SYSTEMATIC INVESTIGATION OF COPLANAR WAVEGUIDE MIC/MMIC STRUCTURES USING A UNIFIED STRIP/SLOT 3D ELECTROMAGNETIC SIMULATOR

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ABSTRACT

The electrical properties of coplanar waveguide MIC/MMIC structures like open and short end, gap, step, bend, tee and capacitor have been studied using an efficient, unified strip/slot 3D electromagnetic simulator. Parasitic slot mode excitation, the effects of air bridges and equivalent circuit representations are discussed for frequencies to 60 GHz and higher.

OVERVIEW

Very recently, coplanar waveguide (CPW) as a transmission line and circuit medium has impressively demonstrated once again its suitability for broadband mm-wave applications in a 5-100 GHz MMIC amplifier /1/. Since CPW was first proposed by C.P. Wen in 1969 /2/, its transmission line properties (characteristic impedance, effective dielectric constant and loss) have been described by a variety of approaches, analytical and numerical /2/-/5/. A detailed discussion of some of the advantages of coplanar waveguide as a microwave integrated circuit medium was first provided by Houdard in 1976 /6/. However, it appears that systematic efforts to the characterization of coplanar waveguide junctions and discontinuities for CAD have been relatively sparse during the last 15 years, for reasons which will be addressed in our presentation. As a result of this, the microwave CAD packages leading the market do not contain models for elementary CPW circuit structures required for accurate simulation in coplanar waveguide MIC/MMIC design. Only under the pressure of MMIC design requirements in the last few years and with the availability of modern ANAs, some equivalent circuit data for coplanar waveguide discontinuities became available meanwhile, see for example refs. /7/-/9/. Numerical approaches to this problem published so far include the static finite difference method /9/, the spectral domain full-wave technique in a shielded medium /10/ and a similar technique for open structures /11/, for example.

The paper presented here reports on a systematic investigation of coplanar waveguide open and short end, gap, 90° abrupt bend, 90° curved bend, T-junction and series interdigital capacitor with a view towards the CAD of CPW type MICs and MMICs high into the mm-wave region. For this purpose, a unified strip/slot 3D full-wave electromagnetic simulator /12/ has been applied after having passed an extensive test and verification phase. This simulator allows to numerically solve microstrip type and CPW type problems, both in terms of either current density or electric field on the substrate surface, depending on a user's choice, see ref. /13/ for the mathematical background. It is, however, not the scope of our contribution to describe the simulator /12/ in detail, this will be published elsewhere. The central topic of our paper is to summarize the results obtained in a recent unpublished study on CPW discontinuities and junctions /14/ and in related project work at Jansen Microwave, West Germany. An important part of the results and the discussion addresses the problem of parasitic slot mode excitation in nonsymmetrical CPW structures like bends and T-junctions. The numerical simulations presented are partially for CPW structures without airbridges and partially with airbridges. The respective comparisons shown demonstrate clearly the importance of properly suppressing the parasitic slot mode in CPW circuits. In this context, also, the physical background of why parasitic mode excitation in CPW type MICs is more severe than in microstrip MICs is outlined, and also complexity limitations for CPW type MICs/MMICs. Equivalent circuit representations for the various discontinuities are discussed along with typical model parameter values and the functional dependencies on geometrical parameters. Comparison with previously published measured and computed data will also be provided. Most of the data presented are for GaAs and alumina substrates with operating frequencies up to 60 GHz and in some cases higher.

The results generated for CPW structures, the CAD methodology used with the unified strip/slot 3D simulator and the physical insight provided represent a significant advance in the knowledge basis available today for CPW type MIC/MMIC design.

UNISIM 3D EM SIMULATOR

The UNISIM simulator /12/ used for the systematic investigation reported here is shown schematically in Fig. 1 below. From a mathematical point of view it represents a generalization and extension of the approaches reported in ref./16/. It has been written for configurations involving a maximum of up to 6 dielectric layers and allows to switch between an electric field integral representation of problems and a current density integral type formulation, i.e. the inverse problem representation. This duality is indicated in Fig. 1. Accordingly, UNISIM can handle strip type MIC/MMIC geometries with and without lateral ground planes involved as well as CPW-type MIC/MMIC configurations without and with airbridges. The latter case is abbreviated here as BCPW (bridged CPW). BCPW geometries are handled in the simulator by first generating a 2n-port representation including the dominant parasitic (odd) CPW mode and then reducing to a fundamental CPW n-port representation by applying suitable airbridge descriptions. This is a hybrid approach of taking the bridges into account which is efficient and gives insight into the parasitic mode physical phenomena. As indicated in Fig. 1 switching between current density and electric field representations is possible on all levels of the simulator. This allows to choose the most adequate and efficient type of em numerical algorithm for a given problem. A regular grid with intertwined rooftop functions is used for the representation of current density or electric field, respectively. Problems with complex geometry and up to 60000 rooftop functions have been handled on a HP9000/835 computer.

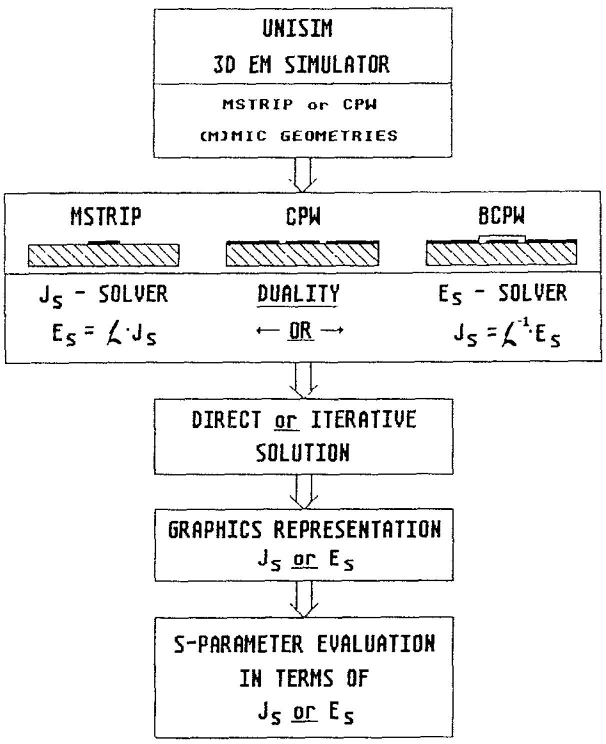

Fig. 1 Schematic of the unified strip/slot 3D em simulator

STUDY RESULTS AND DISCUSSION

In the limited space available here only a few representative results can be given. As a first class of structures, CPW discontinuities with a longitudinal symmetry axis are described in Table 1. This includes CPW short end, open end, gap and step in width. For these structures, excitation with the fundamental CPW mode does not lead to mode conversion into the parasitic odd mode (coupled slot mode). Therefore, the use of airbridges is not necessary. The equivalent circuit element values caracterising such symme-

short end (RP)	equiv. circuit (RP, L)	Substrate: GaAs s/w= 40μm/40μm; L=16pH s/w=160μm/40μm; L=50pH s/w= 40μm/160μm; L=19pH
open end (RP, g)	equiv. circuit (RP, C)	Substrate: GaAs g=s s/w= 20μm/20μm; C=2.1 fF s/w=20μm/160μm; C= 16 fF s/w=160μm/20μm; C=2.9 fF
gap (RP1 RP2, g, w2)	equiv. circuit (RP1, C1, RP2, C2, C3)	Substrate: GaAs g=80μm s1/w1 = 220μm/40μm s2/w2= 80μm/320μm C1= 7fF, C2= 0.2fF, C3=0.1fF
step (RP1=RP2, w2)	equiv. circuit (RP1, L1, L2, RP2, C)	Substrate: Alumina s2/w2 = 60μm/600μm s1/w1=240μm/240μm L2=3fH; L1,C negligible

Table 1 Typical equiv. circuit data for symmetric CPW discontinuities
Note: Slot width s = (d-w)/2

tric CPW discontinuities are relatively small as can be seen in Table 1 for a few selected geometries. They have been obtained by generating the respective equivalent circuits from the em numerical data using the modeling features of a commercial simulator /15/. The substrates used in Table 1 are 200µm GaAs and 635µm alumina, respectively, suspended one substrate thickness above ground.

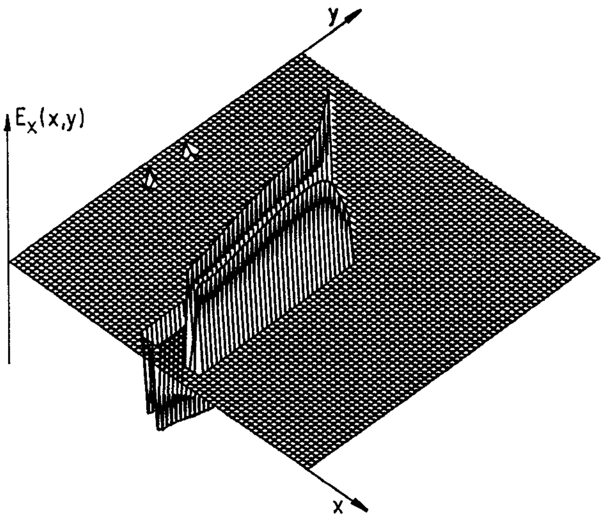

Fig. 2 Computed slot field distribution for a CPW 90° bend on 25 mil alumina suspended above ground f = 20 GHz, w/s = 180µm/90µm Only x-component of E is shown

As a first result for a CPW structure that includes parasitic mode excitation the field distribution of a 90^{o} is shown in Fig. 2. It can be clearly seen that the boundary conditions for E_x are satisfied in the bend region. E_x becomes singular at the external corner of the CPW inner conductor, which is properly approximated by the numerical solution. At the second port and feed line of the bend structure nothing is visible within the scale of Fig. 2, except a slight field disturbance created at the second port by the source distribution used. Note, that the sources themselves are not shown in Fig. 2. Since E_x is the longitudinal component on the second feed line, it is negligibly small there. Due to the small slot width of s = 90µm in Fig. 2, parasitic mode excitation is also small for this case.

A few further bend results are given in Fig. 3 including a curved 90^{o} structure with a mean radius curvature of r=100µm. The circular boundary of that structure has been approximated when using UNISIM by choosing a sufficiently fine grid and a stepped contour. The results shown are for a thick 500µm GaAs substrate with ground metallization on the bottom side. The CPW dimensions in Fig. 3 are w=20µm and s=15 µm. Related to the frequency range of Fig. 3, the slot dimensions are again small, so that the simulations with and without airbridges do not show much difference in the transmission phase, i.e. in the electrical length seen between the two reference planes RP1 and RP2. The mean length of the curved structure A is slightly smaller than that of the abrupt bend which can also be seen clearly. The interpretation is more complicated for the reflexion magnitudes shown in the top of Fig. 3, since this is not only caused by bend parasitic effects, but also effected by slight changes in the reference impedance chosen (here 50 Ohms). This will be discussed in more detail in the presentation.

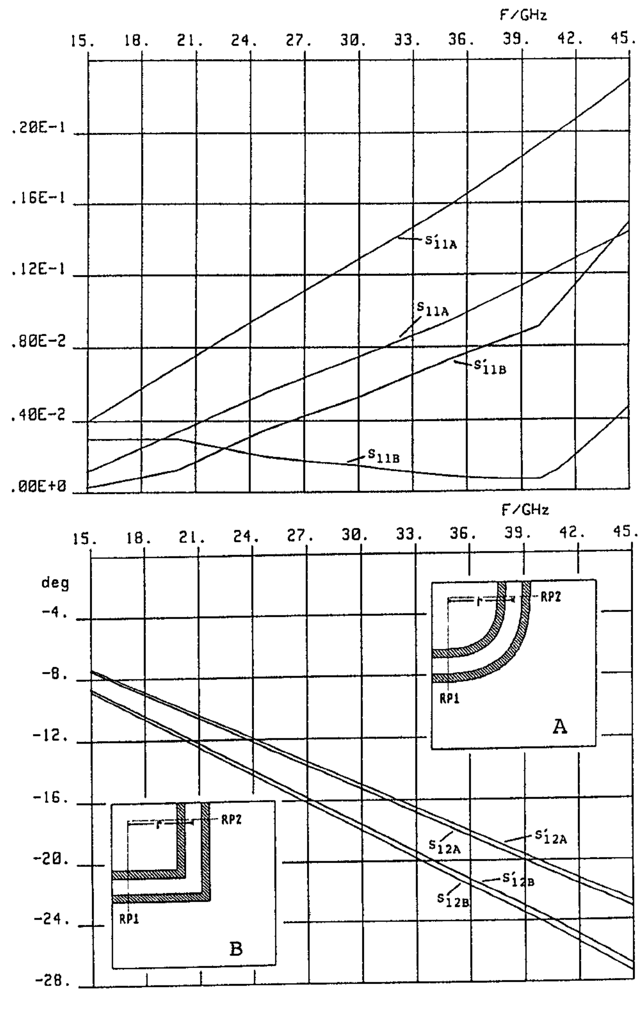

Fig. 3 CPW 90° structures on 500µm GaAs S-parameters without (S_{ij}) and with (S'_{ij}) airbridges in the reference planes
Top: Reflexion magnitudes
Bottom: Transmission phases

The S-parameters for a CPW T-junction with and without airbridges are given in Fig. 4 for a 200µm GaAs substrate in the frequency range of 5 to 55 GHz. The CPW feedline dimensions are s/w=80µm/80µm and the substrate is suspended above ground. Close to ideal electrical behaviour results for the T-junction with bridges. Due to parasitic slot mode excitation, the T-junction without bridges deviates from ideal performance already at quite low frequencies. The cut-off frequency of the parasitic mode for this computation is at 38 GHz and it is obvious that without bridges the T-junction would be useful only up to about 35 GHz. This stresses the need for proper grounding in CPW-type MICs/MMICs. Further details and results will be given in the presentation.

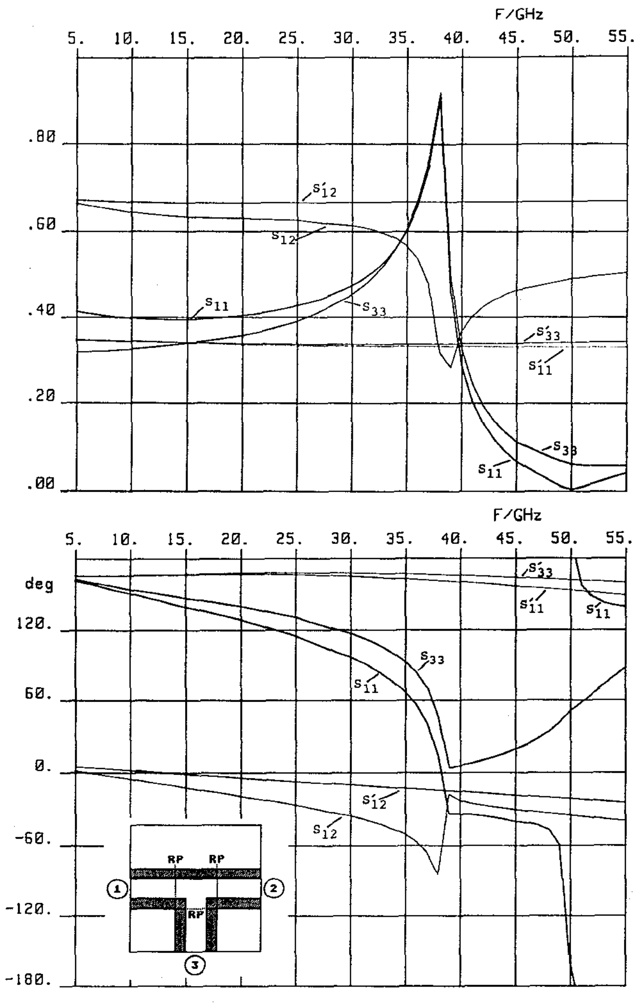

Fig. 4 CPW T-junction on 200µm GaAs, S-parameters without (S_{ij}) and with (S'_{ij}) airbridges in the reference planes
TOP: Magnitudes, Bottom: Phases

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