FINITE-DIFFERENCE ANALYSIS OF OPEN AND SHORT CIRCUITS IN COPLANAR MMIC'S INCLUDING FINITE METALLIZATION THICKNESS AND MODE CONVERSION

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ABSTRACT

Open and short circuits as used in MMIC's are investigated by means of a Finite-Difference method in the frequency domain. Both mode conversion and finite metallization thickness are accounted for. For the open stub, noticeable mode conversion is observed whereas the short circuit behaviour shows a significant dependence on metallization thickness.

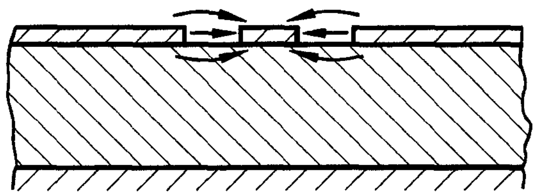
INTRODUCTION

For state-of-the-art MMIC's, the uniplanar concept becomes more and more important. In such circuits, the coplanar waveguide is used as basic transmission-line element, which provides some advantages compared to the conventional microstrip structures (see [1]). On the other hand, only few modelling tools are available for coplanar MMIC's and accurate descriptions of line discontinuities are still required, even for the simple open and short circuit. As well known, the following two points need special consideration when modelling CPW configurations:

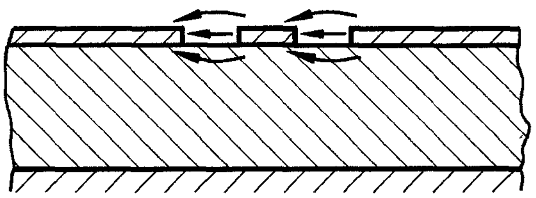
- The line parameters exhibit a significant dependence on metallization thickness t [2].
- Due to the backside metallization of the substrate and a floating potential of the ground metallizations two parasitic modes can be excited [3,4], the "slot-line" mode and the parallel-plate mode (see Fig. 1).

So far, only a few papers have been published investigating coplanar open and short circuits. Moreover, those investigations do not consider the typical miniaturized line geometries used in MMIC's [3,5] or they assume zero metallization thickness [6].

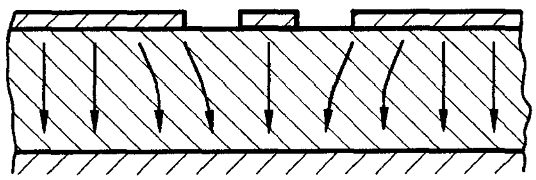
The original contributions of this paper are mainly that the influence of the metallization thickness is considered as well as the mode conversion from the coplanar mode into the parasitic parallel-plate mode. (Note that the slot-line mode is not excited here because of the symmetry.) Realistic MMIC dimensions are applied and thus the results provide useful information for the design of coplanar MMIC's.



coplanar mode



slot-line mode



parallel-plate mode

Fig. 1: The three fundamental modes

RESULTS

A three-dimensional Finite-Difference formulation in frequency domain [7] is used to derive the generalized scattering matrix. This requires waveguide ports to be defined. Regarding the parallel-plate mode, therefore, modes propagating in four directions are considered as illustrated by Fig. 2. The resulting scattering behaviour for the CPW mode is given in terms of the effective length extension l_{ext}. This quantity describes the capacitance and inductance due to the fringing fields at the open and short circuit by a length increase of the homogeneous coplanar waveguide.

The effective length extension l_{ext} can also be related to the transmission-line parameters in the following way:

$$l_{ext} = \begin{cases} \frac{C_o}{C'} & \text{for open circuits} \\ \frac{L_o}{L'} & \text{for short circuits} \end{cases} \quad (1)$$

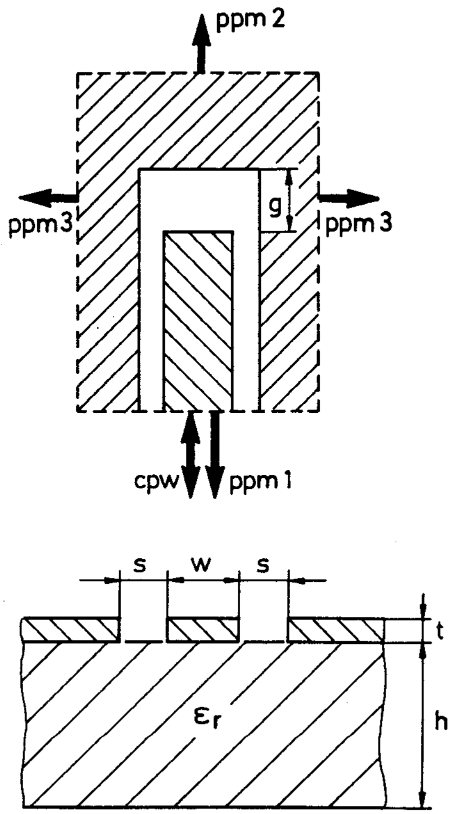


Fig. 2: The open and short-circuit structure and the different modes considered
($h = 200\mu m$, $\varepsilon_r = 12.9$, $w = 15\mu m$, $s = 10\mu m$, $g = 10\mu m$ and $40\mu m$ for open circuit, $g = 0$ for short circuit).

Where L' and C' represent the distributed line capacitance and inductance of the CPW ,while C_o and L_o denote the end capacitance of the open circuit and the end inductance of the short circuit, respectively. One should note that a variation of metallization thickness influences both the end reactance and the corresponding distributed line parameters.

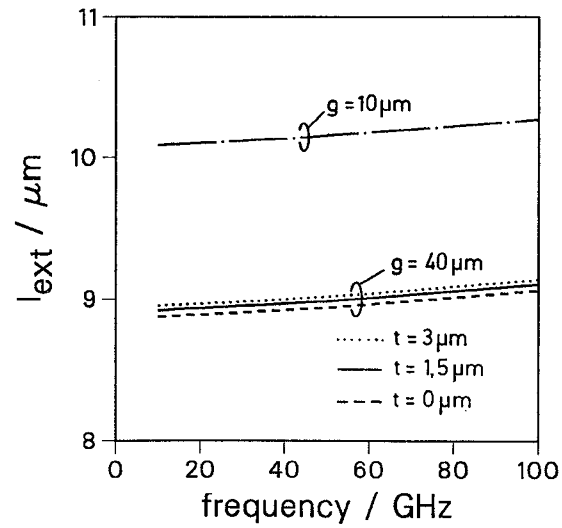


Fig. 3: Length extension l_{ext} of the open circuit against frequency
($g = 10\mu m$ and $40\mu m$, respectively, $t = 0 \ldots 3\mu m$, as specified).

OPEN CIRCUIT

Fig. 3 presents the frequency characteristics of l_{ext} for the open circuit. Two different values of spacing g (see Fig. 2) are studied as well as metallization thicknesses t in the range of $0 \ldots 3\mu m$. Due to the miniaturized cross-sectional dimensions of the structure dispersion remains negligible. Also, the variation due to metallization thickness is very small (see Fig. 4), because the end capacitance is dominated by the fields within the high-permittivity substrate.

Regarding mode conversion (see Fig. 5) one should mention, that about 1% of the power turns from the coplanar mode into the parallel-plate modes, also in the limit of zero frequency. This phenomenon can be explained by the existence of a backside metallization and the finite lateral dimensions of the CPW. Thus, one has an unsymmetric loading for the multi-mode system formed by the CPW and the parallel-plate mode.

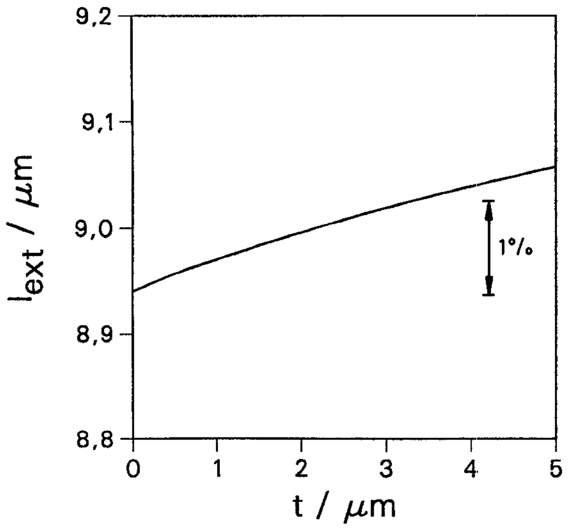


Fig. 4: Effective length extension l_{ext} of the open circuit against metallization thickness t (f = 50GHz, $g = 40\mu m$).

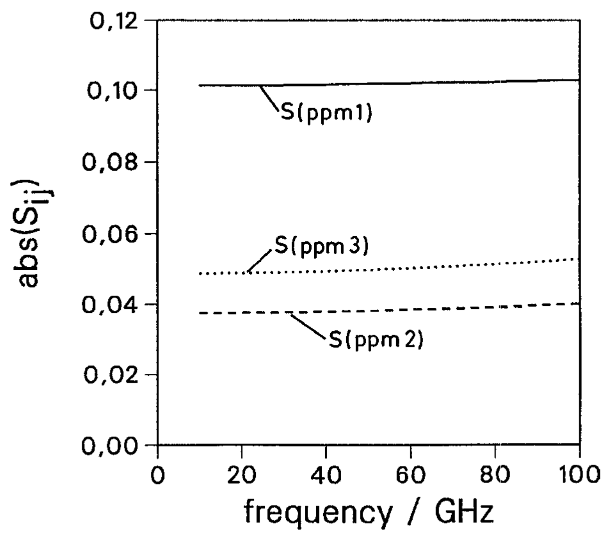


Fig. 5: Transmission coefficents $S(ppm1)$, $S(ppm2)$, $S(ppm3)$ of the CPW mode into the parallel-plate modes $ppm1$, $ppm2$, $ppm3$, respectively (open circuit, for definition of the modes see Fig. 2, $t = 3\mu m$).

SHORT CIRCUIT

In analogy to the open-circuit results, the length extension l_{ext} shows negligible dispersion within the frequency range up to $100GHz$. As demonstrated by Fig. 6, however, metallization thickness t influences l_{ext} significantly. Considering a $3\mu m$ thick metallization, for instance, the assumption $t = 0$ causes 27% error in l_{ext}.

It is interesting to note that, from the homogeneous transmission-line parameter L' one would expect l_{ext} to increase with growing thickness t. In Fig. 6, however, the oppesite behaviour is observed. One concludes that the end inductance L_o dominates the t dependence of l_{ext} and that it shows a substantial decrease when increasing t.

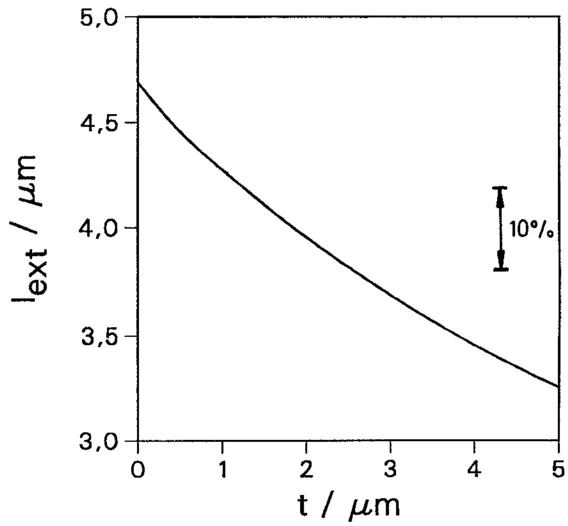


Fig. 6: Effective length extension l_{ext} of the short circuit against metallization thickness t (f = 50GHz).

Generally, the values of l_{ext} are smaller than those for the open circuit, i.e. the parasitic effects are less pronounced when using a short-circuit termination.

Fig. 7 presents information on the mode conversion of the short circuit. The absolute values for the excitation of the parallel-plate mode are substantially lower than in the open circuit case. Also, mode conversion vanishes for zero frequency due to the symmetrical loading in the corresponding equivalent-circuit model.

Furthermore, one observes a difference in the short and the open circuit characteristics regarding the transmission coefficients $S(ppm2)$ and $S(ppm3)$, which refer to the parallel-plate modes propagating into the grounded sections (see Fig. 2). In the open case, $S(ppm2)$ and $S(ppm3)$ assume similar values whereas in the short circuit case $S(ppm3)$ clearly exceeds $S(ppm2)$. This indicates that the short transmits more power to the sides than in forward direction. The open circuit, on the other hand, does not exhibit such a distinct direction in exciting parasitic modes. Further work is necessary to establish detailed theory on that characteristic.

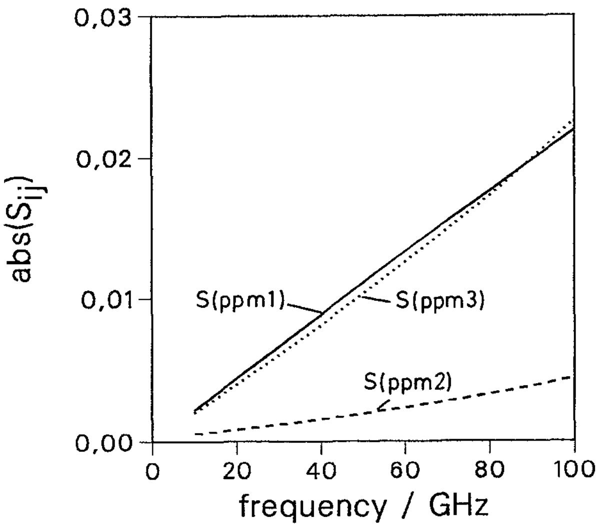


Fig. 7: Transmission coefficients $S(ppm1)$, $S(ppm2)$, $S(ppm3)$ of the CPW mode into the parallel-plate modes $ppm1$, $ppm2$, $ppm3$, respectively (short circuit, for definition of the modes see Fig. 2, $t = 3\mu m$).

CONCLUSIONS

The following conclusions can be drawn regarding modelling and application of coplanar open and short circuits in MMIC's:

- The short circuit appears to be the more favourable alternative because less parasitics are involved. Length extension l_{ext} as well as transmission to parasitic parallel-plate modes are smaller than for the open circuit.
- The properties of the short circuit depend significantly on metallization thickness t. Hence, modelling tools based on the assumption $t = 0$ become questionable. The resulting deviations are of the order of 10...30% for realistic thickness values t. Therefore, improved descriptions are to be developed.

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