ANALYSIS OF MULTIPLE COUPLED MICROSTRIP DISCONTINUITIES FOR MICROWAVE AND MILLIMETER WAVE INTEGRATED CIRCUITS

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Abstract

A novel technique is introduced which allows the analysis of multiple coupled microstrip discontinuities including those structures that are embedded by multiple coupled transmission line sections such as coupled right angle bends. The method, based on the fullwave 3D moment method, is verified by comparing the simulated results of a microstrip coupler to those obtained from an experimentally verified 2D spectral domain technique. In addition, the effect of the coupled line spacing on the S parameters of typically encountered coupled microstrip discontinuities is demonstrated.

Introduction

In recent years a number of methods have been developed for the fullwave analysis of microstrip discontinuities (1-10). These techniques have been applied to analyze those microstrip discontinuities that do not require coupled transmission lines at the reference planes of the discontinuity. However, in order to analyze the wide class of discontinuities that are embedded between coupled line sections, new techniques need to be developed. Figure 1 shows a class of coupled microstrip discontinuities as they are encountered in many MMIC circuits.

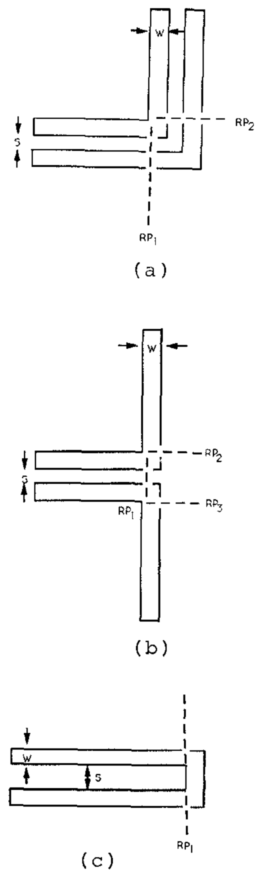

Figure 1: typical multiport coupled microstrip discontinuities

In previous approaches (1-7), the technique used for the extraction of S parameters from the electromagnetic field solution is to define a suitable excitation at the circuit ports, perform an electromagnetic field simulation, evaluate the current distribution on transmission line sections, and extract from these the wave amplitudes. Given the set of excitations and the corresponding wave amplitudes the S parameters are determined. Line impedances and propagation constants have to be determined a priori. If multiple coupled lines are to be considered, the extraction of S parameters would require the consideration of all transmission line modes resulting in a rather complex and unstable procedure. The approach demonstrated in (8) makes certain assumptions that could not be met for the examples given here. In (7) the reference planes cannot be specified and the results contain the effect of the stray fields at the ports. In addition, suitable excitation vectors have to be specified. According to (11) further development has been directed towards the removal of the discontinuity effect due to the circuit ports. In (10) a resonant procedure has been employed which requires successive solutions to

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the electromagnetic field problem. The resonance method is straight forward to apply for the analysis of simple geometries. However, the analysis of discontinuities that are embedded by coupled line sections proves to be not practical.

The present contribution describes a method that now allows the analysis of multiple coupled microstrip discontinuities that are embedded within multiple coupled transmission line sections. Based on the electromagnetic field solution a deembedding technique is employed that leads to the removal of the discontinuity effects associated with the network ports. Scattering parameters are obtained with respect to specified reference planes. No excitation vectors have to be specified and the evaluation of the current distribution along transmission line sections is not required. S parameter results can be normalized to arbitrary reference impedances. The presented technique has been implemented in the electromagnetic program EXPLORER.

Theory

The theory presented in the following applies to an arbitrary number of circuit ports. However, the method is described by using a four port discontinuity which simplifies the illustration of the concept. Figure 2a shows the four port discontinuity DUT, embedded by two coupled line sections between two reference planes RP_1 and RP_2. The associated circuit model is shown in Figure 2b. The error networks E_l and E_r describe the electromagnetic field disturbance due to the port discontinuity. Note that the coupled ports such as P_1/P_2 and P_1'/P_2' are situated at the same physical location. Coupled transmission line sections connect to the discontinuity four port S at the reference planes RP_1 and RP_2. The effect of the four port discontinuity is described by the four port S. The entire circuit can then be modelled by the error networks E_l and E_r, two coupled transmission line sections and the four port S. The distance between the reference planes and the port locations has to be chosen large enough such that the field disturbance due to the microstrip discontinuity is sufficiently small at the location of the ports.

The characterization of the discontinuity four port S (Figure 2b) is begun by computing the scattering matrix N with respect to ports P_1, P_2, P_3, P_4. In order to identify the network matrices of the error networks E_l and E_r

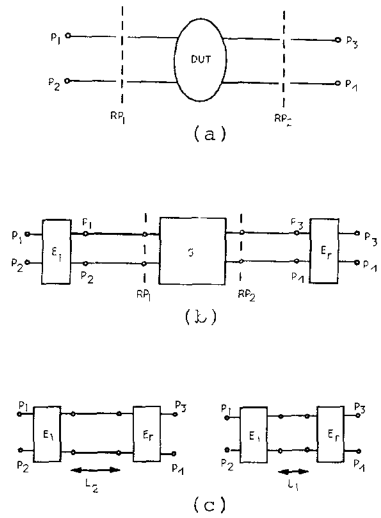

Figure 2: (a) general coupled line four port discontinuity

(b) network model for circuit in (a) with error networks, coupled line sections and four port discontinuity
(c) two standards used to identify the error network

the scattering parameters for two coupled line sections of different length have to be computed and this situation is shown in figure 2c. Once E_l and E_r are determined, the network matrix for the coupled line sections C_i with length l_i (i=1,2) can be derived. In a final step the matrices E_l, E_r, C_i and N are post processed to obtain the four port discontinuity matrix S.

The electromagnetic field simulation used here is based on the accelerated moment method which is described in (10). The accelerated scheme has been used in a deterministic procedure. The n-port network matrix N is computed directly from the system matrix M of the moment method:

$$N = L\ (M) \qquad (1)$$

where L represents a non linear operator that maps the m dimensional moment matrix M into the n dimensional network impedance matrix N. In relating the field quantities to network quantities the integral relation for the terminal impedance as a function of the terminal current and electric field has been employed (12). After defining desired normalization impedances, the scattering matrix can be derived from the impedance matrix by standard methods. At this point N represents the network with respect to the ports including the discontinuity effect at the port location. In order to obtain the scattering matrix S of the multiport discontinuity with respect to the reference planes RP_i (Figure 2), the multiple coupled transmission lines together with the port discontinuities need to be deembedded to obtain

$$S = P\ (N, E_l, E_r, C_i) \quad (2)$$

by simple matrix arithmetic. P represents a non linear operator. The network matrices N, E_l, E_r, C_i are computed following the procedure outlined in the previous paragraph.

Results

In order to verify the validity of the presented technique, the scattering parameters of an 11dB edge coupled microstrip coupler are computed and compared to results obtained from SuperCompact through 30GHz (13). The multiple coupled line model in SuperCompact is based on a rigorous two dimensional spectral domain technique which has been verified by various experimental data. The length of the coupler was chosen to be 4.572mm, the width of the microstrip line was 0.5715mm and the spacing between the lines was 0.1905mm. The metal was deposited on a 25mil Alumina substrate. The dimensions of the microstrip perfect conducting housing were 4.7625mm, 6.985mm and 4.573mm in width, height and length, respectively. Figure 3a shows the result of the comparison if the port discontinuity is included in the computation, e.g. the error networks E_l and E_r in Figure 2b have not been removed. Results for the reflection and transmission magnitude show significant differences compared to the results obtained from SuperCompact for frequencies above 5 GHz. These differences are attributed to the presence of the stray fields at the port locations. Note that the 3D electromagnetic simulation, like the actual measurement, shows the effect of the stray fields at the circuit ports. Figure 3b includes the removal of the port discontinuity which allows the accurate description of the DUT. The results compare favorably to those obtained from SuperCompact.

Selected transmission phases of the coupled microstrip bends of Figure 1a, 1b and 1c are shown in Figure 4,5 and 6, respectively. For all cases the metallization was deposited on a 20 mil GaAs substrate. The w/h ratio was chosen to be 0.732 and the shielding box was 4.572mm in height.

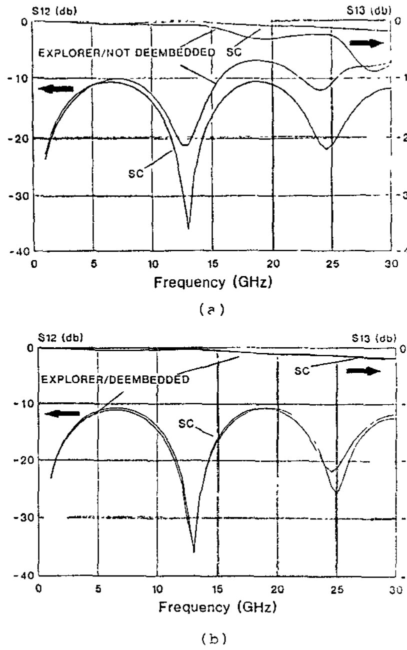

Figure 3: the sattering parameter of an edge coupled 11 db coupler 2 is the coupled port, 3 is the direct port

(a) without removal of the port discontinuity

(b) with removal of the port discontinuity

Conclusion

In summary, a method based on the 3D electromagnetic field solution has been presented that allows the analysis of multiple coupled microstrip discontinuities as they are encountered in many microwave and millimeter wave integrated circuits. A deembedding procedure has been introduced that now makes it possible to characterize coupled discontinuities even if they are embedded between multiple coupled transmission line sections. The effect of the port discontinuity on the scattering parameters of a microstrip coupler has been demonstrated and S parameters for typical microstrip coupled two and four port discontinuities were computed.

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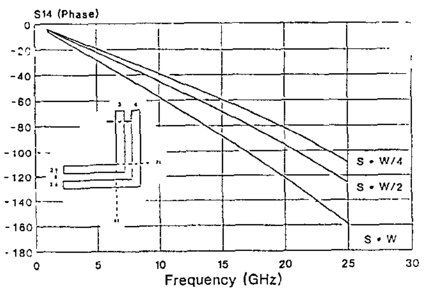

Figure 4: transmission phase S_{14} of the structure in figure 1a

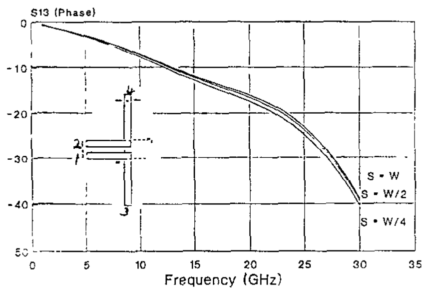

Figure 5: transmission phase S_{13} of the structure in figure 1b

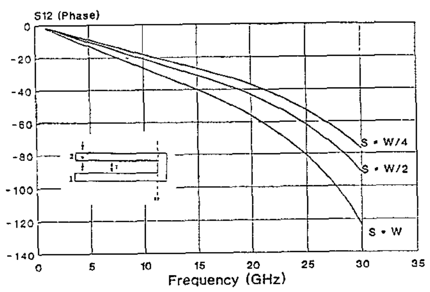

Figure 6: transmission phase S_{12} of the structure in figure 1c

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