THE EFFECT OF SUBSTRATE ANISOTROPY ON THE DOMINANT-MODE LEAKAGE FROM STRIPLINE WITH AN AIR GAP

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ABSTRACT

The fundamental properties of dominant leaky modes that exist on stripline structures having a small air gap above the conducting strip and uniaxial anisotropic substrates are summarized. Dominant leaky modes have a quasi-TEM strip current, and are often strongly excited by conventional stripline feeds. These leaky modes result in undesirable crosstalk and spurious stripline performance. New physical effects introduced by the substrate anisotropy are discussed.

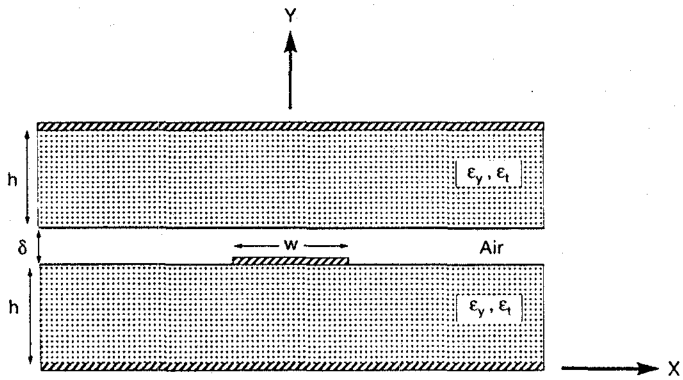

Figure 1: Geometry of a stripline with uniaxial-anisotropic layers, having an air gap above the conducting strip.

1. INTRODUCTION

It was recently reported [1] that a dominant leaky mode exists on a stripline transmission line when a small air gap is present above the conducting strip. This mode radiates into the fundamental TM_0 mode of the background structure, resulting in a complex propagation constant. The leaky mode has fields that are improper (increasing) in the transverse directions away from the strip, and hence excitation of this mode may result in undesirable crosstalk and spurious performance. The leaky mode is present in addition to the conventional bound mode. Both modes have a similar current distribution on the strip, resembling that of a quasi-TEM mode (and hence the leaky mode is referred to as a *dominant* leaky mode, as opposed to a higher-order leaky mode). However, the field distributions of the two modes are very different for small air gaps. The leaky mode has a field that closely resembles that of the conventional TEM stripline mode that exists when no air gap is present. In contrast, the bound mode has a field that resembles the parallel-plate mode that exists on stripline with no air gap. Hence, when an air gap is introduced into stripline, the conventional TEM mode becomes a leaky mode, and is strongly excited by a conventional stripline feed. The bound mode, on the other hand, is only weakly excited when the air gap is small. This conclusion has important practical implications, since a small air gap is often introduced inadvertently during manufacturing.

In this presentation, the fundamental properties of the leaky mode will be discussed for the more general uniaxial anisotropic structure of Fig. 1, where ϵ_y and ϵ_t denote the normal and transverse permittivities. The properties of the leaky mode will first be briefly reviewed for the case of an isotropic substrate, with $\epsilon_y = \epsilon_t$. The effects of making the substrate uniaxially anisotropic will then be discussed in detail. It will be demonstrated that a *negative* uniaxial substrate ($\nu = \epsilon_t/\epsilon_y > 1$) tends to suppress leakage, while a *positive* uniaxial substrate ($\nu = \epsilon_t/\epsilon_y < 1$) tends to enhance leakage. Also, some interesting differences in the dispersion characteristics arise because of the anisotropy.

2. FORMULATION

The propagation constant $k_{z0} = \beta - j\alpha$ of the bound and leaky modes are determined by standard spectral-domain techniques [2], in which the current is assumed to be z-directed and represented as

$$J_z(x) = \left(\frac{2}{\pi w}\right) \frac{1}{\sqrt{1-(2x/w)^2}}. \quad (1)$$

This simple current representation accurately describes the dominant bound and leaky modes over the range of parameters of interest here (this has been verified by using a more complete basis function expansion of the current). A transcendental equation for the unknown propagation wavenumber k_{z0} is derived by enforcing the electric-field integral equation using Galerkin's method. The resulting equation has the form

$$\int_{-\infty}^{\infty} \tilde{J}_z(k_x)\tilde{G}_{zz}(k_x, k_{z0})\tilde{J}_z(-k_x)\, dk_x = 0. \quad (2)$$

The propagation wavenumber for the bound modes is determined by performing the integration along the real axis in the complex k_x plane. For the leaky modes, the path of integration is deformed around the TM_0 poles of the spectral-domain Green's function $\tilde{G}_{zz}$, as shown by the path C_1 in Fig. 2.

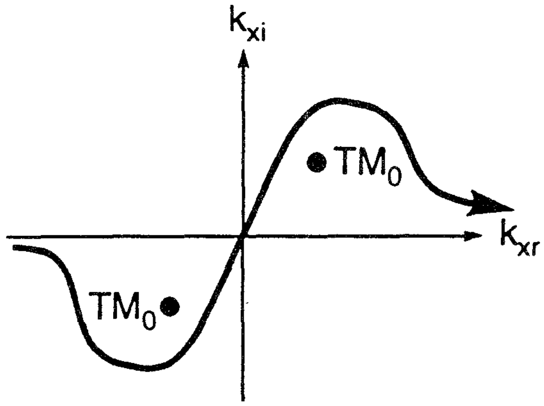

Figure 2: Integration path in the complex k_x plane used to determine the wavenumber of the leaky dominant-mode solution.

3. RESULTS

3.1 Isotropic Stripline

Figure 3 shows the phase constant β for the bound and leaky modes that exist on a stripline with an isotropic substrate versus the thickness δ of the air gap above the conducting strip. Also shown for convenience is the wavenumber β_{TM_0} of the TM_0 background mode.

For a zero-thickness air gap the leaky mode and the bound mode are both TEM modes, as is the TM_0 parallel-plate mode (the bound mode becomes identical to the parallel-plate mode in this case). For small non-zero air gaps the leaky mode has a phase constant that is below that of the TM_0 mode, corresponding to physical leakage. In this region the field of the leaky mode has the form of a stripline-like mode, while the field of the proper mode resembles that of the parallel-plate TM_0 mode. As the air gap increases, the phase constant of the leaky mode increases beyond β_{TM_0}, entering into the "spectral-gap" region [3], where the mode begins to lose physical meaning. For a sufficiently large air gap the leaky mode splits into two improper real modes ($\alpha = 0$), which are nonphysical. The attenuation constant α, shown in Fig. 4, increases from zero to a maximum value as the air gap increases, and decreases to zero at the splitting point. As the air-gap thickness increases from zero, the field of the proper mode changes slowly from that of the parallel-plate mode to that of the stripline dominant mode.

3.2 Uniaxial Stripline

Figure 5 shows the phase constant for a substrate that has a positive uniaxial anisotropy (sapphire). As for the isotropic case, the field of the leaky mode

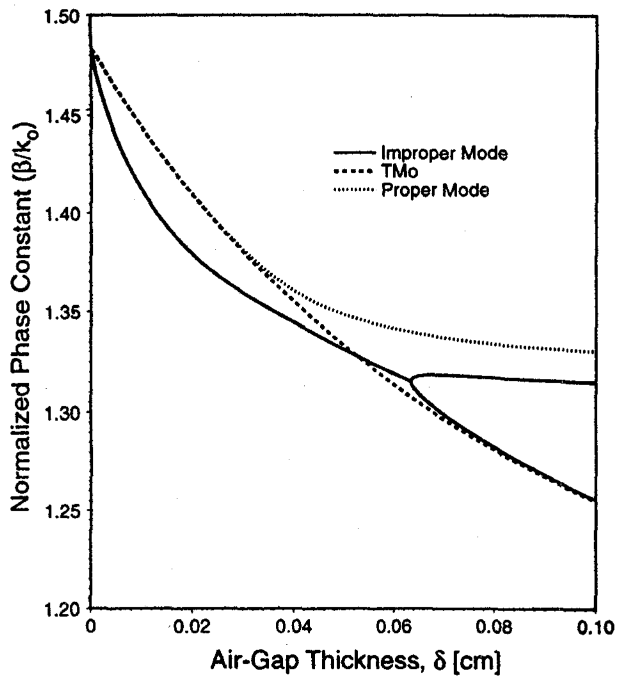

Figure 3: Normalized phase constant β/k_0 for the proper and improper modes, and k_{TM_0}/k_0, versus the air-gap thickness δ for the stripline structure of Fig. 1 with an isotropic substrate, having $\epsilon_{ry} = \epsilon_{rt} = 2.2$ and $w = h = 0.1$ cm, at 3.0 GHz.

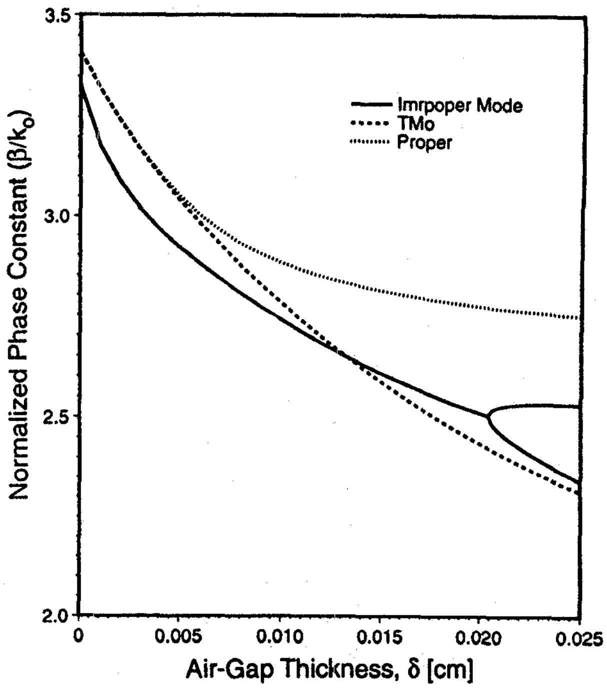

Figure 5: Normalized phase constant β/k_0 for the proper and improper modes, and k_{TM_0}/k_0, versus the air-gap thickness δ for the stripline structure of Fig. 1 with a positive uniaxial (sapphire) substrate, having $\epsilon_{ry} = 11.6 > \epsilon_{rt} = 9.4$ and $w = h = 0.1$ cm, at 3.0 GHz.

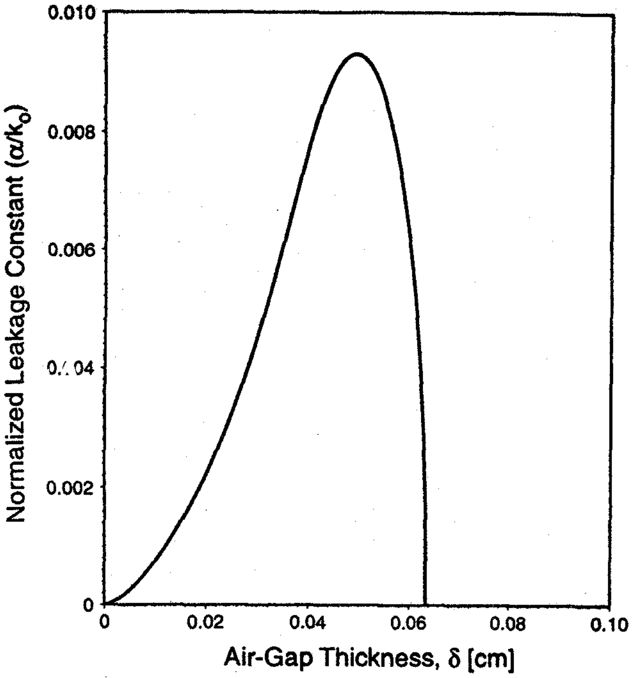

Figure 4: Normalized leakage constant α/k_0 versus the air-gap thickness δ for the stripline structure of Fig. 3.

is stripline-like, while the field of the proper mode is parallel-plate-like. For a zero-thickness air gap the proper mode and the TM_0 parallel-plate mode again become coincident as a TEM mode, while the phase constant of the leaky mode remains *below* β_{TM_0}. For non-zero air-gap thicknesses this plot is similar to that for the isotropic case (Fig. 3). The corresponding attenuation plot (not shown) is also similar to that for the isotropic stripline (Fig. 4) and shows no leakage for zero air-gap thickness.

Figure 6 shows a plot of the phase constant for a substrate that is negative uniaxial (Epsilam-10). The overall dispersion curve is very similar to that for the isotropic case of Fig. 3 except for the behavior for small air gaps, so only that part of the plot is shown in Fig. 6. For a sufficiently small air-gap thickness there is a second splitting point, below which two improper real solutions exist. In this region there is no leakage. The field of the improper mode corresponding to the upper curve

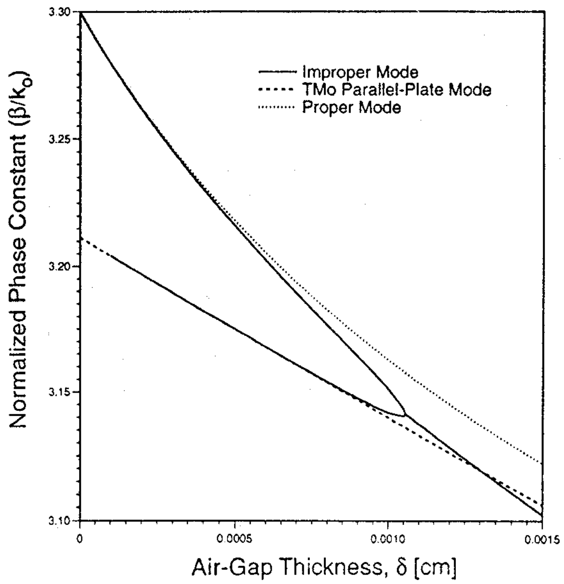

Figure 6: A magnified plot showing the normalized phase constant β/k_0 for the proper and improper modes versus the air-gap thickness δ in the first spectral-gap region (small air gaps) for the stripline structure of Fig. 1 with a negative uniaxial (Epsilam-10) substrate, having $\epsilon_{ry} = 10.3 < \epsilon_{rt} = 13.0$ and $w = h = 0.1$ cm, at 3.0 GHz.

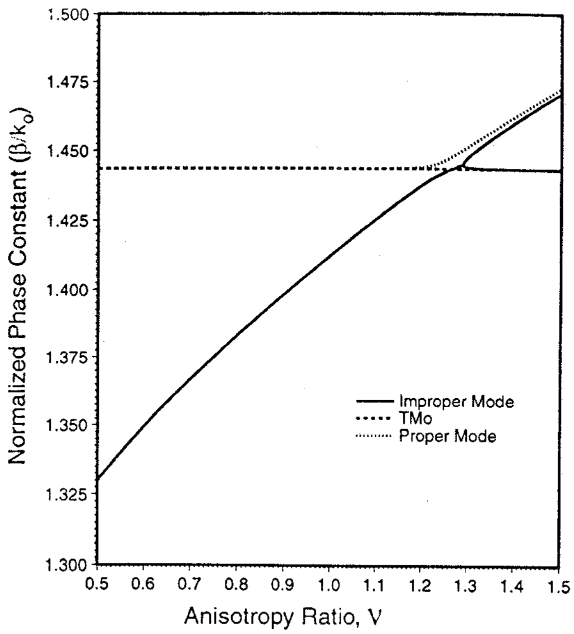

Figure 7: Normalized phase constant β/k_0 for the proper and improper modes, and k_{TM_0}/k_0, versus the anisotropy ratio $\nu = \epsilon_{rt}/\epsilon_{ry}$ for the stripline structure of Fig. 1 with a uniaxial anisotropic substrate, having $\epsilon_{ry} = 2.2$ and $w = h = 0.1$ cm, at 3.0 GHz.

is stripline-like, while the field for the lower curve changes rapidly from a parallel-plate-like field to a stripline-like field as δ increases toward the lower splitting point.

In Fig. 7 the normalized phase constant is shown versus the anisotropy ratio ν for a fixed air-gap thickness and ϵ_{ry}. A negative uniaxial anisotropy ($\nu > 1$) tends to suppress leakage by moving the solution locus closer toward the spectral gap region, until the solution splits into two nonphysical improper real modes. A positive uniaxial anisotropy ($\nu < 1$) tends to enhance leakage.

4. REFERENCES

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