Spurious Radiation from a Practical Source on a Leaky Covered Microstrip Line

William L. Langston, Jeffery T. Williams, and David R. Jackson

Department of Electrical and Computer Engineering,
University of Houston, Houston, Texas, 77204-4793, USA

Francisco Mesa

Department of Applied Physics 1,
University of Seville, Seville, 41012, Spain

Abstract — The radiated fields from the currents induced on a covered microstrip transmission line by a finite-gap voltage source are presented. The behavior of the bound-mode and continuous-spectrum fields is studied. It is determined that leaky-mode fields can contribute to cross-talk and other interference effects near the source and within an angular leakage region, while bound-mode radiation fields are the predominant mechanism for these effects further away from the gap source outside the leakage region.

I. Introduction

The existence of leaky modes on printed circuit transmission lines has recently been the subject of considerable interest. These modes are usually undesirable since they result in increased attenuation of the signal, and may result in cross-talk with adjacent circuit components and other spurious effects, including interference with bound modes that also propagate on the line. Of particular interest is the existence of leaky dominant modes on the structure. A dominant leaky mode is one in which the current distribution on the conducting strip closely resembles that of the quasi-TEM mode of propagation. Therefore, such a leaky mode is expected to be strongly excited by a customary feed. Leaky dominant modes have been found on a number of planar transmission line structures including multilayer stripline structures [1] and microstrip lines with isotropic and anisotropic substrates [2].

More recently, theoretical work has focused on studying the current on stripline and microstrip structures due to an excitation from a small, finite-length gap feed on the line [3]. It was shown that the total current on the strip excited by the source can be decomposed into the sum of the well-known bound-mode current and a continuous-spectrum current. The continuous-spectrum current was further decomposed into the sum of all physical leaky-mode currents and a *residual-wave* current. The residual-wave current is simply that component of the continuous-spectrum current that is not a part of the leaky-mode currents. From this analysis the physical significance of any leaky modes excited by the source can be ascertained. It was demonstrated that spurious transmission effects can result due to the interference of the bound-mode and the continuous-spectrum currents even when a leaky mode is not physically meaningful. When a leaky mode is physical, serious perturbing effects can be observed.

In this summary the calculation of the *fields* radiated by the bound-mode and continuous-spectrum currents excited by a finite source on covered microstrip transmission lines will be presented. Given these fields, one can address, in a meaningful fashion, issues associated with cross-talk between adjacent transmission lines and other circuit elements resulting from the fields radiated by the transmission line. In this summary, results will be given for a case where a physically meaningful leaky mode is the predominant mode on the structure. In the presentation, results will also be given for cases where the bound mode is predominant and cases where the bound mode and the continuous spectrum are approximately equal.

II. Summary of Analysis

A diagram of the covered microstrip structure (two-layer stripline) with a small, but finite gap source is shown in Fig. 1. The conducting strip is assumed to be infinite in

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the $\pm z$ directions and all of the conductors are assumed to be perfect conductors. For simplicity, the strip width W is assumed to be small so that the transverse component of the current can be neglected. Therefore, the current density along the strip is given by

$$J_z(x,z) = I(z)\eta(x) , \tag{1}$$

where $\eta(x)$ is the normalized transverse shape function for the strip current $I(z)$. An electric field integral equation in terms of $I(z)$ is developed and solved by applying the Galerkin method in the spectral domain [3]. In this solution the field of the gap source is Fourier transformed and is, thus, represented as a superposition of infinite line-source excitations with a uniform progressive phase shift. The electric field from these sources induce the strip current. The total strip current is then expressed as [3]

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

where C_Z is the Sommerfeld-type path shown in Fig. 2a. From the Galerkin solution procedure, the transform of the strip current is given by

$$\tilde{I}(k_z) = \frac{2\pi \, \tilde{E}_{GAP}(k_z)}{\int_{C_X} \tilde{G}_{ZZ}(k_x, k_z, h) \tilde{\eta}^2(k_x) \, dk_x} , \tag{3}$$

where $\tilde{E}_{GAP}$ is the Fourier transform of the impressed electric field of the gap source, $\tilde{G}_{ZZ}$ is the $\hat{\mathbf{z}}\hat{\mathbf{z}}$ component of the spectral-domain dyadic electric-field Green's function at $y = h$, and $\tilde{\eta}$ is the Fourier transform of the transverse profile of the strip current density.

The total current (2) may be decomposed by suitably deforming the path of integration in the k_z plane (Fig. 2). If the original path in Figure 2a is deformed around the TM_0 branch cut, as shown the figure, the total current can be expressed as the sum of the residue contribution at the bound mode (BM) pole – the bound-mode current – and the contribution of the integral around the branch cuts in the lower half plane – the continuous-spectrum current. Further, as shown in Fig. 2b, if the branch cut integral is deformed to enclose all of the branch cuts along the negative imaginary axis and a vertical steepest-descent path, the continuous-spectrum current can be further decomposed. This decomposition is into leaky-mode currents due to the residues of any leaky-mode poles that are captured in the physical region of the k_z plane, plus a residual term (residual-wave current) accounting for

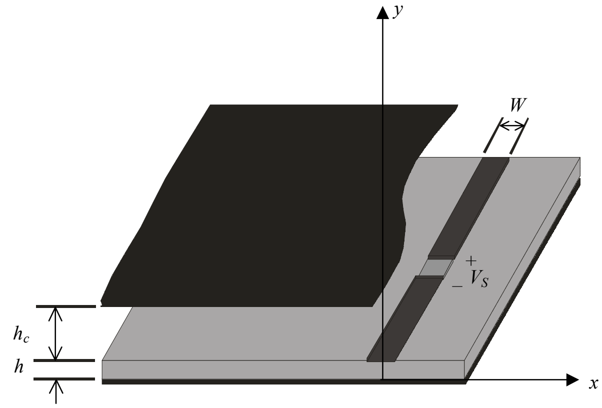

Fig.1 Covered microstrip structure with a small, finite-length gap source.

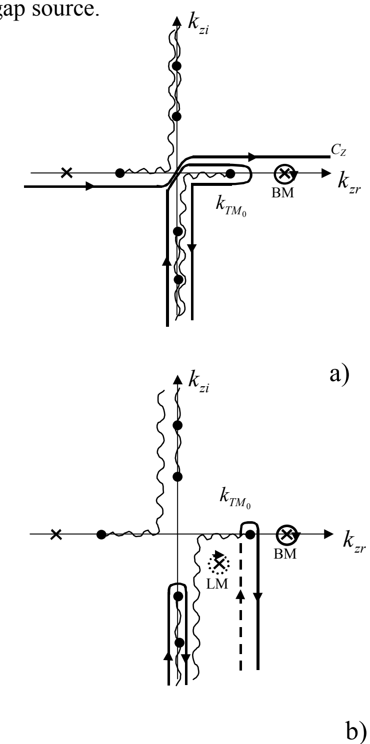

Fig. 2. Complex k_z plane showing: a) the original path of integration used to calculate the total strip current, b) the deformed path used to decompose the total strip current into bound mode, leaky mode, and residue wave components.

that part of the continuous spectrum that is not well represented by the leaky-mode currents. For lossless structures, the bound-mode current has no decay, the leaky-mode currents decay exponentially, and the residual-wave current decays, asymptotically, as $z^{-3/2}$ [4].

Once determined, the strip current can be used to find the fields radiated by the line and feed. Assuming that only the TM_0 parallel-plate mode is above cutoff in the background structure, the fields radiated by the strip can be formulated in terms of the fields radiated into this mode by a z-directed infinitesimal electric dipole by integrating over the strip current. The result is

$$E_y(x,y,z) = A\,f(y)\int_{-\infty}^{\infty}\int_{-W/2}^{W/2} I(z')\eta(x')H_1^{(2)}(k_{TM_0}\rho')\bullet \cos\phi'\,dx'dz' \quad (4)$$

where A is a constant that can be determined by spectral-domain methods,

$$\rho' = \left[(x-x')^2 + (z-z')^2\right]^{1/2}, \quad \phi' = \tan^{-1}\left[\frac{x-x'}{z-z'}\right] \quad (5)$$

$$f(y) = \begin{cases} \cos(k_{y1}y) & ; y < h \\ \dfrac{\varepsilon_r \cos(k_{y1}h)}{\cos(k_{y0}h_c)}\cos(k_{y0}(h+h_c-y)) & ; y > h \end{cases} \quad (6)$$

$k_{y1} = [\varepsilon_r k_0^2 - k_{TM_0}^2]^{1/2}$, and $k_{y0} = [k_0^2 - k_{TM_0}^2]^{1/2}$.

III. Results

In this summary, a covered microstrip with the following parameters will be examined: $h = 0.02\lambda_0$, $h_c = 0.455h$, $W = h$, and the relative permittivity of the dielectric substrate ε_r is 2.2. These parameters will apply to all of the results presented. For this specific covered microstrip the leaky mode is dominant [5]. This is clearly demonstrated by observing the strip current for this structure in Fig. 3. As shown in this figure, the continuous-spectrum current (dominated by the leaky-mode current) is significantly stronger than that for the bound mode. In fact, for this case the interference between the bound and leaky-mode currents results in a nearly complete transmission null on the line [5].

Figures 4, 5, and 6 show plots of the normalized substrate voltage at $x = 0.1\lambda_0, \lambda_0$, and $4\lambda_0$, respectively. For this discussion the substrate voltage V_h is defined as the vertical integral of the radiated electric field in the substrate from *0* to *h*. The substrate voltage corresponds, qualitatively, to the *cross-talk* signal that would be impressed upon a circuit component at that location. These results clearly demonstrate strong radiation fields associated with the leaky-mode current of the strip, as expected. The leaky-mode radiation field is very strong in the region near the gap feed, coming off at a steep angle. Relative to the other radiation fields, the leaky-mode field becomes more dominant as the transverse distance away from the strip increases. Also, as *x* is increased the leaky-mode fields extends over a wider range of *z*.

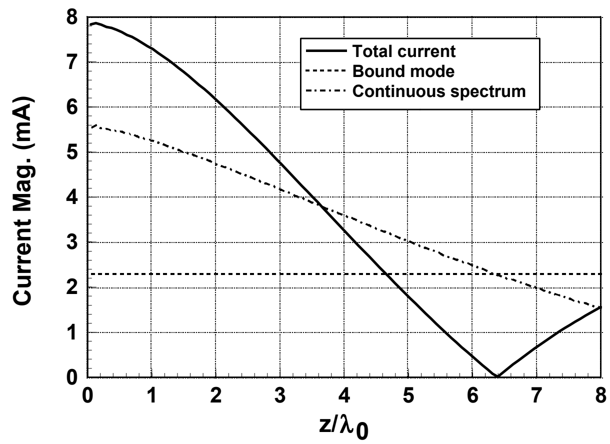

Fig. 3. Strip current magnitude for a covered microstrip ($h = 0.02\lambda_0$, $h_c = 0.455h$, $W = h$, and $\varepsilon_r = 2.2$) with a 1V gap source.

Surprisingly, the bound-mode field radiated from the strip is also strong away from the line. The bound-mode fields are associated with the radiation from the infinite line current along the strip (the bound-mode near field), which produces fields that decay exponentially from the strip, plus the fields radiated as a result of the slope discontinuity in the bound-mode current at the gap source. In fact, the oscillations in the bound-mode field in Fig. 4 and 5 are a result of the interference between the fields associated with these two mechanisms. This interference disappears at sufficiently large transverse distances from the strip due to the exponential decay of the bound-mode near field. In this example, however, this decay is relatively slow since the bound mode propagates with a phase constant that is only slightly larger than that of the TM_0 parallel-plate mode. Thus, the oscillations in the bound-field do not disappear until x is approximately $3-4\lambda_0$. For large z the leaky-mode fields have been essentially radiated; as a result the bound-mode fields are predominant in this region.

The surface contour plot in Fig. 7 clearly shows the behavior of the total radiated field in the region relatively close to the gap source. In this figure the leaky-mode radiation is readily seen to propagate away from the line about a specific angle of leakage, and this leakage field is strong. As a result, much energy is lost due to leakage radiation. In fact, the calculated bound mode efficiency, which is defined as the power propagating in the bound mode in both directions along the line relative to the total power provided by the gap source, is only 7.3% for this structure. It is also interesting to note that the peak leakage field is not at the source, but rather down the line from the source. Measured from this point, the observed angle of leakage closely matches the classically predicted leakage angle.

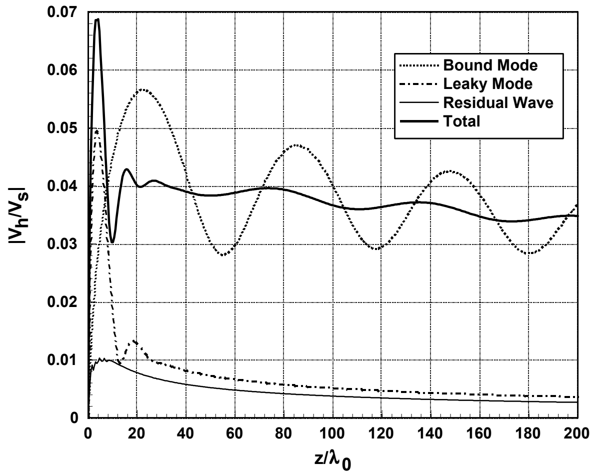

Fig. 4. Normalized substrate voltage for the covered microstrip of Fig. 3 at $x = 0.1\lambda_0$.

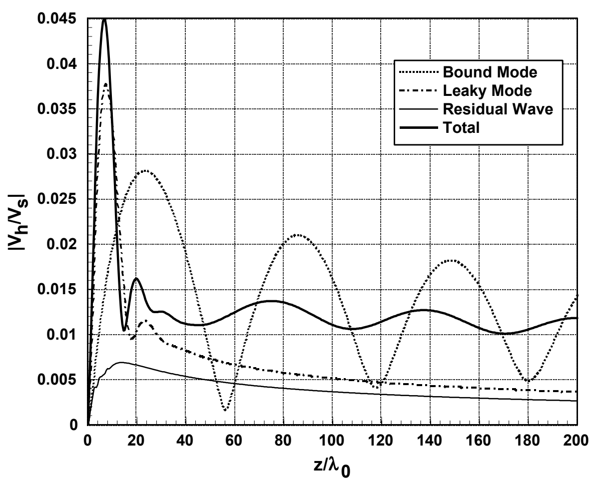

Fig. 5. Normalized substrate voltage for the covered microstrip of Fig. 3 at $x = \lambda_0$.

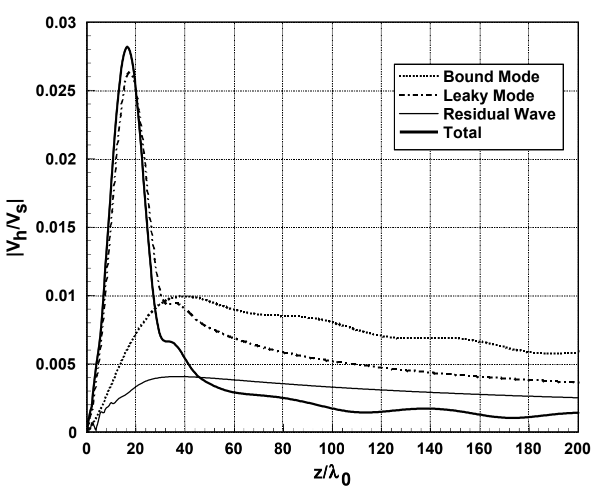

Fig. 6. Normalized substrate voltage for the covered microstrip of Fig. 3 at $x = 4\lambda_0$.

V. Conclusion

The results presented lead to some unexpected general conclusions. For some transmission line structures that support a dominant leaky mode, cross-talk between the line and other circuit elements is predominantly due to leakage when the elements are near the source, or along the angle of leakage. However, when the element is outside the leakage region and further from the source, cross-talk – although weaker – is primarily due to bound-mode radiation.

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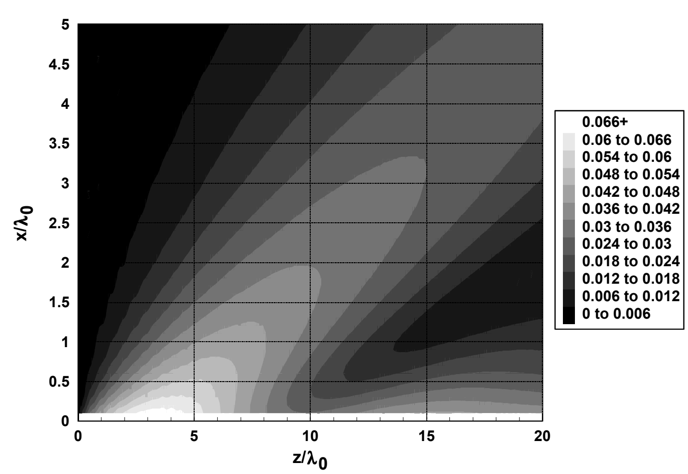

Fig. 7. Total normalized substrate voltage for the covered microstrip of Fig. 3 in the region near the gap feed.