HIGH FREQUENCY CONDUCTOR AND DIELECTRIC LOSSES IN SHIELDED MICROSTRIP

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Abstract-
An integral equation method is developed to calculate the dispersion of non-perfectly conducting microstrip lines. Both dielectric losses in the substrate and conductor losses in the strips and ground plane are considered. Multiple conductors on several layers can be studied using an impedance boundary formulation for the derivation of the Green's function. The microstrip losses are evaluated by using a frequency-dependent surface impedance which is derived by solving the fields in the conductors. This surface impedance replaces the conducting strip and takes into account the thickness and skin effect of the strip at high frequencies. Good agreement with available literature data is shown.

INTRODUCTION

The effect of conductor losses in microstrip circuits and especially MMIC's is important to the circuit designer who is concerned with dissipation and power loss. Several studies have been performed to calculate the dispersion in microstrip structures at microwave frequencies considering dielectric and conductor losses. Conductor losses have first been analyzed by Wheeler [1] and Pucel [2] where a technique based on the *incremental-inductance rule* was used. Other approaches to the problem of losses include quasi-TEM models and the conventional perturbation technique as in [3] using a spectral-domain approach. However, these methods are limited to the case where the thickness of the strip is much larger than the skin depth. In the present study, a method is applied that represents conductor losses in microstrip lines by using a frequency-dependent impedance boundary, thus taking into account the skin-effect problem. The procedure applied for the solution of this problem is very powerful and general. In fact it can be applied to any number of problems including thin metallizations. The proposed method will be applied to various interconnects and their propagation characteristics will be studied in the presence of other lines or under the effect of the shielding cavity.

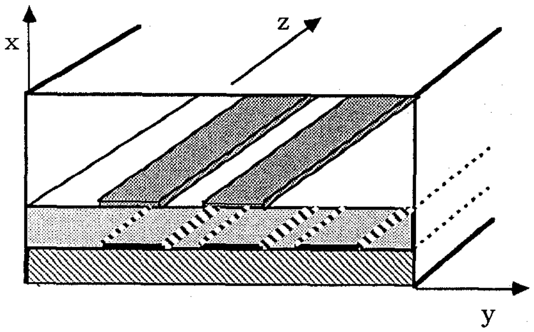

Figure 1: Shielded microstrip line configuration

THEORETICAL DERIVATION

Shielded planar microstrip transmission lines inside an inhomogeneously filled waveguide are considered as shown in Figure 1. Both dielectric losses in the substrate and conductor losses in the strip and ground plane are accounted for. The side walls are assumed perfect conductors. Because of the shielded structure, these lines propagate hybrid modes which have non-zero cut-off frequencies with the exception of the dominant mode. The LSE and LSM modes propagating along the z-direction can be obtained by solving the related boundary value problem.

The dyadic Green's function for the problem is derived in the spectral domain using the boundary conditions on the perfectly conducting walls and an equivalent impedance boundary condition on the interfaces. The current has a transverse component and a longitudinal component. Their variation in the y-direction is chosen such that the edge conditions on the strips are satisfied. The electric field is then given by Pocklington's integral equation as

$$\bar{E}(x=x') = \int\int \bar{\bar{\Gamma}}(x/x') \cdot \bar{J}(y')\, e^{-jk_z^{MS}z'}\, dy'\, dz', \quad (1)$$

where k_z^{MS} is the unknown complex propagation constant of the microstrip. The Fourier transform used is given by

$$\bar{\bar{\Gamma}} = \frac{1}{2\pi} \int_{-\infty}^{\infty} \tilde{\bar{\bar{\Gamma}}} e^{-jk_z z} dk_z. \quad (2)$$

Substituting (2) in (1) and using the sifting property of the Fourier transform, the electric field becomes

$$\bar{E}(x = x') = \int \tilde{\bar{\bar{\Gamma}}}(x/x') \,.\, \bar{J}\, dy' \,|_{k_z = k_z^{MS}}. \quad (3)$$

One more condition needs to be applied, i.e. the boundary condition on the microstrip. For perfect conductors, the tangential electric field vanishes on the line. In this study, we approximate the strip with an equivalent non-zero frequency-dependent surface impedance boundary extending over the surface of the strip. It is desirable that this surface impedance describes, in a physical equivalent sense, the frequency-dependent field penetration in the lossy strips. In [5],[6] an integral equation formulation was presented for the evaluation of the frequency-dependent longitudinal current distribution in rectangular microstrip lines. This method allows us to compute the per unit length resistance $R(f)$ and the per unit length internal inductance of the strip $L_{in}(f)$ as function of frequency. An equivalent longitudinal surface impedance can be defined then as

$$Z_l(f) \equiv \frac{E_z}{H_y} = (R(f) + j\, 2\pi f\, L_{in})w, \quad (4)$$

where w is the width of the strip. As far as the transverse component of the current is concerned, the standard surface impedance for an infinite resistive plane is used,

$$-\frac{E_y}{H_z} \equiv Z_s = (1+j)\frac{1}{\sigma\delta}, \quad (5)$$

where σ is the conductivity of the strip and δ the skin depth at the frequency of interest. Despite the fact that the width of the strip is finite, use of (5) is justified by the fact that the strip is assumed to be infinite in the direction perpendicular to the flow of the transverse component of the current. In addition, for most practical purposes, $|J_y| \ll |J_z|$, therefore the dominant part of the conductor loss is due to the longitudinal component of the current, for which the more accurate longitudinal surface impedance $Z_l(f)$ has been proposed. The boundary condition for the magnetic field on the surface impedance boundary gives

$$\hat{n} \times \bar{H} = \bar{J}. \quad (6)$$

In view of (4-6), (3) becomes

$$\int \{ \tilde{\bar{\bar{\Gamma}}}(x/x') \,.\, \bar{J}\, dy' - Z_{l,s}\, \bar{J} \} \,|_{k_z = k_z^{MS}} = 0 \quad (7)$$

which is the pertinent integral equation for the problem. The formulation of the Green's function results in a simple expression involving a single summation over the modes in the y-direction. The resulting homogeneous equation is solved for the microstrip propagation constant at the plane $z = 0$ with as many as a thousand modes to insure convergence. The method of moments is applied using a variation of Galerkin's procedure. Entire domain functions are used to solve for the current distribution. The above expression can be easily programmed on a personal computer to evaluate the propagation constant of the dominant and higher order microstrip modes.

RESULTS

The objective of this study is to determine the dispersion characteristics of single and multiple microstrip lines on single and multilayered substrates. Based on the theory derived in the previous section, a computer program has been developed to calculate the complex zeros of an analytic complex function using the Muller's algorithm with deflation.

Results on attenuation due to lossy dielectrics compare very well with available data. When considering conductor losses, the normalized phase constant of the dominant mode is seen to be slightly larger when no substrate losses are considered (see Figure 2). As the loss tangent of the substrate increases, the phase constant is smaller than in the case of a perfect conductor. As frequency increases, the phase constant tends toward the perfect conductor case. The attenuation constant of the dominant mode increases as expected when including conductor losses (see Figure 3). Attenuation for the case of a single strip and coupled strips is shown in Figures 4 and 5 respectively. Results are compared to the perturbation method in the spectral domain [3],[4] and to the finite-element method [7] . The method presented in this paper will be implemented to evaluate high frequencies dielectric and conductor losses for various interconnects and results will be presented.

CONCLUSIONS

An integral equation approach is applied to calculate the propagation constant of multiple strips on multilayered substrates. An equivalent impedance boundary is employed that takes into account the finite conductivity of the strips and extends to the case where the thickness of the conductor is of the same order of magnitude as the skin depth. Phase constant and attenuation for single and coupled strips are presented.

ACKNOWLEDGMENTS

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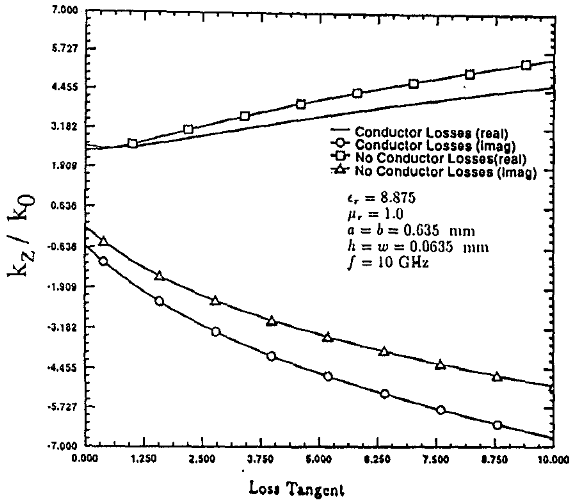
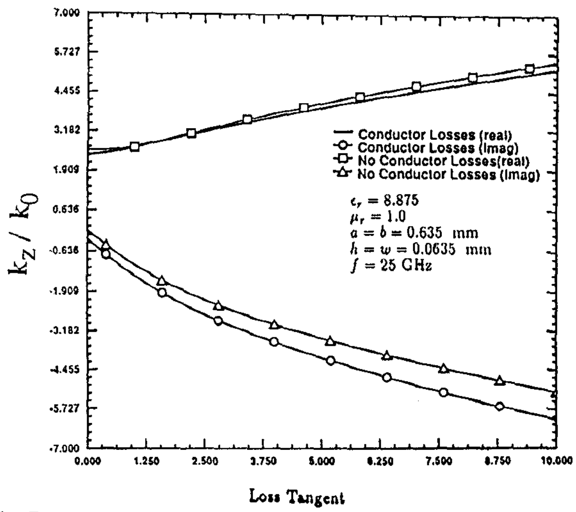
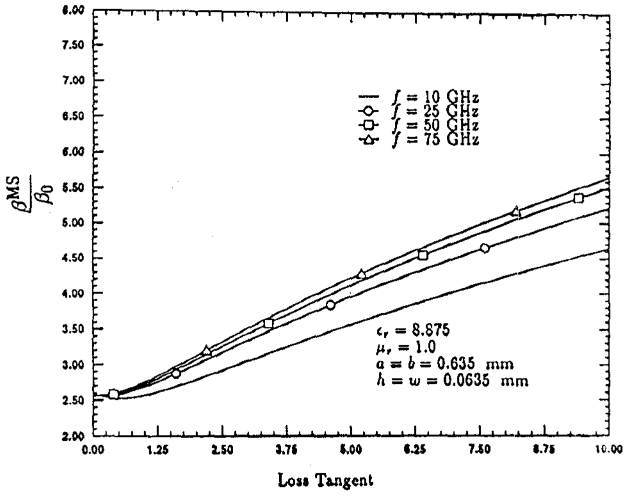


a. Propagation constant vs. loss tangent at $f = 10$ GHz

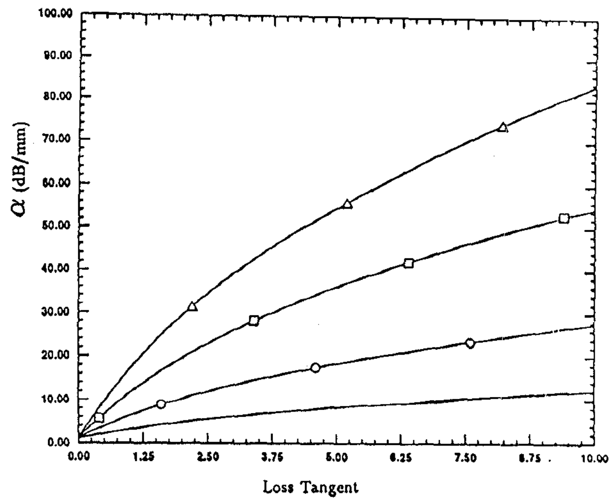


b. Propagation constant vs. loss tangent at $f = 25$ GHz

Figure 2: Effect of conductor losses on propagation constant of the dominant microstrip mode as a function of loss tangent



a. Phase constant as a function of substrate loss tangent



b. Attenuation constant as a function of substrate loss tangent

Figure 3: Effect of conductor and dielectric losses on propagation constant of the dominant microstrip mode as a function of frequency

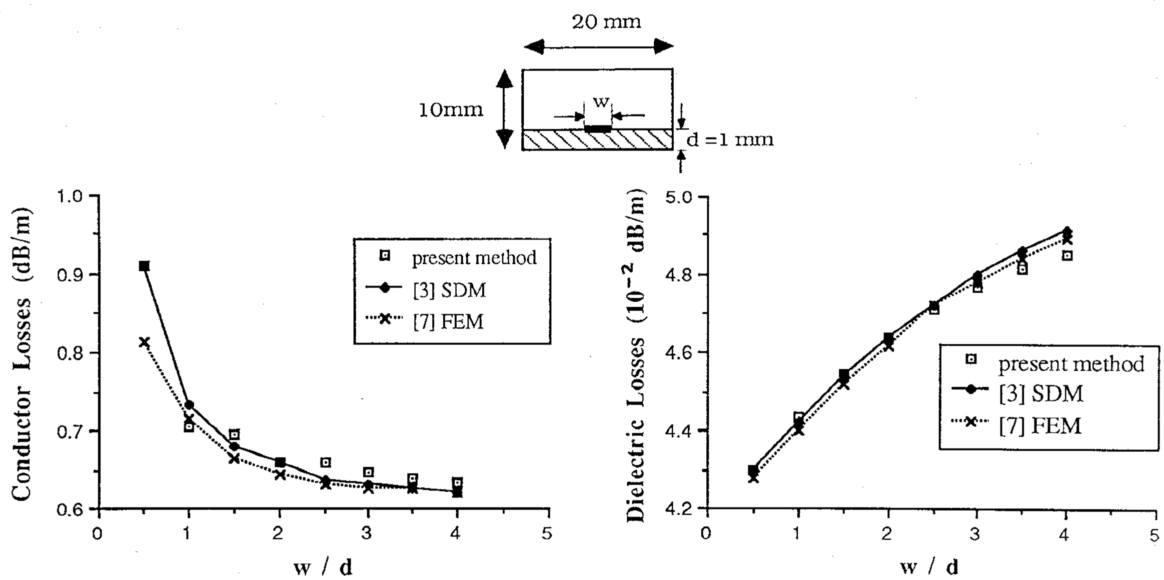


Figure 4: Conductor and dielectric losses of a single strip versus strip width: — present method, ($\epsilon_r = 10$, $\sigma = 3.33 \times 10^7$ S/m, $\tan\delta = 2 \times 10^{-4}$, $f = 1$ GHz)

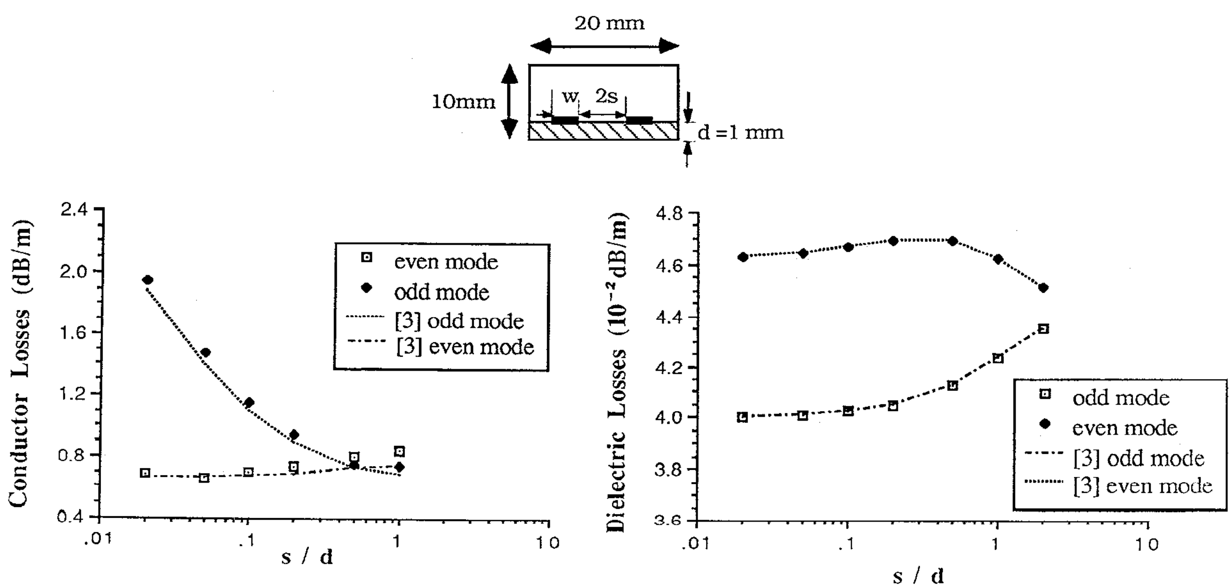


Figure 5: Conductor and dielectric losses of coupled strips versus line separation: — present method, w / d =1, $\epsilon_r = 10$, $\sigma = 3.33 \times 10^7$ S/m, $\tan\delta = 2 \times 10^{-4}$, $f = 1$ GHz)