Mutual Coupling Between Broadside Printed Dipoles Embedded in Stratified Anisotropic Dielectrics

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Abstract - The mutual coupling between two broadside printed dipoles in stratified anisotropic dielectrics is evaluated using newly derived spectral domain immittance functions. It is shown that an increase in the permittivity in the layer below the dipoles in the direction of the optical axis can significantly increase the mutual coupling while an increase in the permittivity in the direction orthogonal to the optical axis in the layer above the dipoles could be used to reduce the mutual coupling. The isotropic cases are compared to published literature and commercial software for validation and good agreement is shown.

Introduction

The study of printed antennas embedded in stratified anisotropic material has received considerable attention in the past few years [1]-[3]. This is because it is well known that many microwave substrates actually posses anisotropic properties [4]. In the past significant work has been done to model the mutual coupling between printed dipoles in layered dielectrics [5]-[6]. But, in much of the previous work the layered material has been exclusively isotropic. In fact, very little work has been done outside of electromagnetic bandgap (EBG) feed networks and transmission lines [3] to model the mutual coupling between elements in layered anisotropic dielectrics.

In this work the mutual coupling between two printed dipoles in stratified anisotropic dielectrics is modeled. In particular, the coupling between the dipoles is determined using newly derived spectral domain immittance functions based on Hertz vector potentials for various material properties. The isotropic results presented here are compared to commercial software and published literature for validation. This study determines which individual component or components of the anisotropic ratio of the material most greatly affects the coupling between the printed dipoles. Knowing this information, for example, is especially important when designing a printed antenna array in a multi-layered printed circuit board or implementing Radio Frequency Identification tags in close proximity.

The new spectral domain immittance functions

The problem in Figure 1 will be used to determine how the coupling between the printed dipoles is affected by the anisotropic layers. This structure consists of two layers of anisotropic dielectrics with a printed dipole on layer 1 (dipole A) and a printed dipole on layer 2 (dipole B). The dipoles both have a length L, width W,

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are driven with a delta source at the origin and are assumed to be thin-wires. Thus, it is understood that the current does not vary with respect to the width of the conductor. This then requires only the tangential component of the electric field in the x-direction to be enforced to satisfy the tangential boundary conditions. It is assumed that each layer has an optical axis in the y-direction and the kth layer has a thickness of d_k, a permeability of μ_0 and is uniaxially anisotropic ($\varepsilon_{xk} = \varepsilon_{zk}$) with permittivity $[\varepsilon_k]$. Next, the Hertz vector potentials $\bar{\Pi}_e$ and $\bar{\Pi}_h$ are introduced to solve for the fields in each anisotropic layer and the region above the top layer. $\bar{\Pi}_e$ is denoted as the electric Hertz potential and $\bar{\Pi}_h$ is denoted as the magnetic Hertz potential. Since the optical axis is chosen to be in the y-direction, the y-components of $\bar{\Pi}_e$ and $\bar{\Pi}_h$ are chosen to yield a TM and TE mode with respect to the optical axis, respectively [2]. Then, the total solution in each region will be the sum of the TM and TE solutions. Next, the fields in the kth region are written in terms of the Hertz vector potentials in the following manner:

$$\bar{E}_k = -j\omega\mu_0 \nabla \times \bar{\Pi}_{kh} \tag{1}$$

$$\bar{H}_k = j\omega\varepsilon \nabla \times \bar{\Pi}_{ke}. \tag{2}$$

Moreover, $\bar{\Pi}_e$ and $\bar{\Pi}_h$ is a solution, respectively, to the following wave equations [2]

$$\nabla^2 \bar{\Pi}_{ke} + \omega^2 \mu_0 \varepsilon_0 \varepsilon_{k1} \bar{\Pi}_{ke} + (\varepsilon_{k1} - \varepsilon_{k2}) \frac{1}{\varepsilon_{k2}} \frac{\partial^2 \bar{\Pi}_{ke}}{\partial y^2} = 0 \tag{3}$$

and

$$\nabla^2 \bar{\Pi}_{kh} + \omega^2 \mu_0 \varepsilon_0 \varepsilon_{k2} \bar{\Pi}_{kh} = 0. \tag{4}$$

Furthermore, the Fourier transform ($\widetilde{\Pi}_{ek}$ and $\widetilde{\Pi}_{hk}$) is applied to (3) and (4) to greatly simplify the numerical integration. This then leads to the spectral (or transform) domain wave equations [2]. Then, by using the assumed solutions to the spectral domain wave equations, enforcing the boundary conditions and factoring, final expressions for $\widetilde{\Pi}_{ek}$ and $\widetilde{\Pi}_{hk}$ are obtained in terms of the structural parameters of Figure 1. Then $\widetilde{\Pi}_{ek}$ and $\widetilde{\Pi}_{hk}$ are substituted into the spectral domain expressions of (1) and (2) to represent the field in the kth layer. This results in the following spectral domain immittance functions in region 2 [2]:

$$\widetilde{E}_{x2}(\alpha, y, \beta) = \widetilde{J}_{x1} \widetilde{Z}_{xx1} + \widetilde{J}_{x2} \widetilde{Z}_{xx2} \tag{5}$$

where $\widetilde{J}_{x1}$ represents an x-directed dipole current on layer 1, $\widetilde{J}_{x2}$ represents an x-directed dipole current on layer 2 and $\widetilde{Z}_{xx1}$ and $\widetilde{Z}_{xx2}$ are referred to as the spectral domain immittance functions. Once the expressions for $\widetilde{Z}_{xx1}$ and $\widetilde{Z}_{xx2}$ are derived the moment method is used to solve for the unknown currents $\widetilde{J}_{x1}$ and $\widetilde{J}_{x2}$. The steps leading to (5) are quite extensive and are beyond the scope of this paper. A thorough derivation of $\widetilde{Z}_{xx1}$ and $\widetilde{Z}_{xx2}$ can be found in [2]. New abbreviated expressions for $\widetilde{Z}_{xx1}$ and $\widetilde{Z}_{xx2}$ will be presented at the conference.

Results

The dipoles in Figure 1 have a length of 15 cm, a width of 0.5 mm and a source frequency of 500 MHz. This resulted in a dipole length of $.25\lambda_0$. In the first example

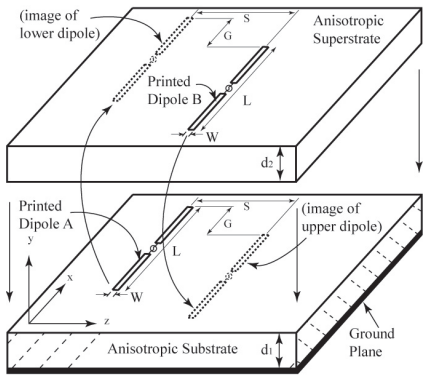

Figure 1: Expanded view of two printed dipoles embedded in anisotropic layers.

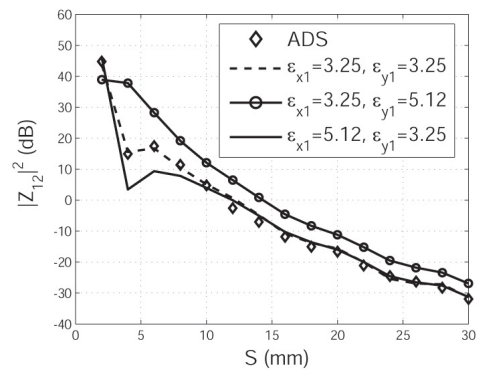

Figure 2: Mutual coupling between printed dipoles on an anisotropic substrate.

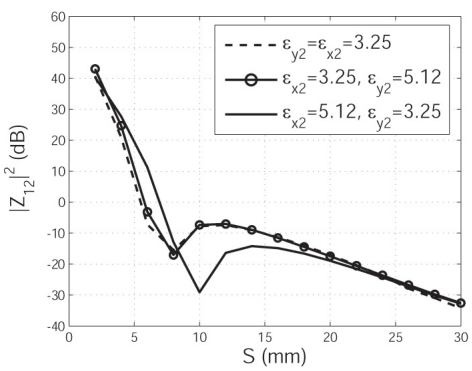

Figure 3: Mutual coupling between printed dipoles with an anisotropic cover.

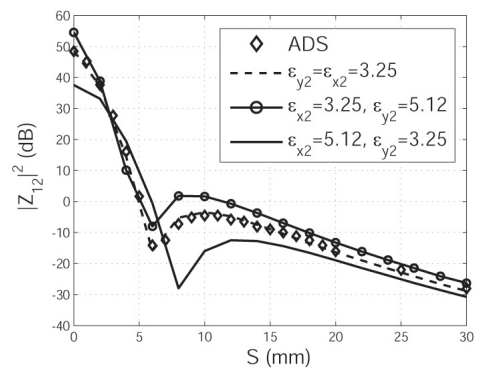

Figure 4: Mutual coupling between printed dipoles separated by an anisotropic layer.

the thickness of layer 1 was set at $d_1 = 1.58$ mm and the thickness of layer 2 was set at $d_2 = 0$ (i.e. layer 2 was removed and dipole B was placed on layer 1). The value of G was set at G = 0 and S was varied for the broadside configuration. The mutual coupling between the printed dipoles was computed and is shown in Figure 2 for various values of $[\varepsilon_1]$. It is shown that the isotropic results agree with the results from the commercial software ADS [7] and that the coupling has the same properties of coupled antennas shown in published literature [5]. The mutual coupling is the largest for the anisotropic values of $\varepsilon_{x1} = 3.25$ and $\varepsilon_{y1} = 5.12$. This is because the TM_0 is the dominant mode in layer 1. The TM_0 mode has a y-directed field which corresponds to the direction of the optical axis and the $\varepsilon_{y1} = 5.12$ value. Next, an anisotropic layer 2 of thickness $d_2 = 1.58$ mm was placed above both of the broadside dipoles on layer 1 and the values of $[\varepsilon_2]$ were varied. The thickness of layer 1 was set at $d_1 = 1.58$ mm and the permittivity was set at $\varepsilon_{x1} = 3.25$ and $\varepsilon_{y1} = 3.25$ (isotropic). The results for various values of $[\varepsilon_2]$ are shown in Figure 3. It is shown that the overall mutual coupling between the dipoles is reduced by the second anisotropic layer. In some cases the coupling is reduced by more than 30dB. The mutual coupling in Figure 3 is reduced mostly by the anisotropic values of $\varepsilon_{x2} =$

5.12 and $\varepsilon_{y2} = 3.25$ and virtually unaffected by the anisotropic values of $\varepsilon_{x2} = 3.25$ and $\varepsilon_{y2} = 5.12$. This is because the surface wave mode along the boundary between layers 1 and 2 has an electric field component in the x-z plane (i.e. orthogonal to the optical axis) which corresponds to the larger value of $\varepsilon_{x2} = 5.12$. Therefore, the effects of layer 1 on the mutual coupling are completely opposite of layer 2. This effect should be kept in mind during the design process. Finally, dipole B was placed on layer 2 and dipole A remained on layer 1. The layer thicknesses remained at $d_1 = d_2 = 1.58$ mm with permittivity $\varepsilon_{x1} = 3.25$ and $\varepsilon_{y1} = 3.25$. The values of $[\varepsilon_2]$ were varied for the broadside configuration and the mutual coupling is shown in Figure 4. Both anisotropic permittivities impact the mutual coupling between the dipoles in different manners. The increased coupling that occurs when ε_{y2} is increased from 3.25 to 5.12 is believed to be a result of the lower resonant frequency of dipole B which results in a stronger more coupled surface wave launched from the dipole.

Conclusion

The mutual coupling between two broadside printed dipoles in stratified anisotropic dielectrics was evaluated using newly derived spectral domain immittance functions. It is shown that an increase in the permittivity in the layer below the dipoles in the direction of the optical axis can significantly increase the mutual coupling while an increase in the permittivity in the direction orthogonal to the optical axis in the layer above the dipoles could be used to reduce the mutual coupling.

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