LEAKAGE IN COPLANAR WAVEGUIDES WITH FINITE METALLIZATION THICKNESS AND CONDUCTIVITY

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ABSTRACT

The interesting phenomenon of leakage in a practical coplanar waveguide structure with finite metallization thickness and conductivity is investigated. By applying the modified spectral-domain approach, its attenuation constants due to both leakage and conductor loss are compared and discussed. In particular, the effective dielectric constant and attenuation constant are carefully studied, together with the current distributions within the metallic signal strip and ground planes.

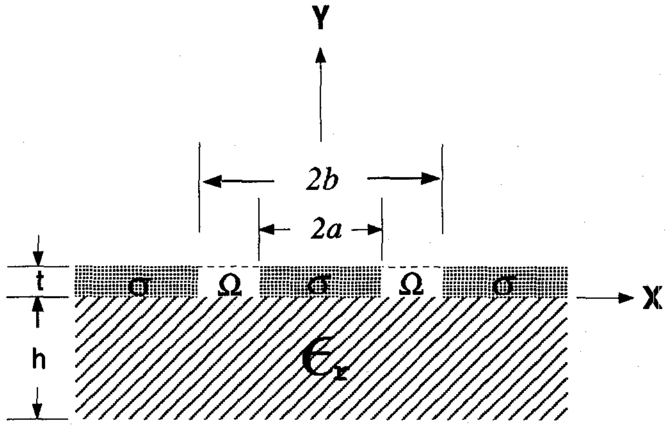

Fig. 1: Cross section of coplanar waveguide.

1 INTRODUCTION

The leakage phenomenon in planar transmission line structures receives increased attention because this power leakage may produce undesired cross talk and package effects [1]-[5]. Up to now, all studies on leakage are usually conducted under the assumptions of infinitely thin conductors and infinite conductivity. Accompanied with the development of monolithic microwave integrated circuits (MMIC's), the thickness of signal strip and ground planes may be comparable to the skin depth, and the effect of finite conductivity may complicate the leakage phenomenon. Particularly for some practical MMIC structures, the attenuation due to leakage may be less than that due to conductor loss, an interesting phenomenon not fully discussed before. In this study, the modified spectral-domain approach [6] is applied to treat this complicated leakage and conductor-loss phenomena associated with the coplanar waveguide in which the thickness and conductivity of signal strip and ground planes are finite.

2 FORMULATION

The cross section of coplanar waveguide (CPW) is shown in Fig.1 in which the electric field $\mathbf{E}(\mathbf{r})$ within the slot regions Ω may be expressed as [6]

$$\mathbf{E}(\mathbf{r}) = -\sigma \int_{\Omega} \bar{\bar{\mathbf{G}}}(\mathbf{r}-\mathbf{r}') \bullet \mathbf{E}(\mathbf{r}')\, d\mathbf{r}'. \quad (1)$$

Here, $\bar{\bar{\mathbf{G}}}$ is the dyadic Green's function for the structure which has a conducting layer of conductivity σ and thickness t over a dielectric layer of dielectric constant ϵ_r and thickness h. It should be emphasized that the conductor is now regarded as a lossy layer therefore the effect of lossy signal

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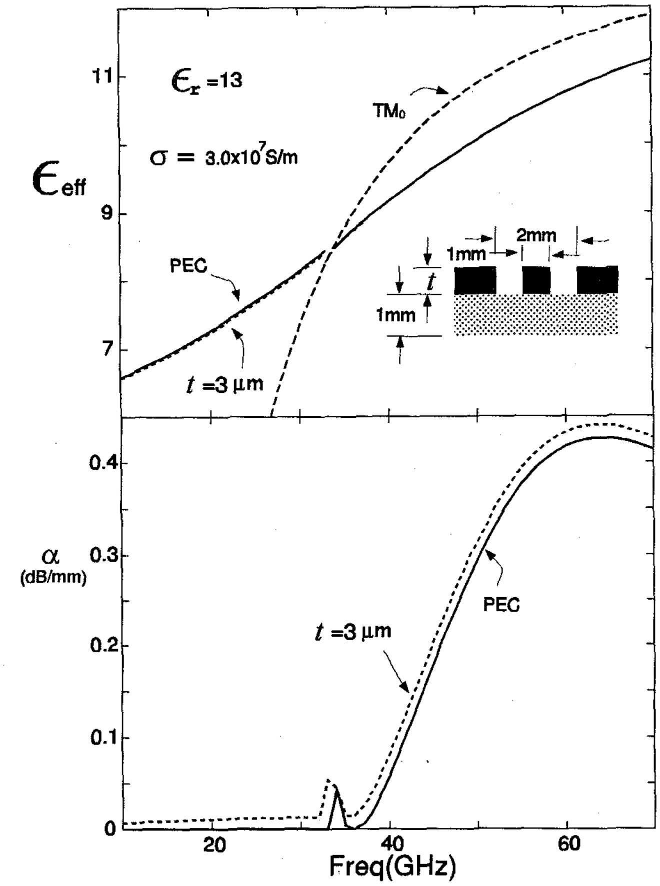

Fig. 2: Comparison of effective dielectric constant ϵ_{eff} and attenuation constant α with those of PEC case.

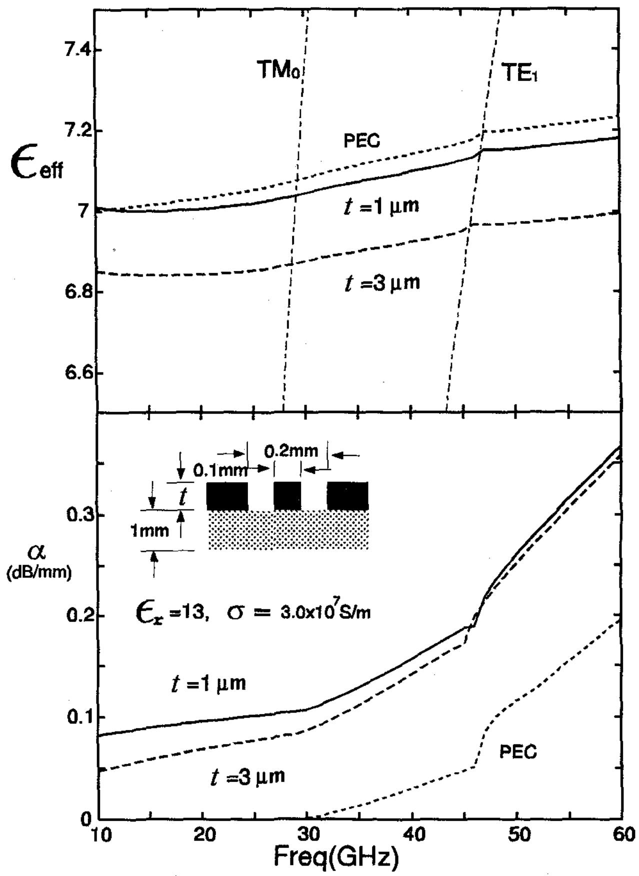

Fig. 3: Effective dielectric constant ϵ_{eff} and attenuation constant α versus frequency with metallization thickness t as parameters.

strip and ground planes may be discussed through these Green's functions. By weighting both sides of (1) by any arbitrary function $\mathbf{w}(\mathbf{r})$ and then integrated, one may get a two-dimensional integral equation. Because the y-dependence form of the spectral-domain Green functions is a linear combination of $\exp(j\beta y)$ and $\exp(j\beta y')$, thus, if the bases of $\mathbf{E}$ are properly chosen, the integral equation can be reduced to a one-dimensional one as in the conventional spectral-domain approach [6]. In this study of extending the computational range to the higher frequency, the required CPU time may drastically increase, because the worst-case asymptotic limit of the integrand is of the order $1/k_x^2$. To give efficient computation, the asymptotic form of the part of the Green's functions which correspond to the free-space contributions is derived. After some analytical integrations, the integrand may be reduced to the order of $1/k_x^3$, which improves the convergence speed.

3 NUMERICAL RESULTS

In this study, numerical results such as effective dielectric constant $\epsilon_{eff} = \beta^2/k_0^2$ $(k_0^2 = \omega^2\mu_0\epsilon_0)$ and attenuation constant α are carefully studied.

To show the effects of finite metallization thickness and finite conductivity, Fig. 2 considers the coplanar waveguide structure with $b/t = 300$ and compares our results with those of zero-thickness perfect electric conductor(PEC) case [7]. As expected, the attenuation due to finite conductivity is dominant as the frequency is less than the critical frequency for leakage. For frequencies greater than the critical frequency such that the fundamental CPW mode becomes leaky, the attenuation due to leakage is larger than that due to conductor loss and the effects of finite metallization thickness and finite conductivity is not significant.

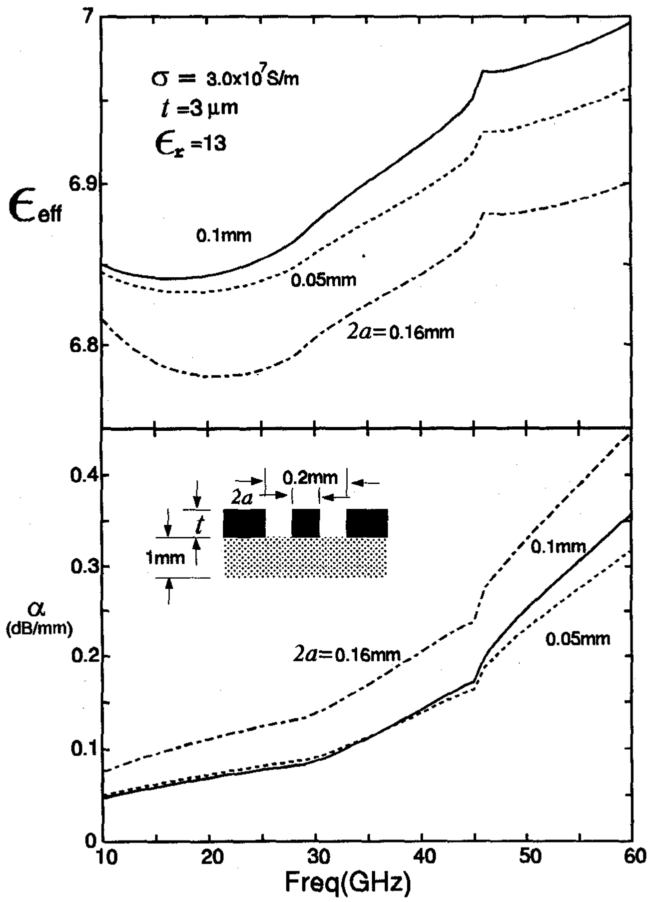

Fig. 4: Effective dielectric constant ϵ_{eff} and attenuation constant α versus frequency with strip width $2a$ as parameters.

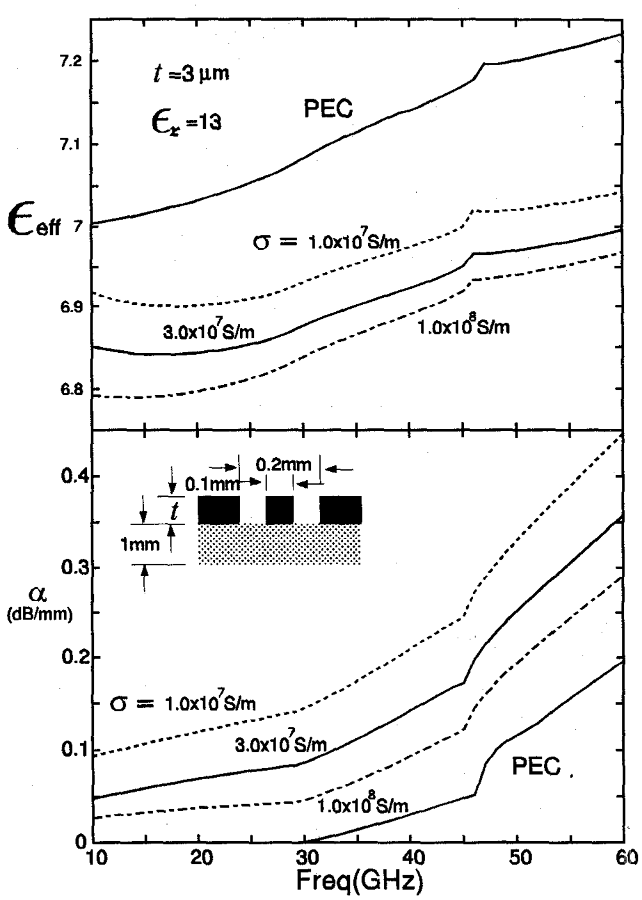

Fig. 5: Effective dielectric constant ϵ_{eff} and attenuation constant α versus frequency with conductivity σ as parameters.

However, if the b/t ratio is about 30 as in the one of Fig. 3, the effects of finite metallization thickness and finite conductivity on both effective dielectric constant and attenuation constant may not be neglected. Specifically, for frequencies from 30 GHz to 60 GHz in Fig. 3, the attenuation predicted by the zero-thickness PEC structure is much less than that of a practical structure which takes both leakage and finite-conductivity effects into consideration. Thus the assumption of zero metallization thickness and PEC ($t = 0$, $\sigma = \infty$) is no longer reasonable, suggesting the need of developing a more accurate CAD tool to model the practical coplanar waveguide structure. Also shown in Fig. 3 is the effect of changing the metallization thickness. As expected, the difference between the effective dielectric constant for zero-thickness PEC structure and that for $t = 1\mu$m is small. Specifically, the zero-thickness PEC assumption can adequately be used in predicting the effective dielectric constant if $(b - a)/t > 50$.

Shown in Fig. 4 are the effective dielectric constant and attenuation constant versus frequency with strip width $2a$ as parameters. It is found that, the effective dielectric constant for $2a = 0.16$mm ($a/b = 0.8$) behaves more dispersive than the others, and the corresponding attenuation is larger. Thus, to design a coplanar waveguide with low loss and small dispersion, the a-to-b ratio should not be large.

The effect of increasing the conductivity σ is presented in Fig. 5. Here, as expected, both the effective dielectric constant and attenuation constant decrease as conductivity increases. By the contribution of the internal inductance of conductor, the curve of effective dielectric constant presents a local maximum in the low frequency range.

Fig. 6 shows the distributions of longitudinal current J_z on signal strip (Fig. 6(a)) and ground planes (Fig. 6(b)). As expected, the current on

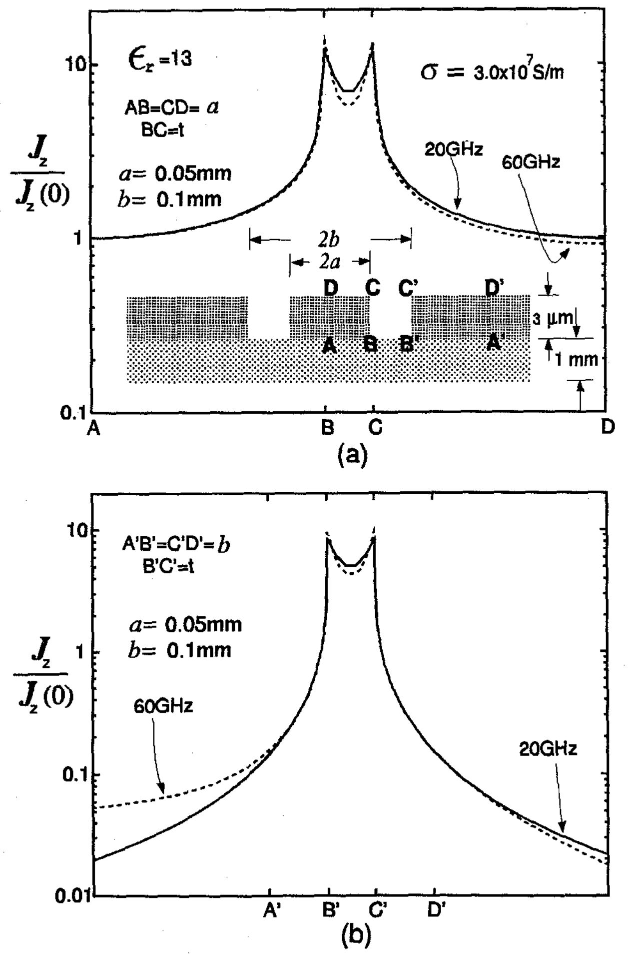

Fig. 6: Longitudinal current distributions on signal strip and ground planes.

the upper side (CD) of signal strip and that on the upper side (C'D') of ground plane are both decreased as frequency increases. However, the current on the lower side (B'A') of ground plane at 60 GHz is much larger than that at 20 GHz. As predicted, the CPW structure at 60 GHz already excites the leaky surface wave which is propagated along the lower (substrate) part of the conducting structure.

4 CONCLUSIONS

In this work, the leakage effect and conductor loss associated with coplanar waveguides of finite metallization thickness and finite conductivity are investigated. In particular, the attenuation due to leakage and that due to conductor loss are compared and discussed in detail with strip width a, thickness t, and conductivity σ as parameters. Besides, the current distributions within the metallic signal strip and ground planes are also presented.

Acknowledgment

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