Surface Wave Leakage Phenomena in Coupled Slot Lines

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***Abstract*— Surface wave leakage phenomena of coupled slot lines are investigated with spectral domain analysis. When the guided mode in the coupled slot lines changes from bound mode to leaky mode, there is a frequency range, called "spectral gap," where only nonspectral solutions exist. If the width of the center conductor or slots is increased beyond a certain value this spectral gap may disappear, resulting in a frequency range where both bound mode and leaky mode can exist simultaneously.**

I. Introduction

POSSIBLE surface wave leakage of dominant and higher-order modes of planar transmission lines has been investigated intensively in [1]–[5]. When the propagation mode of the leaky planar transmission lines changes from purely bound wave to leaky wave, there is usually a frequency range, called "spectral gap" in [5], in which only nonspectral solutions exist. Various spectral gap regions of different planar transmission lines, including coplanar strips, coplanar waveguide, slot line, and microstrip on anisotropic substrate, exhibit similar mode transition patterns [2], [5]. In these typical spectral gap patterns, purely bound wave exists only for the frequencies below the spectral gap, and complex leaky wave exists only for the frequencies above the spectral gap. In the spectral gap, nonspectral solutions that are not captured in the steepest descent plot exist. These nonspectral modes do not contribute to the total fields. In [5], it is shown that the spectral gap patterns of conductor-backed coplanar strips depend on the dimensional parameters of the structure and evolve in a way that is quite different from that of the typical spectral gap patterns mentioned above. As the strip width of the conductor-backed coplanar strips is increased beyond a certain value, the typical spectral gap disappears, resulting in a frequency range where both the bound mode and the leaky mode exist simultaneously. This frequency range of simultaneous propagation of both modes widens if the strip width is further increased.

Uniplanar circuits have been proposed as a wideband structure for MMIC [6], with circuit realizations of combiner, divider, and frequency doubler reported in [7]–[8]. Basic transmission line structures in uniplanar circuits are slot line, coplanar waveguide, and coupled slot lines. In this letter, the surface wave leakage properties of the coupled slot lines are presented. It is found that when the width of the center conductor or the width of the slots is increased, the spectral gap mode patterns evolve in a similar way to those of the conductor-backed coplanar strips mentioned in [5]. In other words, there is also a frequency range where both bound mode and leaky mode exist for the coupled slot lines with appropriate dimensions. The simultaneous presence of two modes definitely affect the design of coupled slot lines circuits since a source intended to excite one mode will also excite the other mode.

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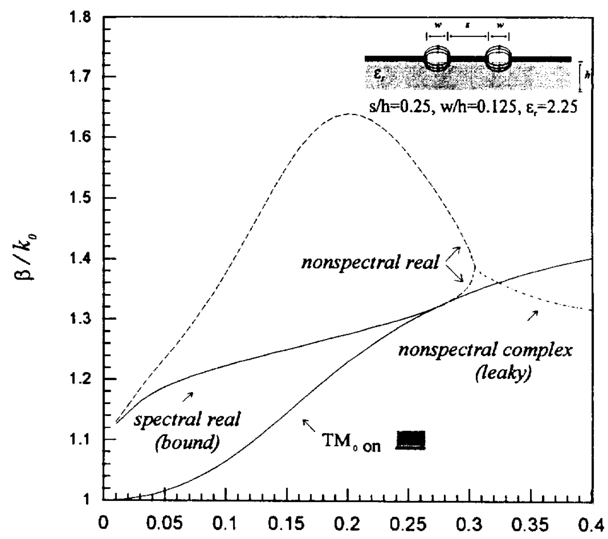

Fig. 1. Behavior of the normalized propagation constants as a function of normalized frequency for coupled slot lines when the slots are narrow.

II. Mode Pattern Evolution of Coupled Slot Lines

The coupled slot lines with their symmetrical properties of electric fields indicated are shown in the inset of Fig. 1. The coupled-slot mode is the even mode of a coplanar waveguide structure with an electric wall symmetric plane, while the coplanar waveguide mode is the odd mode and a magnetic wall symmetric plane is assumed. Using the familiar spectral domain approach method with appropriate deformation of the spectral domain integration contour to include proper surface wave poles [9], the normalized propagation constants of both the bound mode and the leaky mode of the coupled slot lines can be obtained.

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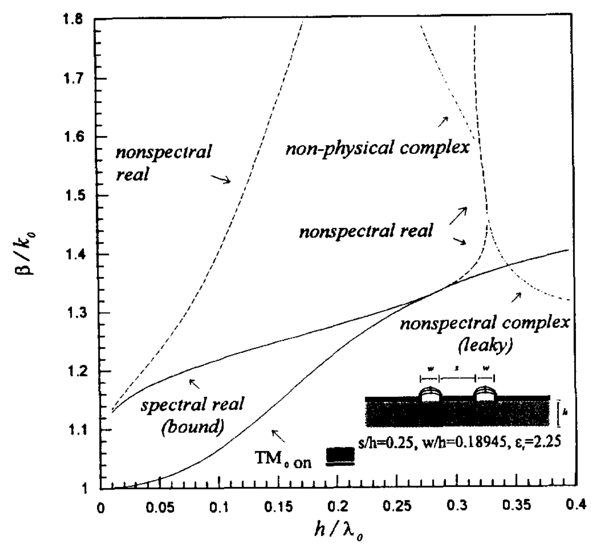

Fig. 2. Behavior of the normalized propagation constants as a function of normalized frequency for coupled slot lines when the slots are slightly wider than those of Fig. 1.

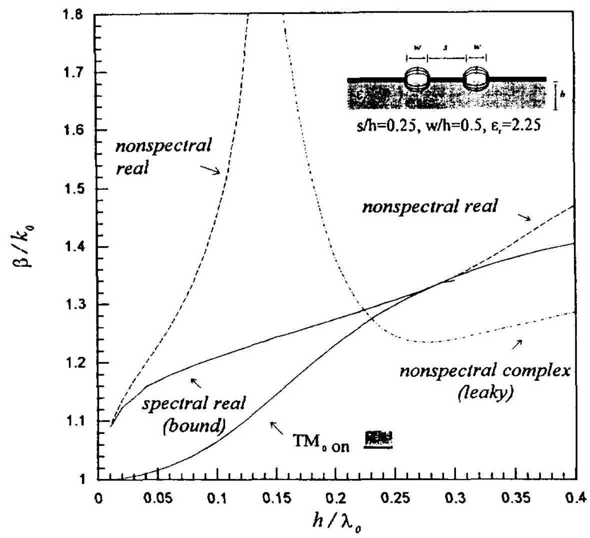

Fig. 3. Behavior of the normalized propagation constants as a function of normalized frequency for coupled slot lines when the slots are much wider than those of Fig. 1.

The normalized propagation constants of the coupled slot lines shown in Fig. 1 exhibit the typical spectral gap mode transition. The normalized leaky constants of the leaky mode are omitted here due to the length limitation of this letter. In Fig. 1, we found that there is a frequency range (the abscissa is the normalized frequency), called "spectral gap" in [5], where there are only nonspectral modes that are obtained by including improper surface wave poles contribution in the spectral domain integration contour. These nonspectral modes are shown as dashed line in Fig. 1. Since these modes are not physical, they will not contribute to the total fields. For frequencies below this spectral gap, the coupled slot lines only support bound mode (shown in Fig. 1 as solid line) and for frequencies above, leaky modes only (shown as dotted-dashed line in Fig. 1). There is a clear distinction of the frequency ranges where each mode can propagate.

When the normalized slot width (w/h in Fig. 1) of the coupled slot lines in Fig. 1 is increased from 0.125 to 0.189, with all the other dimensional parameters fixed, a nonphysical leaky mode appears below the spectral gap frequency range and it joins the upper branch of the nonspectral real solution, as shown in Fig. 2. This is similar to the results obtained in [5] when the width of the strips of conductor-backed coplanar strips are increased. When the normalized slot width is further increased to 0.5, as shown in Fig. 3, the new nonphysical leaky mode joins the leaky mode solutions shown in Fig. 2, and the spectral gap disappears. There is a frequency range where both modes can propagate. This phenomenon presents a problem in designing coupled slot lines circuits since a source intended to excite the bound coupled-slot mode will excite the leaky mode as well, causing crosstalk between neighboring transmission lines and power loss in the guided mode.

If the width of the center conductor (s in Fig. 1) is increased with the other dimensional parameters fixed, the mode patterns evolve similarly as discussed above for the case of varying

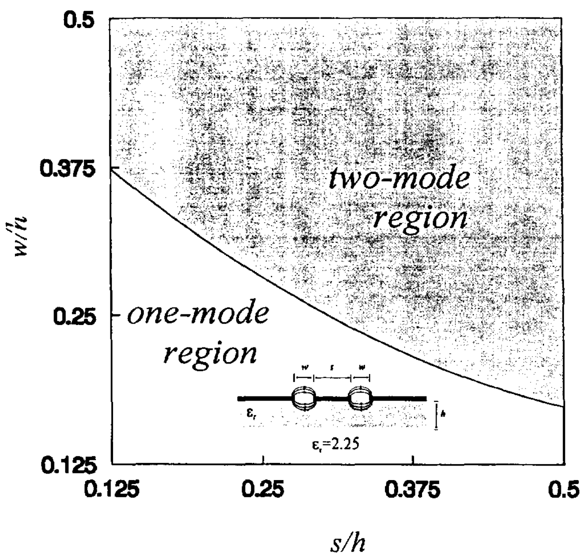

Fig. 4. Relation between the dimensional parameters and the existence of the spectral gap. Coupled slot lines of dimensions in the shaded area have a frequency range that can support both bound mode and leaky mode simultaneously.

the slot width. Fig. 4 gives the dimensional parameters that determine the existence of the spectral gap. The shaded area labeled as "two-mode region" means that coupled slot lines of these dimensional parameters have a frequency range that both bound mode and leaky mode can propagate simultaneously.

III. CONCLUSION

Interesting evolution of mode patterns of coupled slot lines with different dimensions are presented. The mode patterns evolve in a similar way to that of the conductor-backed coplanar strips. When the width of the center conductor or the width of the slot is increased beyond a certain value, the coupled slot lines can support both bound wave and leaky wave in some frequencies.

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