The Danger of High-Frequency Spurious Effects on Wide Microstrip Line

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Abstract — **It has been found that remarkably severe spurious effects can occur in the current excited on microstrip line at moderate to high frequency, when the strip is wide ($w/h > 3$). This newly observed effect occurs because one or more leaky modes approaches the branch point at k_0 in the complex longitudinal wavenumber plane. This effect only occurs when the strip is wide. This effect can be disastrous, since the continuous-spectrum part of the current then decays very slowly with distance from the source, so that the total strip current excited by the source exhibits spurious oscillations out to very large distances from the source. An approximate design rule for predicting this effect is given, which is accurate for wide strips ($w/h > 6$)**

I. Introduction

It has been shown recently that leaky modes may exist on microstrip line with an isotropic substrate [1]. These leaky modes, if excited sufficiently by a practical source, will result in significant spurious effects such as power loss and crosstalk, as well as interference with the desired bound mode that is also excited from the source. This interference typically takes the form of oscillations in the total current on the strip, when plotted versus distance from the source [2]. The interference arises because the bound mode and the leaky mode have different propagation wavenumbers. Usually, the interference effect dies out with distance relatively quickly, within a few wavelengths from the source, because the leaky mode has a complex wavenumber and hence decays exponentially with distance from the source. However, it has been discovered that when the strip is fairly *wide* ($w/h > 3$, roughly), *important exceptions* can occur. In particular, for such wide strips, a frequency region will exist where the spurious oscillations extend out to *extreme distances* from the source, possibly as large as many tens of wavelengths. The purpose of this summary is to report this new finding, and to investigate it in some detail by using a semi-analytical model for the current excited on a microstrip line by a voltage gap source, as was used in [2]. The geometry of the microstrip line with a voltage gap source is shown in Fig. 1.

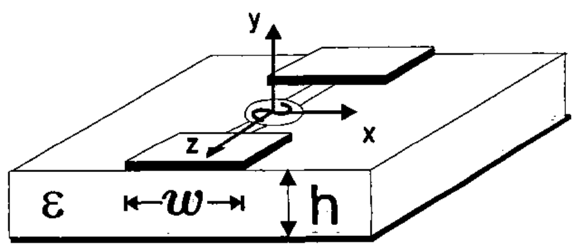

Fig. 1. A microstrip line that is infinite in the z direction, fed by a 1 Volt gap source at $z = 0$.

In [2], the current excited on a microstrip line by a voltage gap source was studied for moderate strip widths. It was demonstrated that spurious effects in the current on the microstrip line increase with frequency, becoming very significant when the substrate thickness is approximately one-tenth of a free-space wavelength. This is because the continuous-spectrum (radiating part) of the current on the microstrip line continuously increases with frequency, eventually becoming comparable in magnitude to the bound-mode current roughly in this frequency range. However, it is not always a leaky mode that is responsible for the increase in the continuous spectrum as the frequency increases. Mathematically, the continuous-spectrum current on the line consists of a sum of any physical leaky-mode currents, together with "residual-wave" currents [3]. The residual-wave currents account for that part of the continuous spectrum current that is not channeled into a leaky mode. High-frequency spurious effects on microstrip line with a moderate strip width may

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be due to either a leaky mode or a residual-wave current, or a combination of the two [2], depending on the frequency range and the substrate permittivity. In all cases, however, the trend is that the continuous-spectrum current continuously increases in magnitude as the frequency increases. Hence, the spurious effects continuously increase with frequency for microstrip with a moderate strip width. To avoid such effects, the frequency should be chosen low enough so that the substrate thickness is less than about $0.1\ \lambda_0$.

In contrast, the newly discovered effect reported here for *wide* microstrip lines occurs in a particular frequency range, which depends on the width of the strip. The frequency range over which the effect is observed may be fairly narrow. However, when this effect does occur, the resulting interference observed in the strip current is extremely severe, much more so than for the moderate strip width cases. This new effect is due to one or more leaky modes approaching the k_0 branch point in the longitudinal k_z wavenumber plane, which is the plane used in the construction of the current from the voltage gap source. As a leaky mode approaches the branch point at $k_z = k_0$, the leaky mode nears the boundary of the transition region that defines the frequency range where the mode is physical. Near the branch point the attenuation constant of the leaky modes are found to be quite small, so that they can propagate to very large distances before decaying significantly. This explains the long-range spurious effects that are observed. Interestingly, such effects are only observed for wide strips. When the strip width is small or moderate ($w/h < 3$), the leaky modes do not approach the branch point. As will be demonstrated, an approximate design rule for predicting the frequency at which the leaky-modes approach the branch point can be given.

II. Summary of Analysis

The current density on the strip is represented in a basis function expansion as

$$J_{sz}(x,z) = \sum_n A_n T_n^z(x) I_n^z(z) \tag{1a}$$

$$J_{sx}(x,z) = \sum_n B_n T_n^x(x) I_n^x(z), \tag{1b}$$

where the transverse shape functions $T_n^z(x)$ and $T_n^x(x)$ are chosen to be Chebyshev polynomials weighted by appropriate edge-singularity terms. A complete basis function expansion is needed for accurate results, since wide strips will be investigated. Galerkin's method in the spectral domain is applied to solve the electric field integral equation, which equates the tangential electric field on the strip to that of the impressed gap voltage at the source, and zero on the metal strip. A closed-form solution for the Fourier transform of the strip-current functions $I_n^z(z)$ and $I_n^x(z)$ is obtained (the details are omitted here). Each current function is represented as an inverse Fourier transform, for example as

$$I_n^z(z) = \frac{1}{2\pi} \int_{C_z} \tilde{I}_n^z(k_z) e^{-jk_z z} dk_z\ , \tag{2}$$

where path C_z is deformed around poles and branch points [2].

The total current in Eq. (2) can be decomposed by suitably deforming the path of integration in the k_z plane [2] to a path around the branch cut. The residues from the captured bound-mode poles determine the bound-mode current on the strip, and the integration around the branch cut defines the continuous-spectrum current on the line that is produced by the gap source.

III. RESULTS

In this summary, a microstrip on a substrate with a relative permittivity of $\varepsilon_r = 2.2$ and a thickness of 1.0 mm is examined. Results are presented for various strip widths, corresponding to w/h = 1, 3, and 6. The first case is considered to be a moderate strip width, while the last two cases are wide strips.

A dispersion plot for w/h = 1 is shown in Fig. 2. A surface-wave leaky mode (thick solid curve) begins at about 26 GHz and becomes physical at 32 GHz, where it crosses the dispersion curve for the TM_0 surface-wave mode. It becomes nonphysical at 46 GHz, where it crosses the $\beta = k_0$ line. A space-wave leaky solution (thick dashed curve) is also found to exist, but this solution never becomes physical, as the phase constant is always above k_0. Figure 3 shows the trajectory of the two leaky-mode solutions in the k_z plane, which simultaneously displays the phase and attenuation constants versus frequency. Although the phase constant of the surface-leaky mode crosses the $\beta = k_0$ line (twice), the attenuation constant remains high at these frequencies, so that the trajectory does not approach near to the point $k_z = k_0$. Consequently, although the continuous-spectrum current increases in strength with frequency, the spurious oscillations die out relatively quickly with distance from the source. A typical result is shown in Fig. 4 at 70 GHz. The total current on the strip is plotted versus distance from the source, along with the two components of the total current, the bound-mode (BM) current and the continuous-spectrum (CS) current. It is seen that the continuous-spectrum current decays fairly quickly with distance, which damps out the oscillations in the total current.

A dispersion curve for the case $w/h = 3$ is shown in Fig. 5. Near 65 GHz, both the surface-wave leaky solution and the space-wave leaky solution approach $\beta = k_0$. The trajectory plot in Fig. 6 shows that both of these leaky modes approach the point $k_z = k_0$ near this frequency. A plot of the current on the microstrip line at 64.3 GHz is shown in Fig. 7. Note that the spurious oscillations in the total current show a *very small* decay with distance. In fact, at a distance of eight wavelengths the oscillation amplitude is only slightly less than it was at a distance of one wavelength. This is because the CS current decays very slowly with distance, as seen in Fig. 7.

This effect is not limited to one particular strip width, but evidently occurs whenever the strip width is large. For example, Fig. 8 shows a trajectory plot for the case $w/h = 6$ (the dispersion plot is omitted for brevity). The surface-leaky solution and space-leaky solutions approach the point $k_z = k_0$ in the complex plane near 40 GHz. Figure 9 shows a plot of the strip current at 39 GHz, and it is once again seen that the CS current is nearly flat with distance, resulting in spurious oscillations that persist to very large distances from the source.

It is found that an approximate equation for predicting a rough frequency range where the spurious effects will occur for wide strips is

$$f = \frac{c}{w\sqrt{\varepsilon_r - 1}}, \tag{3}$$

with c the speed of light. This simple equation is relatively accurate for $w/h > 6$. For $w/h = 6$, this equation predicts 45.6 GHz, whereas the actual frequency for which maximum spurious effects occur is at about 40 GHz.

III. CONCLUSIONS

Very severe spurious high-frequency effects may occur on microstrip line at certain frequencies, when the strip width is large ($w/h > 3$). These spurious effects are due to a strong continuous-spectrum current excitation on the line due to a source (or discontinuity) on the line. The continuous-spectrum current becomes very strong because one or more leaky mode poles approach the branch point $k_z = k_0$ in the complex plane. An approximate formula for predicting this effect was given, which is relatively accurate when the strip width is very wide ($w/h > 6$).

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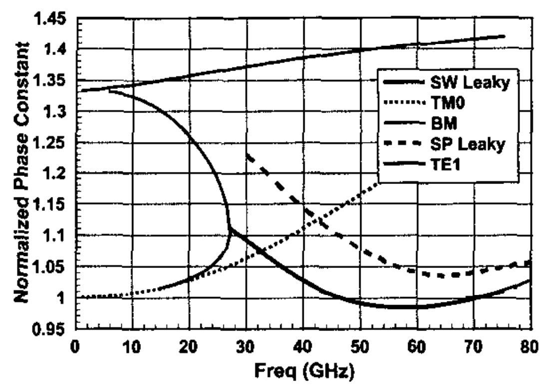

Fig. 2. Dispersion plot for $w/h = 1$, showing a surface-wave (SW) leaky solution (thick solid curve) and a space-wave (SP) leaky solution (thick dashed curve).

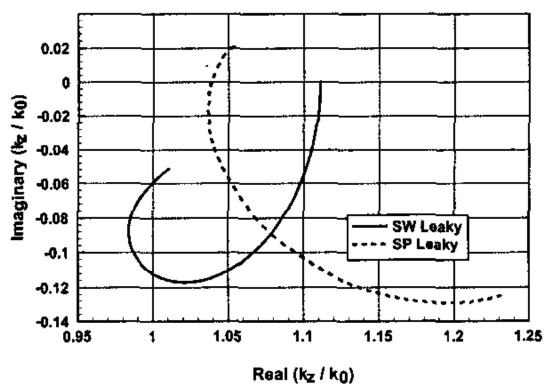

Fig. 3. Trajectory of the leaky-mode solutions in the k_z plane as a function of frequency for $w/h = 1$.

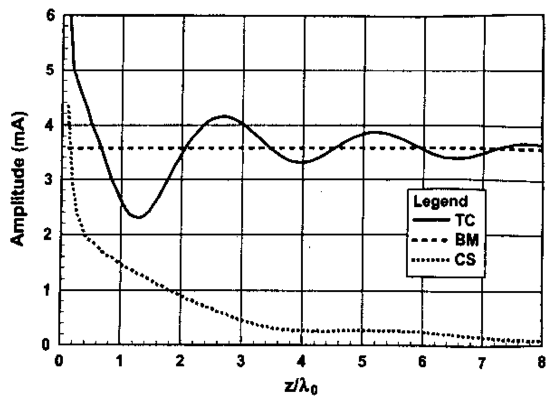

Fig. 4. Current on the line versus distance from the source, for w/h = 1 at 70 GHz. The total current (TC) is shown along with the bound-mode (BM) and continuous-spectrum (CS) currents.

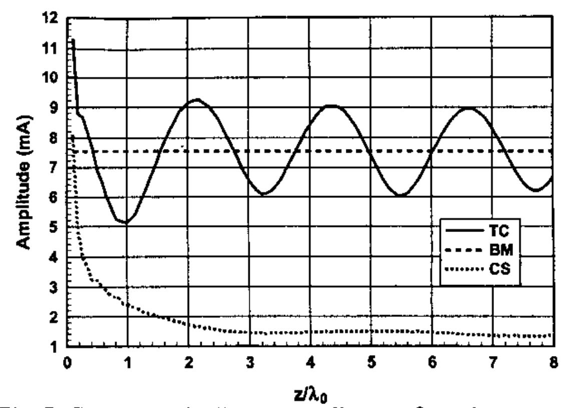

Fig. 7. Current on the line versus distance from the source, for w/h = 3 at 64.3 GHz. The total current (TC) is shown along with the bound-mode (BM) and continuous-spectrum (CS) currents.

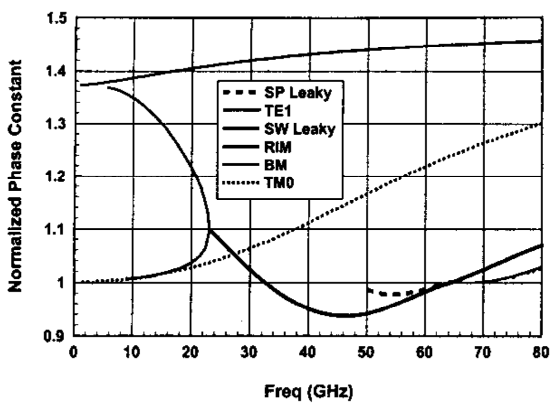

Fig. 5. Dispersion plot for w/h = 3, showing a surface-wave (SW) leaky solution (thick black curve) and a space-wave (SP) leaky solution (thick dashed curve).

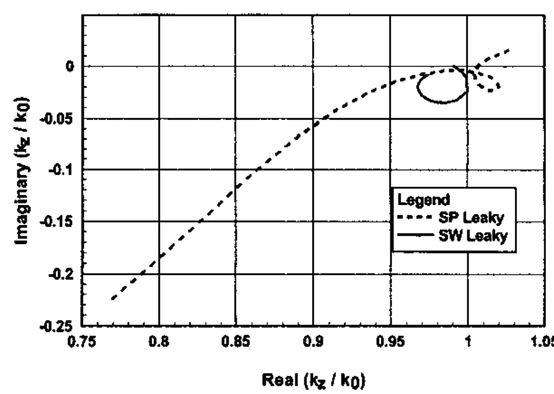

Fig. 8. Trajectory of the leaky-mode solutions in the k_z plane as a function of frequency for w/h = 6.

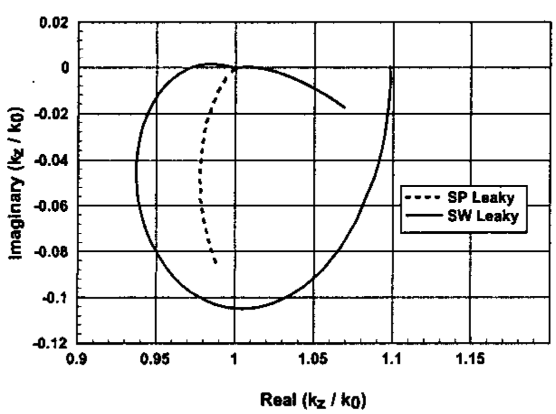

Fig. 6. Trajectory of the leaky-mode solutions in the k_z plane as a function of frequency for w/h = 3.

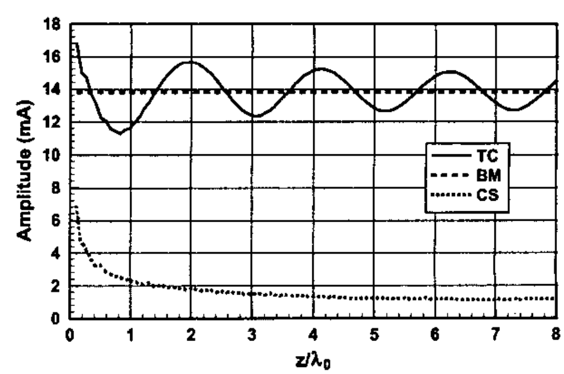

Fig. 9. Current on the line versus distance from the source, for w/h = 6 at 39.0 GHz. See Fig. 7 for the legend style.