

HYBRID FEM ANALYSIS OF THICK CPW DISCONTINUITIES WITH NONRECTANGULAR CROSS SECTION

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ABSTRACT

In this paper, a hybrid finite element method is proposed to analyze the coplanar waveguide discontinuities with finite metallization thickness and nonrectangular cross section. It has been shown that not only the metallization thickness but also the conductor edge profile can produce noticeable effects on circuit performance and should be taken into account for accurately modeling the coplanar waveguide discontinuities.

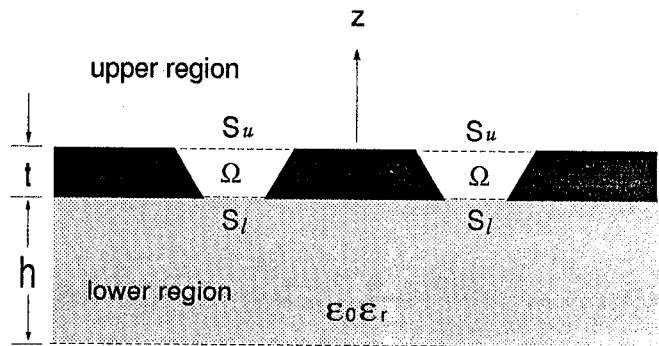


Fig.1 : Cross section of coplanar waveguide with finite metallization thickness

1 INTRODUCTION

The uni-planar transmission line structure based on the coplanar waveguide (CPW) has been developed as a circuit element for monolithic microwave integrated circuits (MMIC). Accurate analysis and characterization of CPW discontinuity is important in designing the MMIC because tuning or trimming of MMIC's is infeasible. As the line size shrinks, the finite metallization thickness may play a significant role in determining the circuit performance and should be taken into account.

Several papers have been presented to characterize CPW discontinuity structures with finite metallization thickness [1] -[5]. In those works, they only dealt with slots of rectangular cross section. A recent study shows that, not only the finite metallization thickness but also the conductor edge profile will affect the electrical characteristics of uniform CPW lines [6]. It is then necessary to account for the effects of conductor edge profile for accurately modeling the CPW discontinuities. In

this study, the hybrid finite element method is applied to treat the CPW discontinuity with finite metallization thickness and nonrectangular cross section.

2 FORMULATION

The cross section of coplanar waveguide with finite metallization thickness is shown in Fig.1. The solution region Ω lies between the upper and lower slot surfaces S_u and S_l , respectively. By applying the variational reaction theory [7], the variational equation for the unknown electric field in Ω can be derived with suitable integral equations for the exterior field, *i.e.*,

$$\begin{aligned} \Psi = & \frac{1}{2} \iiint_{\Omega} (\bar{E} \cdot \bar{E} - \frac{1}{k^2} \nabla \times \bar{E} \cdot \nabla \times \bar{E}) d\Omega \\ & + \sum_{p=u,l} \frac{1}{2} \iiint_{S_p} \hat{n}_p \times \bar{E}(\bar{r}) \cdot \bar{G}_p \cdot \hat{n}_p \times \bar{E}(\bar{r}') ds' ds \end{aligned}$$

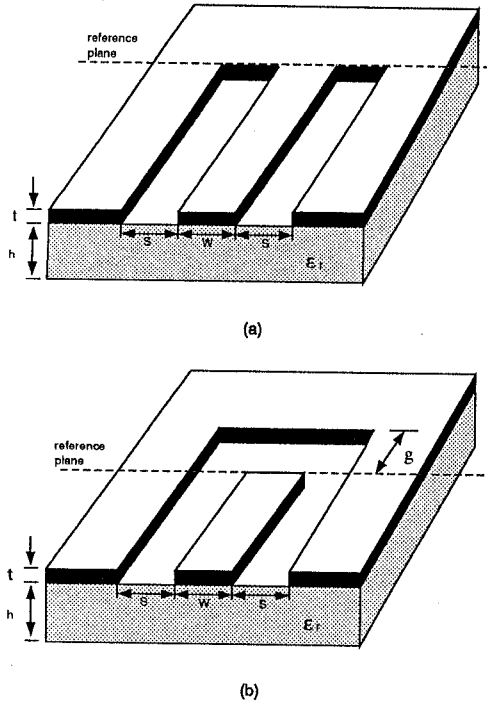


Fig.2 : The CPW discontinuity structures : (a) short end and (b) open end.

$$+ \frac{1}{j\omega\epsilon_0} \iint_{S_u} \bar{H}^{inc} \cdot \hat{n}_u \times \bar{E}(\bar{r}) ds \quad (1)$$

where \hat{n}_p ($p = u, l$) is the unit vector outward normal to the slot surface S_p and \bar{G}_p denotes the Green's function of the upper half space or the lower layered medium [8].

Using vector edge basis functions, the finite-element method is employed to discretize (1) into a matrix form which can be solved by the Gaussian elimination method. Given the electric fields on the slot surface, the matrix pencil approach is then utilized to extract the scattering coefficients [8] and from which, the normalized impedance and admittance of the CPW discontinuities. In the limiting case of zero metallization thickness, the analysis is reduced to a moment method analysis using Galerkin's approach with rooftop basis functions [8].

3 NUMERICAL RESULTS

A number of analyses have been performed to characterize CPW with finite metallization thickness, including both the effective dielectric

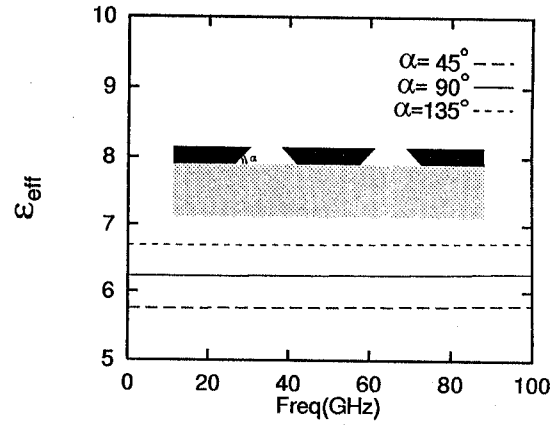


Fig.3(a)

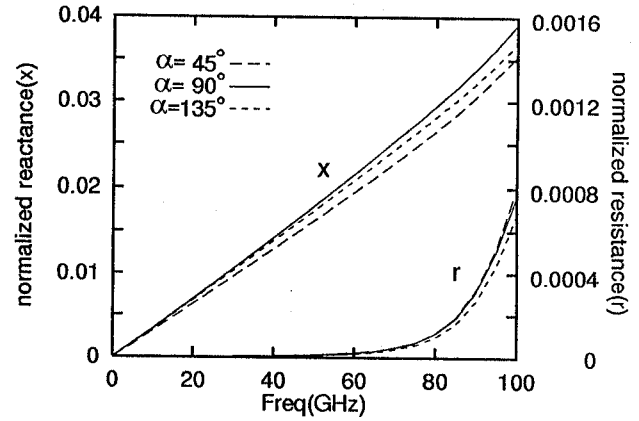


Fig.3(b)

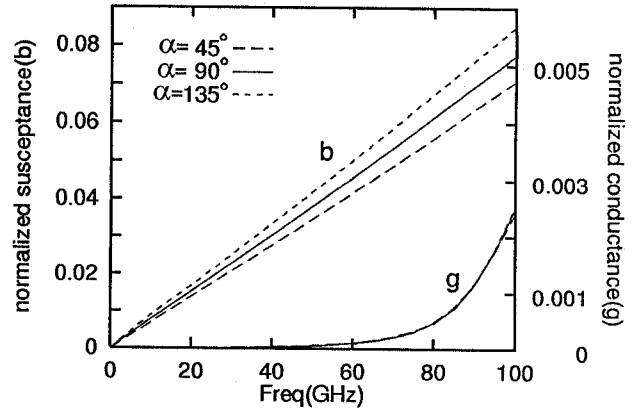


Fig.3(c)

Fig.3 : (a) Effective dielectric constant ϵ_{eff} , (b) the normalized short-end impedances, and (c) open-end admittances versus frequency with edge angle α as a parameter. (line parameters : $w = 20 \mu m$, $s = 15 \mu m$, $t = 3 \mu m$, $h = 200 \mu m$, and $\epsilon_r = 12.9$. Gap width $g = 15 \mu m$ for open end.)

constant of uniform CPW lines and end effects of the short- and open-ended discontinuities shown in Fig.2.

Fig.3(a) shows the edge profile effects on the effective dielectric constants which are extracted from the full wave analysis of a CPW short end. The case of $\alpha = 90^\circ$ corresponds to the rectangular conductor cross section. It can be found that the effective dielectric constant of $\alpha = 45^\circ$ is smaller than that of the rectangular conductor cross section. This is expected since the fields are more concentrated in the air region due to the sharp edge at top surface of strip. The results of $\alpha = 135^\circ$ are opposite to those of $\alpha = 45^\circ$ since the fields are more concentrated in substrate region due to the sharp edge at bottom surface of strip.

Fig.3(b) and (c) show the results of the normalized short-end impedances and open-end admittances versus frequency for the three different cases. For open end discontinuity, the equivalent capacitance increases as the edge angle α becomes larger. However, the equivalent inductance of the short end discontinuity decreases as the cross section deviates from the rectangular shape.

Fig.4 shows the dependence of some circuit parameters on the metallization thickness with edge angle α as a parameter. As expected, when the thickness of the conductor tends to zero, the results calculated by hybrid FEM move toward the values obtained by the moment method in the zero thickness limit. For effective dielectric constant, the thicker the metallization is, the more significant influence the edge angle exhibits.

For the equivalent extension lengths, it can be found from Fig.4 that the results of $\alpha = 45^\circ$ are similar to those of $\alpha = 135^\circ$ for the CPW short end discontinuity. The reason is that the equivalent end inductances are mainly dependent on the conductors, being almost independent of the dielectric medium in the substrate. In contrast, the substrate has a strong influence on the electric field, which determines the capacitances. It is interesting to note the different behaviors for $\alpha = 45^\circ$ and $\alpha = 135^\circ$ in equivalent length extension for the CPW open end discontinuity.

4 CONCLUSIONS

In this work, the hybrid finite element method has been applied to analyze the effects of conductor thickness as well as nonrectangular conductor

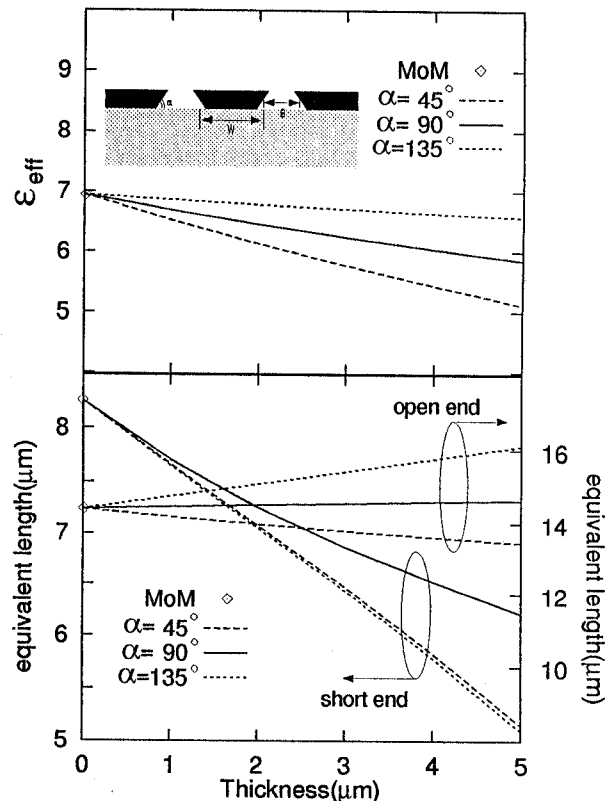


Fig.4 : Effective dielectric constant ϵ_{eff} and the equivalent length extensions of the short and open ends versus metallization thickness t with edge angle α as a parameter. (line parameters : $w = 20 \mu m$, $s = 15 \mu m$, $t = 3 \mu m$, $h = 200 \mu m$, and $\epsilon_r = 12.9$. Gap width $g = 15 \mu m$ for open end, frequency is at 50 GHz.)

cross section on the CPW discontinuities for the first time. Surface wave and radiation effects are included in the integral equation formulation in terms of suitable Green's functions. It has been applied to investigate the effective dielectric constants of CPW lines as well as the equivalent circuit parameters of the short- and open-ended discontinuities. Numerical results have shown that these effects must be accounted for to obtain accurate and reliable predictions of the circuit performance for MMIC applications.

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