Surface-Wave-Like Mode in Slot Line

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Abstract— **Propagation properties of the surface-wave-like mode in slot line are investigated with the spectral domain analysis. This surface-wave-like mode is an odd dominant mode with a magnetic wall symmetric plane placed at the center of the slot. Its field distribution is similar to that of the TM_0 mode supported by the surrounding structure. It exists in the lower frequency regime and evolves into a nonphysical and nonspectral real mode in the higher frequency regime. Unlike other surface-wave-like modes in planar transmission line, the surface-wave-like mode in slot line does not evolve into a leaky mode.**

I. Introduction

Most open planar transmission lines have different propagation properties in different frequency regimes. In the higher frequency regime, surface wave leakage usually occurs. In the lower frequency regime, a surface-wave-like mode might exist. These propagation phenomena result in either extra power loss or cross-talk with neighboring circuits. Possible surface wave leakage of dominant modes of planar transmission lines has been investigated intensively in [1]–[5]. Surface-wave-like modes in coplanar waveguide and coplanar strips were proposed in [5]–[7]. These surface-wave-like modes are perturbed modes of the supporting structure in nature and have been proven as a general effect in planar transmission lines after investigations by researchers in recent years.

When a guiding structure supports several dominant modes, the undesired dominant mode with the same field symmetry as the desired dominant mode will always be excited, and the undesired dominant mode with different field symmetry may be inadvertently excited if there are unsymmetrical discontinuities in circuits. Fortunately, in structures with typical dimensional parameters, the surface-wave-like modes either in coplanar waveguide (same field symmetry case) or in slot line (different field symmetry case) are not easily excited due to their field distributions. Their fields decrease very slowly in the transverse direction and are quite different from those of the conventional coplanar waveguide mode and the conventional slot line mode concentrating near the slot regions. But when the first slot line higher-order mode (same field symmetry case) is employed as a leaky wave antenna, the slot width must be wide enough to support the higher-order mode. In such structures, the fields of the surface-wave-like mode will concentrate near the slot region and be more easily excited. The mode evolution patterns, field distributions, and geometric dependence of propagation properties of the surface-wave-like mode in slot line obtained by the spectral domain approach will be described in the following sections.

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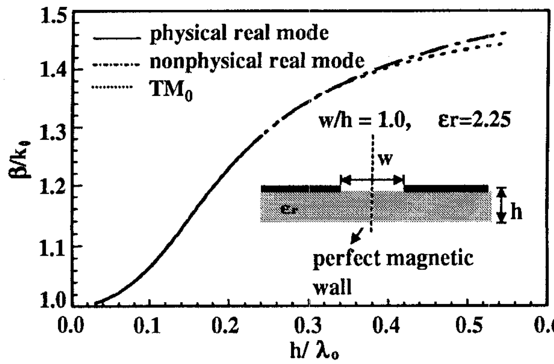
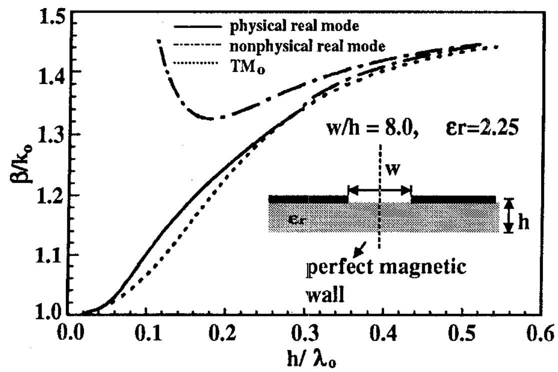


(a)



(b)

Fig. 1. Behavior of the normalized phase constants of the surface-wave-like mode as a function of normalized frequencies with different aspect ratios (w/h). (a) Narrow slot case. (b) Wide slot case.

II. Mode Evolution Pattern

A slot line with a magnetic wall symmetric plane at the center of the slot is shown in the inset of Fig. 1. It can be treated as a special case of a coplanar waveguide without a center strip. So, the existence of the slot line surface-wave-like mode can be affirmed as being a special case in [6]. In the letter, w is the slot width; h is the substrate thickness; λ_0 is the free space wavelength, and frequency is normalized by the substrate thickness for convenience. For clear exhibition, the dispersion curves of the surface-wave-like mode in slot line with typical dimensions are not shown here because they are very close to that of TM_0 mode. When

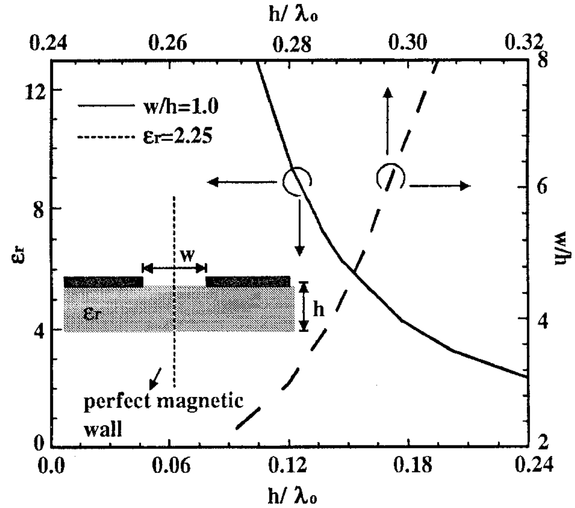


Fig. 2. The variation of the termination frequency of the physical surface-wave-like mode due to different dielectric constants (solid line) and different slot widths (dashed line).

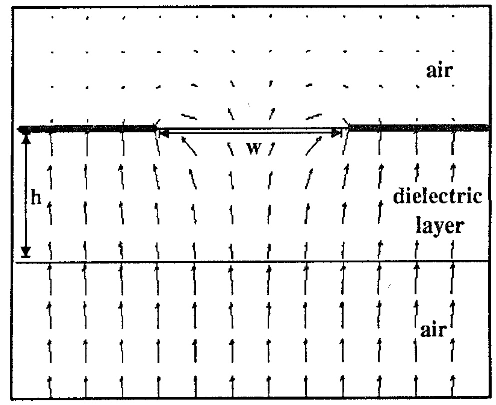


Fig. 3. The vector plot of the electric field distribution of the surface-wave-like mode with $w/h = 1$ and $h/\lambda_0 = 0.15$.

the slot is narrow, the mode evolution pattern of the surface-wave-like modes is as shown in Fig. 1(a). In low-frequency regime, the dispersion curve of the propagation constants of the surface-wave-like mode is very close to the left of that of the TM_0 mode due to small perturbation (small w/λ_0). If the frequency is increased, the mode evolves as follows. First, the dispersion curves of the propagation constants of the surface-wave-like mode and the TM_0 mode move away from each other due to larger perturbation. After the maximum separation of these two curves, they move close to each other again until they combine together. The maximum separation is larger with wider slot width, as shown in Fig. 1(b), and also larger with higher dielectric constant. The combination of curves means the termination of the physical mode. After the combination of these curves, the physical surface-wave-like mode disappears and evolves into a nonphysical and nonspectral real mode (defined in [2]). The mode evolution pattern of the surface-wave-like mode in slot line is not as complicated as that in coplanar waveguide due to no mode coupling effect between the surface-wave-like mode and the conventional dominant mode in [6], since there is no other dominant mode with the same field symmetry present. If the dominant mode in [6] is removed, the separate pieces of the surface-wave-like mode would join together and they would look exactly as in Fig. 1. The nonspectral and nonphysical mode is obtained by including improper surface wave pole in the spectral domain integration (surface wave pole is forcably captured in the integration contour when the propagation constant of the surface-wave-like mode is larger than that of the TM_0 mode) [8]. So, the mode is not physical and will not contribute to the total field [2]. If the frequency is further increased, the dispersion curve of the nonspectal and nonphysical mode will move away from that of TM_0 mode very slowly, as shown in Fig. 1(a). When the slot is wide enough, the mode evolution pattern is as shown in Fig. 1(b) and is similar to that with narrower slot, except the behavior of the nonspectral and nonphysical mode. The nonspectral and nonphysical real mode in Fig. 1(b) moves away from the dispersion curve of the TM_0 mode as the frequency increases and then combines with an additional improper real mode that does not exist in structures in [5]–[7]. After the combination, there is no surface-wave-like modes existing. The mode evolution pattern of the improper real mode in slot line with wide slot width is different from those in [6]. Since there is no other dominant mode (the conventional coplanar waveguide mode in [6] and [7] or the conventional coplanar strips mode in [5]), the complex mode coupling phenomenon between the surface-wave-like mode and the conventional mode in [5]–[7] does not happen. It results in that the surface-wave-like mode in slot line cannot evolve into a complex leaky mode as shown in Fig. 1. So, no surface wave leakage phenomenon is observed in this surface-wave-like mode in slot line. The range of geometric parameters of structures in which the physical surface-wave-like mode can exist is as shown in Fig. 2. The physical surface-wave-like mode can exist in a higher-frequency region with wider slot and lower dielectric constant. And the dielectric constant influences the variation of the termination frequency more strongly than the slot width.

III. Field Distribution

The typical field distribution of the surface-wave-like mode in slot line is as shown in Fig. 3. Except for the field near the slot, the field distribution is similar to that of the TM_0 mode. The field distribution changes due to different slot widths, operational frequencies, and dielectric constants. If the slot disappears, the surface-wave-like mode degenerates into the TM_0 mode. If the slot is present, it perturbs the field distribution of the TM_0 mode. And the TM_0 mode evolves into the surface-wave-like mode with fields exponentially decaying in the transverse direction. The fields decay more rapidly in structures with wider slot as shown in Fig. 4. The variation of field distribution due to different operational frequencies depends on the separation between the dispersion curves of the physical surface-wave-like mode and that of the TM_0 mode. If the frequency is increased from zero, the

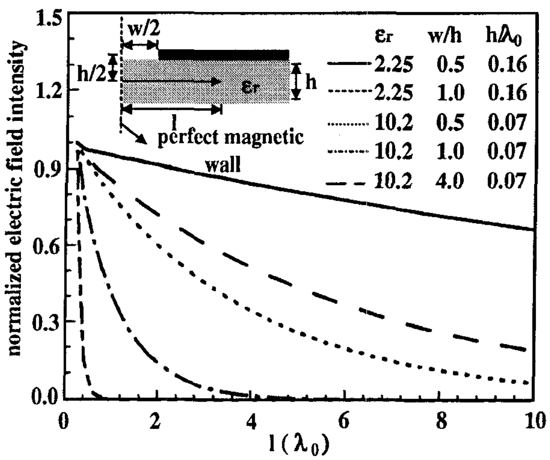


Fig. 4. The normalized electric field intensities with different geometric parameters along the path shown in the inset. The distance l is changed from $0.2\lambda_0$ to $10\lambda_0$ and the normalization is made by the value at $l = 0.2\lambda_0$.

separation increases as shown in Fig. 1(b). The fields outside the slot will decay more rapidly. However, with the separation decreasing in higher frequency regime as shown in Fig. 1(b), the fields outside the slot decay more slowly again. When the combination of curves is reached, the fields far way from the slot distribute uniformly as those of the TM_0 mode. For the nonspectral and nonphysical mode, its field distribution is also similar to that of TM_0 mode. But its fields increase exponentially in the transverse direction, so the mode is a nonphysical mode. Also, its fields increase more rapidly if the separation between its dispersion curve and that of the TM_0 mode is increased. The variation of field distribution due to different dielectric constants is as shown in Fig. 4. It is shown that the fields decay more rapidly outside the slot in structures with higher dielectric constant.

IV. Conclusion

The propagation properties of the surface-wave-like mode have been presented in this letter. No mode coupling effect and surface wave leakage occur in the surface-wave-like mode in slot line. Moreover in wider slot cases, the improper real mode disappears in the higher-frequency regime. These phenomena are different from those in [5]–[7]. In structures with lower dielectric constant and wider slot, the physical surface-wave-like mode disappears in the higher-frequency regime. In structures with higher dielectric constant and wider slot, the fields concentrate more near the slot region. The surface-wave-like mode is easier to be excited in such structures.

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