MODAL TRANSITION PHENOMENA IN SHIELDED MICROSTRIP WITH ANISOTROPIC SUBSTRATES

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ABSTRACT

Modal transitions involving the quasi-TEM mode and higher-order modes in shielded microstrip and suspended microstrip with anisotropic substrates are studied. For the class of anisotropy studied, at higher frequencies the largest eigenvalue may not correspond to the quasi-TEM mode. It is shown that the dispersion curves of the quasi-TEM and higher order modes do not intersect, but rather pass through a transition/coupling region and interchange mode types.

I. INTRODUCTION

Recently, there has been an interest in the leakage properties of printed transmission lines commonly used in high-speed integrated circuits [1]. It has been demonstrated that the fundamental mode of a single microstrip line on a properly oriented anisotropic substrate can be leaky. In [1] it was shown that this leakage can occur in microstrip for a uniaxial anisotropic substrate with $\epsilon_{\|} < \epsilon_{\perp}$. The optical axis is assumed to be perpendicular to the surface of the substrate (in the y direction, see Fig. 1). The microstrip electric fields for the quasi-TEM mode are predominantly under the strip and in the y-direction, so the effective dielectric constant approaches $\epsilon_{\|}$ in the high frequency limit. The TM_z surface waves in an open structure will also have a high-frequency effective dielectric constant approaching $\epsilon_{\|}$. On the other hand, the TE_z surface wave has an effective dielectric constant approaching $\epsilon_{\perp}$ at high frequencies. One may therefore expect the dispersion curve of the quasi-TEM mode and a TE_z surface wave to cross at some sufficiently high frequency if $\epsilon_{\perp} > \epsilon_{\|}$. In [1] it was shown that this is indeed the case and that above this critical frequency the so-called dominant mode may leak.

The leakage effect reported in [1] was unique in that it was associated with the anisotropic nature of the substrate and is not possible for microstrip on an isotropic substrate. This suggests that there may be other phenomena associated with planar structures on anisotropic substrates that have been over looked because they are not witnessed for isotropic substrates. Most planar microwave and millimeter wave integrated circuits usually reside in a shielded structure. In a lossless shielded structure, the microstrip will obviously not have a complex phase constant above the critical frequency reported in [1]. It is therefore important to see how potential leakage in an open structure manifests itself in a shielded structure.

Like the TM_z surface waves in an open structure, the TM_y modes of dielectric loaded waveguide in a closed structure have effective dielectric constants approaching $\epsilon_{\|}$ in the high frequency limit. The TE_y mode, like the TE_z surface wave, has an effective dielectric constant approaching $\epsilon_{\perp}$ at high frequencies. As in the open structure, the quasi-TEM mode of shielded microstrip has an effective dielectric constant approaching $\epsilon_{\|}$ at high frequencies. Thus, in the closed structure one might expect that there would be some critical frequency at which the lowest order TE_y mode dispersion curve would cross that of the quasi-TEM mode (at higher frequencies other TE_y modes would be expected to cross) for a properly oriented anisotropic substrate ($\epsilon_{\perp} > \epsilon_{\|}$). For cases where the side walls are relatively far from the strip (or the strip is narrow) one would expect the dispersion curves of the higher order modes of shielded microstrip to be very similar to those of the TE_y and TM_y modes without the strip [2], and therefore the higher order microstrip modes are designated as TE'_y and TM'_y. It is shown in this work that near the frequencies at which the TE_y and quasi-TEM dispersion curves cross, the quasi-TEM and associated TE'_y higher order mode do not intersect but interchange in a mode coupling fashion, with the TE'_y mode assuming the larger phase constant and the quasi-TEM the lower. At frequencies above the region where the dispersion curves bend, the field types (mode types) associated with the two dispersion curves switch. This dispersion curve bending has been shown between TE'_y and TM'_y higher order modes of boxed microstrip over an isotropic substrate [2]. The novel feature of this work is that the dispersion curve bending occurs in the quasi-TEM microstrip mode (as well as to higher order modes) and thus the mode switching results in a situation in which the slowest mode in the box is no longer the quasi-TEM mode. This phenomena is associated with the anisotropic nature of the substrate and is not possible for isotropic substrates. This work therefore shows that the field plots are critical in determining mode identification for shielded microstrip on a properly oriented uniaxial anisotropic substrate. For realistic substrate thickness, the leakage to surface waves in an open structure and this modal transition region in a closed structure occur at relatively high frequencies for microstrip. Results are also presented for suspended microstrip on an anisotropic substrate and it is shown that this mode switching occurs at significantly lower frequencies for this case.

The new features of this work are the understanding of a mode-coupling-type transition region for shielded microstrip with a particular anisotropy. The techniques used to make the computations are the Spectral Domain Technique (SDT) [3] and a full-wave vector magnetic field FEM analysis [4]. The paper is arranged as follows. Dispersion curves are presented for shielded microstrip which clearly show the bending when the TE_y' and quasi-TEM modes approach each other at a sufficiently high frequency. Fields are then given which show that the mode types associated with the dispersion curves have switched for frequencies above the transition region. Similar effects are evident in the dispersion curves shown for suspended microstrip.

II. MODE COUPLING/TRANSITIONS

The term "coupling" applied to the dispersion curves in the "transition" regions (illustrations of which follow) implies two things: that the curves are reminiscent of those for periodically loaded or coupled waveguides (codirectional for the cases considered), and that the mode field distributions for the two eigenmodes involved in the transition are dissimilar to those for the same modes on either side of the transition region and cannot be clearly identified with either mode. The eigenmodes are of course all orthogonal when inner products are taken over the shield cross-section. As will become evident, the modes on either side of the transition region are perturbations of the open-structure quasi-TEM mode and the dielectric loaded waveguide or box-modes, while those in the transition region differ from both. One would therefore expect an increase in insertion loss when using a TEM launcher and probe if the frequency of operation corresponds to a transition region, where none of the modes are clearly quasi-TEM. Specific examples illustrating these effects follow.

Consider the shielded microstrip structure of Fig. 1. This is the same structure as considered in [1] with the addition of a shield. The permittivity corresponds to Epsilam-10 with $\epsilon_\perp = 13$ and $\epsilon_\parallel = 10.3$. In Fig. 2 are plotted the dispersion curves of the TM_{y11}, TE_{y11}, TE_{y13}, and TE_{y15} modes associated with a dielectric loaded waveguide as in Fig. 1 with the strip absent. These are the TM_y and the first three TE_y modes of lowest cutoff frequency. The mode designation TE_{ymn}/TM_{ymn} corresponds to the mth root of the transcendental equation associated with the TE_y/TM_y mode with $k_x = n\pi/a$, where a is the width of the box. The dispersion curves for the geometry of Fig. 1 were computed using the SDT and the results are shown in Fig. 3. To get the degree of resolution required to compute these points, roots of the determinant were searched only in the region of interest, ie., for values of β/k_o above that computed for the TM_{y11} box-mode. For the frequency range presented there are as many as ten TE_y' and TM_y' modes above cutoff. However, only those that cross the quasi-TEM mode are of interest in this study. Mode identification must be carefully considered for these calculations because of the continual coupling or mode swapping.

The novel feature of these results is that this modal interaction occurs to the quasi-TEM mode. This, as discussed above, is due to the fact that the TE_y' modes have larger values of β/k_0 at high frequencies that the quasi-TEM mode. This arises because of the fact that $\epsilon_\perp > \epsilon_\parallel$ and is not expected to occur for microstrip with an isotropic substrate. To get a physical understanding of what is occurring at these transition regions where the dispersion curves of the TE_y' and quasi-TEM modes approach each other, interchange and then bend away from one another, field plots are presented. All field plots are for the transverse magnetic field (in the x-y plane). Due to symmetry, fields are only plotted for half the cross-section with a magnetic wall (even modes) at the center of the strip and perpendicular to the substrate.

Figure 4 gives the fields for the quasi-TEM mode at point 1, the TE_{y11}' mode at point 2, and the fields at points 3 and 4, as shown in Fig. 3. One sees by inspecting these four figures that the mode types have interchanged for frequencies above the transition, ie., the largest eigenvalue above the coupling region is the TE_{y11}' and the second largest the quasi-TEM. The same phenomena happens higher in frequency with the quasi-TEM and the TE_{y13}' modes. It is important to note that this transition phenomena or mode switching occurs at a frequency approximately where the geometry in [1] may leak. Figure 5 shows the power density for the eigenmodes associated with the three largest eigenvectors (points 5, 6, and 7 in Fig. 3). It is clear that the third mode (point 7) is the quasi-TEM mode and that for the others the power is not confined (guided) by the strip.

Consider now the suspended microstrip geometry depicted in Fig. 6. Computed values for the region of the dispersion curves which is of interest here is presented in Fig. 7. Notice that a similar situation exists as in Fig. 3 (although it is not as pronounced), but now the frequency is lower and the curves are not so closely spaced.

CONCLUSION

Based on a study of the dispersion curves and field plots, the mode-crossings which have been associated with possible leakage of the dominant microstrip mode with anisotropic substrates in an open structure, have been shown to be transitions or coupling regions between the dominant quasi-TEM mode and higher-order modes in the closed structure. The mode types interchange after the transition and the largest phase constant may not be associated with the quasi-TEM mode. At the frequencies of strong coupling the modes cannot be clearly identified as either microstrip or box-mode type. As a result of the mode coupling the identification of the mode type becomes complicated and field plots are necessary.

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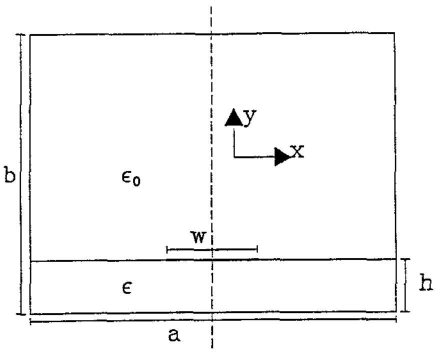

Figure 1. Shielded microstrip with a uniaxial anisotropic substrate defined by $\epsilon_{||} = 10.3, \epsilon_{\perp} = 13.0$ with the y axis as a reference. The dimensions are w=1.0mm, h=1.0mm, a=9.0mm and b=5.0mm.

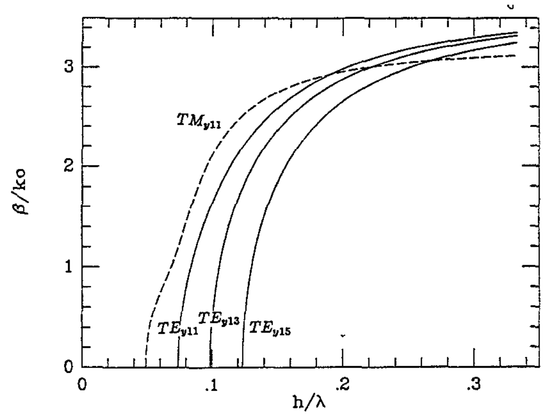

Figure 2. Dispersion curves for the first three even box modes for the geometry illustrated in Figure 1.

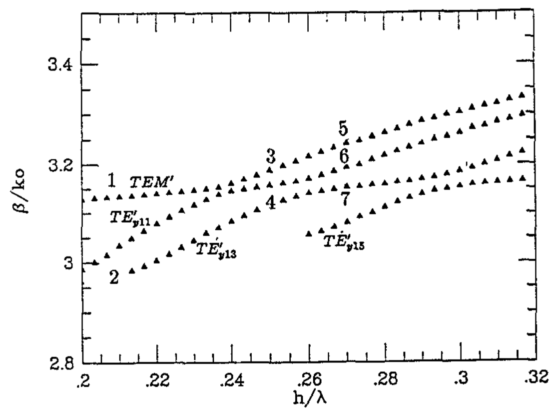

Figure 3. Expanded view of the microstrip dispersion curve showing the interaction region of the quasi-TEM microstrip mode (Mode 1) with the next higher order even mode (Mode 2, a quasi TE mode) and the interactions of the higher order modes.

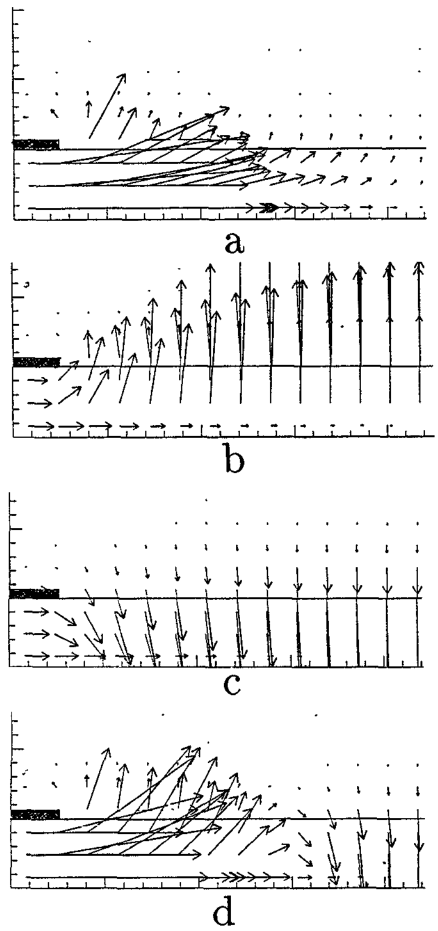

Figure 4. a) Transverse magnetic field (**Ht**) of the microstrip mode (Mode 1 on the dispersion curve) at point 1. b) Transverse field for the second mode at point 2. (h/λ = 0.21) c) Mode 1 transverse magnetic field after first transition. (point 3) d) Mode 2 transverse field at point 4. ($h/\lambda = 0.25$).

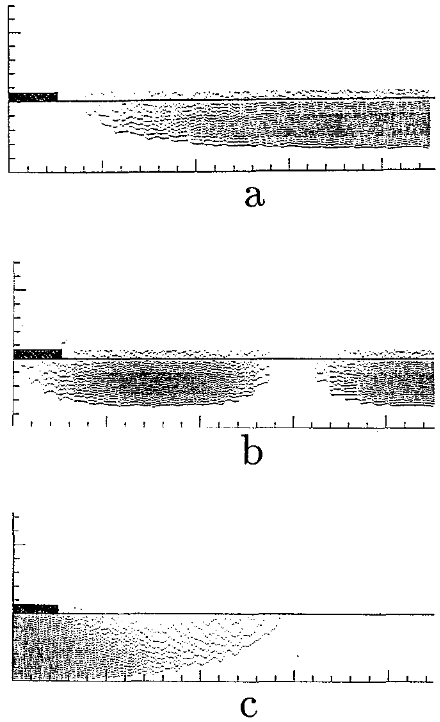

Figure 5. Grey scale plots showing the power distribution for a) Mode 1 at point 5, b) Mode 2 at point 6 and c) Mode 3 at point 7 after the second transition. ($h/\lambda = 0.27$) Notice that the third mode corresponds to a microstrip mode.

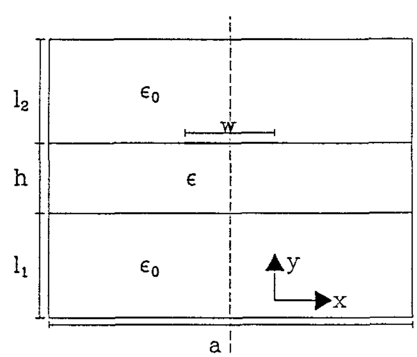

Figure 6. Geometry of the suspended microstrip: w=1.0mm, h=2.0mm, $l_1 = l_2$=4.0mm, a=9.0mm, $\epsilon_{||}$ = 10.3, $\epsilon_{\perp}$ = 13.0.

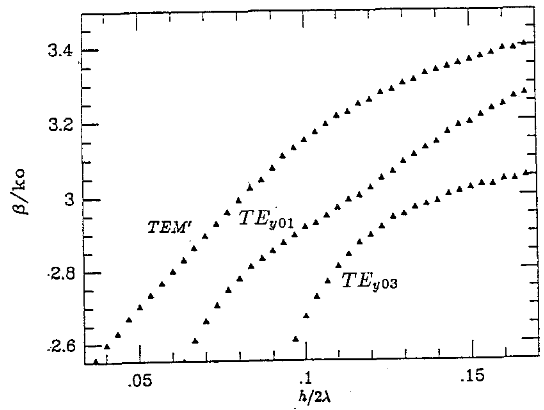

Figure 7. Suspended microstrip dispersion curve for the geometry in Figure 6.