SURFACE-WAVE LEAKAGE PROPERTIES OF COPLANAR STRIPS

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ABSTRACT

Propagation characteristics of coplanar strips (CPS), balanced transmission line widely used in uniplanar circuits, is investigated with the spectral domain analysis. Besides the conventional coplanar strips mode, an extra surface-wave-like dominant mode can be supported by coplanar strips in lower frequency region. The bound modes evolve into a complex leaky mode in higher frequency region in a similar way to those of coplanar waveguide (CPW). No sharp and deep minima in leakage constants are found after the onset of the leakage, as in the coplanar waveguide case. Furthermore, the physical complex mode disappears in wider strip cases.

INTRODUCTION

CPW is the dominant transmission structure adopted in uniplanar circuits, yet it is an unbalanced transmission line. For mixer and antenna applications, in order to obtain a uniplanar balanced line structure, such as slotline or coplanar strips, various baluns using CPW-slotline transition or CPW-CPS transition have been investigated in [1]-[3]. Besides being a balanced-line structure, coplanar strips also find applications in high impedance lines and high-speed pulse transmission. Yet there are some inherent disadvantages such as coupling to other line due to the lack of shielding and higher discontinuity loss due to coupling to TE_0 mode [4]. Also, like other planar transmission line, CPS may leak power into surface wave of the surrounding dielectric waveguide or couple to another dominant mode at higher operating frequency, causing undesired crosstalk and power loss.

Possible surface wave leakage of dominant and higher-order modes of planar transmission lines has been investigated intensively in [5]-[9]. The transmission properties of CPW and slotline in the transformation circuit between balanced and unbalanced transmission lines have been studied thoroughly in [5]-[8]. However, there is little effort made for the propagation characteristics of CPS, especially in the phenomena about surface wave leakage. In [9], it is shown that the spectral gap patterns of conductor-backed CPS 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 of slotline, microstrip line and CPW. As the strip width of conductor-backed CPS 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.

In this paper, surface wave leakage properties of CPS are presented. It is found that the mode pattern is quite different from that of conductor-backed CPS. The spectral gap mode patterns evolve in a similar way to those of CPW [8]. CPS can support another dominant mode with field distribution similar to that of the surface wave mode of surrounding structure in lower frequency region. But the mode evolution of CPS is different from that of CPW in wider strip cases. The dispersion curve of nonspectral complex mode in CPS with wider strips does not cross that of TE_0 mode, resulting in the disappearance of surface wave leakage.

MODE PATTERN EVOLUTION OF CPS

CPS with their symmetrical properties of electric fields indicated is shown in Fig. 1. It is the odd mode of a coupled strip structure with an electric wall symmetric plane. Using the familiar spectral domain approach method with appropriate deformation of spectral domain integration contour to include proper surface wave poles [10], the normalized propagation constants of both the bound mode and the leaky mode of CPS can be obtained.

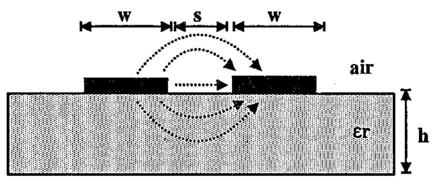

Fig. 1 The geometric structure of coplanar strips with electric field indicated.

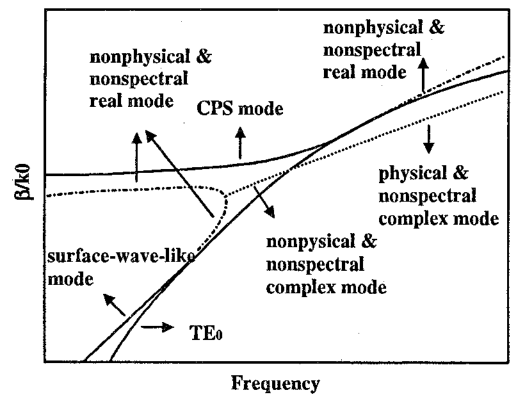

Fig. 2 The mode transition pattern of coplanar strips near the spectral gap.

The normalized propagation constants of CPS with narrower strip width shown in Fig. 2 exhibit the typical spectral gap mode transition pattern. The dashed lines are nonphysical and nonspectral real modes and the dotted line before the crossed point to the dispersion curve of TE_0 mode is nonphysical and nonspectral complex mode. They are obtained by including improper surface wave poles in the spectral domain integration contour. These modes are not physical and they will not contribute to the total field. The dotted line after the crossed point is leaky mode that is obtained by including the proper surface wave poles. Two dominant bound modes exist for CPS in the lower frequency regime. The upper solid line is the traditional CPS mode. The lower solid line is the surface-wave-like mode with field distribution similar to that of the TE_0 mode of the surrounding structure. The lowest solid line is TE_0 mode. They are similar to the results obtained in [8]. But in wider strip cases, we find that there are some differences in the mode transition pattern of CPS. They will be presented later in this paper.

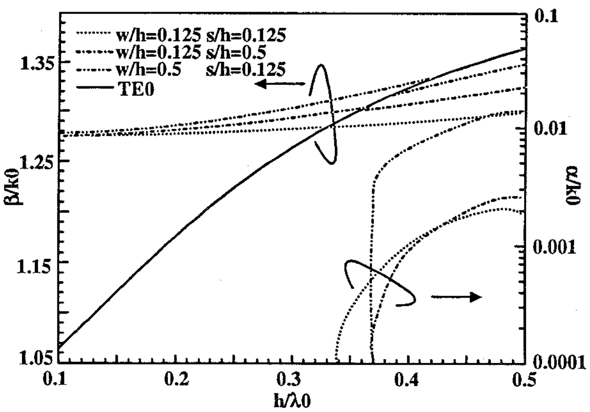

Fig. 3 Behavior of the normalized phase constants and the normalized attenuation constants as a fuction of normalized frequency for coplanar strip with different structural parameters.

NUMERICAL RESULTS AND DISCUSSIONS

The mode pattern of CPS is quite different from that of conductor-backed CPS, it has features similar to the mode pattern of CPW. Both CPW and CPS can support extra surface-wave-like dominant modes. These modes can be treated as perturbed modes of dielectric slab waveguide. The phenomena may occur when the modes on the guided structure and the surface wave of surrounding structure have the same symmetric properties. The electric fields of both CPS mode and TE_0 mode have the same symmetric property with electric wall symmetric plane orthogonal to the dielectric interface at the center of the structure. Conductor-backed CPS can not support extra surface-wave-like mode (TM_0), because it has different symmetric property from TM_0 mode. Another interesting phenomena is that when CPS mode is in the leaky region, there is no sharp and deep minima in leakage constant happening in CPW structure [8]. This phenomena is due to that the change of field distribution from surface-wave-like mode to CPS mode [8] in the mode coupling region happens before the occurence of complex leaky mode.

The normalized propagation constants with different structural parameters in narrower strip cases are shown in Fig. 3. It is shown that if the width and spacing of the strips increase, the CPS mode becomes more dispersive and the surface wave leakage occurs in higher frequency. Also, we find that the amounts of power leakage and transverse currents in strips depend mainly on the strip width, not on the strip spacing. The leakage of power increases with increasing strip width. This is due to that the transverse current is larger in wider strip cases and the transverse current can excite the electric field in the transverse direction strongly, causing more power to couple to the TE_0 mode.

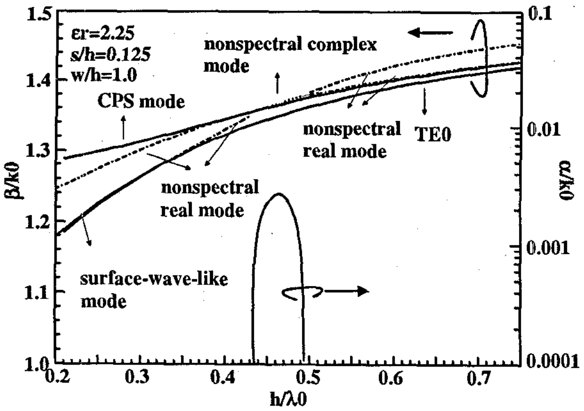

Fig. 4 Behavior of the normalized phase constants and the normalized attenuation constants as a function of normalized frequency for coplanar strips with w/h=1.0.

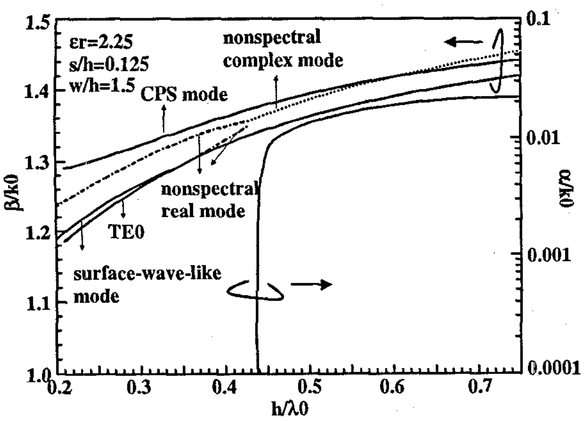

Fig. 5 Behavior of the normalized phase constants and the normalized attenuation constants as a function of normalized frequency for coplanar strips with w/h=1.5.

For the termination of surface-wave-like mode, we find that it is not sensitive to the structural parameters, strip width and strip spacing, but the phase constant of surface-wave-like mode is higher in wider strip cases. Namely, the dispersion curves of surface-like-mode and TE_0 mode are away from each other. The difference between the dispersion curves caused by strip spacing is very little. This is due to that the surface-wave-like mode is the perturbed mode of TE_0 mode supported by surrounding structure in nature and the strip width can strongly dominate the perturbation.

Additionally, if the strip width is increased beyond some certain values, we find that the mode evolution pattern shown in Fig. 2 will change. First, if the strip width is increased beyond a certain value, the dispersion curve of nonspectral complex mode will not cross that of TE_0 mode, but crosses that of CPS mode and then turn into two nonspectral real modes as shown in Fig. 4. Also, the CPS mode becomes more dispersive than TE_0 mode and will not be terminated as shown in Fig. 2 in this frequency region. These effects result in the disappearance of the surface wave leakage. Second, if the strip width is further increased, the mode pattern evolves as shown in Fig. 5. The dispersion curve of the nonspectral complex mode still crosses that of CPS mode, but does not evolve into two nonspectral real solutions. The complex mode is nonphysical and there is no surface wave leakage in this case, either.

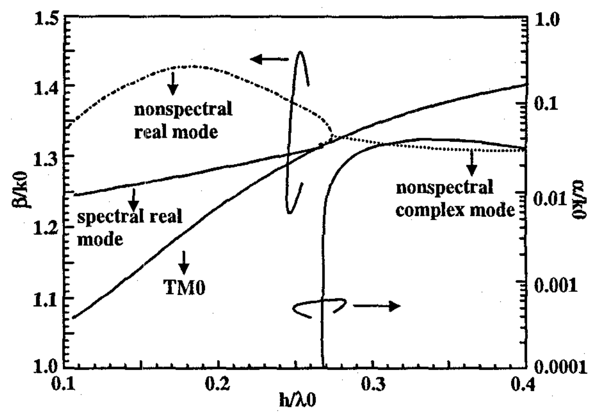

Fig. 6 Behavior of the normalized phase constants and the normalized attenuation constants as a fuction of normalized frequency for slotlines.

For comparison, the propagation characteristics of slotlines, another widely used uniplanar balanced line, is also shown in Fig. 6. Unlike CPS, slotline does not support an extra bound mode in lower frequency region. This can be explained by the fact that field distribution on the symmetrical plane required by the slotline can not support TM_0 mode. From the propagation characteristics presented, we have the following observations for the choice of CPS or slotline as the uniplanar balanced line:

1. In narrower strip cases, CPS are less dispersive than slotline. But in wider strip cases, their dispersion properties are almost the same. This is due to that slotline can be treated as CPS with infinite strip width.

2. In narrower strip cases, Surface wave leakage occurs in higher frequency for CPS than for slotline. But in wider strip cases, the surface wave leakage may disappear in CPS structure. And the power leakage is smaller for CPS, too. Yet, CPS has a surface-wave-like mode , which may be inadvertently excited.

CONCLUSIONS

Interesting evolution of mode patterns of CPS is presented. It is shown that CPS have mode transition pattern similar to that of CPW. They can support another surface-wave-like dominant mode for lower frequency before the spectral gap and complex leaky mode for higher frequency above the spectral gap. But there is no sharp and deep minima in leakage constants for CPS and the surface wave leakage may disappear in wider strip cases. Also, the phenomena of difference about mode pattern between the traditional CPS and conductor-backed CPS has been given clear explanation in physics. The influence of structural parameter is also investigated here. It is shown that CPS with wider strip width and spacing have larger power leakage and their surface wave leakage occur at higher frequency.

ACKNOWLEDGMENT

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