A NUMERICAL TRL DE-EMBEDDING TECHNIQUE FOR THE EXTRACTION OF S-PARAMETERS IN A $2^{1/2}$D PLANAR ELECTROMAGNETIC SIMULATOR

B. Linot*, M.F. Wong*, Member IEEE, V. Fouad Hanna*, Senior Member IEEE
O. Picon**, Member IEEE

*France Telecom - CNET
**Universite de Marne-la-Vallée

Abstract

A numerical application of the TRL calibration for a planar discontinuity is proposed to be used in electromagnetic simulators in order to calculate its scattering matrix without the need of either defining the port characteristic impedance as in the slotted line numerical simulation or of normalising with respect to a specified value of reference impedance as in other known de-embedding methods. The proposed technique is applied, in a $2^{1/2}$D planar electromagnetic simulator using integral equations technique solved by the moment method, on a case study of a step in width coplanar waveguide discontinuity and we have demonstrated how many numerical problems encountered previously when using other techniques were eliminated.

Introduction

The way to extract the S-parameters of simulated planar discontinuities has been the subject of intensive works during the last twenty years [1]. The utilized techniques usually reproduce the experimental measurements. Once, the electric or magnetic current distributions are determined along the ports that surround the discontinuity, using a convenient numerical technique, one of two techniques is adopted for determining the discontinuity S-parameters.

The first one [2] is the slotted line method which makes use of the standing wave in a uniform zone of each port far enough from the discontinuity and either of the source or the load. So long ports must be used, which can stress an already numerically intensive calculation. This method fails to determine the S-parameters for asymmetric discontinuities without using the characteristic impedances of ports surrounding the discontinuity. As is known there is a difficulty in defining Z_0 for lines supporting non-TEM modes.

The second technique [3-5] is a de-embedding technique that characterises standards to remove port discontinuity effects. This method gives the S-parameters normalized in all ports to a reference impedance (e.g. 50 Ω).

In this paper, we propose an alternative to the second method : a numerical application of the TRL calibration [6,7] for a planar discontinuity for determining its S-parameters without the need of either defining the port characteristic impedances as in the first method or normalizing with respect to a specified value. Furthermore this procedure allows an easy and direct comparison between simulated and measured results, and a good comprehension of physical phenomena. Also the method doesn't assume any model for port discontinuity and can be applied to shielded as well as unshielded circuits.

Outline of the technique

A rigorous electromagnetic analysis based on the use of the integral equations technique solved by a 2D method of moment is applied on the discontinuity to be studied and on three standards of each different transmission line surrounding the discontinuity : a Thru (non-zero length of transmission line), a Reflect which is an open end or a short-circuit end, and a Line.

Without loss of generality, applying this technique on a coplanar waveguide structure, the obtained integral equations can be written in a matrix form [8] as given in equation (1). In this equation, $\left[\tilde{Y}\right]$ is the matrix of moment method, $[V]$ is the voltage vector (equivalent to the equivalent magnetic current), and $[I]$ is the electric current vector.

$$\left[\tilde{Y}\right][V] = [I] \qquad (1)$$

We distinguish in the matrix equation (2) between the terms related to the unknowns by a u , and the terms related to the sources by a s. The sources are impulsional generators and can be considered as a raw approximate model of wafer probes.

$$\begin{bmatrix} \tilde{Y}_{uu} & \tilde{Y}_{us} \\ \tilde{Y}_{su} & \tilde{Y}_{ss} \end{bmatrix} \begin{bmatrix} V_u \\ V_s \end{bmatrix} = \begin{bmatrix} I_u \\ I_s \end{bmatrix} \qquad (2)$$

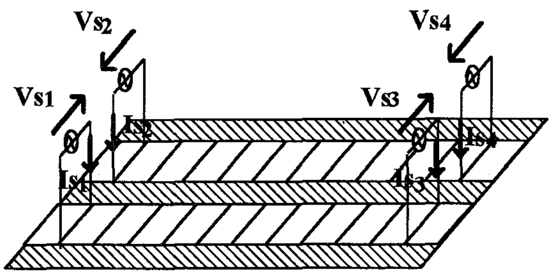

Figure 1 : Representation of the source models for a coplanar waveguide transmission line.

The resolution of the integral equations consists in the computation of the unknown equivalent magnetic currents (or voltages) Vu, as it is given in equation (3).

$$[V_u] = [\tilde{Y}_{uu}]^{-1}(-[\tilde{Y}_{us}][V_s]) \qquad (3)$$

Then to calculate the matrix admittance at the input port, two states of independent excitations are used. In the first one, the sources are at the port 1 and the port 2 is short-circuited. For the second state, we invert the sources and the short-circuits. The excitation voltages are of the same amplitude and of opposite directions in order to be able to excite the fundamental quasi-TEM coplanar mode.

For each state of excitation, we calculate the source currents, Is, using the relation (4).

$$[\tilde{Y}_{su}][V_u] + [\tilde{Y}_{ss}][V_s] = [I_s] \qquad (4)$$

The admittance matrix is then obtained and converted firstly to 50 Ω normalized scattering matrix, then to the transfer scattering matrix.A conventional TRL methodology can now be followed with numerical data input instead of experimental one.

Results

We have applied the TRL technique to the simulation of a coplanar waveguide step in width impedance (fig. 2). The obtained S-parameters normalised with respect to 50 Ω are presented in figure 3. These S-parameters can be considered as those obtained with a standard calibration technique with reference planes at the coaxials or wafer probes level. We can notice that the transmission parameters are lower than 15 dB.

Then the S-parameters, after the de-embedding with the TRL procedure, are compared to those calculated with the slotted line technique (fig. 4). In this case the de-embedded S-parameters have dramatically changed from those before the de-embedding procedure. When using the slotted line technique, characteristic impedances of the two ports surrounding the step are determined from a quasi-static analysis. We can notice a general good agreement between the results, except for the amplitude of the transmission parameters S12 and S21. For the ancient technique, the reciprocity is not verified (i.e. $|S12| \neq |S21|$) and the amplitude of S12 goes up to values greater than 1.0. While results using our technique do not suffer from these problems and give stable results that can be directly compared to those of an experimental TRL calibration.

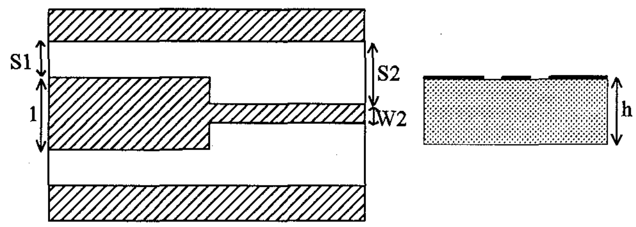

Figure 2 : Step impedance coplanar waveguide (ε_r=9.6, h=0.635 mm, s_1=1.5 mm, w_1=0.6 mm, s_2=0.3 mm, w_2=1.2 mm).

Conclusion

A numerical application of the TRL calibration for a planar discontinuity is proposed to be used in electromagnetic simulators in order to calculate its scattering matrix without the need of either defining the port characteristic impedance as in the slotted line numerical simulation or of normalising with respect to a specified value of reference impedance as in other known de-embedding methods. The proposed technique is applied, in a $2^{1/2}$ D planar electromagnetic simulator using integral equations technique solved by the moment method, on a case study of a step in width coplanar waveguide discontinuity and we have demonstrated how many numerical problems encountered previously when using other techniques were eliminated.

References

1 R.H. Jansen, "Some notes on S-parameter de-embedding algorithms for 3D electromagnetic simulators", IEEE MTT Workshop on simulation of microwave and millimeter-wave components using full-wave techniques", Albuquerque, NM, June 1, 1992.

2 B. Linot, M.F. Wong, O. Picon, V. Fouad-Hanna, M. Drissi, "A rigorous dispersive characterization of radiating coplanar waveguide discontinuities and junctions", EuMC 1994, vol.2, pp. 1918-1923.

3 J.C. Rautio, "A de-embedding algorithm for electromagnetics", Int. Journal of Microwave & Millimeter-Wave Computer-Aided Engineering, vol. 1, no. 3, pp. 282-287, 1991.

4 A. Hill, J. Burke, K. Kottapalli, "Three-dimensional electromagnetic analysis of shielded microstrip circuits", Int. Journal of Microwave & Millimeter-Wave Computer-Aided Engineering, vol. 2, no. 4, pp. 286-296, 1992.

5 A. Skrivervik, J.R. Mosig, "Impedance matrix of multiport microstrip discontinuities including radiation effects", AEÜ, vol. 44, no. 6, 1990, pp. 453-461.

6 G.F. Engen, C.A. Hoer, "Thru-Reflect-Line" : An improved technique for calibrating the dual six-port automatic network analyzer", IEEE Trans. MTT, vol. 37, no. 12, Dec. 1979, pp. 987-993.

7 D. Rubin, "De-embedding mm-wave MICs with TRL", Microwave Journal, June 1990.

8 R.F. Harrington, "Field Computation by Moment Methods", New York, Macmillan, 1968.

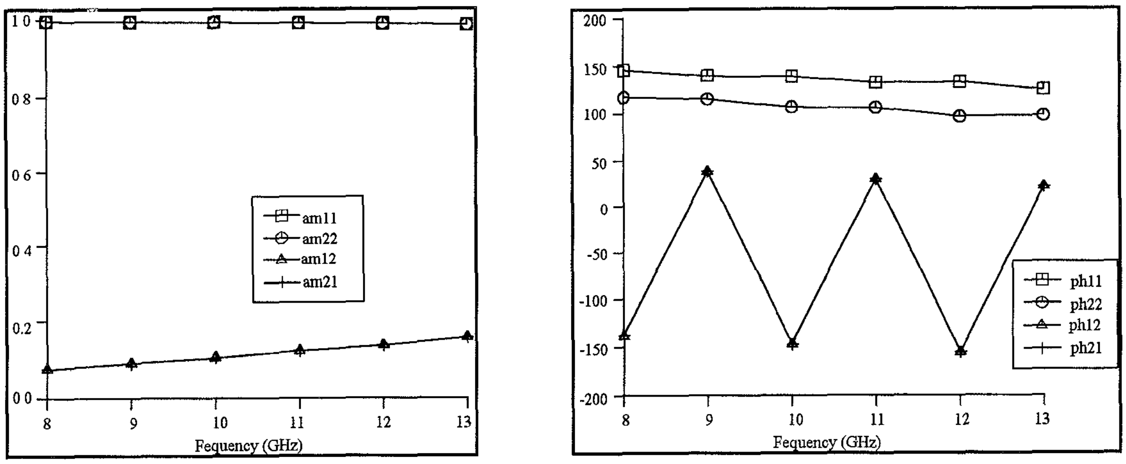

Figure 3 : 50 Ω normalized S-parameters before the TRL calibration.

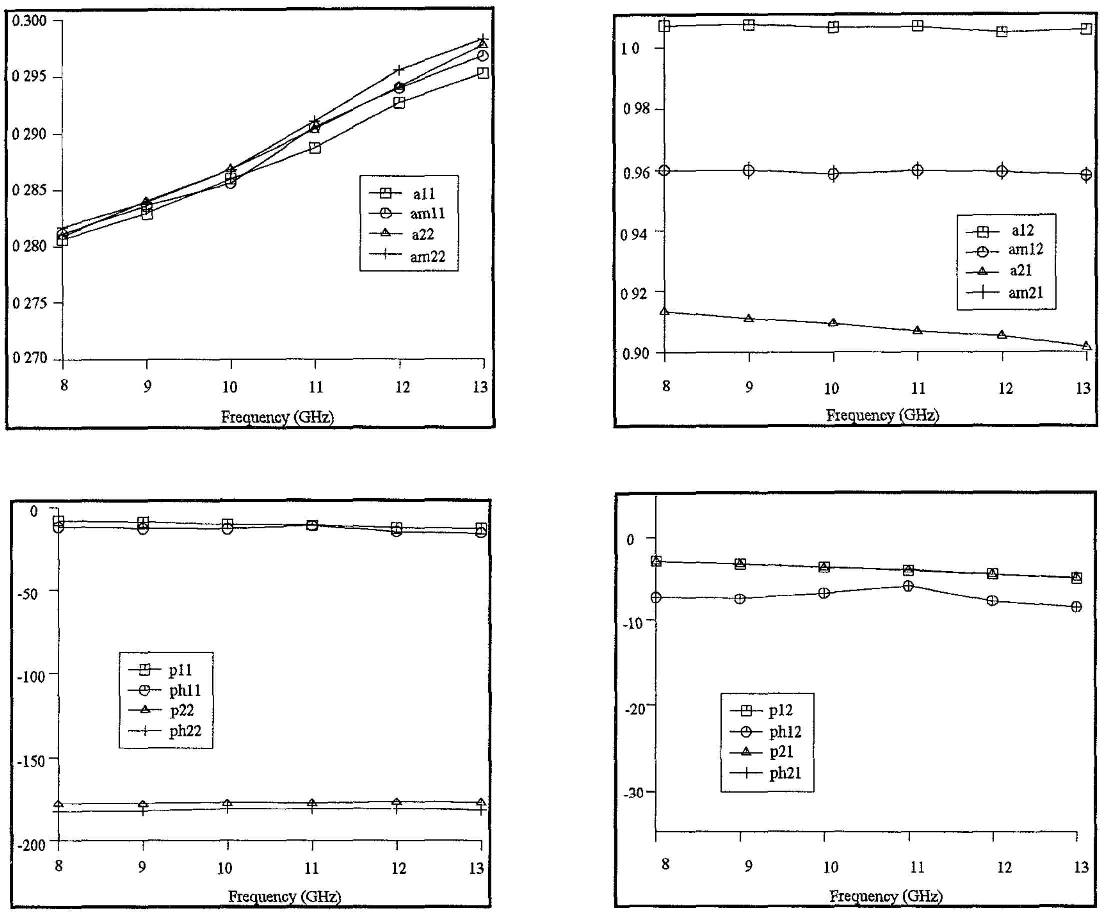

Figure 4 : Variation of the de-embedded S-parameters, as a function of the frequency. The "a" and "p" refer to the amplitudes and phases of S-parameters when using the slotted-line technique, while the "am" and "ph" refer to the amplitudes and phases when using the TRL de-embedding technique.