{J}_x$ and $\widetilde{J}_z$, as

$$\widetilde{E}_x = \widetilde{Z}_{xx}\widetilde{J}_x + \widetilde{Z}_{xz}\widetilde{J}_z \tag{14}$$

$$\widetilde{E}_z = \widetilde{Z}_{zx}\widetilde{J}_x + \widetilde{Z}_{zz}\widetilde{J}_z \tag{15}$$

Then, Galerkin method is used as described in [7]. The basis functions used in this work are those given by [7]. The determinantal equation which gives the patch complex resonant frequency ($F_{res} = F_r + jF_i$) is obtained.

To determine the radiation pattern, the far field is expressed as function of the transformed electric field components at $y = h_{12}$ (Fig. 1), by using the phase stationary method [8]. The far field expressions are [9]

$$E_\theta(\phi,\theta) \propto \sin\phi \, \tilde{E}_z(\alpha,\beta) \tag{16}$$

$$E_\phi(\phi,\theta) \propto \cos\theta \cos\phi \, \tilde{E}_z(\alpha,\beta) + \sin\phi \, \tilde{E}_x(\alpha,\beta) \tag{17}$$

with

$$\alpha = \omega^2 \mu_0 \varepsilon_0 \sin\theta \cos\phi \tag{18}$$

$$\beta = \omega^2 \mu_0 \varepsilon_0 \cos\theta \tag{19}$$

III. NUMERICAL RESULTS

The results obtained for the resonant frequency and the radiation pattern are depicted in Fig. 2 to 5. In Fig. 2, the patch resonant frequency is shown against its length, for several values of h_2. Notice that the shape of the curves obtained for different values of h_2 is about the same. This is an expected result because of the high value of H_0 = 5024 Oe. γ = 2.855 MHz/Oe. A very good agreement was observed for microstrip patches on a single ferrimagnetic layer, when the results obtained in this work are compared to those available in [2].

The radiation patterns are shown in Figs. 4 and 5, for the E and H planes, respectively. The shapes of these curves are similar to those obtained for microstrip patches on isotropic dielectric substrates. Once again this is due to the high value of H_0 = 5024 Oe. γ = 2.855 MHz/Oe.

Fig. 3 depicts the behavior of the resonant frequency against the normalized external magnetic field, $H_0 / (4\pi M_s)$. Note that, when $H_0 / (4\pi M_s)$ increases, the resonant frequency increases, suggesting tuning possibilities, through the variation of the magnitude of $\overline{H}_0$.

A comparison between the results of this work, for the particular case of a suspended microstrip patch on isotropic substrate is shown in Fig. 6. The results of this analysis were obtained by setting $\mu_r = 1$ and $k_r = 0$. A very good agreement was observed with the results from [1], for suspended microstrip patch antennas.

IV. CONCLUSION

The analysis of rectangular microstrip patches on layers were studied, in order to investigate the effect produced by the magnetic anisotropy of the grounded layer. The analysis was developed in the Fourier domain, by using Hertz potentials and moment method, showing accuracy and efficiency. The theoretical analysis and the numerical results suggest that this analysis may be used to investigate other parameters of the antenna and/or their arrays.

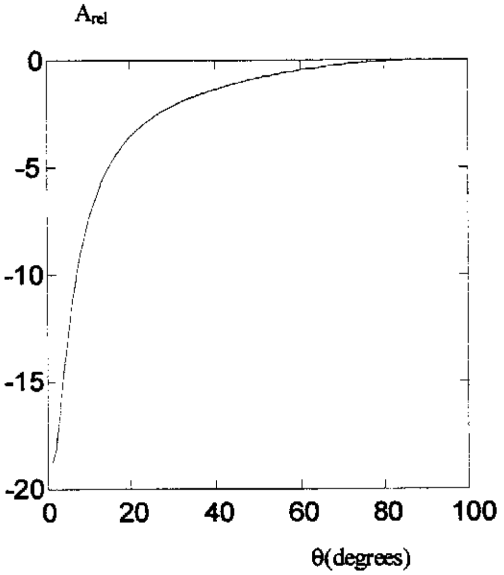

Fig. 4 : Radiation pattern $E_\theta(\phi = \pi/2, \theta)$: w = 0.4 cm; L = 1.0 cm; h_1 = 0.127; $h_2 = h_1/2$; ε_{r1} = 15.2; ε_{r2} = 2.35; H_0 = 5024 Oe; $4\pi M_s$ = 1200 G; F_r = 6.43+j0.0064 GHz.

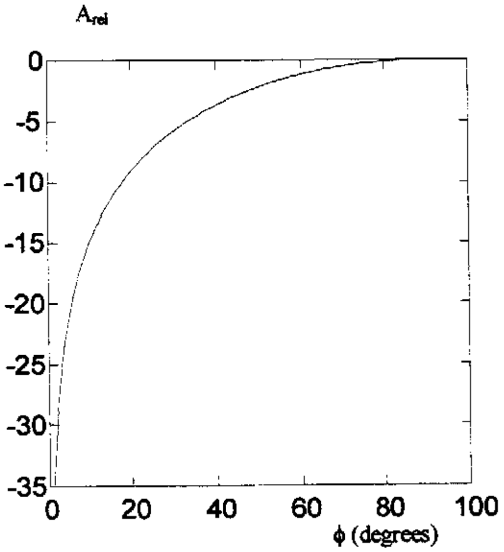

Fig. 5 : Radiation pattern, $E_\theta(\phi, \theta = \pi/2)$: w = 0.4 cm, L = 1.0 cm, h_1 = 0.127, $h_2 = h_1/2$, ε_{r1} = 15.2, ε_{r2} = 2.35, H_0 = 5024 Oe, $4\pi M_s$ = 1200 G, F_{res} = 6.43+j0.0064

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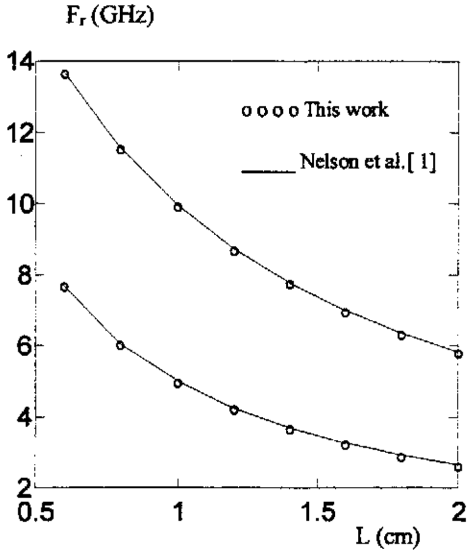

Fig.6: Resonant frequency versus patch length :
____ $w = 0.1$ cm, $h_1 = 0.1651$ cm, $h_2 = 0.0254$ cm, $\varepsilon_{r1} = 1.0$, $\varepsilon_{r2} = 9.6$
\- - - - $w = 0.4$ cm, $h_1 = 0.127$ mm, $h_2 = 0.0$, $\varepsilon_{r1} = 9.6$.

REFERENCES

[1] - R.M. Nelson, D.A. Rogers and A.G. d'Assunção, "Resonant frequency of a rectangular microstrip patch on several uniaxial substrates", *IEEE Trans. Antennas Propagat.*, v. AP-38, N. 7, pp. 973-981, July 1990.

[2] - A.G. d'Assunção and E.J.A. Dantas, "On the resonant frequency of magnetized rectangular microstrip patch resonators", *IEEE AP-S Antennas Propagation Symp.*, Ann Arbor, MI, pp. 1508-1511, June 1993.

[3] - D.M.Pozar, "Radiation and scattering characteristic of microstrip antennas on normally biased ferrite substrates", *IEEE Trans.Antennas Propagat.*, AP-40, N. 9, pp. 1084-1092, September 1992.

[4] - M.R.M.L.Albuquerque, A.G.d'Assunção and A.J. Giarola, "Dynamic characteristics of microstrip lines on magnetized ferrimagnetic substrates", *20th European Microwave Conf. Dig.*, p. 1317-1321, Budapest, Hungary, 1990.

[5] - E.J.A.DANTAS, "Características do ressoador retangular de microfita sobre substratos ferrimagnéticos Magnetizados" (M.Sc. thesis). Federal University of Rio Grande do Norte, Natal, RN, Brazil, 1993, 80 p.

[6] - H.-Y. Yang, J.A. Castanheda and G. Alexoupolos, "The RCS of a microstrip patch on an arbitrarily biased ferrite substrate", *IEEE Trans. Antennas Propagat.*, AP-41, N. 12, pp. 1610-1614, December 1993.

[7] - D.M. Pozar, "Radiation and scattering from a microstrip patch on a uniaxial substrate", *IEEE Trans. Antennas Propagat.*, vol. AP-35, N. 6, pp. 613-621, June 1987.

[8] - R.E.Collin and F.J.Zucker, *Antenna theory*, McGraw-Hill Company, 1969.

[9] - T. Itoh and W. Menzel, "A full-wave analysis method for open microstrip structures", *IEEE Trans. Antennas Propagat.*, vol. AP-29, N. 1, pp. 63-67, January 1981.

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