ANALYSIS OF MICROSTRIP LINE STEP-DISCONTINUITIES AND ITS APPLICATION TO A CASCADED CONFIGURATION

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ABSTRACT

An abrupt change in microstrip linewidth, commonly called a microstrip impedance step, is a discontinuity that appears frequently in MMICs, such as, stepped impedance transformers and matching networks for example. Therefore, the accurate description of these step-discontinuties is important for the computer-aided design of conventional and monolithic MICs.

In this work we have studied the set of modes that appears in a boxed microstrip in order to apply modal analysis in the spectral domain to the study of simple and cascaded step discontinuities.

In order to check its precision, our method has been applied to a nine section low-pass filter, made up of a cascade of microstrip step discontinuities. Several filters have been designed, built and tested at different frequencies. We have compared these designs with Touchstone and shown that at low frequencies both methods give similar results, but when the frequency is higher, the Touchstone results are farther from the experimental results than the design obtained with the modal analysis method.

1- INTRODUCTION

Microstrip discontinuities in hybrid MICs have been the object of considerable interest since the late 1960s. Nonetheless, we cannot say that their influence on the behavior of the circuit has been completely and satisfactorily assessed. Frequency and thickness rescaling suggests that the effect of discontinuities should not be greater in MMICs than in hybrid MICs, but rather somewhat smaller. However, spurious radiation may become important. Early models were based on lumped-parameter equivalent circuits, the elements of which could be derived from quasi-static capacitance and inductance estimates [1,2] . Lumped models are fast and easily included in CAD programs; however, they are usually inaccurate beyond a certain frequency, which depends on the kind of discontinuity considered and on substrate dielectric constant.

The closed-circuit waveguide approach has proved to be the most accurate characterization method that can be introduced without too many difficulties into a CAD circuit analysis tool [3]. Its accuracy has also been tested recently in MMICs. However, this approach fails to model accurately some discontinuities, such as the impedance step.

It is the aim of this work to describe cascades of step discontinuities which constitute a basic configuration in the design of integrated microwave circuits.

Other methods for obtaining a more accurate frequency-dependent solution have been attempted previously [4,5].

More recently a rigorous formulation for a single step discontinuity in microstrips has been published [6]. This method gives good results for a single step, but it does not lend itself readily to the treatment of cascades of strongly coupled discontinuities.

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In this paper we have applied modal analysis in the spectral domain to the analysis of simple and cascaded step discontinuities.

In order to study cascaded discontinuties in integrated microwave circuit we must determine the generalized scattering matrix to study the cascaded discontinuities. This, in turn, requires a good selection of modes characterizing the simple discontinuity in order to obtain rapid convergence, avoid overflow problems and minimize CPU time.

Many numerical difficulties are encountered in the determination of the zeros of the characteristic equation; the determinant of the characteristic matrix has, in principle, doubly infinite sets of zeros and poles, which become a finite number of singly infinite sets as a result of truncating the characteristic matrix. Since the set of modes must be complete and orthogonal, a selection of modes has been made based on the coupling that exists between them.

By applying this criterion we have performed the modal analysis in the spectral domain. To check the accuracy of the numerical results, the above method has been applied to nine-section low-pass filters made up of a cascade of microstrip step discontinuities. It has been designed using 50Ω input and output lines. Capacitive lines, and inductive lines have been made with wide and narrow strip lines respectively.

By discarding the modes which can be considered as non-orthogonal, the theoretical results for frecuency response of low-pass filters provide an excellent convergence and good agreement with the experimental ones.

2- APPLICATION OF MODAL ANALYSIS TO A SIMPLE DISCONTINUITY

Figure 1 shows the step-discontinuity.

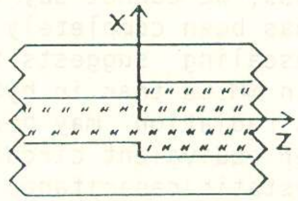

Fig. I

The boundary conditions are satisfied by means of an infinite series of appropiate modes on each side of the junction. The properties which characterize the junction can be determined if it is known how the power is distributed among the different modes. The transversal field for each mode on each side of the junction is written as:

$$\vec{e}_i(x,y,z) = a_i\, \vec{e}_i(x,y)\, e^{\pm \gamma_i z}$$
$$\vec{h}_i(x,y,z) = a_i\, \vec{h}_i(x,y)\, e^{\pm \gamma_i z} \qquad (1)$$

After applying the boundary conditions we obtain the following system of equations:

$$\sum_{i=1}^{\infty} \left[(1+\rho_{ai}) a_i I^{(a,a)}_{[i,m]} + \sum_{\substack{r=1 \\ r\neq i}}^{\infty} a_{ri}\, I^{(a,a)}_{[r,m]}\right] = \sum_{i=1}^{\infty}\sum_{j=1}^{\infty} b_{ij} I^{(b,a)}_{[j,m]} \qquad (2)$$

$$\sum_{i=1}^{\infty} (1-\rho_{ai}) a_i I^{(b,a)}_{[n,i]} = \sum_{i=1}^{\infty}\sum_{j=1}^{\infty} b_{ij} I^{(b,b)}_{[n,j]} \qquad (3)$$

with

$$I_{[p,q]} = \frac{\int_S (\vec{e}_{rp} \wedge \vec{h}^{*}_{sq}) d\vec{s}}{\left[\int_S (\vec{e}_{rp} \wedge \vec{h}^{*}_{rp}) d\vec{s}\right]^{1/2} \left[\int_S (\vec{e}_{sq} \wedge \vec{h}^{*}_{sq}) d\vec{s}\right]^{1/2}} \quad (4)$$

Consider the fact that for obvious reasons these are only M modes in the waveguide "a" and N modes in the waveguide "b", and also that equations (2) and (3) are satisfied for each proper incident mode i(i=1,2,...M) and for each proper mode in wave guide b, j (j=1,2,..., N). Then, if we consider the discontinuity as the junction of M+N ports, this will be characterized by a scattering matrix S:

$$[S] = \left[\begin{array}{c|c} [S_{11}] & [S_{12}] \\ \hline [S_{21}] & [S_{22}] \end{array}\right] \quad (5)$$

The resolution of the former system of equations allows $[S_{11}]$ and $[S_{21}]$, to be calculated. To calculate $[S_{22}]$ and $[S_{12}]$ it is necessary to know what happens when the signal incides on waveguide "a" from waveguide "b", which can be determined by applying a reasoning analogous to the proceeding one.

3- CASCADED DISCONTINUITIES: GENERALIZED SCATTERING MATRIX

Non that the generalized scattering matrix of a simple discontinuity has been obtained, we shall developed the procedure for obtaining the scattering matrix for a set of cascaded discontinuities. In figure 2 shows two discontinuities separated by a distance l. The lines "1", "2" and "3" are considered to have M, N and P modes, respectively; then, the total generalized matrix $[S^t]$ as a function of S^1, S^2 and l has the form:

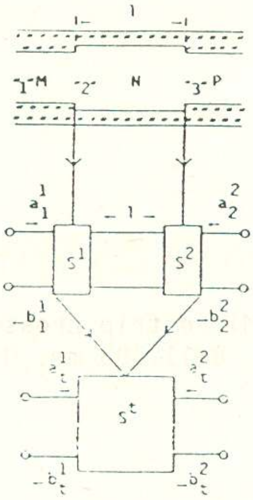

Fig. II

GENERALIZED SCATTERING MATRIX

$$S^t_{11}(MxM) = [S^1_{11}]+S^1_{12}[T]([I]-[S^2_{11}][T][S^1_{22}]T)^{-1}[S^2_{22}][T][S^1_{21}]$$

$$S^t_{12}(MxP) = [S^1_{12}][T]([I[-[S^2_{11}][T][S^1_{22}])^{-1}[S^2_{12}]$$

$$S^t_{21}(PxM) = [S^2_{21}][T]([I]-[S^1_{22}][T][S^2_{22}][T])^{-1}[S^1_{21}]$$

$$S^t_{22}(PxP) = [S^2_{22}]+[S^2_{21}][T]([I]-[S^1_{22}][T][S^2_{22}][T])^{-1}[S^1_{22}][T][S^2_{12}]$$

The (NxN) unity matrix is denoted by I, and T represents the (NxN) diagonal matrix of equal non-zero terms $e^{-j\beta_i l}$, where β_i is the phase constant of the mode i in the waveguide "2".

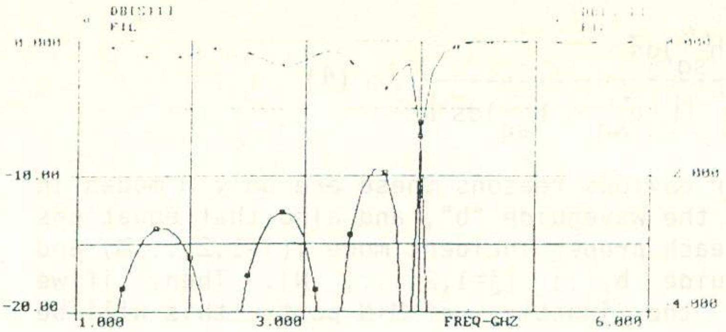

Fig. III Touchstone frequency response without width change analysis.

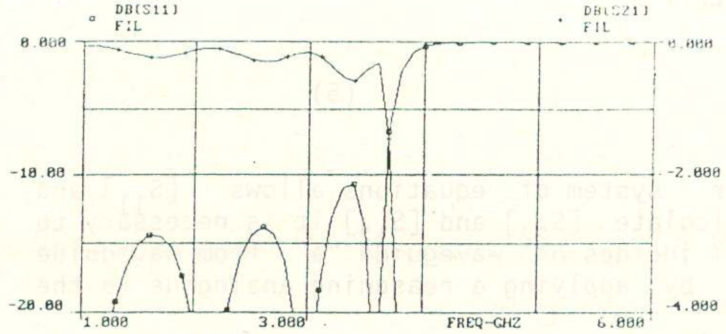

Fig. IV Touchstone frequency response including width -- change analysis.

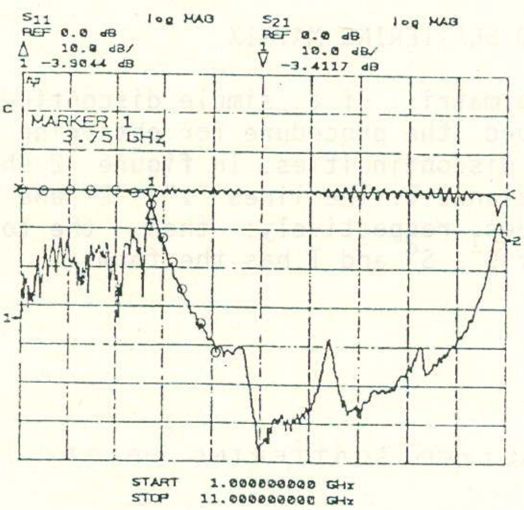

Fig. V Comparison between - theory and experiment.
Θ Calculated

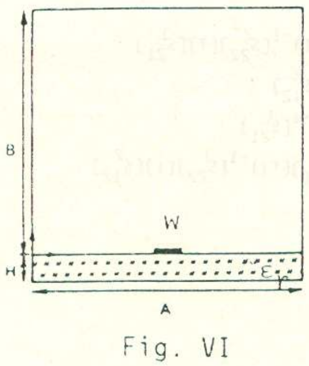

Fig. VI

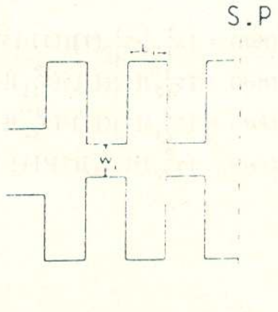

Fig. VII

Fig. VI Microstrip cross section A=12 mm, B=11.303 mm, H=.49 mm εr=2.43

Fig. VIII Half-plan of a low-pass filter:
w1=w11=1.365, w2=w10=4.654, w3=w5=w7=w9=0.57 mm
w4=w8=6.574, w6=6.618, L1=L3=L5=L7=L9=4.5 mm
L2=L8=7.655, L4=L6=8.564 mm

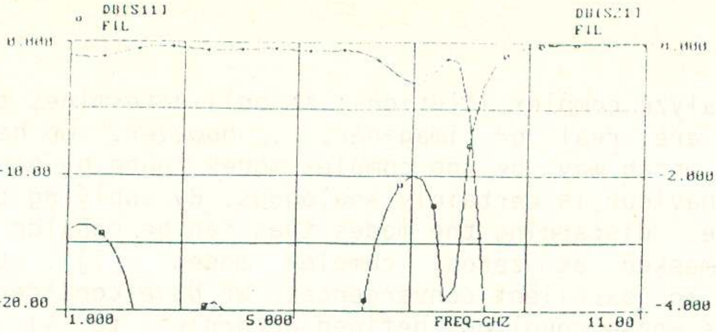

Fig. VIII Touchstone frequency response without width change analysis.

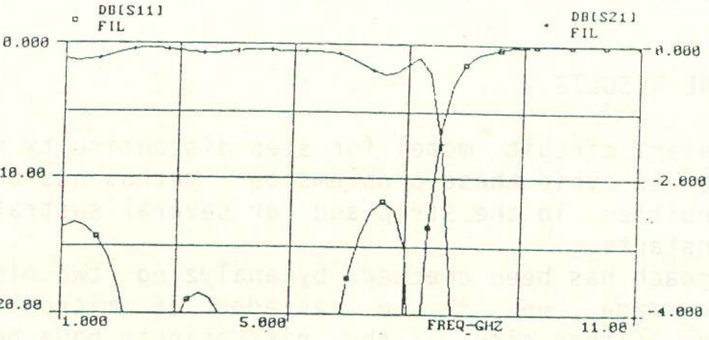

Fig. IX Touchstone frequency response including width -- change analysis

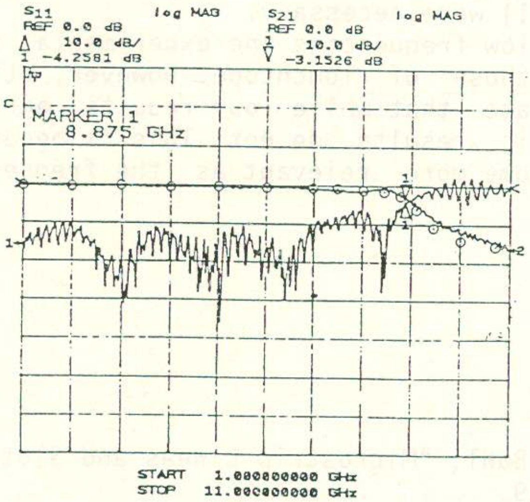

Fig. X Comparision between - theory and experiment.
Θ Calculated.

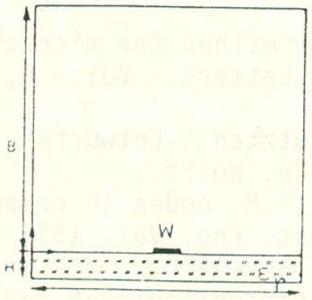

Fig. XI

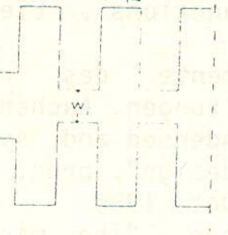

Fig. XII

Fig. XI Microstrip cross section A=10 mm, B=3 mm, H=.635 mm, εr=10.

Fig. XII Half-plan of a low-pass filter:
w1=w11=0.620, w2=w10=1.0786, w3=w5=w7=w9=.15 mm
w4=w8=1.6116, w6=1.642, L1=L3=L5=L7=L9=3 mm
L2=L8=1.4, L4=L6=1.526 mm

3- MODE SELECTION

Our method does not analyze complex solutions: it only determines the propagation constants which are real or imaginary. However, we have obtained modes or solutions which may be the complex modes found by other researchers because their behaviour is certainly analogous. By applying the criteria of elimination, i.e. discarding the modes that can be considered as non-orthogonal (poles masked as zeros, complex modes [7]), the theoretical results provide an excellent convergence. We have considered as non-orthogonal those modes whose coupling, defined according to (4), is greater than 10^{-2}.

4- CALCULATED AND EXPERIMENTAL RESULTS

The conventional equivalent circuit model for step discontinuity has some limitations [8]. In order to avoid these problems our method has been applied to various discontinuities in the strip and for several sustrates with different dielectric constants.

The validity of our approach has been checked by analyzing two nine-section low-pass filters made up of a cascades of microstrip discontinuties; the fields on either side of the discontinuty have been expanded into 4 modes for the first filter (Fig. III-VII) whereas 6 modes for the second filter (Fig. VIII-XII) were necessary.

Figures IV and V show that at low frequencies the experimental results coincide with our results and those of Touchtone. However, at higher frequencies Figures IX and X indicate that while our results agree with experimental ones the quasi-static results do not. This is because the limitations summarized by [8] become more relevant as the frequency and dielectric constant increase.

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