ANALYSIS OF SHIELDED CPW DISCONTINUITIES WITH AIR-BRIDGES

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ABSTRACT

The effect of air-bridges on the performance of various coplanar waveguide (CPW) discontinuities is studied. Specifically, the coupled open-end CPWs and the short-end shunt CPW stub discontinuities are considered. The high frequency effect of the air-bridge is evaluated using a hybrid technique. At first, the frequency dependent equivalent circuit of the planar discontinuity without the air-bridge is derived using the Space Domain Integral Equation (SDIE) method. Then, the circuit is modified by incorporating the air-bridge's parasitic inductance and capacitance which are evaluated using a simple quasi-static model. The frequency response of each discontinuity with and without the air-bridge is studied and the scattering parameters are plotted in the frequency range 30-50 GHz for typical CPW dimensions.

1 INTRODUCTION

Recently, researchers have shown a great deal of interest in coplanar waveguides (CPW) for (M)MICs design due to several advantages such as design flexibility, potential for low dispersion and low radiation, and less dependency on the substrate thickness [1-3]. While there is no need for via holes in CPW circuits, air-bridges are fundamental components mainly used to connect the ground planes in order to suppress the propagation of coupled slotline mode [4]. In addition, they are used to connect CPWs with slotlines or coupled slotlines in uniplanar (M)MICs [5]. Unfortunately, air-bridges represent discontinuities which may cause parasitic effects depending on their electrical size and location. It has been found experimentally that the parasitic effect of a typical air-bridge along a uniform line is negligible. The size of a typical air-bridge is very small; the height is 3 μm and length ranges from 10 μm to 50 μm [4, 5]. However, a 5% change in the resonant frequency of a CPW line resonator including ten air-bridges has been reported in [4].

In this paper, the two CPW discontinuities shown in Fig.1 are studied. In Fig.1a, the air-bridge is used to connect the center conductors of two coupled open-end CPWs, while in Fig.1b it connects the two ground planes of the shunt CPW stub in order to suppress coupled slotline mode. Since the size of a typical air-bridge is very small, a hybrid technique can be used to analyze these discontinuities. First, the frequency dependent equivalent circuit of the discontinuity, without the air-bridge, is derived using the Space Domain Integral Equation (SDIE) method [6-8]. Then, this equivalent circuit is modified by incorporating the air-bridge's parasitic effects. These effects, a series inductance and a shunt capacitance, are evaluated using a quasi-static model. The theoretical method is discussed briefly in section 2, and numerical results for symmetric discontinuities are presented in section 3. Results for non-symmetric CPW discontinuities will be shown in the symposium. Moreover, experiments will be performed to validate the obtained theoretical results.

2 THEORY

The CPW under consideration is shown in Fig.2 where it is assumed to be inside a rectangular cavity of perfectly conducting walls. The cavity dimensions are chosen such that the CPW fundamental mode is not affected by higher order cavity resonances. The theoretical method used to study CPW discontinuities, in the absence of air-bridges, is based on a space domain integral equation which is solved using the method of moments. The SDIE approach has been previously applied to study several CPW discontinuities and has shown very good accuracy, efficiency and versatility in terms of the geometries it can solve [6-8]. Since the theoretical method is presented in detail in [7, 8], a brief summary will be given here.

The boundary problem pertinent to any CPW discontinuity may be split into two simpler ones by introducing an equivalent magnetic current $\bar{M}_s$ on the slot apertures. This surface magnetic current radiates an electromagnetic field in the two waveguide regions (above and below the slots) so that the continuity of the tangential electric field on the surface of the slots is satisfied. The remaining boundary condition to be applied is the continuity of the tangential magnetic field on the surface of the slot apertures which leads to the following integral equation

$$\hat{x} \times \int_S \int [\bar{\bar{G}}_0^h(\bar{r}/\bar{r}') + \bar{\bar{G}}_1^h(\bar{r}/\bar{r}')] \cdot \bar{M}_s(\bar{r}') \, ds' = \bar{J}_s \quad (1)$$

where $\bar{\bar{G}}_{0,1}^h$ are the magnetic field dyadic Green's functions in the two waveguide regions [7, 8] and $\bar{J}_s$ denotes an assumed ideal electric current source exciting the coplanar waveguide mode (gap generator model).

The integral equation (1) is solved using the method of moments where the unknown magnetic current is expanded in terms of rooftop basis functions. Then, Galerkin's method is applied to reduce the above equation to a linear

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system of equations

$$\begin{pmatrix} Y_{yy} & Y_{yz} \\ Y_{zy} & Y_{zz} \end{pmatrix} \begin{pmatrix} V_y \\ V_z \end{pmatrix} = \begin{pmatrix} I_z \\ I_y \end{pmatrix} \qquad (2)$$

where $Y_{ij}(i = y,z; j = y,z)$ represent blocks of the admittance matrix, V_i is the vector of unknown y and z magnetic current amplitudes, and I_j is the excitation vector which is identically zero everywhere except at the position of the sources. Finally, the equivalent magnetic current distribution and consequently the electric field in the slots are obtained by matrix inversion.

In case of symmetric CPW structures, the aperture fields form standing waves of the fundamental coplanar waveguide mode away from the discontinuity. Consequently, using the derived electric field, an ideal transmission line method [9] is applied to determine the scattering parameters and evaluate the elements of the equivalent circuit.

Fig.3a shows the equivalent circuit (π-model) for the CPW discontinuities shown in Fig.1 in the absence of the air-bridges. For the structure of Fig.1a, X_1 and X_2 represent the fringing and coupling effects respectively between the two coupled open-ends. However, for the CPW stub discontinuity of Fig.1b, X_1 and X_2 represent the reactances due to the coplanar waveguide and the coupled slotline modes respectively which are excited in the CPW stub. It is the purpose of the air-bridges to short the series reactance in both discontinuities. Fig.3b shows the new equivalent circuit after taking the air-bridge into consideration. The air-bridge can be modeled as an air-filled microstrip line [4, 5], and the design formulas in [10] are used to evaluate its parasitic capacitance C_a and inductance L_a. A parallel plate waveguide model can be also used since the air-bridge height is very small (typically 3 μm). Both models give a capacitance C_a in the order of 1-10 pF and an inductance L_a in the order of 1-10 nH. Finally, new scattering parameters are evaluated from the modified equivalent circuit.

3 NUMERICAL RESULTS

In the numerical results shown here, the considered CPW discontinuities are printed on a 300 μm GaAs substrate (ϵ_r = 13) with an inner conductor width of 75 μm and slot width of 50 μm. The characteristic impedance of such line is approximately 50 Ω. The slot width of the open-end and the CPW stub are both 25 μm.

3.1 Coupled open-end CPWs

Fig.4 shows $mag(S_{12})$ for the coupled open-end CPW discontinuity (without air-bridge) as a function of frequency for different separation distances. It can be seen that the coupling between the two lines is small even with a separation distance of 20 μm. It is worth mentioning that such structure is widely used as a test fixture for making precise scattering parameters measurements of a wide variety of active and passive circuit elements. This is performed by mounting the element (or (M)MIC) on the center area (called ground plane mounting island) and connecting it to the CPW lines using bondwires. Fig.5 shows the fringing and coupling reactances of the equivalent π-model of the discontinuity with reference planes chosen to coincide with the end of the center conductors. It has been found numerically that X_1 varies approximately as $1/f$ and it is always capacitive for any separation distance depending mainly on the center conductor and slot widths. This behavior is not clear in Fig.5 because of the large vertical scale. On the other hand, the value and nature of X_2 depends on the separation distance besides the center conductor and slot widths.

Fig.6 shows $mag(S_{12})$ for the same discontinuity with an air-bridge connecting the center conductors (with a height of 3 μm). It can be noticed that the insertion loss in this case is very small compared to the case without the air-bridge shown in Fig.4. The variation of $mag(S_{12})$ with respect to frequency and length of air-bridge is analogous to the one found experimentally in [4] . Thus, it is indeed reasonable to model the air-bridge quasi-statically as long as it is adequately small.

3.2 A shorted-end shunt CPW stub

Fig.7 shows the scattering parameters of a shorted-end shunt CPW stub discontinuity (without the air-bridges) with a stub length of 550 μm. It can be noticed that such structure behaves as a series stub (instead of a shunt stub) with a resonant frequency 46.5 GHz. Fig.8 clarifies this by showing that the series reactance X_2 resonates at this frequency while the shunt reactance X_1 resonates at 49.5 GHz (at which the length of the stub is approximately a quarter of a coplanar mode wavelength). However, the effect of this latter resonance does not appear in Fig.7 because of the existence of the series reactance X_2. It has been found that these two resonant frequencies are approximately independent of the separation distance between the two coplanar lines (ranging from 20-80 μm) depending mainly on the stub length. A similar equivalent circuit of this discontinuity is proposed in [10] where the reactances are assumed to be inductive, which is not always true as shown in Fig.8.

Fig.9 shows the scattering parameters of the same discontinuity with air-bridges connecting the ground planes of the CPW stub. The air-bridges are chosen with width of 10 μm and height of 3 μm. These air-bridges ensure that the two ground planes of the CPW stub are at the same potential and suppress the coupled slotline mode. This results in shorting the series reactance and thus reducing the equivalent circuit to a shunt reactance (with air-bridge parasitic effects). Fig.9 shows that this structure is indeed a shunt stub not a series one.

4 CONCLUSIONS

Two different CPW discontinuities involving air-bridges (coupled open-end CPWs and shorted-end shunt CPW stub) have been analyzed using a hybrid technique. In this approach, the planar structure without the air-bridge is analyzed with the SDIE method and a frequency-dependent equivalent circuit is derived. Then, the effect of the air-bridge is taken into account quasi-statically by modifying the equivalent circuit appropriately and the new scattering parameters are computed. It has been found that the coupling is very small between two open-end CPWs, when they are not connected with an air-bridge, even with small separation distances. In addition, it has been found that a shorted-end shunt CPW stub behaves as a series stub if the two ground planes of the CPW stub are not connected together due to the presence of the coupled slotline mode. It is the air-bridge, whose parasitic effects are typically negligible, that makes these structures behave as required. Experiments will be performed for both discontinuities with and without air-bridges to validate the theoretically derived data. In addition, results for non-symmetric CPW discontinuities will be shown in the symposium.

5 ACKNOWLEDGMENT

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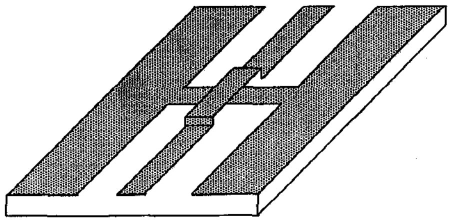
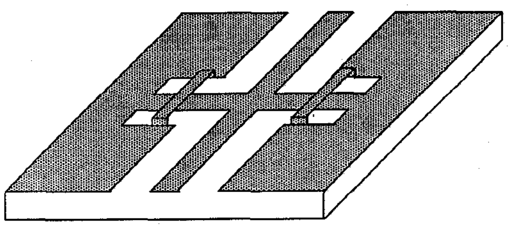


(a)



(b)

Figure 1: (a) Coupled open-end coplanar waveguides with an air-bridge. (b) A coplanar waveguide shorted-end shunt stub.

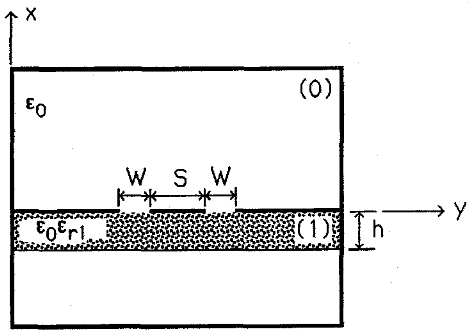
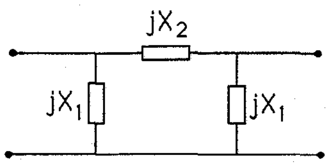
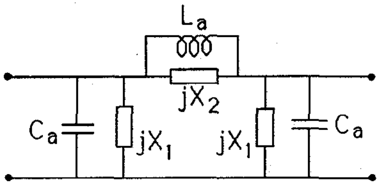


Figure 2: A cross section of a coplanar waveguide inside a cavity.



(a)



(b)

Figure 3: (a) Equivalent circuit of the CPW discontinuities shown in Fig.1 without the air-bridges. (b) Equivalent circuit of the CPW discontinuities shown in Fig.1 with the air-bridges taken into account.

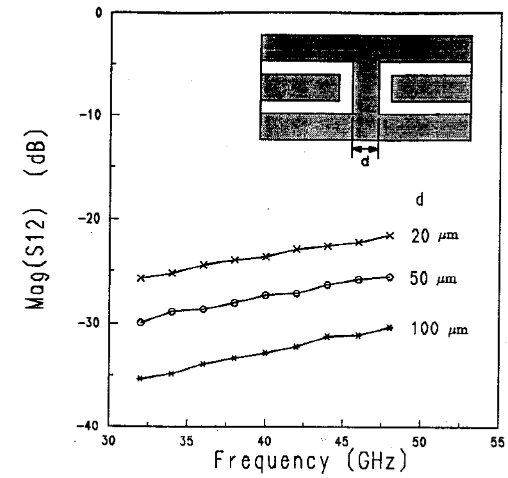


Figure 4: Mag(S_{12}) for the coupled open-end CPWs discontinuity without the air-bridge for different separation distances. (Dimensions are stated in the text)

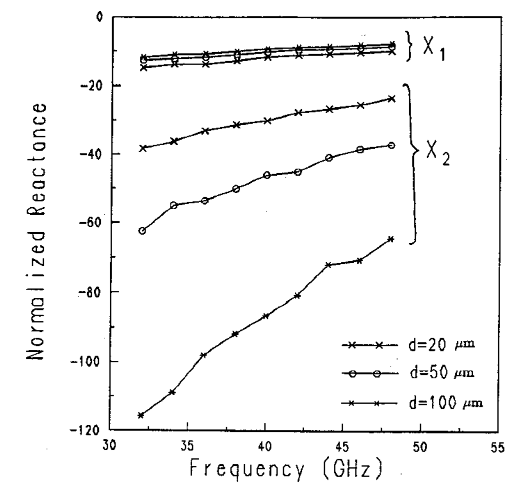


Figure 5: Coupling and fringing reactances for the coupled open-end CPWs discontinuity without the air-bridge for different separation distances.

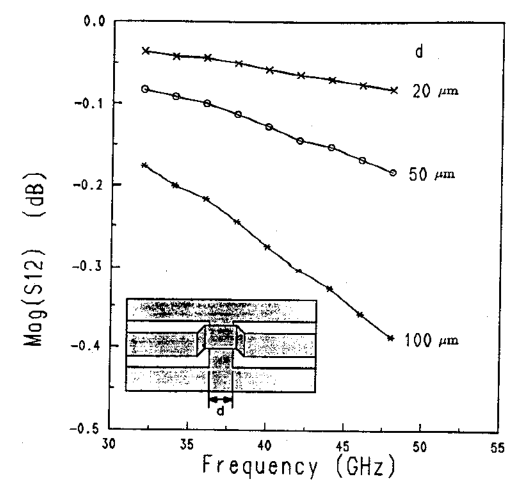


Figure 6: Mag(S_{12}) for the coupled open-end CPWs discontinuity with an air-bridge of height 3 μm.

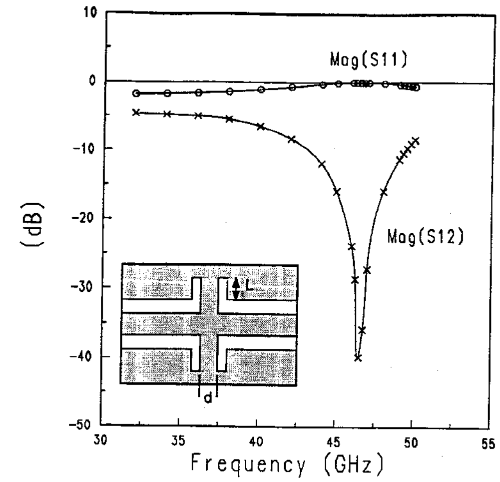


Figure 7: Scattering parameters of a shorted-end shunt CPW stub without air-bridges, L=550 μm, d=20 μm.

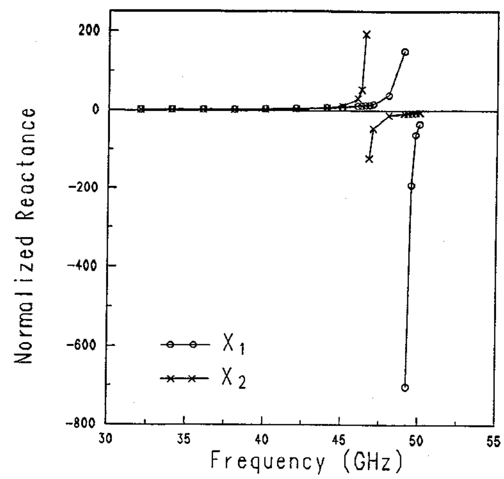


Figure 8: Series and shunt reactances for a shorted-end shunt CPW stub without air-bridges, L=550 μm, d=20 μm.

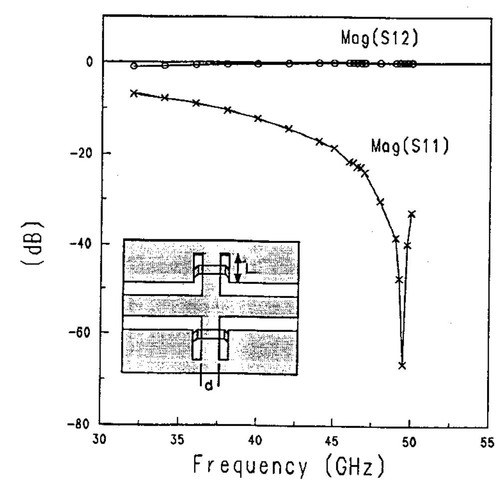


Figure 9: Scattering parameters of a shorted-end shunt CPW stub with air-bridges, L=550 μm, d=20 μm.