RESONANT PHENOMENA IN CONDUCTOR-BACKED COPLANAR WAVEGUIDE(CBCPW)

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Abstract

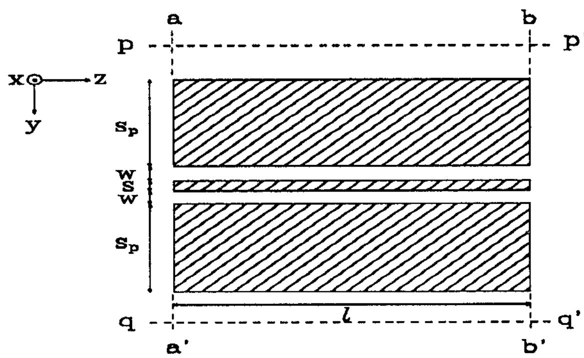
The resonant phenomena found in CBCPW integrated through line are investigated in details both experimentally and theoretically. Two CBCPW through-line test circuits are built and tested. One has uniform side planes and the other contains two slits in the middle of side planes. Three techniques are applied to investigate the resonant phenomena, namely, the patch antenna cavity model, the multi-mode model, and the full-wave space-domain integral equation approach. The measured transmission($|S_{21}|$) and reflection($|S_{11}|$) characteristics of the through lines are reported. At a representative resonant frequency of the measured data, the electric current distributions are displayed to demonstrate the fact that the side planes of the CBCPW contribute to the resonance in a way similar to planar patch antenna or two-dimensional planar circuits.

I. Introduction

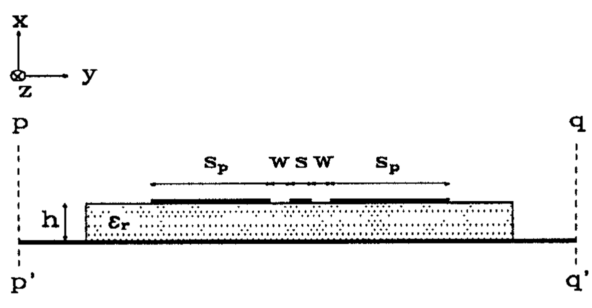
While the coplanar waveguide (CPW) and its variants such as CBCPW and uniplanar technology are increasingly popular[1,2], the overmoded and leaky modes propagation characteristics associated with CPW circuit have been under rigorous investigation recently [3-6]. In practice, the suppression of the undesired propagation modes, namely, the coupled slot-line mode and microstrip-like mode, is often necessary when broadband performance is desired [2,6]. Quite often the CPW transmission and return loss characteristics exhibit ripples or in a more specific term, resonances, in the S-parameter measurements [5,6].

In this paper, for the first time, we will present a viewpoint that the side planes of the CPW circuits contribute to the resonance in a way similar to the two-dimensional planar circuit or patch antenna [7]. In other words, the side planes act like two-dimensional resonators. Two examples shown in Figures 1 and 2 are employed to illustrate our viewpoint both theoretically and experimentally.

Parts (a) and (b) of Fig.1 are the top and front views of the CBCPW through line. The reference planes a-a' and b-b' are two



(a)



(b)

Fig.1 The 50 Ω CBCPW through line with l/s_p=3.0. The physical dimensions are s=w=0.508mm, s_p=6.0mm, and l=18.0mm. The material parameters are: ϵ_r=10.2 and h=0.635mm.

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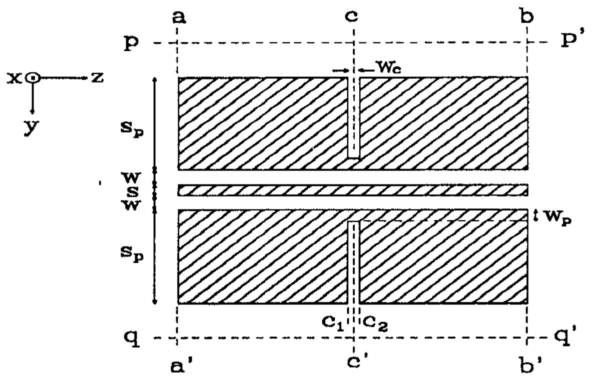

Fig.2 The same 50 Ω CBCPW through line as that shown in Fig. 1, except that two slits exist in the side planes. $w_c = 1.016$mm and $w_p = 1.00$mm.

vertical conducting planes with two small holes allowing external connections to the Cascade MTF-26 test fixture. Fig.2 incorporates the same 50Ω CBCPW through line as shown in Fig.1 except that the side planes have two slits along c-c' of width w_c.

If only the CPW mode were excited, the transmission and reflection characteristics of the two CBCPW through lines shown in Fig.1 and Fig.2 should exhibit almost identical responses. In practice, however, they are very different. The explanation for this will be discussed in later sections of this paper.

II. Method of Analysis: A full-wave Space-Domain Integral Equation Approach Using Mixed Potential Eigenfunction Expansion Technique

In contrast to the conventional full-wave formulations for CPW analyses, where the unknown variables for the Green's function are the slot electric field components, a new formulation using the conductor strip current components as unknowns is adopted. The Green's function of the new approach is a direct result of extending the mixed potential mode-matching method described in [8] by assuming the metal strips are infinitely thin perfect conductors. Referring to Fig.1, the TE-to-y and TM-to-y Hertzian potentials are employed to obtain the y-directed eigenfunctions in the non-layered region. All those layered regions, not shown in Fig.1 and Fig.2, incorporate TE-to-x and TM-to-x Hertzian potentials. Interested readers would refer to [8] fo. details.

III. The Observed Resonances in Scattering (S)-Parameters Measurements and Their Modes of Resonances

Two CBCPW circuits as shown in Fig. 1 and Fig. 2 had been built and tested. The side planes of the two through lines at a-a' and b-b' are grounded by wrapping copper foils alongside the substrate vertical planes. The measured S-parameters of the test circuits corresponding to Fig. 1 and Fig. 2 are shown in Fig. 3 and Fig. 4, respectively. Up to 7 resonant peaks (dips) for S_{11}(S_{21}) are seen in both figures for 1-to-12 GHz frequency span.

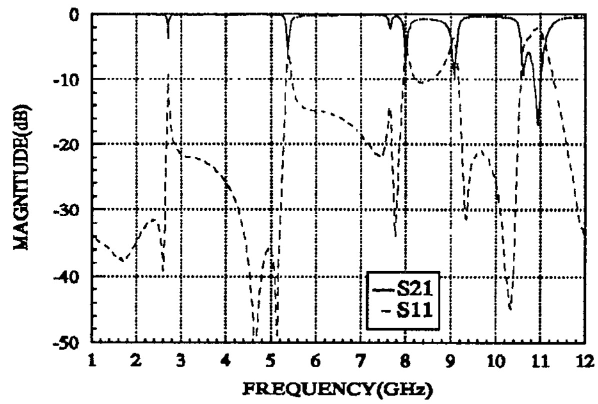

Fig.3 The measured characteristics of the CBCPW through line shown in Fig. 1.

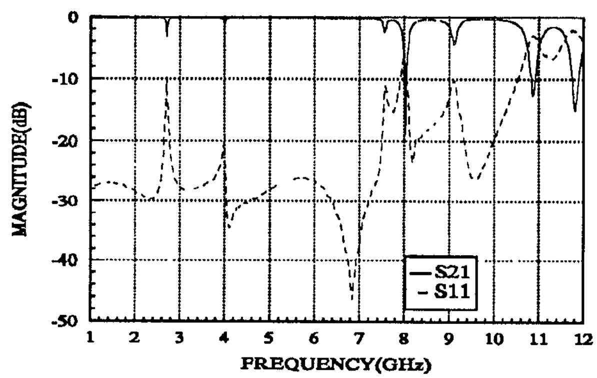

Fig.4 The measured characteristics of the CBCPW through line shown in Fig. 2.

Comparing the resonant positions of Fig. 3 and Fig. 4, the two slits existing in the CBCPW through line do have certain influence on their relative positions of resonance. The first resonant point at 2.71 GHz is not affected by the slits at the center of the side planes. The second resonance, however, is shifted dramatically from 5.38 GHz to 4.00

GHz by the slits in the side planes of Fig. 2.

It is already well-known in [6] that the resonances will occur in the form of extra higher-order mode, i.e. the MSL (microstrip-like) mode, in a CBCPW through line which has narrow-width side planes. In our test circuits shown in Fig. 1 and Fig. 2, however, the l/s_p ratio is 3 to 1. The number of extra higher-order modes is more than one when frequency is below 12 GHz. This corresponds to extending our view of the one-dimensional resonance in [6] to the two-dimensional one in the present study. The simple patch antenna model[7] does give correct number of resonances and predicts where the resonance should occur with good accuracy. Limited by the space, the details of these calculation will be presented in other form.

The method employing the MSL modes described in [6] for finding the resonant frequencies was also applied here and good agreements between theory and measurement are obtained for the case of Fig.1. The third technique employing the full-wave approach described in Section II aims at obtaining the current distributions on the conductor strips at both resonant and through states, which enable us to understand how resonances occur at various frequencies. The following Section IV will elaborate upon this.

IV. Visual Representation of Resonant Phenomena by Displaying the Current Distribution on the Conductor Strips of CBCPW

Employing the rigorous 3-D full-wave technique described in Section II, we calculate the resonant frequencies of structures shown in Fig.1 and Fig.2. In the case of structure shown in Fig.1, the results obtained by the 3-D analyses are very close to those obtained by the multi-mode model. And they altogether are very close to the measured values. The resonant frequencies obtained by measurements and theory differ by less than 4%.

With the aid of the full-wave 3-D program, the current distributions on the central signal line and side planes can be obtained. Parts (a) and (b) of Fig.5 plot the J_z and J_y components on the metal strips of Fig.2 tested at 2.000 GHz which represents a through state. Because of even symmetry, a magnetic wall exists at y=10mm, i.e. the center of the

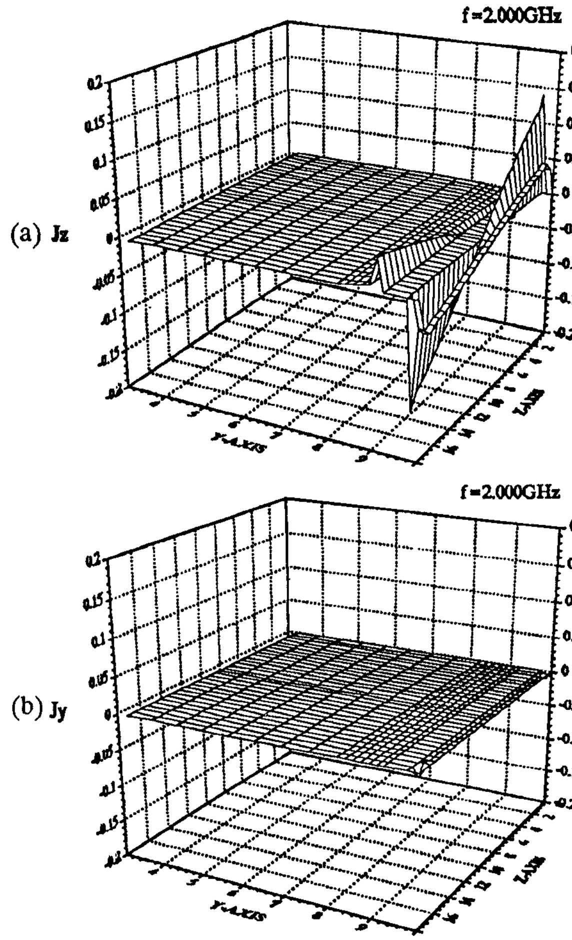

Fig.5 ***Through***(nonresonant) state at f=2.000GHz.
(a) J_z longitudinal current distribution
(b) J_y transverse current distribution

signal strip. As shown in Fig.5, the current distributions concentrate on the central signal lines($9.746 \leq y \leq 10$) and only a fraction of currents reside on the edge of the side plane. A singular current distribution at the edge of the signal conductor is observed. Furthermore the opposing edges of the central signal line and the side plane show out-of-phase current distributions. All of these characteristics just discussed suggest that the through state at 2.000 GHz indeed operates at CPW mode having measured return loss greater than 28 dB shown in Fig.4. Thus the slits have negligible influence on the through line when it operates predominately at CPW mode. On the contrary, for example, the first resonance occurs at 2.823 GHz, and most electromagnetic energy is carried by the side planes in the form of microstirp-like(MSL) mode as seen in parts (a) and (b) of Fig.6, where most curr-

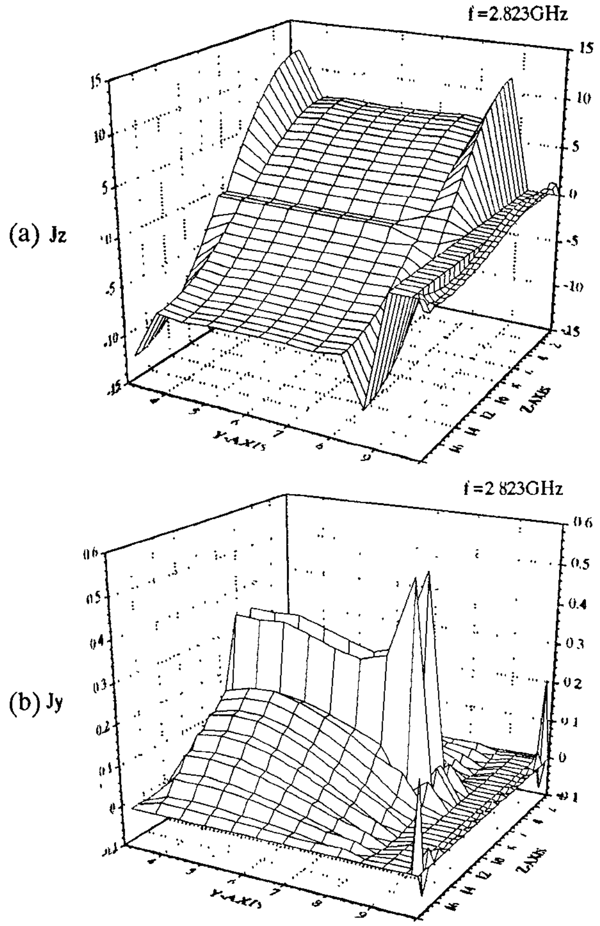

Fig.6 ***Resonant*** state at f=2.823GHz.
(a) J_z longitudinal current distribution
(b) J_y transverse current distribution

ents distribute in the side plane. When resonance occurs, the MSL mode dominates and results in significant transmission loss as observed in the through-line measurement. Note that the small slits can not stop the resonance.

V. Conclusion

The resonant phenomena in CBCPW through-line circuits are investigated both experimentally and theoretically. The patch antenna model and the multi-mode model are applied to help understanding the origin of resonances existing in the two proposed test circuits shown in Figs.1 and 2. A rigorous three-dimensional full-wave space-domain integral equation technique is invoked to help visualizing the current distributions in both through and resonant states of the CBCPW test circuits. The results thus obtained validate the conclusions drawn by the patch antenna model and the multi-mode model. Unless some means of suppressing the resonant phenomena are exercised, the CBCPW MMIC or hybrid MIC could experience certain forms of resonances and they should be designed with extreme cautions for broadband applications.

Acknowledgement

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