Mutual Coupling Between Coax-fed Rectangular Microstrip Antennas Embedded in Layered Uniaxial Anisotropic Dielectrics

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Abstract - The mutual coupling between two coax-fed rectangular microstrip antennas embedded in uniaxial anisotropic dielectrics is evaluated. An interesting trade-off is shown where an increase in the permittivity in the direction of the optical axis in the substrate reduces the traditionally stronger E-plane coupling while it increases the traditionally weaker H-plane coupling. The computations from the commercial software used in this work are validated by successful comparison with published results.

Introduction

One of the most common types of printed antennas is the rectangular microstrip antenna [1] shown in Fig. 1 a). Rectangular microstrip antennas have been used extensively in the latest development of novel microstrip arrays such as rectenna arrays for power harvesting circuits and steerable patch arrays with tunable PRI/NRI phase shifters. In these applications, many rectangular microstrip antennas are in close proximity with each other. Thus, it is very important to understand the mutual coupling between these antennas. One aspect of a printed antenna array that can affect the mutual coupling between elements is the dielectric anisotropy of the materials that may be used to form the substrate or superstrate on which the antennas are printed on. This anisotropy may be found in naturally occurring materials (such as sapphire and alumina [2]), composite laminate materials (for example AR-1000, formerly known as Epsilam-10 [3]) and “engineered” [4] materials. Whether this anisotropy is an unintended consequence of the manufacturing process or not, its effects on the performance of antennas and other devices can be appreciable. As a recent example, the orientation of a microstrip antenna on a fiber-reinforced substrate was shown to appreciably affect the resonant frequency of the antenna and its radiation pattern [5].

This work investigates the mutual coupling between two rectangular microstrip antennas embedded in layered anisotropic dielectrics. Specifically, this work shows how each individual component of the permittivity of each dielectric layer affects the coupling in both the E- and H-planes. The coupling is computed by using the commercial software package HFSS [6]. The isotropic results computed in HFSS are successfully validated by comparison with the published mutual coupling results by Pozar [1]. Other than the investigation on the coupling between the printed dipoles in [7], much less work has been done on modeling the coupling between antennas in layered anisotropic dielectrics.

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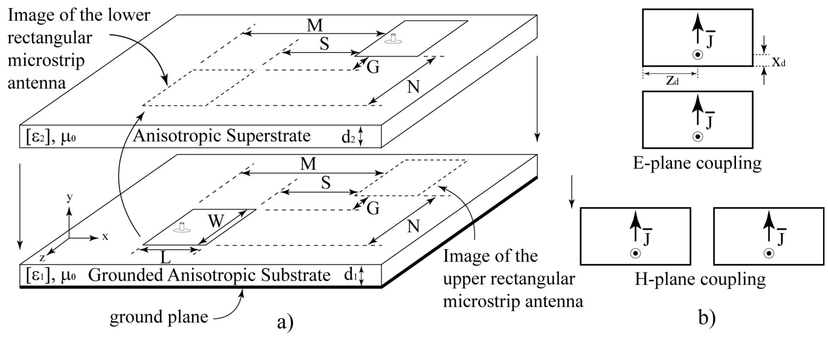

Figure 1: a) Expanded view of two rectangular microstrip antennas in parallel-in-echelon arrangement for coupling calculations, and b) E- and H-plane coupling.

Rectangular Microstrip Antennas in Anisotropic Dielectrics

The arrangement in Fig. 1 a) was used to investigate the coupling between two rectangular microstrip antennas in layered anisotropic dielectrics. It was assumed that each layer had an optical axis in the y-direction and that the k^{th} ($k = 0$ or 1) layer had a thickness of d_k, a permeability of μ_0 and was uniaxially anisotropic ($\varepsilon_{xk} = \varepsilon_{zk}$) with permittivity tensor $[\varepsilon_k]$. Both patches were fed with a coaxial cable (from the ground plane) and both had a length of $L = 6.55$ cm and a width of $W = 10.57$ cm. The source frequency was set at 1.41 GHz (to correspond to the results in [1]) and the dimensions of the coax were chosen such that the characteristic impedance was 50 Ω with a dielectric relative permittivity of $\varepsilon_r = 4.25$. The position of the coax was chosen by isolating a rectangular patch on a single grounded isotropic substrate with a permittivity of $\varepsilon_r = 4.25$ and a thickness of $d = 1.58$ mm and numerically calculating the feed point for optimum S_{11}. This resulted in a feed position of $x_d = 16.8$ mm and $z_d = 52.85$ mm ($W/2$) where x_d and z_d are shown in Fig. 1 b).

Results

For the first case, the thickness of the grounded anisotropic substrate was set at $d_1 =$ 1.58 mm and the thickness of layer two was set to $d_2 = 0$ (i.e., the antennas are on the same layer and do not have a superstrate). Then the mutual coupling between the two antennas was computed using HFSS. The mutual coupling between the antennas in both the E- and H-planes (Fig. 1 b)) is shown in Figs. 2 and 3, respectively, for various anisotropic ratios of the substrate. For validation, the isotropic results from HFSS are also shown to agree very well with the published isotropic results from Pozar [1]. It is shown that the largest change in coupling between the antennas is a result of(i.e., y-direction). This is because the only surface wave propagating for substrates of this thickness is the TM_0 mode [1], which has an electric field with a dominant y-component. This y-component corresponds to the larger ε_{y1} value. Also shown in Figs. 2 and 3 is that an increase in ε_{y1} reduces the E-plane coupling between the antennas while increasing the H-plane coupling. This would indicate a decrease in E-plane radiation and an increase in H-plane radiation from the antenna.

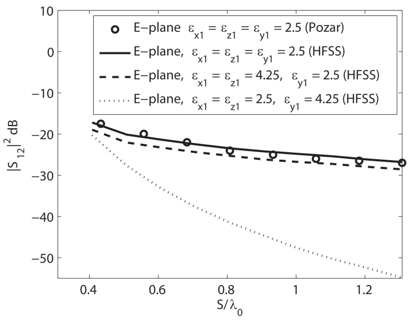

Figure 2: E-plane coupling on a single anisotropic substrate with $G = N = 0$.

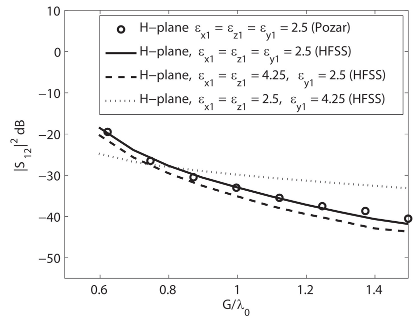

Figure 3: H-plane coupling on a single anisotropic substrate with $S = 0$.

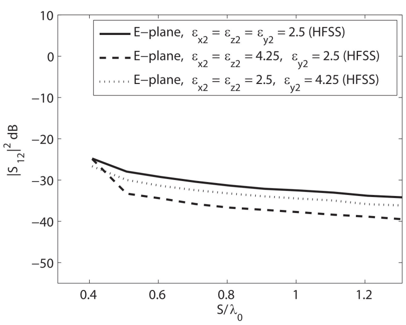

Figure 4: E-plane coupling with a single anisotropic superstrate with $G = 0$.

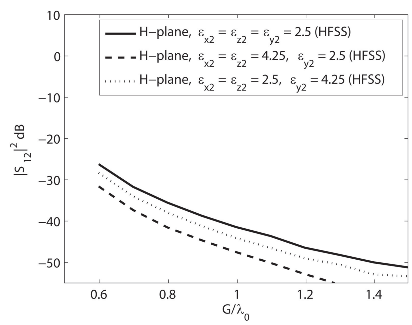

Figure 5: H-plane coupling with a single anisotropic superstrate with $S = 0$.

Next, both antennas remained on the top of the first layer and an anisotropic superstrate was added above both antennas. The thickness of both dielectrics was set to 1.58 mm and the substrate was defined to be isotropic with $\varepsilon_1 = 4.25$. The substrate was defined to be isotropic to allow for the investigation on how the individual anisotropic properties of the superstrate affected the mutual coupling between the printed antennas. The results from this investigation are shown in Figs. 4 and 5. The coupling was reduced mostly by an increase in the permittivity in the direction orthogonal to the optical axis in the superstrate (i.e., due to ε_{x2} and ε_{z2}). This is because the radiation of a rectangular microstrip antenna is mainly due to the tangential electric fields (i.e., E_x and E_z) at the boundary of the two anisotropic dielectrics. Thus, the electric field components are mostly affected by the values of ε_{x2} and ε_{z2}. This characteristic is similar to the results reported in [7].

Finally, one of the rectangular microstrip antennas was place on top of the second anisotropic layer as shown in Fig. 1 a). The thickness of both dielectrics was again set to 1.58 mm and the substrate was defined to be isotropic with $\varepsilon_1 = 4.25$. The anisotropic ratio of the layer separating the antennas was varied and the mutual coupling for both the E- and H-planes was computed. The results from these computations are shown in Figs. 6 and 7. It is shown that for these instances the coupling in both the E- and H-planes are reduced by an increase in each component of $[\varepsilon_2]$ which is similar to the results shown in Figs. 4 and 5.

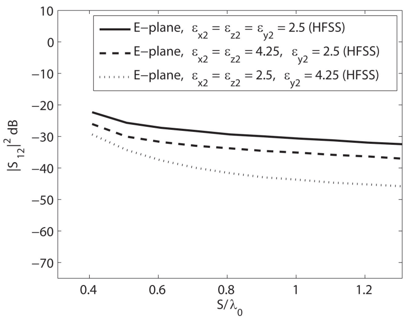

Figure 6: E-plane coupling with a single anisotropic layer separating the antennas with $G = 0$.

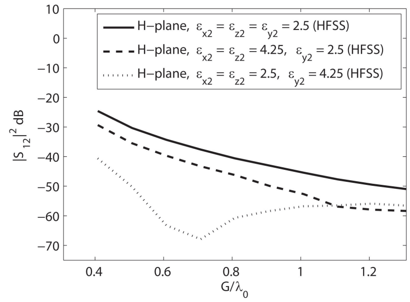

Figure 7: H-plane coupling with a single anisotropic layer separating the antennas with $S = 0$.

Conclusion

The mutual coupling between two coax-fed rectangular microstrip antennas embedded in anisotropic dielectrics was investigated. In particular, it was determined how each individual component of each anisotropic dielectric layer affected the coupling between the microstrip antennas. It was shown that an increase in the permittivity in the direction of the optical axis in the substrate would decrease the E-plane coupling but increase the H-plane coupling. Also, the isotropic results from HFSS were validated by successful comparison with published results.

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