A SYSTEMATIC INVESTIGATION OF COPLANAR LINES AND DISCONTINUITIES

W. Menzel, M. Klaiber

Microwave Techniques, University of Ulm, D-89069 Ulm, Germany

ABSTRACT

A systematic investigation of coplanar lines is presented with respect to, on the one hand, different computation methods, and on the other hand, different effects like passivation layer, metallisation thickness, and skin effect. For the computation of the transmission line parameters of coplanar lines on MMICs, as a result, methods including the metallisation thickness have to be chosen. For low frequencies, skin effect plays an important role, for higher frequencies (> 80 GHz), only the losses due to the skin effect have to be taken into account. Furthermore, some discontinuities - shunt and series capacitances and T-junctions - are investigated, too, resulting in partly new approaches for equivalent circuits suitable for CAD systems.

INTRODUCTION

Coplanar lines have gained increasing interest due to their uniplanar properties and the lack of vias, backside processing and (mostly) substrate thinning. A great number of references, e. g. [1] - [6], are dealing with the design of transmission lines and discontinuities. This work was intended to point out clearly the potentials of different computation methods as well as the effects of passivation, metallisation thickness and skin effect. On the other hand, some selected discontinuities including all these effects were investigated, trying to achieve accurate, but easy to handle equivalent circuits.

TRANSMISSION LINES

The coplanar transmission line of interest in this paper is realized on 0.45 mm thick InP (ε_r = 12.61; GaAs or Si could be handled equally), has a 200 nm thick passivation layer of Si_3N_4, a metallisation thickness of 3 µm, a center conductor width of 20 µm, and a slot width of 17 µm (see Fig. 1 a). Modified transmission line geometries have been investigated equally, resulting in rather similar performance as will be demonstrated here for the (ca.) 50 Ω lines. For the selected computation methods, different simplifications had to be introduced as it is shown in Fig. 1 b - c. For the spectral domain calculation, an infinitely thin metallisation was chosen ([7], Fig. 1c), for a conventional mode matching analysis, a relative complex structure as given in ([8], Fig. 1b) can be regarded, while some idealization is necessary for the mode matching calculation including the skin effect ([6], Fig. 1d). Fig. 2 gives the real part of the effective dielectric constant for these methods. Due to the neglected metallisation thickness, the results of the spectral domain method are too high; at low frequencies the computed values including conductor losses (skin effect) are increased compared to the other curves, while for higher frequencies, both mode matching calculations get close together.

DISCONTINUITIES

As discontinuities, shunt and series capacitances and a T-junction [5] have been chosen as examples, Fig. 3. The included airbridges were calculated without conductor losses [8] as they are very short and have an airbridge height of 4µm being much larger than the thickness of the passivation layer. The thin film transmission lines in the interior of the structures, on the other hand, have a dielectric height of only 200 nm and therefore must include this effect [6].

I. Shunt capacitance

This type of capacitor mainly is used as an RF block capacitance in the bias supply of MMICs and consists of a section of transmission line separated from a ground plane by a very thin dielectric layer (passivation layer of Si_3N_4). Due to this configuration, the performance of the shunt capacitance is strongly influence by the skin effect. In the example given here, a line width of the capacitor region equal to the connecting transmission lines (20 µm) and a capacitor length of 120 µm were chosen, resulting in a static capacitance of 800 fF. Its transmission behavior modeled under different assumptions - an ideal shunt capacitance (dotted line) and a full-wave model (solid line) - is plotted in Fig. 5 compared to the results of an equivalent circuit according to Fig 4. In this model, the airbridges are represented by an equivalent capacitance (36 fF) and an inductance (10 pH) each, the thin film capacitance itself by a parallel plate transmission line. Such an ideal parallel plate line can be modeled analytically including the skin effect; thus a very short computation time for a CAD system is achieved. The results of this equivalent circuit are plotted in Fig. 5 with the dot-dashed line; the result hardly differs from the full wave solution and nearly can not be distinguished from the solid line of the full wave result.

II. Series capacitance

The series capacitance typically is used as a DC block or as a matching element; it partly has some geometrical similarity compared to the shunt capacitance, but its performance is completely different. Basically, two modes can propagate in the capacitor element, however, the coplanar mode is dominating in the thin film structure. The chosen equivalent circuit for the series capacitor is displayed in Fig. 6, and computational results of an ideal series capacitance, of the field theoretical approach, and of the equivalent circuit are given in Fig. 7. For the return loss, there is some difference between full-wave calculation and equivalent circuit results, but this occurs at rather low levels having a limited influence on the overall circuit performance. In this case, the capacitor area once again was 20 µm by 120 µm, resulting, as before, in a static capacitance of 800 fF, and the airbridge height was 4 µm. The equivalent circuit element values result in R = 2 Ω and L = 0.12 pH.

III. T-junction

The T-junction according to Fig. 3 (line widths 20 µm, slot widths 17 µm, airbridge height 4 µm) basically shows a nearly perfect performance over the complete frequency range of investigation; the full wave characterization as well as a computation based on an equivalent circuit [consisting of series inductances in the three branches (14.1 pH in the straight arms, 12.6 pH in the orthogonal arm), and a shunt capacitance (14.7 fF) in the center of the junction] are nearly constant and identical over the investigated frequency range (Fig. 8).

CONCLUSION

The presented investigations show:

- For the computation of the transmission line parameters of coplanar lines on MMICs, methods including the metallisation thickness and the passivation layer have to be chosen.
- For low frequencies, skin effect plays an important role, for higher frequencies (> 80 GHz), only the losses due to the skin effect have to be taken into account.
- Among the selected discontinuities, skin effect plays an important role for the shunt capacitance.
- Equivalent circuits for all three discontinuities have been proposed.

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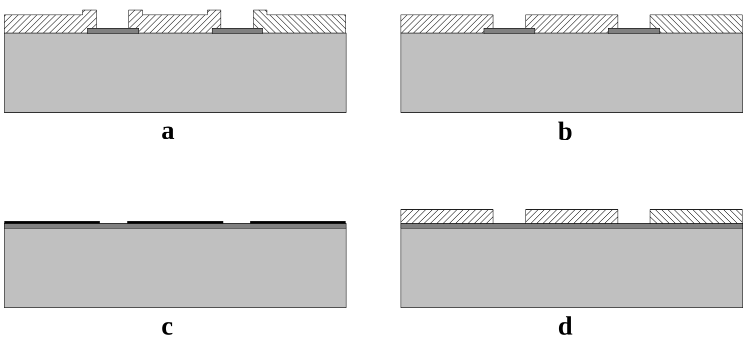

Fig. 1: Basic structure (a) and modifications for calculations with the spectral domain method (c), conventional mode matching technique (b) and mode matching technique including conductor losses(d).

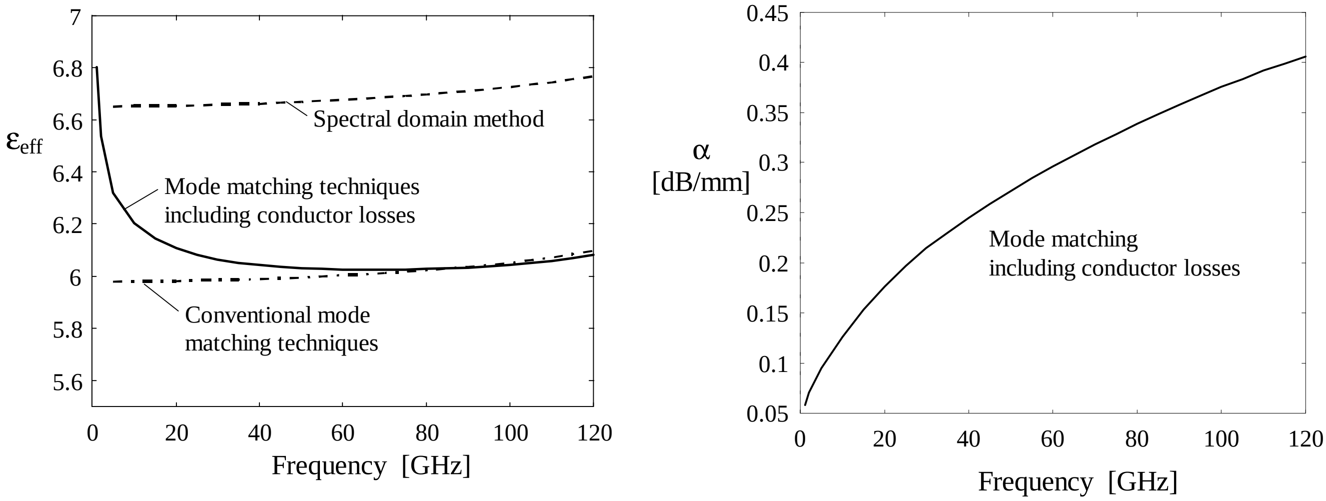

Fig. 2: Effective dielectric constants for the different calculation methods and attenuation coefficient (for skin effect calculations only)

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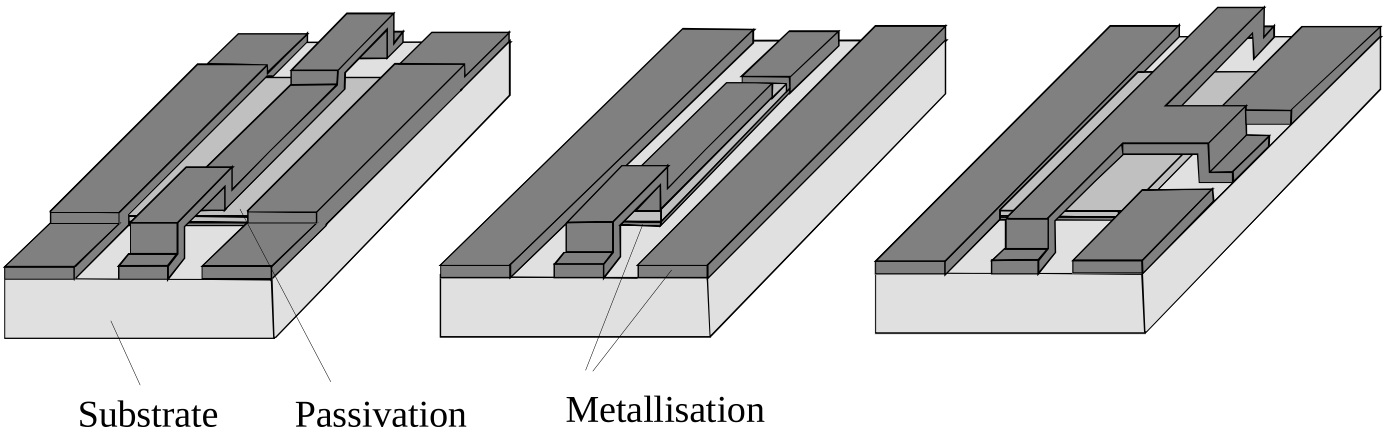

Fig. 3: Basic structures for shunt capacitance, series capacitance, and T-junction.

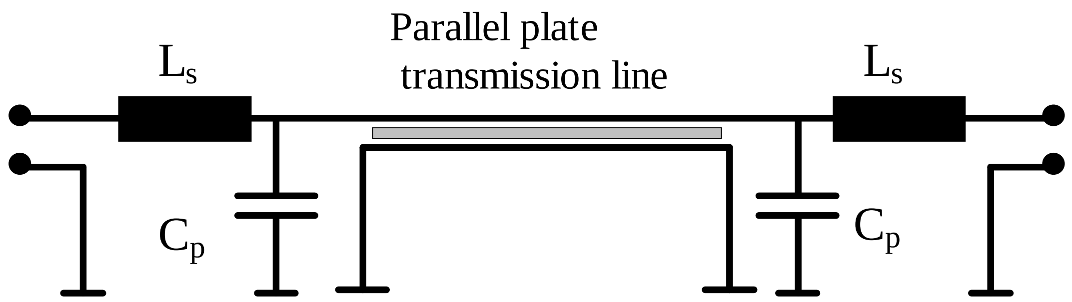

Fig. 4: Equivalent circuit for shunt capacitance.

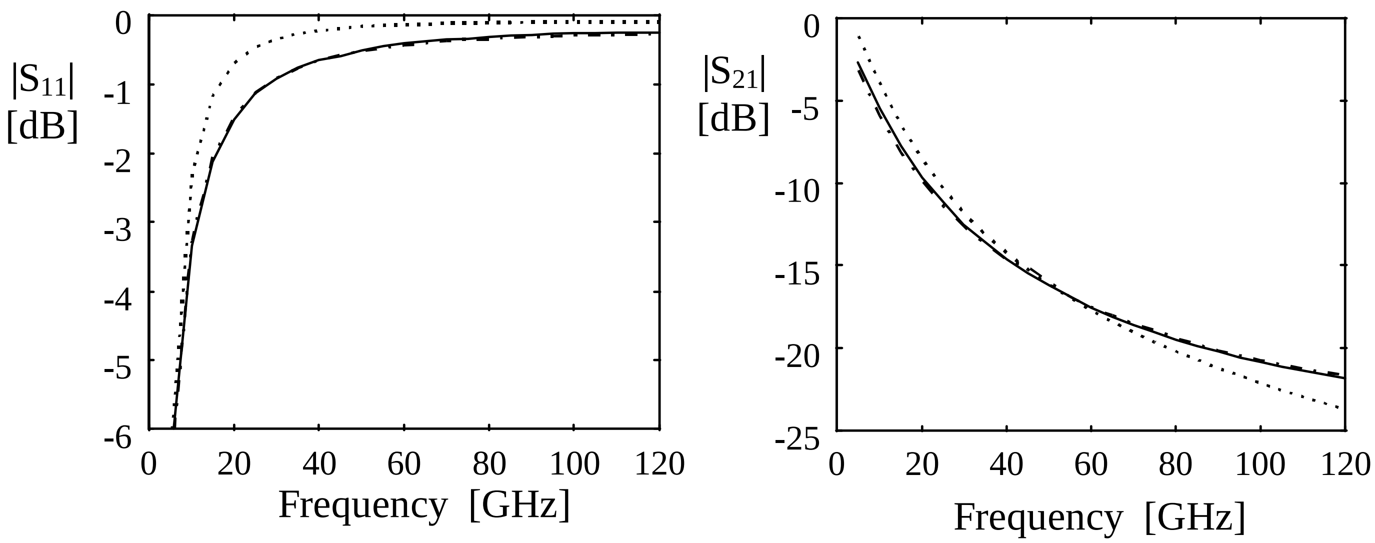

Fig. 5: Transmission properties of shunt capacitance (— Full-wave calculation, ... discrete concentrated capacitance, - ˙ - ˙ - equivalent circuit).

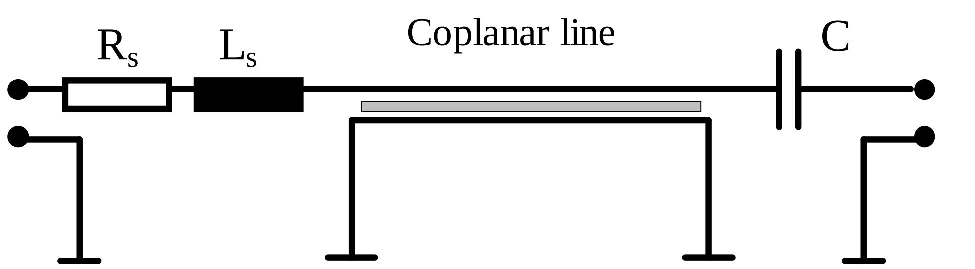

Fig. 6: Equivalent circuit for series capacitance

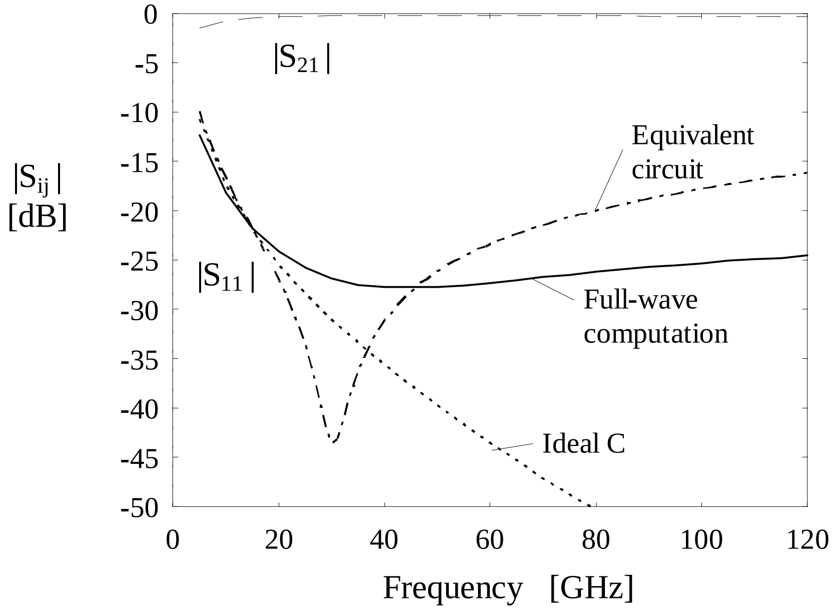

Fig. 7: Return and insertion loss of ideal capacitance, full-wave calculation and equivalent circuit of series capacitance.

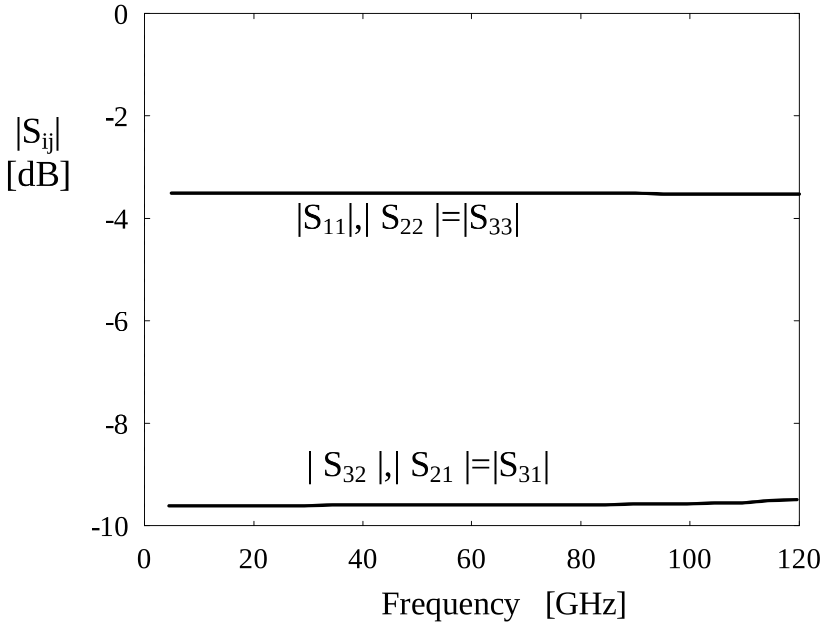

Fig. 8: S-parameters of the coplanar T-junction.