Equivalent Inductances of Coplanar-Stripline Step Discontinuities

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ABSTRACT

The equivalent inductance of an equivalent circuit model to characterize a coplanar stripline (CPS) step discontinuity is analyzed based on the duality concept of alternatively determining the equivalent capacitance of its complementary structure, *i.e.*, the coplanar waveguide (CPW) step discontinuity in the free space. In this study, numerical results for CPS step discontinuity structures, obtained from the equivalent circuit model and full-wave momentum simulator, are presented and compared with the measured data. Good agreement among these results reveals that this model is useful in characterizing the CPS step discontinuities.

1 INTRODUCTION

The coplanar stripline (CPS) structure is efficient in the use of wafer area. With easier insertion of series and shunt devices, it offers flexibility in the design of planar microwave and millimeter-wave circuits. Due to the balanced nature of CPS, it is a basic component of uniplanar balanced circuits such as mixer [1], antenna, and optoelectronic device. But the research works into CPS circuit components are quite limited, and only some CPS discontinuities were examined recently [2],[3]. Since the CPS is the dual structure of coplanar waveguide (CPW), it has all the advantages of CPW, including less dispersive effect and small radiation losses in discontinuities. Therefore, it is advantageous to represent the CPS component by an equivalent circuit model based on the quasi-static approximation. In this study, the discontinuity inductance of the equivalent circuit model to discuss the CPS step discontinuity (Fig. 1(a)) will be investigated in detail. This CPS step discontinuity structure is a fundamental component in implementing the planar microwave and millimeter-wave integrated circuits.

2 FORMULATION

From the duality concept, one may compute the equivalent inductance of the CPS step discontinuity (Fig.1 (a)) from the equivalnet capacitance of its complementary CPW step change (Fig. 1(b)) in the free space [4]

$$L_{cps} = \frac{1}{4}\frac{\mu_0}{\epsilon_0} C_{cpw}(\epsilon_r = 1).$$

The capacitance of complementary CPW step discontinuity structure in the free space may further be calculated, based on the variational technique as given by [5],

$$C = \lim_{l_1, l_2 \to \infty} [2W_e(l_1, l_2) - W_e^{(1)}(2l_1) - W_e^{(2)}(2l_2)]$$

where

$$\begin{aligned} W_e(l_1, l_2) &= \frac{1}{2}\int_R \int_R G(\vec{\rho}, \vec{\rho}\,')\vec{M}(\vec{\rho}) \\ &\quad \bullet \vec{M}(\vec{\rho}\,')\, dS' dS \\ W_e^{(i)}(2l_i) &= \frac{1}{2}\int_{R^{(i)}} \int_{R^{(i)}} G(x, x')\vec{M}(x) \\ &\quad \bullet \vec{M}(x')\, dx' dx, i = 1, 2. \end{aligned}$$

Here R and $R^{(i)}$ are the slot regions with lengths $l_1 + l_2$ and l_i as shown in Fig. 1(b). $\vec{M}$ is the equivalent magnetic current along the slot, while $G(\vec{\rho}, \vec{\rho}\,')$ and $G(x, x')$ are the associated three-dimensional and two-dimensional Green's functions of the CPW structure, respectively.

3 NUMERICAL RESULTS

Fig. 2 compares the discontinuity inductances for inductive slit structure obtained from the quasi-static analysis with the measured data [3]. The S-parameters of the CPS inductive slit structure obtained from the equivalent circuit model and *HP momentum* simulator are shown in Fig. 3 in which the measured data [3] are also included for comparison. The CPS slit structure with smaller B shown in the insert of Fig. 2 can approximately be modeled by an inductive element, so its equivalent circuit has two step discontinuity inductances connected in series with a CPS of length B, strip width W-A, and slot width S+$2A$. Comparison of these results shows that the momentum simulation and the equivalent circuit modeling are satisfactory in characterizing the slit discontinuity structure.

The equivalent inductance of CPS step discontinuity structure versus step width S_2 is shown in Fig. 4. As expected, the inductance increases as the step width increases. Fig. 5 presents the S-parameters of the CPS step discontinuity modeled by the equivalent circuit with and without discontinuity inductances. Also included in Fig. 5 are the momentum simulated results for comparison. The equivalent circuit model without including the effect of discontinuity inductance is obviously inadequate as we compare the results with the momentum simulated ones. The difference between the results from the momentum and equivalent circuit with discontinuity inductance can be attributed to the negligence of the discontinuity capacitance in the CPS step structure. In addition to the series inductance, the shunt capacitance should be included to obtain the complete equivalent circuit for CPS step discontinuity.

4 CONCLUSIONS

Based on the duality concept, this paper has presented a quasi-static analysis of the equivalent inductance of CPS step discontinuity. Comparison among the results of equivalent circuit model, full-wave simulator, and measurement shows that this model is adequate and feasible in dealing with the CPS step discontinuities.

References

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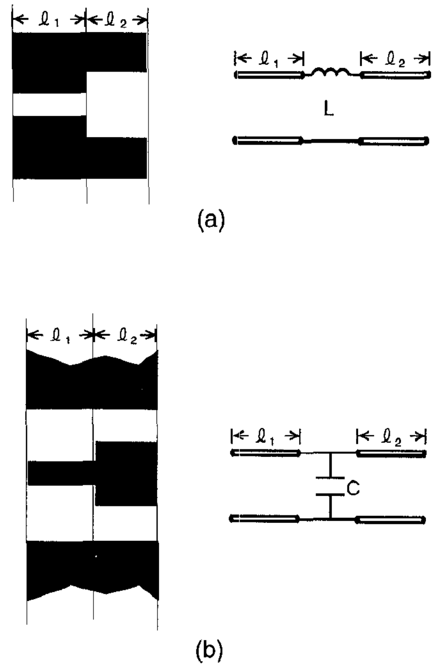

Figure 1: (a) CPS step discontinuity and its equivalent circuit model with discontinuity inductance. (b) The complementary CPW step discontinuity structure and its equivalent circuit model with discontinuity capacitance.

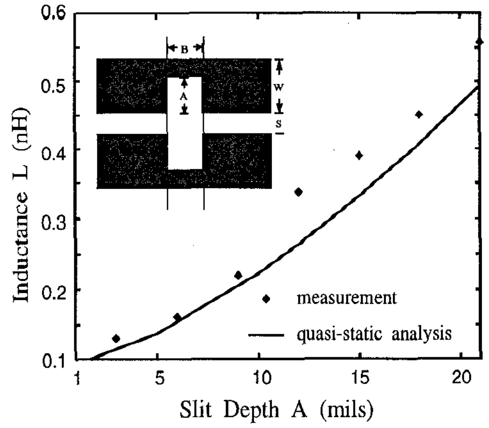

Figure 2: Equivalent inductance of CPS slit structure by the quasi-static analysis as compared to the measured data [3]. (Dielectric thickness=762 μm, ϵ_r=10.2, W=762 μm, S=101 μm, A=531.8 μm, and B=180.3 μm.)

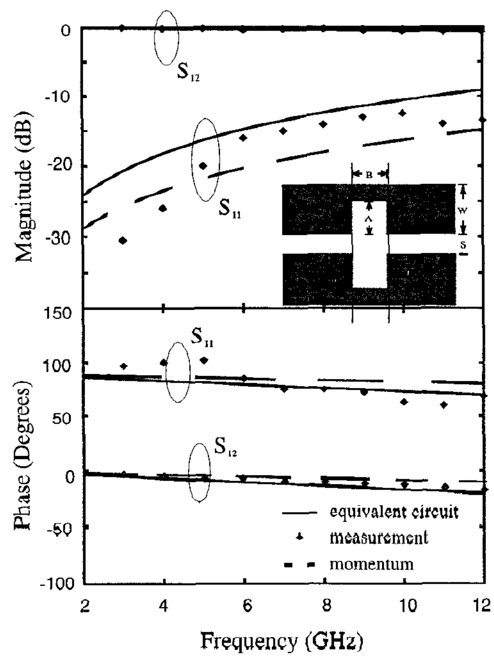

Figure 3: S-parameters of CPS slit structure obtained from equivalent circuit model, measurement [3], and full-wave momentum simulator. (Dimensions are the same as Fig. 2.)

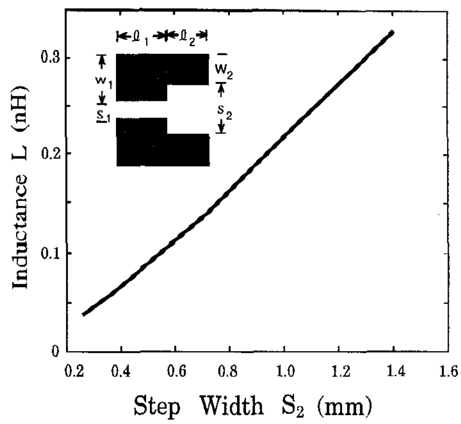

Figure 4: Equivalent inductance of CPS step discontinuity structure.(Dielectric thickness=635 μm, ϵ_r=9.8, W_1=762 μm, S_1=30.4 μm, ℓ_1=508 μm, W_2=76.2 μm, ℓ_2=254 μm.)

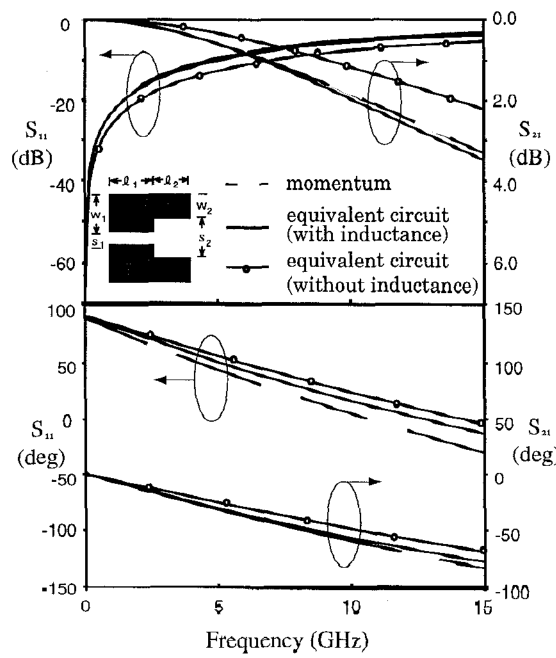

Figure 5: S-parameters of CPS step discontinuity structure obtained from the equivalent circuit model with and without discontinuity inductance as well as those from the full-wave momentum simulator.(Dielectric thickness=635 μm, ϵ_r=9.8, W_1=762 μm, S_1=30.4 μm, ℓ_1=508 μm, W_2=76.2 μm, S_2=1402 μm, ℓ_2=254 μm.)