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Spectral Domain Modeling of Ferrite-Loaded Device by Iterative GREEN's Function Computation for Multilayer Structures

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Abstract—A spectral dyadic Green's function of multilayer structure containing arbitrarily biased magnetic layer is developed. A systematic iterative procedure for structure with more than 3 layers is developed by numerical computation of transfer matrix. Applied to practical device such as differential ferrite loaded phase shifter good agreement is obtained between measured and computed results. The use of singularity extraction techniques allows to bypass the numerical truncation of Fourier transform and accelerate the convergence speed.

I. INTRODUCTION

Multilayered structures play an important role in microwave integrated devices [1-7]. Ferrite materials are extensively used in non reciprocal devices such as phase shifter [2], isolator [3] and circulator [4]. The Space Domain Approach (SDA) is one of the most popular numerical methods for investigating the electromagnetic behaviors of many passive structures [4]-[7]. However, the spectral domain dyadic Green's function for a magnetic substrate arbitrarily biased does not have a simple closed form; the use of spectral Green's function is quite difficult for magnetic anisotropic substrate and becomes more complicated for multilayer structures. An accurate method, based on the calculation of the transfer matrix in each layer, was developed by Brian et al [8] for formulating the spectral dyadic Green's function for a multilayer structure. In contrast, it's an analytical method which is available only for dielectric layers. The method of Elshafiey[7] was developed only for a magnetic layer biased normally. The development of a method for an arbitrary polarization on multilayer structure is necessary.

The aim of this work is to combine the Transverse Operator Method [9] with the spectral domain approach in order to compute numerically the Spectral Dyadic Green's Function[10], and investigate the propagation characteristics of a multilayer structure. The developed method makes it possible to study the convergence of characteristic propagation in both microstrip and coplanar configurations with a lossless or lossy anisotropic magnetic layer.

II. THEORY

Fig. 1 shows the cross section of a coplanar configuration in a stratified structure involving magnetic layers with an arbitrary direction bias. The zero thickness metallic circuit is located at $z = z_i$ of the planar structure that contains N layers of thickness h_i which $1 \leq i \leq N$. The general structure is symmetric about the z -axis normal to the $(x$ - o - y) plane through the middle center conductor and it is uniform and infinite along the y axis. In Fig. 1, the outermost surface

and the thin metal strips are assumed to be perfect electric conductors (PECs). It is assumed that the electromagnetic field is exponential in the longitudinal direction as $e^{-jk_y y}$ where $k_y = \beta - j\alpha$ is the complex propagation constant, β is the phase constant and α is the attenuation constant.

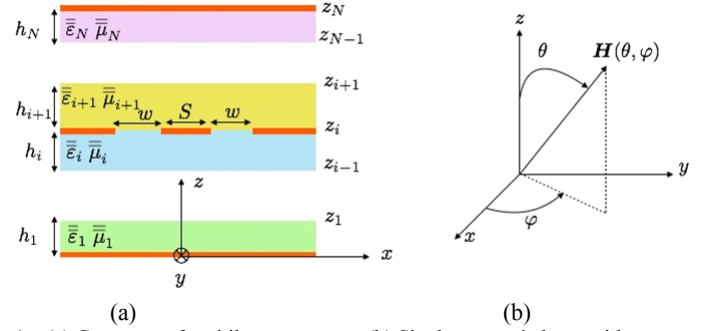


Fig. 1. (a) Geometry of multilayer structure. (b) Single magnetic layer with arbitrarily bias.

A Green's function in the spectral domain is derived which relates the tangential electric field $\tilde{\mathbf{E}}$ on one surface to the electric surface currents $\tilde{\mathbf{J}}_s$ on the same surface as:

$$\tilde{\mathbf{J}}_s(k_x, k_y) = \tilde{\mathbf{G}}(k_x, k_y) \tilde{\mathbf{E}}(k_x, k_y) \quad (1)$$

With $\tilde{\mathbf{G}}(k_x, k_y)$ is the spectral Green's function defined by

$$\tilde{\mathbf{G}}(k_x, k_y) = \frac{1}{Z_0} \bar{\eta}_0 \left(\tilde{\mathbf{Y}}_{Bottom} \cdot \tilde{\mathbf{Y}}_{Top} \right) \quad (2)$$

With \mathbf{Y}_{Bottom} and \mathbf{Y}_{Top} are, respectively, the admittances matrices in the layers below and above the metal strip.

To obtain these two matrices the transverse operator formulation [9] is applied. A four field components vector $\tilde{\Phi}^{(i)} = [\tilde{E}_{xi}, \tilde{E}_{yi}, jZ_0 \tilde{H}_{xi}, jZ_0 \tilde{H}_{yi}]^T$ inside each layer can be expressed in a matrix relation

$$\tilde{\Phi}^{(i)}(z_i) = e^{-j\bar{\eta}_i \cdot \bar{L}_i(z)} \tilde{\Phi}^{(i,0)} = \tilde{K}_i \tilde{\Phi}^{(i,0)} \quad (3)$$

$\tilde{\Phi}^{(i,0)}$, being a constant vector to be determined according to the boundary condition, $\bar{\eta}_i \cdot \bar{L}_i$ a matrix defined in [10] and related to the characteristic of the i th layer and $e^{-j\bar{\eta}_i \cdot \bar{L}_i(z)}$ a (4×4) matrix.

The integral equation in (1) can be transformed into system of linear equation by using the Ritz-Galerkin technique. The unknown tangential electric field will be approximated by a linear combination of appropriate basis functions

$$E_x(x) = \sum_{i=1}^{N_s} \sum_{n=1}^{M_x} a_{in} e_{xn}(x) \quad (4a)$$

$$E_y(x) = \sum_{i=1}^{N_s} \sum_{n=1}^{M_y} b_{in} e_{yn}(x) \quad (4b)$$

which leads to the following matrix equation

$$\mathbf{\Gamma}(k_y, \omega) \mathbf{C} = 0 \quad (5)$$

\mathbf{C} being a column vector of the unknown coefficients and $\mathbf{\Gamma}$ the Galerkin matrix. The non trivial solution of (5) gives us the characteristic equation for the complex propagation constant

$$|\mathbf{\Gamma}(k_y, \omega)| = 0 \quad (6)$$

As infinite integrals are involved in (1) with spectral domain singularities, a technique of extraction of singularities has been developed leading to more accurate and numerically efficient computation of Galerkin matrix [10].

III. NUMERICAL RESULTS

The convergence of the normalized propagation constant with the number of basis function (Chebyshev polynomials) for a fixed frequency is studied first. The results of forward and backward complex propagation constant for a coplanar line are compared to the results from [4]. It is clear that 6 basis functions are adequate to achieve a good convergence of the propagation constant.

Table 1. Convergence of the forward and backward complex propagation constant $\gamma/k_0 = k_y/k_0$ with number of basis function. $f = 10$ GHz
 $w = S = 300 \mu\text{m}$, $h_d = 1$ mm, $\epsilon_{rd} = 9.6$, $h_f = 365 \mu\text{m}$, $\epsilon_{rf} = 15$
 $4\pi M_s = 140$ kA/m, $H_0 = 198$ kA/m, $\alpha = 0.05$, $\theta = 90^\circ$, $\phi = 0^\circ$.

(M_x, M_y)	k_y-/k_0	k_y+/k_0
1x1	2.652693 - j0.06234	2.796931 - j0.0094
2x2	2.638209 - j0.06050	2.787699 - j0.0081
3x3	2.630139 - j0.05299	2.782411 - j0.0081
4x4	2.630139 - j0.05299	2.782411 - j0.0081
5x5	2.630139 - j0.05299	2.782411 - j0.0081
[6]	2.6172 - j0.055	2.7605 - j0.0234

An experimental validation has been taken with a ferrite-Low Temperature Co-Fired Ceramic (LTCC) based coplanar line. The fabricated coplanar waveguide makes use of a transversally magnetized LTCC-ferrite ($\theta=90^\circ$, $\phi=0^\circ$). The magneto static and microwave properties of this substrate were previously reported in the demagnetized state only [10], using multilayer solenoidal and toroidal multilayer transformers. Fig. 2 shows the differential phase shift calculated numerically and measured experimentally from 1 to 12 GHz at a magnetic bias field of 110 kA/m. A good agreement was observed between calculation and experiment in this range of frequency.

IV. CONCLUSION

The numerical investigating a multilayered structure containing anisotropic magnetic substrates/superstrates magnetized along an arbitrary direction has been taken. An efficient algorithm based on this technique has been developed

to compute numerically the SDGF for a stratified planar structure containing anisotropic magnetic materials. Quick convergent solutions are obtained by singularities extraction technique. Experimental validation of our method has been taken with a ferrite-LTCC based coplanar waveguide with satisfactory agreement.

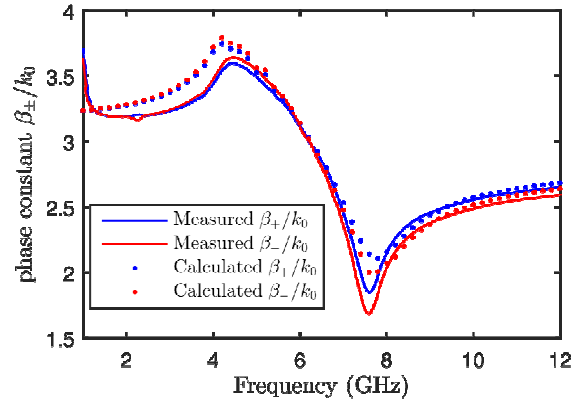


Fig. 2. Comparison between calculated and measured differential phase shift at an applied bias field of 110 kA/m

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