EXCITATION OF THE PARASITIC PARALLEL-PLATE LINE MODE AT COPLANAR DISCONTINUITIES

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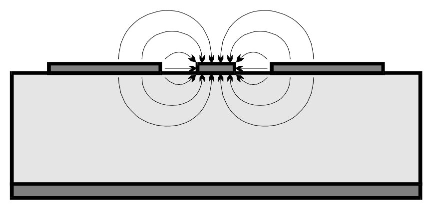
ABSTRACT

The excitation of the parasitic parallel-plate line mode at conductor-backed coplanar MMIC discontinuities and package feed-throughs is analyzed. The basic mechanism is investigated and a simplified description is presented. The model is validated by comparison to 3D Finite-Difference results.

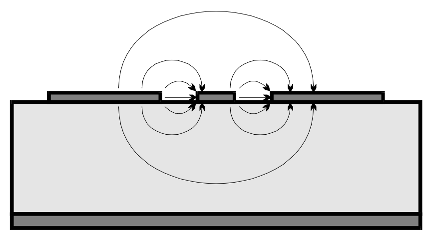
INTRODUCTION

Coplanar waveguides (CPW) are used in monolithic microwave integrated circuits (MMICs) more and more, since this transmission-line concept allows to circumvent costly backside processing and offers low-dispersive mm-wave properties.

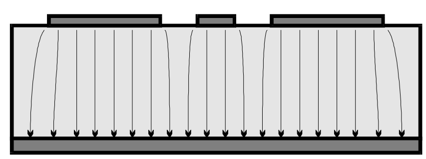
Such MMICs do not require backside metallization. In most practical applications, however, a metallic plane on the substrate backside exists formed, for instance, by the chuck of the wafer-prober station or the bottom plane of the package. This conductor-backed coplanar geometry may cause strange effects since an additional fundamental mode, the parallel-plate line mode (PPL, see Fig. 1c), appears. It has the same symmetry as the CPW mode and, therefore, cannot be suppressed by air bridges. As illustrated by Fig. 1 this PPL mode is closely related to the voltage difference between the ground conductors on top of the substrate and on the backside.



a) coplanar mode (CPW)



b) slot-line mode



c) parallel-plate line mode (PPL)

Fig. 1: The 3 fundamental modes supported by a conductor-backed coplanar waveguide.

A particular disadvantage of the PPL mode is that undesired coupling between different parts of a circuit becomes possible [1]. So far, quantitative results on this coupling can be predicted only by computationally expensive 3D field simulations. For circuit design, however, it would be highly desirable to have faster tools at hand that are capable of determining the coupling coefficients.

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In this paper, a new simplified model describing the coupling between the coplanar mode and the parallel-plate line mode is presented. The formulation meets the requirements of practical circuit design. Additionally, it helps in understanding the phenomena and in assessing the influence of the different parameters.

Generally, power from the coplanar mode can be transferred to the parallel-plate line mode by two different effects: the leakage effect [2,3] and coupling between the modes at discontinuities. Since the leakage phenomena occur only for laterally open structures, this paper concentrates on the mode-coupling issue.

THE BASIC EFFECT

In order to demonstrate significance of the parasitic mode coupling, a coax-to-CPW wall feedthrough is studied (see Fig. 2). A CPW circuit consisting of two stubs is packaged and connected to coaxial lines at two opposite ports. The substrate is 254µm thick Al_2O_3. The structure is analyzed by means of a 3D Finite-Difference method in the frequency domain (FDFD) [4].

Ideally, the transmission between the CPW stubs should be zero. The results in Fig. 3, however, show that resonance peaks above -5dB occur already at frequencies below 30 GHz. This cannot be tolerated in practical circuit design. The peaks can be explained by half-wavelength resonances of the parallel-plate line mode that propagates within the substrate independently of the metallization structure on the substrate surface. Thus, a parasitic path exists between the otherwise isolated ports.

In Fig. 3, also the effect of using a low-permittivity Teflon slab below the substrate is studied. Although such a transmission-line structure is non-leaky (see [2,3]), severe coupling is observed. This emphasizes the importance of the parasitic parallel-plate line mode.

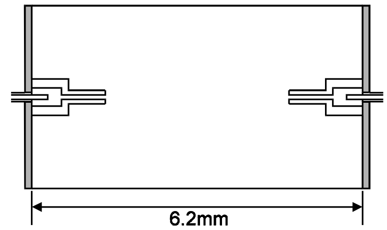

Fig. 2: Test structure with 2 coax-to-CPW transitions and CPW short stubs on Al_2O_3 substrate (top view).

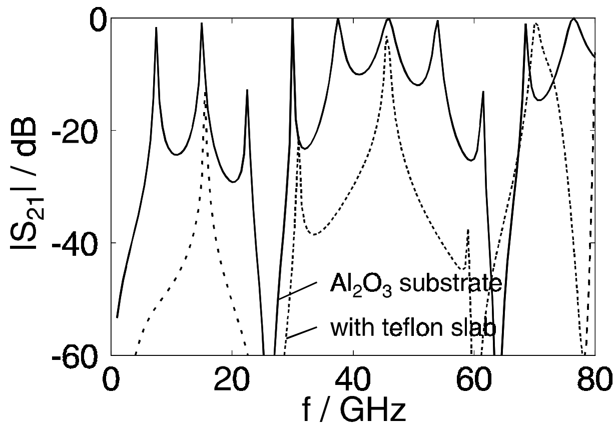

Fig. 3: Transmission coefficient S_{21} between the two coaxial ports as a function of frequency (FDFD simulation); results for structure of Fig. 2 on 254µm Al_2O_3 substrate and with an additional 2 mm thick Teflon slab below the substrate.

THE NEW MODEL

In the following, the open circuit as shown in Fig. 4 is used as an example to explain the theory describing the mode coupling. The structure under investigation consists of the transition between a conductor-backed coplanar waveguide with finite ground planes (port A) and a microstrip-like transmission line (port B). Assuming a symmetric structure the slot-line mode (see Fig. 1b) is not excited and, thus, can be neglected.

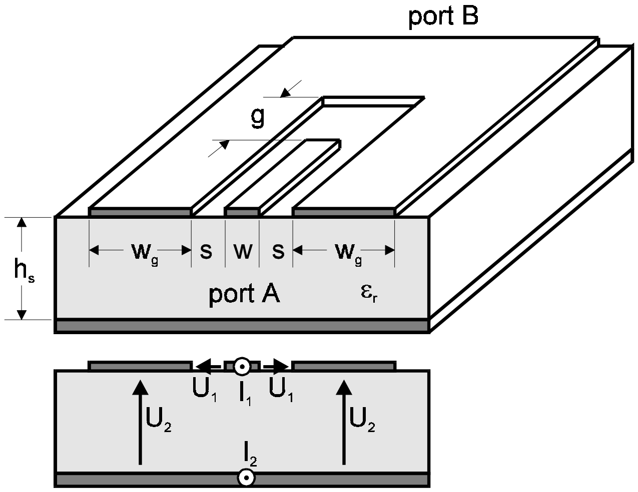

Fig. 4: Open stub of a conductor-backed CPW with finite ground metallizations and the conductor-voltage and current definition at port A (the dimensions are w = 20µm, s=15µm, w_g=95...215µm and thus b= w+2s+2w_g=240...480µm, h_s=80...200µm, g=50µm, GaAs substrate: ε_r=12.9).

Each of the two different fundamental modes, which are supported by the conductor-backed coplanar transmission line structure with finite ground metallizations (port A), can be described by a set of conductor voltages (U_1, U_2) and currents (I_1, I_2). Applying the definitions given in Fig. 4 one has for the coplanar mode:

$$\frac{U_{2,CPW}}{U_{1,CPW}} = C_U \quad , \quad \frac{I_{2,CPW}}{I_{1,CPW}} = C_I \quad \text{and} \quad \frac{U_{1,CPW}}{I_{1,CPW}} = Z_{CPW} \tag{1}$$

The parasitic parallel-plate line mode (PPL), which can be interpreted also as a microstrip mode, is described as follows:

$$\frac{U_{1,PPL}}{U_{2,PPL}} = \text{-}M_U \quad , \quad \frac{I_{1,PPL}}{I_{2,PPL}} = \text{-}M_I \quad \text{and} \quad \frac{U_{2,PPL}}{I_{2,PPL}} = Z_{PPL} \tag{2}$$

Z_{CPW} and Z_{PPL} denote the characteristic impedances of the CPW and the parallel-plate line mode, respectively. At port B, the characteristic impedance Z_{MS} of the microstrip transmission line is defined in the common way.

It is interesting to note that using the definitions given in (1) and (2) one finds that under quasi-TEM conditions the coefficients C_U, C_I, M_U and M_I must satisfy the following equations:

$$C_U = M_I \quad \text{and} \quad C_I = M_U \tag{3}$$

This condition also ensures mode orthogonality (and in lossless systems: power orthogonality) between CPW and PPL mode in the voltage-current formulation according to eqns.(1) and (2).

Now, coupling between the CPW mode and the parasitic parallel-plate line mode can be calculated by satisfying the current and voltage continuity at the discontinuity. Since reactive elements are neglected, this approach yields only the first-order approximation in frequency, which suffices for many purposes. In the case of an open circuit, the amount of power coupling (K_{PPL}) from the CPW to the parasitic mode can be approximated by (4).

$$K_{PPL} = \frac{4a}{(1+a)^2} \quad \text{with}$$
$$a = \frac{Z_{CPW}}{Z_{MS}} \cdot \frac{C_U}{C_I + \frac{1}{C_U} \cdot \left(1 + \frac{Z_{PPL}}{Z_{MS}}\right)} \tag{4}$$

Similar formulas can be derived for short circuits, via holes, air bridges, the CPW-to-coax feedthrough of Fig. 2, transitions between CPW and microstrip, etc. Thus, knowing the voltage and current distribution of the coplanar mode in a longitudinally homogeneous conductor-backed coplanar waveguide configuration, one can directly calculate the power transferred from the CPW mode to the parallel-plate line mode for different types of discontinuities.

VALIDATION AND RESULTS

In order to demonstrate the capabilities of the simplified theory, PPL excitation at the open stub in Fig. 4 was analyzed by a full-wave Finite-Difference method in frequency domain [4,5] and compared to the new approach. Fig. 5 provides the results: The power transferred from the incident CPW mode to the parallel-plate line mode (PPL) is plotted versus substrate thickness h_s for different ground metallization widths ($b = w+2s+2w_g$, see also Fig. 4). The coefficients C_U and C_I in (4) are calculated from the CPW cross-section by the mode-matching technique.

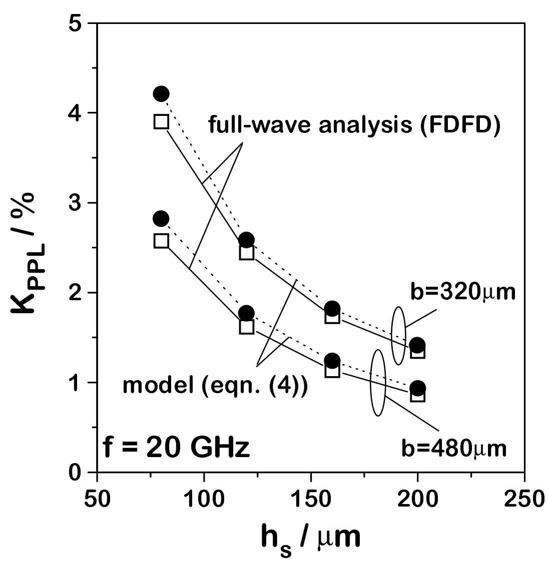

Fig. 5 Power transferred from coplanar mode to parallel-plate line mode (PPL) versus substrate thickness (h_s) for the open circuit shown in Fig. 4.
—□—: Finite-Difference method (f=20 GHz)
····●···· : Model derived from simplified theory (see equation (4)).

Excellent agreement between eqn. (4) and the full-wave results can be observed, which proves the validity of the simplified description.

CONCLUSIONS

A new model is proposed describing the coupling of the CPW mode with the parasitic parallel-plate line mode in conductor-backed coplanar circuits. The simplified approach requires only 2D data of the CPW cross-section. It provides a fast method to predict the coupling quantitatively, and it improves understanding of the coupling phenomena. The novel description can be applied to a variety of coplanar MMIC discontinuities and packaging problems.

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