ANALYSIS OF MMIC JUNCTIONS AND MULTIPORTS BY THE METHOD OF LINES

Larissa Vietzorreck[1] and Reinhold Pregla

FernUniversität, Allgemeine und Theoretische Elektrotechnik,
D-58084 Hagen, Germany

[1] now with: Technische Universität München, Lehrstuhl für Hochfrequenztechnik,
D-80333 München, Germany

Abstract

The approach based on the method of lines for the analysis of cascaded MMIC elements is substantially extended for investigations of 4-port components. Instead of a three-dimensional discretization two crossed two-dimensional discretization line systems are employed for the modeling of the central region. S-parameters of various multiports, T-junctions and crossings containing air-bridges, are calculated.

I. Introduction

Multiport elements with input/output transmission lines perpendicular to each other are widely used in MMIC circuit design (see Fig. 1). Especially corner bends, T-junctions and line crossovers are elementary discontinuities which can be found in almost every planar circuit. These actually quite simple elements often feature an even more complicated interior composition [1]. They can contain air-bridges or via-holes for an isolated crossover of two microstrip lines or suppressing of unwanted mode-conversion in coplanar circuit elements. Empirically, these elements cause strong discontinuity effects at higher frequencies, which may deteriorate the desired signal transmission. Hence an accurate modeling of these types of components is necessary. However, due to the complex structure a rigorous three-dimensional analysis requires a great computational expense. This is especially the case in domain methods where a 3D discretization of the computational domain has to be performed and special absorbing walls are needed for truncation of the input and output regions [2], [3] or a complicated Green's function has to be computed in an extensive calculation [4], [5], [6].

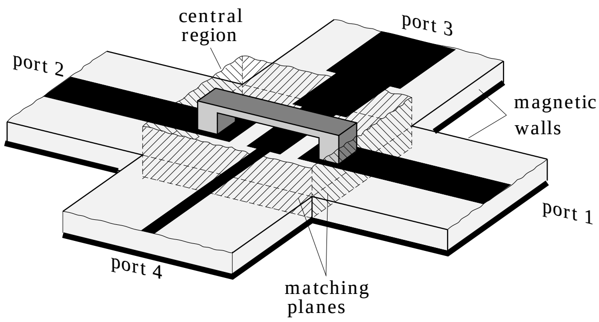


Figure 1: General 4-port structure with central region and matching planes

For the analysis of cascaded two-port components a full-wave approach based on the method of lines (MoL) has been established very successfully [7], [8]. The 2D discretization of the cross-section combined with an analytical calculation in propagation direction avoids a 3D discretization and the need of artificial boundaries in the input/output planes. A great variety of elements has been accurately analyzed with properties like substrate or conductor loss, finite metallization thickness and 3D inhomogenities. However, a fundamental limitation of the approach is the strictly cascaded composition of

0-7803-4471-5/98/$10.00 (c) 1998 IEEE

the structures under investigation due to the analytical calculation on the straight discretization lines. Even the analysis of two-ports with input and output plane not parallel to each other was not possible.

A suitable way to solve this problem using crossed systems of discretization lines has been described previously in [9] for rectangular waveguide junctions. This approach is now extended to hybrid fields and adapted to the much more complicated case of MMIC junctions.

II. Theory

The principle is as follows: instead of a 3D discretization, the field in the central region V is decomposed into two orthogonally propagating waves. They are described on 2D line systems perpendicular to each other, connecting the opposite subsections I and II or III and IV, respectively.

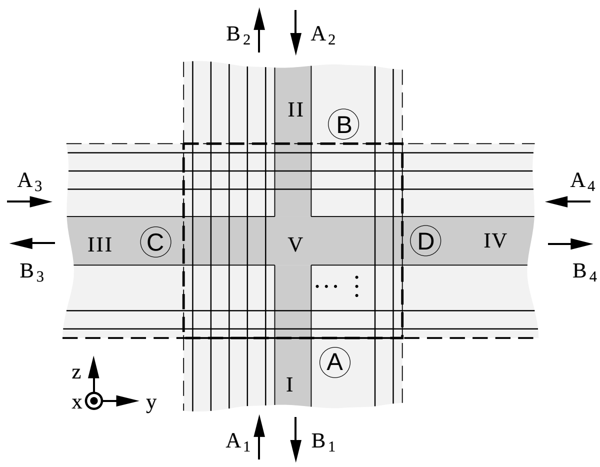


Figure 2: Schematic view of a general 4-port, with central region, matching planes A,B,C,D and discretization lines

An independent analysis is performed for each line system using the mentioned algorithm with a 2D discretization of the cross-section. Magnetic walls are utilized as lateral boundaries. For each line system the field inside the central region is described dependent on a general input at two opposite ports.

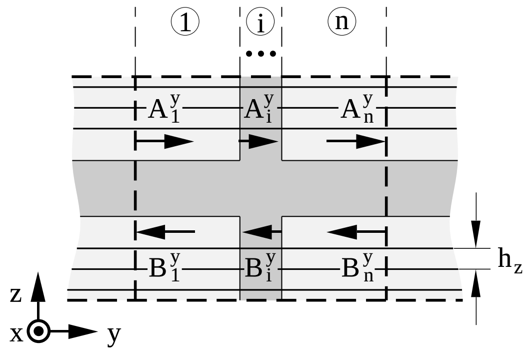


Figure 3: Analysis of a two-port

For a matching plane in propagation direction the tangential field is easily calculated using the generalized scattering matrix $\boldsymbol{S}^y$ of the two-port. Here this is done for the plane $y = 0$.

$$\begin{bmatrix} \mathbf{E} \\ \mathbf{H} \end{bmatrix}_{y=0} = \begin{bmatrix} \boldsymbol{p}_e(\boldsymbol{I} + \boldsymbol{S}_{11}^y) & \boldsymbol{p}_e \boldsymbol{S}_{12}^y \\ \boldsymbol{p}_h(\boldsymbol{I} - \boldsymbol{S}_{11}^y) & -\boldsymbol{p}_h \boldsymbol{S}_{12}^y \end{bmatrix} \begin{bmatrix} \mathbf{A}_1^y \\ \mathbf{B}_N^y \end{bmatrix} = \boldsymbol{R}_d^y \begin{bmatrix} \mathbf{A}_1^y \\ \mathbf{B}_N^y \end{bmatrix} \quad (1)$$

with $\boldsymbol{p}_e$ and $\boldsymbol{p}_h$ known from [7].
In transverse directions the field components are known exactly only on the x and z positions of the discretization lines, in y direction they can be calculated at arbitrary positions. The necessary tangential field components for matching at a plane perpendicular to the propagation direction, e.g. at the position $z = 0$, are determined as follows:

$$\begin{bmatrix} \mathbf{E} \\ \mathbf{H} \end{bmatrix}_{z=0} = \boldsymbol{R}_r^y \begin{bmatrix} \mathbf{A}_1^y \\ \mathbf{B}_N^y \end{bmatrix} \quad (2)$$

$$\boldsymbol{R}_r^y = [\ldots \boldsymbol{R}_{rei}^y \ldots \boldsymbol{R}_{rhi}^y \ldots]^t \quad (3)$$

As we use magnetic walls, the relevant field components, namely $\mathbf{E}_x$ and $\mathbf{E}_y$, are located on discretization lines half a discretization distance h_z away from the matching plane. In order to obtain the values directly in the matching plane, we have to extrapolate the field values on the neighboring two lines by a quadratic extrapolation. (The corresponding $\mathbf{H}_x$ and $\mathbf{H}_y$ values equal zero because of the magnetic wall.)

In the next step the total tangential field of the two line systems is matched with the field of the feed line at each individual port A, B,C or D, demonstrated here for port A:

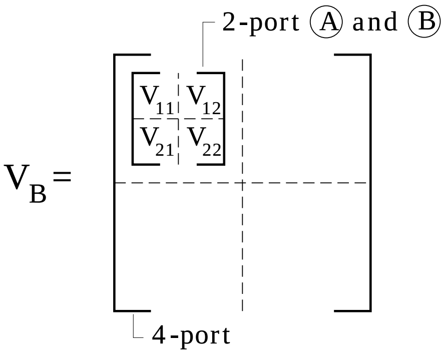
$$\boldsymbol{R}^I \begin{bmatrix} \mathbf{A}^I \\ \mathbf{B}^I \end{bmatrix} = \boldsymbol{R}_d^z \begin{bmatrix} \mathbf{A}_1^z \\ \mathbf{B}_N^z \end{bmatrix} + \underbrace{\begin{bmatrix} \boldsymbol{R}_{re}^y|_{int} \\ \boldsymbol{0} \end{bmatrix} \begin{bmatrix} \mathbf{A}_1^y \\ \mathbf{B}_N^y \end{bmatrix}}_{\text{crossed line system}} \quad (4)$$

with

$$\boldsymbol{R}^I = \begin{bmatrix} \boldsymbol{p}_e & \boldsymbol{p}_e \\ \boldsymbol{p}_h & -\boldsymbol{p}_h \end{bmatrix} \quad (5)$$

In the following the amplitudes $\mathbf{A}_1^y, \mathbf{A}_1^z, \mathbf{B}_N^y$ and $\mathbf{B}_N^z$ are eliminated. The result is a generalized multimode scattering matrix for the 4-port problem. Here $\mathbf{A}_i$ denote the amplitudes of the incoming, $\mathbf{B}_i$ the amplitudes of the outgoing waves.

$$[\boldsymbol{V}_B] \begin{bmatrix} \mathbf{B}_1 \\ \mathbf{B}_2 \\ \mathbf{B}_3 \\ \mathbf{B}_4 \end{bmatrix} = [\boldsymbol{V}_A] \begin{bmatrix} \mathbf{A}_1 \\ \mathbf{A}_2 \\ \mathbf{A}_3 \\ \mathbf{A}_4 \end{bmatrix} \quad (6)$$



If a two-port, e.g. a corner bend, or a three-port (T-junction) is analyzed, the irrelevant ports are closed.

Note that for the whole investigation no time-consuming three-dimensional analysis has to be performed. Only two separate investigations of the 2 two-ports, using the 2D discretization, followed by calculation of the final matrix, is necessary, which – for the 4-port – is at most 4 times as large as the matrices of the 2-port problem.

III. Results

The suggested algorithm is checked by comparing results obtained for various elements with other calculated or measured data. The first test configuration is a T-junction in a microstrip line.

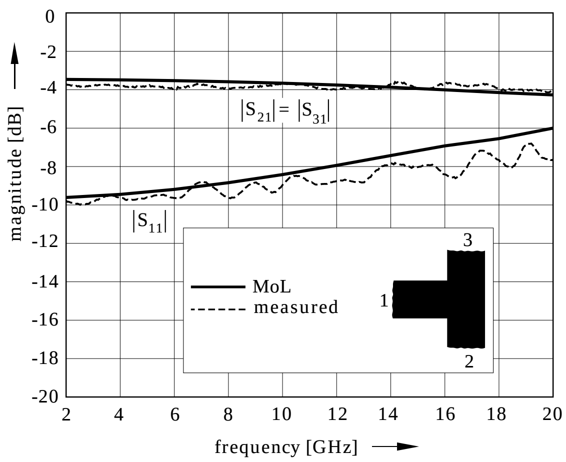


Figure 4: Scattering parameters for a microstrip T-junction of $50\ \Omega$ lines

This very simple element shows a very good agreement with the first data we measured with a HP8720 network analyzer.

The next example is a more complicated one: a crossover of two microstrip lines. Port 1 and 2 are connected with an air-bridge to avoid unwanted metallic contact with ports 3 and 4. S-parameters caused by excitation at port 1 and port 3 are sketched. A good consistency with results obtained by SDA [10] has been observed.

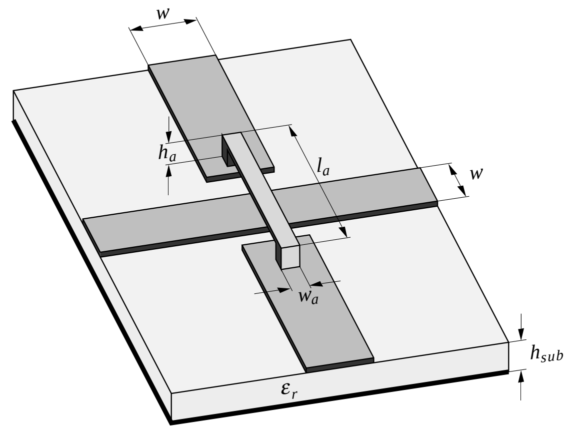


Figure 5: Crossover of two microstrip lines using an air-bridge ($w = 0.635$ mm, $w_a = 0.212$ mm, $h_a = 0.2$ mm, $l_a = 2.752$ mm, $h_{sub} = 0.635$ mm, $\varepsilon_r = 9.8$)

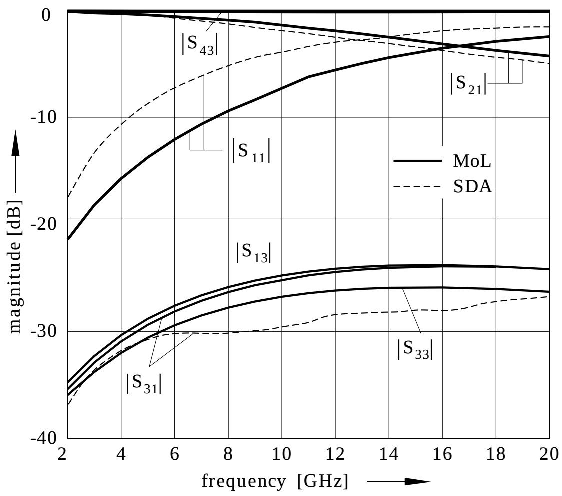


Figure 6: S-parameters for excitation at two different ports compared with results obtained by SDA [10]

The slight difference in the results for S_{31} and S_{13} obtained by the MoL can be deduced from the discretization error, based on the different discretization schemes used for the two parts.

IV. Conclusion

The procedure presented combines all the advantages of the 2D method of lines approach and overcomes the main drawback, the restriction to cascaded 2-ports. Now all kinds of corner bends, T-junctions or crossings, including loss or 3D elements like vias or air-bridges can be analyzed accurately with the MoL avoiding a time-consuming 3D discretization. Investigations of cross-talk, coupling effects or mode conversion of different types of lines are easily possible.

References

[1] F. Mernyei, I. Aoki, and H. Matsuura, "New Cross-T Junction for CPW Stub-Filters on MMIC's", *IEEE Microwave Guided Wave Lett.*, vol. 5, no. 5, pp. 139–141, May 1995.

[2] K. Beilenhoff, W. Heinrich, and H.L. Hartnagel, "Analysis of T-Junctions in Coplanar MMICs", in *IEEE MTT-S Int. Symp. Dig.*, San Diego, USA, June 1994, pp. 1301–1304.

[3] M. Rittweger, N.H. Koster, S. Kosslowski, R. Bertenburg, S. Heinen, and I. Wolff, "Full-Wave Analysis of a Modified Coplanar Air-Bridge Junction", in *European Microwave Conference*, Stuttgart, Germany, Sep. 1991, pp. 993–998.

[4] T.-S. Horng, W.E. McKinzie, and N.G. Alexopoulos, "Full-Wave Spectral-Domain Analysis of Compensation of Microstrip Discontinuities Using Triangular Subdomain Functions", *IEEE Trans. Microwave Theory Tech.*, vol. MTT-40, no. 12, pp. 2137–2147, Dec. 1992.

[5] T. Becks and I. Wolff, "Full-Wave Analysis of Various Coplanar Bends and T-Junctions with Respect to Different Types of Air-Bridges", in *IEEE MTT-S Int. Symp. Dig.*, Atlanta, USA, June 1993, pp. 697–700.

[6] M.-D. Wu, S.-M. Deng, R.-B. Wu, and P. Hsu, "Full-Wave Characterization of the Mode Conversion in a Coplanar Waveguide Right-Angled Bend", *IEEE Trans. Microwave Theory Tech.*, vol. MTT-43, no. 11, pp. 2532–2538, Nov. 1995.

[7] L. Vietzorreck and R. Pregla, "Hybrid Analysis of 3-D MMIC Elements by the Method of Lines", *IEEE Trans. Microwave Theory Tech.*, vol. MTT-44, no. 12, pp. 2580–2586, Dec. 1996.

[8] L. Vietzorreck and W. Pascher, "Modeling of Conductor Loss in Coplanar Circuit Elements by the Method of Lines", *IEEE Trans. Microwave Theory Tech.*, vol. MTT-45, no. 12, pp. 2474–2478, Dec. 1997.

[9] W. Pascher and R. Pregla, "Analysis of Rectangular Waveguide Junctions by the Method of Lines", *IEEE Trans. Microwave Theory Tech.*, vol. MTT-43, no. 12, pp. 2649–2653, Dec. 1995.

[10] T.-S. Horng, "A Rigorous Study of Microstrip Crossovers and their Possible Improvements", *IEEE Trans. Microwave Theory Tech.*, vol. MTT-42, no. 9, pp. 1802–1806, Sep. 1994.