R-4

S-PARAMETERS OF MICROWAVE COMPONENTS COMPUTED WITH THE 3D CONDENSED SYMMETRICAL TLM NODE

J. Uher, S. Liang and W.J.R. Hoefer

Laboratory for Electromagnetics and Microwaves
Electrical Engineering Department
University of Ottawa
CANADA, K1N 6N5

ABSTRACT

The symmetrical condensed node TLM method is used for S-matrix computation of microwave circuits. An edge coupled microstrip bandpass filter and a discontinuous ridge waveguide are analysed as typical examples. The conditions which must be satisfied in S-parameter computation of such circuits are defined. The validity of the method is veryfied by comparison with results obtained by other numerical methods.

INTRODUCTION

Much of the early work on the three-dimensional TLM method has been devoted either to the computation of resonant frequencies of cavities [1],[6] or to the evaluation of disperssion characteristics of various quasi-planar microwave structures [1], [3], [5]. Only very few papers discuss the computation of discontinuities. In [7], for example, three-dimensional discontinuities are analysed using the asymmetrical condensed node TLM-method.

Recently, the symmetrical condensed node 3D TLM method has been introduced [1]. When combined with a variable mesh approach [3], this method is a very powerful tool for the analysis of microwave structures of arbitrary shape. Its main drawback is the very large computer memory required for the processing of the numerical code. With the introduction of a variable mesh technique, however quite complex structures can be analysed, since only in the vicinity of the discontinuity a fine mesh resolution is necessary.

In order to extract the S-parameters from a single impulsive TLM analysis, the problem of wideband absorbing boundaries and source matching in the time domain must be solved. The purpose of this paper is to analyse these problems and to present solutions for S-parameters of realistic, three-dimensional microwave structures.

THEORY

In the condensed node TLM approach the scattering process takes place at one point in space for each node. Fig. 1 shows schematically the arrangement of the transmission line mesh in the 3D space. The ports 1-12 are associated with the so-called link lines while the ports 13-18 are associated with stub-transmission lines. The role of these stub-transmission lines is twofold. In the regular mesh they are used to model dielectric and magnetic properties of the transmission media. In the variable mesh approach they also add capacitance or inductance in order to assure time synchronism in the irregularly graded mesh.

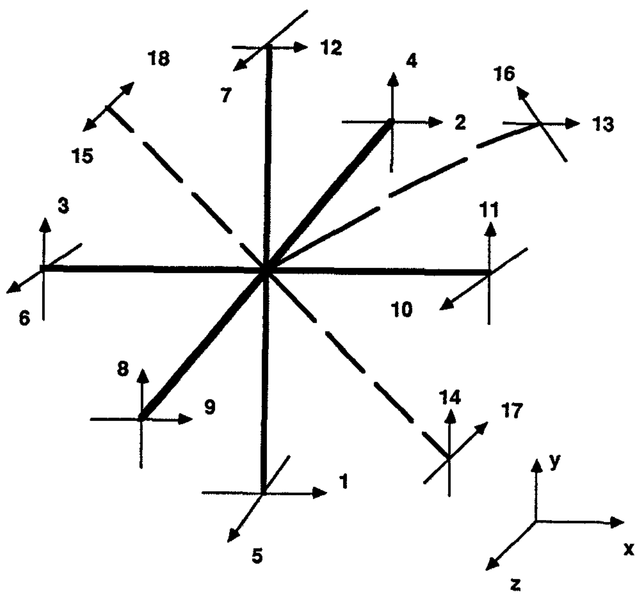

Fig.1 Symmetrical condensed node

CH2848-0/90/0000-0653$01.00 © 1990 IEEE

The TLM algorithm consist of the scattering process which can be described symbolically as :

$$V_{k+1}{}^{i} = C_k S_k V^i + C_k V^s \quad [1]$$

where

V_{k+1}^{i} is a incident voltage impulse at timestep "$k+1$"
C_k is a connection matrix with elements

$$c_{ij} = \begin{cases} 1, & \text{if port "i" is connected to port "j";} \\ 0, & \text{otherwise.} \end{cases}$$

S_k is the TLM impulse scattering matrix
V^s is a scattered impulse

The size of the stub-equipped S-matrix is 18x18.

In the S-matrix characterization of microwave components with the TLM-method, two major aspects must be considered. The first refers to the wide-band absorbing boundaries which must be introduced due to the limitations in the memory of computers. They must be dispersive due to the dispersive nature of the waveguide impedance. Recently, an almost perfectly absorbing boundary has been described [8],[9] based on the numerical Green's Function (also known as Johns matrix) approach. Another approach for solving the problem of residual reflections from imperfectly matched boundaries could involve a termination of a waveguide component by a sufficiently long empty waveguide section, thus ensuring that reflected pulses will not reach the discontinuity before completing the iterative procedure. However, this method is not practical if many iterations are needed.

A graded mesh technique has been used in the TLM method to reduce computational expenditure. Since some regions of the analysed microwave component require a very fine mesh resolution, a fixed mesh would lead to unacceptable memory size. The graded mesh technique described in [3] can be implemented in the form of either continuously variable or stepped mesh size. For the structures showing certain symmetry in their geometry (see Fig. 2a) and possessing only one region where fine mesh resolution is necessary, a continously variable mesh technique may be applied. One of many possible functions describing the distribution of the mesh-size along the x-axis is

$$\Delta u = [x - a/2]^2 + \alpha \quad [2]$$

where

Δu is mesh size
a is the waveguide width
α is the finest mesh size (in the center of the waveguide)

The S-matrix parameter extraction is a very attractive feature of the TLM-method. Provided that the analysed structure has sufficiently fine mesh resolution, and wide band absorbing walls are introduced, the S-parametrs can be obtained by a single impulsive simulation, followed by Fourier Transform. Theoretically the impulsive excitation covers the entire frequency spectrum. In practice, however, the network dispersion limits the frequencies to $\frac{\Delta l \cdot f}{c} \ll 1$.

The transmission coefficient can be calculated from

$$S_{21} = \frac{F[T(t)]}{F[I(t)]} \quad [3]$$

while the input reflection coefficient can be written as

$$S_{11} = \frac{F[A(t)] - F[I(t)]}{F[I(t)]} \quad [4]$$

where :

F[T(t)] is the Fourier Transform of the transmitted impulse response

F[I(t)] is the Fourier Transform of the incident impulse

F[A(t)] is the Fourier Transform of the total (incident + reflected) impulse function in the input port.

Note that I(t) cannot be obtained from the main TLM simulation, but must be computed separately from an analysis of the input section in which the component has been replaced by an absorbing boundary [8].

RESULTS

To demonstrate the possibilities of the condensed symetrical node TLM method we have computed frequency responses of two different structures. From the field theory point of view, both of them represent typical three-dimensional problems. In Fig. 2b the input reflection coefficient of a discontinuous ridge waveguide section is presented. The TLM-results are compared with those obtained by the mode-matching method. Both numerical methods yield very close results. The second structure was an edge coupled microstrip bandpass filter. For the TLM simulation of this structure no wide band absorbing walls are necessary since in the passband only the TEM-mode with almost nondispersive characteristic impedance is propagating. In Fig. 3 b the frequency response of a single-resonator edge-coupled microstrip bandpass filter is shown. The TLM simulation of this structure was performed using a regular mesh . The microstrip lines were terminated with a local reflection coefficient determined from the effective dielectric constant of the microstrip line [7]. The input microstrip-line is longer than the output line. This was necessary in order to define the input wave amplitude at the point where higher order modes (due to impulsive excitation) are sufficiently decayed. The TLM frequency response was compared with results obtained with closed- form design formulas. The agreement between both methods is remarkably good.

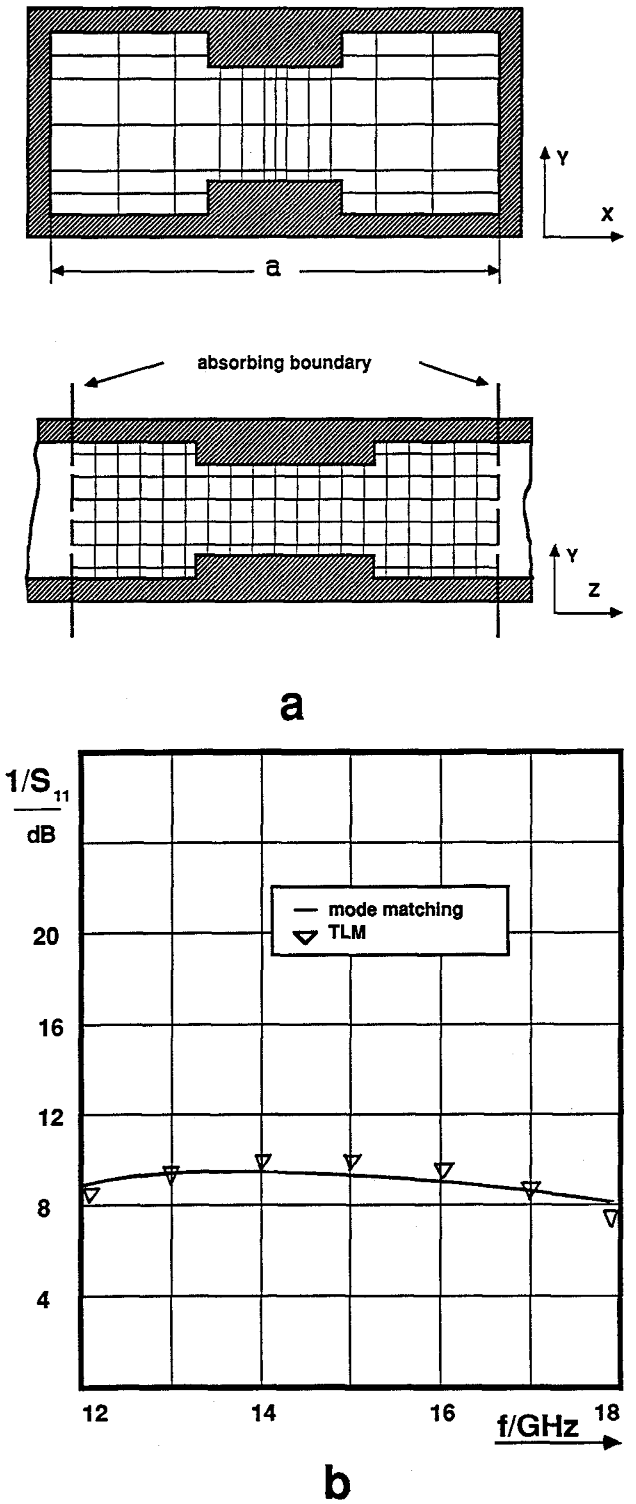

Fig.2 Discontinuous ridge waveguide; a) variable TLM mesh in two sectional views of the structure, b) input reflection coefficient as a function of frequency

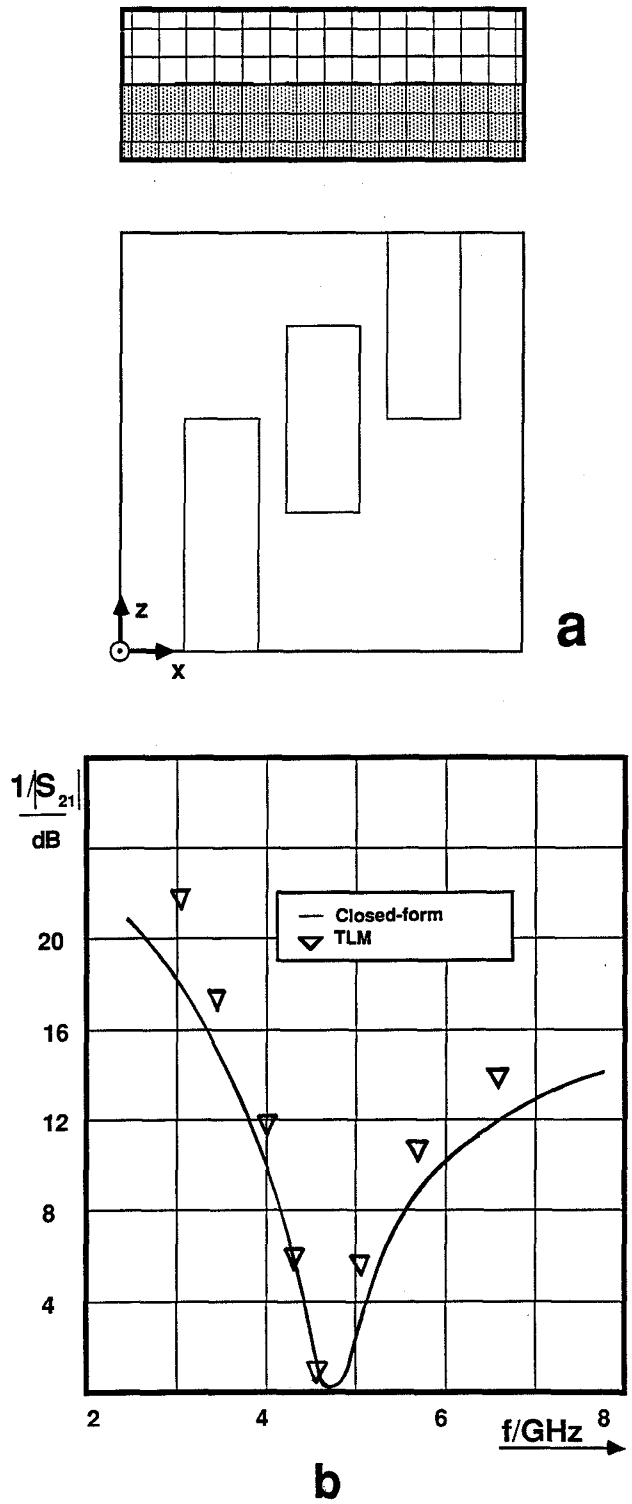

Fig.3 Single-resonator edge-coupled microstrip bandpass filter; a) circuit topology and TLM mesh, b) frequency response

CONCLUSIONS

The S-parameter extraction technique using TLM wideband absorbing boundaries and impulsive excitation yields very good results with considerably less computational effort than the single frequency approach often used in time-domain analysis of microwave structures. Further development in computer hardware and user interfaces will make this approach extremly attractive for computer aided design of microwave components.

REFERENCES

1. P.B. Johns, "Use of condensed and symmetrical TLM nodes in computer-aided electromagnetic design", IEE Proc., Part H: Microwaves, Opt. Antennas, vol. 133, Oct. 1986

2. P.B. Johns, "A symmetrical condensed node for TLM method," IEEE Trans. Microwave Theory Tech.,vol. MTT-35, pp. 370-377, Apr. 1987

3. D.A. Al-Mukhtar and J.E. Sitch, "Transmission-line matrix method with irregularly graded space," IEE Proc., Part. H: Microwaves, Opt. Antennas, vol. 128, pp. 299-305, Dec. 1981

4. W.J.R. Hoefer, "The transmission-line matrix method - theory and application," IEEE Trans. Microwave Theory Tech., vol. MTT-33, pp. 882-893, Oct. 1985

5. G.E. Mariki and C. Yeh, "Dynamic three-dimensional TLM analysis of microstrip lines on anisotropic substrates," IEEE Trans. Microwave Theory Tech., vol. MTT-33, pp. 789-799, Sept. 1985

6. R. Allen, A. Mallik and P.B. Johns, "Numerical results for symmetrical condensed TLM -node," IEEE Trans. Microwave Thory Tech., vol. MTT-35, pp. 378-382, Apr. 1987

7. P. Saguet and W.J,R. Hoefer, "The modelling of multiaxial discontinuities in quasi-planar structures with the modified TLM method," Int. Journal of Numerical Modelling, Vol. 1, pp. 7-17, 1988

8. P. So, Eswarappa and W.J.R. Hoefer, "A two-dimensional TLM microwave field simulator using new concepts and procedures," IEEE Trans. Microwave Theory Tech., vol. MTT-37, pp. 1877-1884, Dec. 1989

9. Eswarappa, Poman P.M. So and Wolfgang J.R. Hoefer, "New Procedures for 2-D and 3-D Microwave Circuit Analysis with the TLM Method," in this digest