ENHANCED MODEL FOR INTERACTING STEP-DISCONTINUITIES

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ABSTRACT

The increase in working frequency and the advent of monolithic technology stress the need of better accuracy in the characterization of passive components.

With this respect, a new lumped equivalent circuit is proposed and tested, able to characterize both the interacting and the non-interacting cascaded step-discontinuities in microstrip.

The model is based on a dynamic approach, utilizes practically frequency-independent lumped elements, is very broadband and easy to be implemented in the presently available commercial packages.

INTRODUCTION

The widespread diffusion of CAD software packages has undoubtedly pushed on the design and the realization of microvave integrated units of increasing complexity and frequency of operation.

Those programs, however, have been created and developed mostly for the design of hybrid microwave integrated circuits (MIC's), where a moderate precision can be accepted due to both the modest accuracy deriving from the use of data-sheets for active device characterization and the possibility of a final "tweaking" on the circuit after realization.

On the other hand, the continuous increase in working frequency and the advent of monolithic technology both concur in pointing out the urgent need of a better characterization for passive components, because of the more accurate modelling provided for active devices as well as the lack of tuning in the realized circuits.

In fact, the models of passive components, presently implemented in the available commercial CAD packages, are normally based on a quasi-static approximation that limits their validity at the lower frequency range. This is the case, among the others, of the single and double (i.e. interacting) microstrip impedance steps, one of the most frequently appearing discontinuity in MIC's, that is the item discussed in the present contribution.

The paper, in particular, proposes and tests a new lumped equivalent circuit, for both interacting and non-interacting cascaded step-discontinuties in microstrip, having the following features:

1) It is derived from a planar approach that has been demonstrated to be effective in many applications;

2) It is based on a dynamic approach, so that it fully describes the frequency behaviour of the discontinuities, including their interaction due to the excitation of higher ordes modes, thus overcoming the limits of the quasi-static approximation;

3) The values of the equivalent components are practically not frequency-dependent, with the exception for the obvious but very moderate dispersion effect, thus avoiding the limited usefulness of already proposed frequency-dependent equivalent elements;

4) The frequency bandwidth of validity is much broader with respect to previously proposed similar models and it is intrinsically potential of a further broadening, by adding more lumped element cells to the model;

5) It is easy to be implemented in the presently available commercial packages.

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THEORETICAL CHARACTERIZATION AND MODELLING

A theoretical characterization based on the electromagnetic behaviour of the structures seems the better approach to obtain the desired accuracy in the simulation of passive networks.

In recent years, in fact, several models have been proposed [1,2] and CAD programs have been presented or announced, all based on an electromagnetic approach. Although often very rigorous, those methods seem to be quite complicate and difficult to use and to implement.

On the contrary, the development of lumped models based on the electromagnetic approach represents a proper merging of the required accuracy with the availability of friendly tools effectively usable in practical circuit design.

This task can be performed starting from an electrical characterization of the rectangular microstrip structure in terms of a [Z] matrix as described in [3,4,5] and here focused on the case of symmetrical structure (Fig. 1).

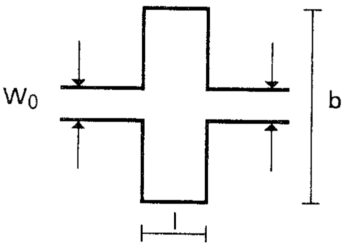

Fig. 1 - Symmetrical rectangular microstrip structure.

Following the above quoted method, the Z-quantities can be rewritten as

(1) $$Z_{11}=Z_{22}=\frac{j\omega\mu h}{bl}\left[\sum_{m=0}^{\infty}\frac{\delta_m}{K^2_{m,0}-\omega^2\mu\,\varepsilon_{m,0}}+\sum_{n=1}^{\infty}\sum_{m=0}^{\infty}\frac{2\delta_m g_n^2}{K^2_{m,2n}-\omega^2\mu\,\varepsilon_{m,2n}}\right]=Z_{11l}+Z_A$$

(2) $$Z_{12}=Z_{21}=\frac{j\omega\mu h}{bl}\left[\sum_{m=0}^{\infty}\frac{\delta_m(-1)^m}{K^2_{m,0}-\omega^2\mu\,\varepsilon_{m,0}}+\sum_{n=1}^{\infty}\sum_{m=0}^{\infty}\frac{2\delta_m g_n^2(-1)^m}{K^2_{m,2n}-\omega^2\mu\,\varepsilon_{m,2n}}\right]=Z_{12l}+Z_B$$

where:

$$K^2_{m,2n}=\pi^2[(m/l)^2+(2n/b)^2]$$

$$\delta_m=\begin{cases}1 & m=0\\ 2 & m\neq 0\end{cases}$$

$$g_n=\sin\left(\frac{n\pi w_o}{b}\right)\Big/\left(\frac{n\pi w_o}{b}\right)$$

and:

$$Z_A=\frac{j\omega\mu h}{bl}\left[\sum_{n=1}^{\infty}\sum_{m=0}^{\infty}\frac{2\delta_{2m}g_n^2}{K^2_{2m,2n}-\omega^2\mu\varepsilon_{2m,2n}}+\sum_{n=1}^{\infty}\sum_{m=0}^{\infty}\frac{2\delta_{2m+1}g_n^2}{K^2_{2m+1,2n}-\omega^2\mu\varepsilon_{2m+1,2n}}\right]=Z_{ev}+Z_{od}$$

(3)

$$Z_B=\frac{j\omega\mu h}{bl}\left[\sum_{n=1}^{\infty}\sum_{m=0}^{\infty}\frac{2\delta_{2m}g_n^2}{K^2_{2m,2n}-\omega^2\mu\varepsilon_{2m,2n}}-\sum_{n=1}^{\infty}\sum_{m=0}^{\infty}\frac{2\delta_{2m+1}g_n^2}{K^2_{2m,2n}-\omega^2\mu\varepsilon_{2m+1,2n}}\right]=Z_{ev}-Z_{od}$$

so that

(4) $$[Z]=\begin{bmatrix}Z_{11l} & Z_{12l}\\ Z_{21l} & Z_{22l}\end{bmatrix}+\begin{bmatrix}Z_A & Z_B\\ Z_B & Z_A\end{bmatrix}$$

with b, l and w_o effective dimensions; $\varepsilon_{m,n}$ the effective permittivity of the (m,n)th resonant mode; h the substrate thickness.

The corresponding [Z] matrix can be so considered as the sum of two [Z] matrices, one corresponding to the two-port representation for a microstrip line of effective length l and width b, and the other one corresponding to a two-port network, in series connection with the first one (Fig.2), that represents the interacting step-discontinuities structure.

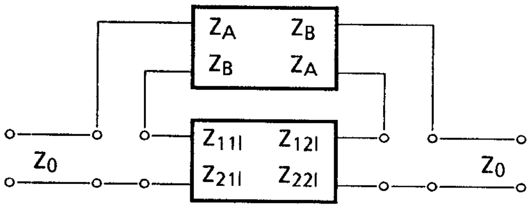

Fig. 2-General representation of the symmetrical rectangular microstrip in terms of [Z] matrices.

The latter two-port network can be represented as in Fig. 3, where Z_{ev} and Z_{od} are summation of all the terms of expressions (3) having an even and odd "m" index respectively.

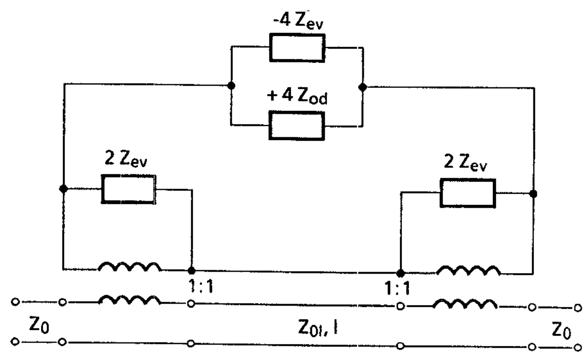

Fig. 3-Equivalent circuit of the symmetrical rectangular microstrip exploding the Z_{ij} composition (i, j = 1, 2).

Finally, in Fig. 4b the general equivalent model of Fig. 3 is particularized for the structure of Fig. 4a.

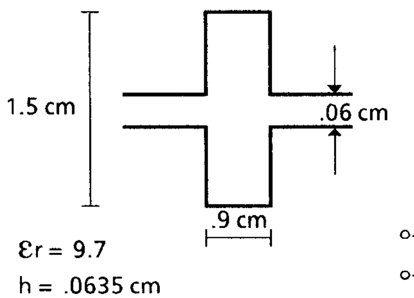

Fig. 4a

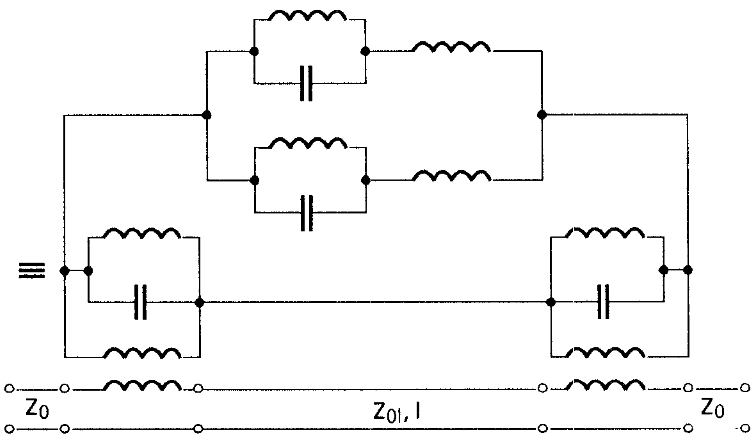

Fig. 4b

The corresponding results, obtained through the implementation of the model of Fig. 4b into the Touchstone ® CAD program are compared with the ones obtained from the existing "mstep" element and the experiments (Fig. 5).

The tight agreement between experiments and simulated behaviour, for both amplitude and phase of the S_{21} parameter, clearly demonstrates the improvement achieved in the modelling.

CONCLUSIONS

The development of a new lumped equivalent circuit to modelize both interacting and non-interacting step-discontinuities in microstrip allows the overcoming of geometrical/frequency limitations or poor accuracy of presently available models. Experiments both confirm the effectiveness of the proposed approach and suggest its usefulness in the design of microwave and millimeter-wave monolithic IC's.

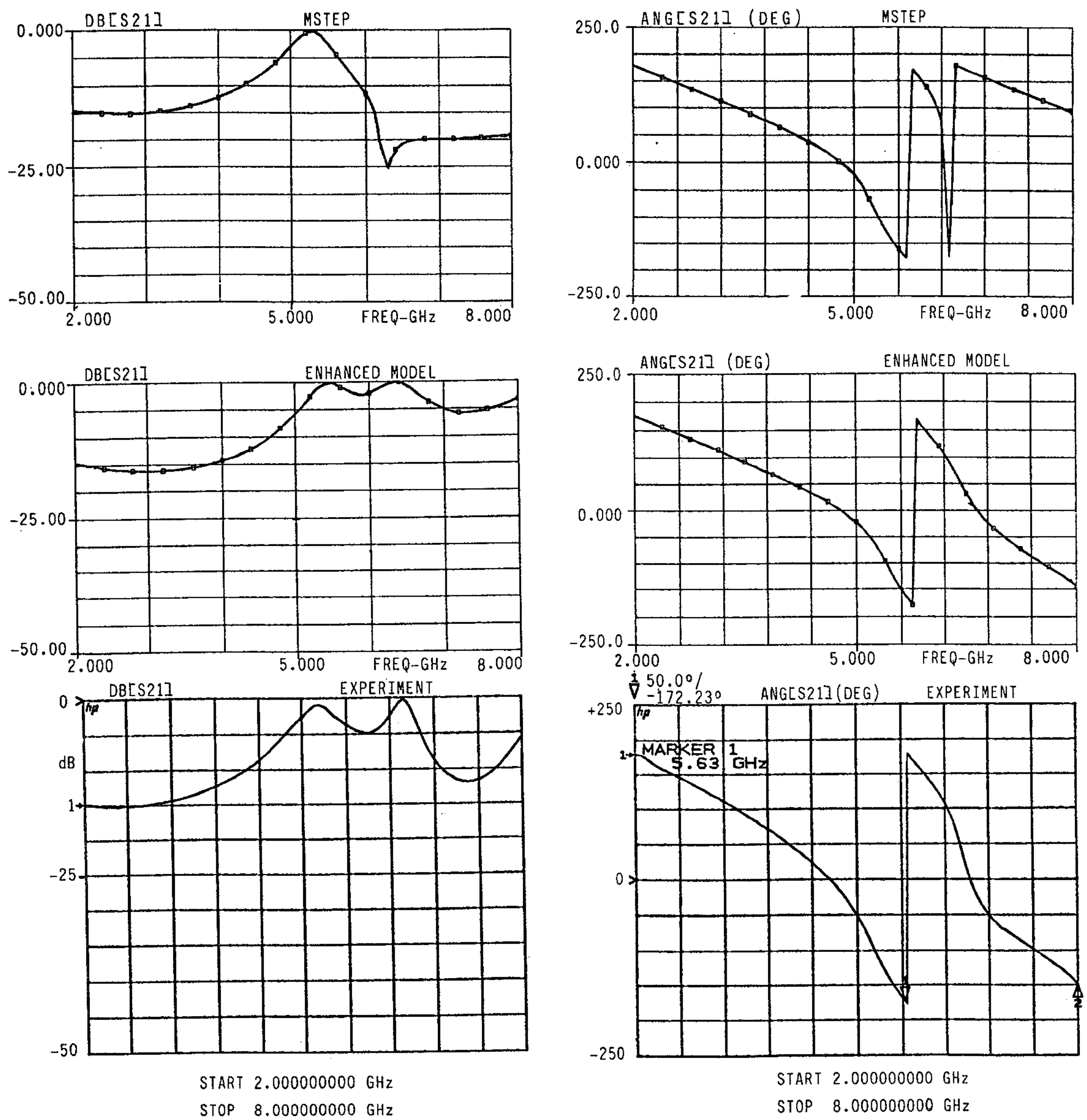

Fig. 5-Comparison between theoretical simulations (new approach and existing "mstep" element) and experiments.

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