Leakage Losses for the Dominant Mode of Conductor-Backed Coplanar Waveguide

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Abstract—**The attenuation constant for the dominant mode of a covered, conductor-backed coplanar waveguide (CBCPW) is computed using the spectral domain technique. Attenuation is due to leakage in the form of the parallel-plate TEM mode in the substrate region. Curves are provided to assist in predicting leakage losses for monolithic microwave integrated circuits.**

I. Introduction

The structure we analyze is shown in Fig. 1. The addition of a conductor backing on the isotropic substrate of a coplanar waveguide provides several advantages in the construction of MMIC's, such as improved mechanical strength and heat sinking capability. However, it is now known that an infinitely wide CBCPW has a dominant quasistatic mode which will always leak energy into the substrate [1], [2]. This leakage occurs in the form of the parallel-plate TEM mode and possibly higher order parallel-plate modes depending on frequency, substrate thickness, and permittivity. Leakage has also been reported for conventional CPW structures [3], [4] which have no conductor backing. However, due to space limitations, this letter will discuss only CBCPW's.

To date, no theoretical results have appeared in the literature to quantify the rate of leakage for CBCPW's. In this letter, we provide several curves which may be used to help predict this component of loss. Assumptions include infinitely wide ground planes, zero conductor thickness, and no conductor or dielectric losses.

II. Full-Wave Analysis

The spectral-domain technique is used to calculate the complex guide propagation constant $k_z = \beta - j\alpha$, where α is the attenuation constant. Fourier transforms of the tangential components of the electric fields ($\tilde{E}_x$ and $\tilde{E}_z$) and current densities ($\tilde{J}_x$ and $\tilde{J}_z$) are related via the coupled system of equations

$$\begin{bmatrix} \tilde{J}_x(k_x) \\ \tilde{J}_z(k_x) \end{bmatrix} = \begin{bmatrix} \tilde{Y}_{xx}(k_x,k_z) & \tilde{Y}_{xz}(k_x,k_z) \\ \tilde{Y}_{zx}(k_x,k_z) & \tilde{Y}_{zz}(k_x,k_z) \end{bmatrix} \begin{bmatrix} \tilde{E}_x(k_x) \\ \tilde{E}_z(k_x) \end{bmatrix}, \tag{1}$$

where $\tilde{Y}_{xx}$, $\tilde{Y}_{xz}$, $\tilde{Y}_{zx}$, and $\tilde{Y}_{zz}$ are spectral-domain dyadic Green's functions. These functions may be formulated with the immittance approach [5], where k_x is the spectral variable.

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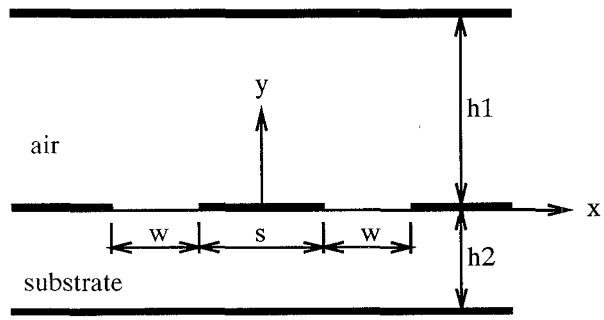

Fig. 1. Cross-sectional view of the covered, conductor-backed CPW.

In this work, we expand the aperture fields in terms of Chebyshev–Maxwellian basis functions:

$$E_x = \sum_{m=1}^{M} c_m \left[f_{xm}(x - \frac{s+w}{2}) - f_{xm}(-x - \frac{s+w}{2}) \right] \tag{2}$$

$$E_z = \sum_{n=1}^{N} d_n \left[f_{zn}(x - \frac{s+w}{2}) + f_{zn}(-x - \frac{s+w}{2}) \right], \tag{3}$$

where

$$f_{xm} = \frac{T_{m-1}(\frac{2x}{w})}{\sqrt{1 - (\frac{2x}{w})^2}} \tag{4}$$

$$f_{zn} = U_{n-1}(\frac{2x}{w})\sqrt{1 - \left(\frac{2x}{w}\right)^2}. \tag{5}$$

This formulation dictates that E_x is an odd function in x while E_z is even. Thus we have imposed a magnetic wall in the plane of symmetry, which is an appropriate boundary condition for the dominant CPW mode. In the Fourier domain, the previous set of basis functions may be written in terms of integer order Bessel functions [6].

The solution for k_z is found by means of Galerkin's method in the spectral domain. However, the contour of integration in the complex k_x plane is deformed from the real axis as discussed in [2] to include the residue contribution associated with wave propagation of one or more parallel-plate modes. The evaluation of Bessel functions with complex arguments is performed using Chebyshev series expansions [7]. An asymptotic extraction technique [8] is used to facilitate evaluation of the tail integrals along the real axis.

Root searching for the complex propagation constant k_z is done by evaluating the system determinant, $u + jv$, of a one term expansion (M=1, N=0) along the real axis to find the

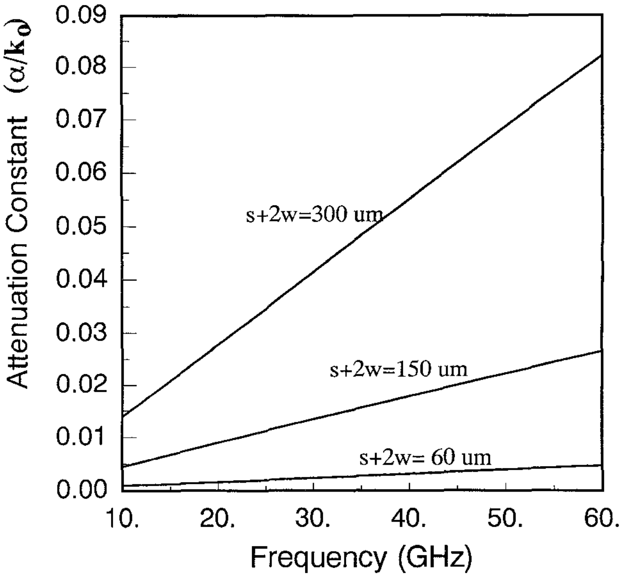

Fig. 2. Normalized attenuation constant α/k_o as a function of frequency for various line widths on a GaAs substrate: $\epsilon_r = 13$, $h1 = 10000 \mu$m, $h2 = 200$ μm, $s/w = 1$.

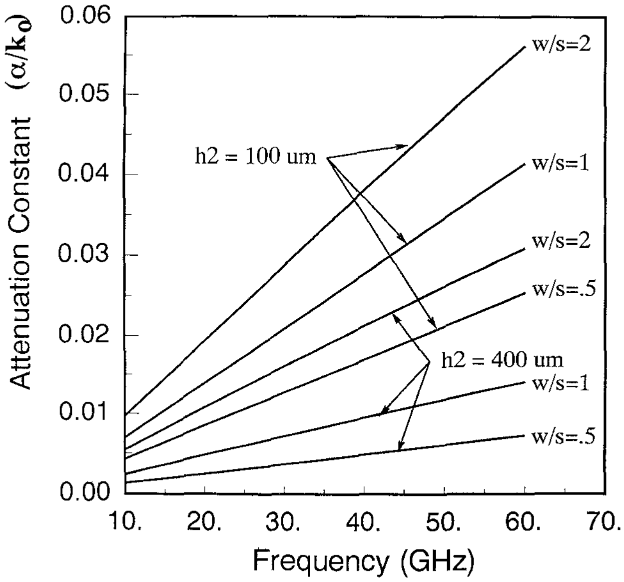

Fig. 3. Normalized attenuation constant α/k_o as a function of frequency for various gap widths on a GaAs substrate: $\epsilon_r = 13$, $h1 = 10000$ μm, $s = 50$ μm.

root $v = 0$. Starting with two initial guesses near this real axis location, we use a linear Lagrange interpolation polynomial to locate the complex root. Then M and N are increased, and the same interpolation scheme is used to polish the root.

III. Numerical Results

Let k_o be the free space wavenumber. As a partial check on our method, a comparison of k_o/β was made against all of the curves of normalized guide wavelength published in [9]. Agreement was obtained to within the accuracy readable from their graphs.

Normalized attenuation constant α/k_o was studied for a wide range of geometric parameters. Fig. 2 shows that, with substrate height $h2$ and aspect ratio w/s held constant, the losses increase dramatically with overall line width $s + 2w$. A comparision of transmission lines printed on 100 and 400 μm GaAs is given in Fig. 3. This shows that, for the same line dimensions, a CBCPW printed on a thicker substrate will have a lower leakage loss. For all cases shown in this letter, leakage occurs only in the form of the dominant TEM parallel-plate mode, no higher order modes contribute.

Computation time on an HP 9000/365 workstation is approximately 30 seconds per frequency using five basis functions (M=3,N=2). This choice gave accuracies of four significant figures for α/k_o, and five for β/k_o for the worst convergence case of wide slots on thin substrates at high frequencies ($w = 100\mu$m, $s = 50$ μm, $h2 = 100$ μm, 60 GHz).

IV. Conclusion

We have outlined a full-wave analysis for determining the complex propagation constant of the dominant CBCPW mode. This analysis accounts for losses due to leakage only, since all materials are considered lossless. It is observed that the normalized attenuation constant, α/k_o, increases almost linearly with frequency. Also, thinner substrates and wider overall line widths ($s + 2w$) exacerbate the leakage problem. Curves of normalized attenuation constant are provided for some representative CBCPW transmission lines printed on GaAs.

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