A WIDE-BAND S-PARAMETER EXTRACTION PROCEDURE FOR ARBITRARILY SHAPED, INHOMOGENEOUS STRUCTURES USING TIME DOMAIN NUMERICAL TECHNIQUES

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Abstract - **A new, simple and very efficient technique for the wide-band extraction of scattering parameters using time domain methods (e.g. FDTD, TLM) is introduced which avoids the hitherto necessary high requirements for appropriate absorbing boundary conditions. The technique is based on the modal S-parameter definition for unmatched ports and achieves, even with standard non-dispersive Mur's absorbing boundaries, excellent and reliable results also for dispersive microwave structures and inhomogeneous input and output ports. The proposed method is verified by excellent agreement with measurements or with mode-matching results.**

I. Introduction

Recent advances in the design of modern waveguide circuits for microwave or millimeter wave applications have precipitated the need for accurate and efficient electromagnetic modeling of the characteristics of these structures. Electromagnetic problems of the most general kind involve nonlinear, inhomogeneous, anisotropic, time-dependent material properties and arbitrarily shaped 3D geometries. Although very desirable, the most part of the involved structures cannot be treated by analytical approaches. Therefore, time domain numerical techniques such as the finite difference time domain (FDTD) or transmission line method (TLM), have found widespread application [1]-[11]. Techniques of improving the efficiency of these flexible but relatively cpu time and storage intensive methods are very desirable.

One of the most important features of time domain numerical techniques is the possibility of wide-band S-parameter calculations within one computational run. This calculation is usually performed by using matched conditions (matched source, matched output ports) cf. e.g. [3]. This implies that the reflection considered at appropriate absorbing walls must ideally be zero. Therefore, high quality absorbing walls which should produce only a minimal numerical reflection over the widest possible frequency band are required where the most severe problems occur at the treatment of inhomogeneous waveguide sections. To solve this complex problem, a variety of absorbing walls are proposed, cf. e.g. [3] - [10].

The absorbing boundaries proposed for inhomogeneous waveguides can be devided roughly into two groups. The first group consists of non-dispersive boundaries [3]. These are easy to be implemented, but they are often only sufficient for reliable results at one specific frequency. Therefore, these boundaries may be applied succesfully only on quasi TEM structures or at waveguides with analytically known dispersion characteristics under monochromatic excitation, [3], [5], [6], [7]. Some of them suffer from stability problems.

The second group includes more general absorbing boundaries which are theoretically suitable for wide-band applications, [4], [8]. However, they are in general complicated to be implemented, require significant preprocessing and, due to additional numerical calculations (e.g. multi-dimensional convolution), they are very cpu time and memory consuming. Moreover, they were not yet suffiently investigated as for the stability behavior. For this reason, modified absorbing boundaries are often applied which are structure oriented, usually for discontinuities having microstrip or homogeneously filled waveguide ports [5], [9], [10].

In this paper, we introduce a new procedure for the wide-band S-parameter extraction of arbitrarily shaped structures with general inhomogenous ports. The procedure is simple to be implemented and well appropriate for time domain numerical techniques such as the FDTD and TLM method. The simplicity of the proposed technique and its wide applicability makes the usage of the conventional cpu time and memory consuming wide-band absorbing boundaries for the time domain analysis of generalized 3D microwave circuits unnecessary.

II. Theory

The basis of our considerations is the common definition of the S-matrix:

$$\mathbf{b} = S\mathbf{a} \tag{1}$$

where $\mathbf{a}$ is the vector of the incident waves, and $\mathbf{b}$ is the vector of the scattered waves. The usual way to calculate the elements of the S-matrix in time domain techiques is to perform the well known matching procedures, so that there is just one nonzero element in the excitation vector $\mathbf{a}$ and each S-parameter can directly be calculated from the ratio of two coefficients. This common extraction technique requires ideal wide-band absorbing boundaries.

The proposed alternative technique is to consider the general modal S-parameter definition (1) in the case of unmatched ports, i.e. to simulate the structure with non-ideal absorbing boundaries. This means, on each port, both incident as well as scattered propagating waves (and/or evanescent modes) appear, even when only one port has been excited. In the case of a general N-port discontinuity, we have to consider a system of N^2 equations in the form:

$$B = SA \tag{2}$$

where $B = (\mathbf{b_1}, \mathbf{b_2}, \ldots, \mathbf{b_N})$ is a matrix formed by N different $\mathbf{b}$-vectors and $A = (\mathbf{a_1}, \mathbf{a_2}, \ldots, \mathbf{a_N})$ is a matrix formed by N different $\mathbf{a}$-vectors. The desired modal S-matrix is now obtained by the multiplication of equation (2) with the inverse of matrix A, from the right side.

The N different vectors $\mathbf{a}$ and $\mathbf{b}$, respectiviley, are calculated by N appropriate simulation runs, each considering a different condition, e.g. the excitation of a different port. If more then one mode are present on a port of the structure under investigation, an extraction of the modal guided power has to be performed. For that purpose, we use the orthogonal mode properties. The required modal field distribution can be obtained by using the efficient 2D FD-TD approach, [11], or an other 2D FD-FD technique.

The transversal electric field $\vec{E}_t^j$ at the position z of port j can be written in the form:

$$\vec{E}_t^j(z) = \sum_{p=1}^{M} \vec{\mathbf{e}}_{tp}^j \left(a_p^j \cdot e^{-\gamma_p z} + b_p^j \cdot e^{+\gamma_p z} \right) , \tag{3}$$

where $\vec{\mathbf{e}}_{tp}^j$ is the transversal field distribution of the electric field of the mode p at port j, and a_p^j , b_p^j are the modal amplitudes. With $\vec{\mathbf{h}}_{tq}^j$ representing the transversal magnetic field distribution of mode q at the same port obtained from the 2D FD-TD approach, the following integration along the cross-section A_j of port j has to be performed:

$$\frac{1}{d_q} \iint_{A_j} \overbrace{\vec{E}_t^j(z)}^{\text{3D FD-TD}} \times \overbrace{\vec{\mathbf{h}}_{tq}^j}^{\text{2D FD-TD}} \, dV_2 = a_q^j \cdot e^{-\gamma_q z} + b_q^j \cdot e^{+\gamma_q z} = w_q^j(z) \ . \tag{4}$$

The normalization constant d_q is calculated from the modal field distributions $\vec{\mathbf{e}}_{tq}^j$ and $\vec{\mathbf{h}}_{tq}^j$ which are both obtained simultaneously from the 2D FD-TD approach, by the following equation:

$$d_q = \iint_{A_j} \vec{\mathbf{e}}_{tq}^j \times \vec{\mathbf{h}}_{tq}^j \, dV_2 \ . \tag{5}$$

Since the propagation constant γ of each mode is also obtained by the 2D FD-TD calculation step, the incident and scattered modal amplitudes a_q^j, b_q^j can be determined by the following two equations, involving the evaluation of (4) at two cross-sections $z = 0$ and $z = \Delta z$ of port j :

$$a_q^j = \frac{w_q^j(z) - w_q^j(z + \Delta z) e^{-\gamma_q \Delta z}}{1 - e^{-2\gamma_q \Delta z}}, \tag{6}$$

$$b_q^j = \frac{w_q^j(z) - w_q^j(z + \Delta z) e^{+\gamma_q \Delta z}}{1 - e^{+2\gamma_q \Delta z}}. \tag{7}$$

If only one mode appears on port j in the considered frequency band and if a voltage or a current can be defined for this mode, $w_q^j(z)$ can be defined directly, and the procedure for the determination of the a_q^j and b_q^j is reduced merely to the evaluation of the eqns. (6) and (7). For the general case, all presented equations have to be taken into account. Additional simplifications are possible if the structure under investigation containins symmetry planes.

III. Results

For a first comparison of the proposed S-parameter extraction technique with standard techniques and different absorbing boundaries (ABC), the return loss of an empty, infinitely long WR-62 waveguide is shown in Fig. 1.

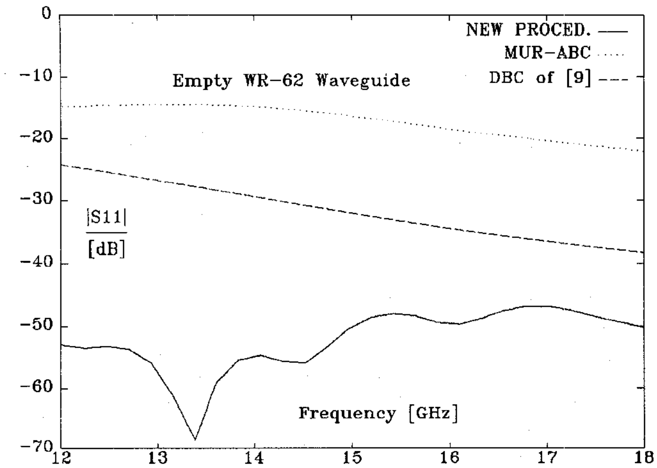

Fig. 1: Return loss of an empty WR-62 waveguide. Comparision with different S-parameter extraction procedures. Standard procedure with MURs ABC (dotted curve) and LITVAs dispersive DBC (dashed curve); new procedure with MURs ABC (solid curve). Applied discretization:10 × 40 cells, 8192 iterations.

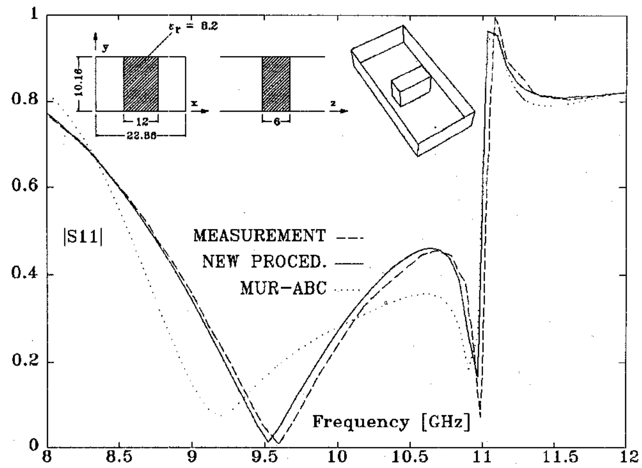

Fig. 2: Return loss of a dielectric-post discontinuity in a WR-90 waveguide. Comparision of the standard S-parameter extraction procedure, using MURs ABC (dotted curve), and the new procedure utilizing the same ABC (solids curve) with measurements of [12] (dashed curve). Applied discretization: 12 × 80 cells, 8192 time iterations.

The dotted curve is the result by using the standard S-parameter extraction together with MURs ABC, showing a return loss of about 15 - 22 dB. A return loss of about 25 - 38 dB is achieved by using the dispersive boundary condition (DBC) of LITVA et al. [5] (dashed curve). The return loss calculated with the presented new procedure is significantly more than 45dB in the whole frequency range (solid curve). The applied discretization for this example was 10 × 40 cells, and 8192 iterations are performed.

The second example (Fig. 2) shows the calculated return loss of a dielectric-post discontinuity in a WR-90 waveguide computed by the standard procedure utilizing MURs ABC (dotted line) and the new procedure (solid line), using the same ABC, compared with measurement data (dashed line) of [12]. While the result of the standard procedure shows a significant difference to the measurement, the new approach demonstrates gives excellent agreement.

Fig. 3 shows the transmission loss of a dual mode filter proposed by IHMELS et. al. in [11] calculated by using the new procedure compared with the results of the combined transverse-resonance / mode-matching method of [11]. Good agreement can be stated (note that the frequency scale is enlarged). The structure was discretized in 3 grids with 28 × 48 × 39, 54 × 54 × 61 and 28 × 48 × 39 cells. A local refined mesh was used, 16384 time-iterations are performed; for the dimensions of the filter see reference [11].

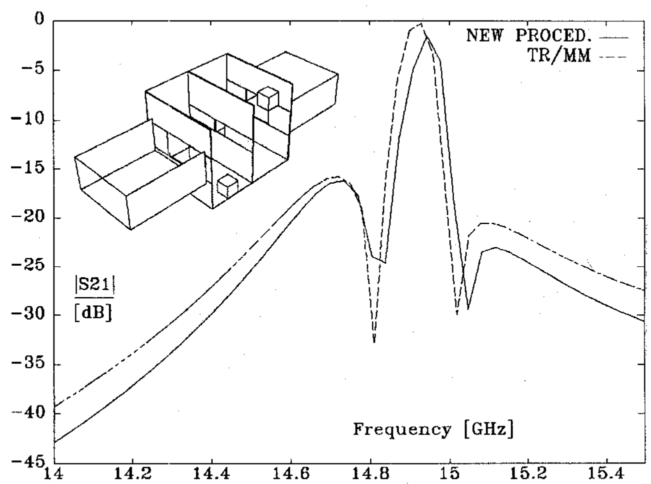

Fig. 3: Transmission loss of the dual-mode filter of [11]. Comparision of the results of the new S-parameter extraction procedure (solid curve) with values obtained from the combined transverse-resonance / mode-matching (TR/MM) method (dashed curve). Applied discretization: 28 × 48 × 39, 54 × 54 × 61 and 28 × 48 × 39 cells, 16384 time iterations.

In order to demonstrate the accuracy and efficiency of the proposed technique also for inhomogeneous ports, in Fig. 4 the calculated and measured return loss of a transition waveguide to shielded dielectric image guide is shown. Good aggreement between the results of the new procedure and measurements can be stated.

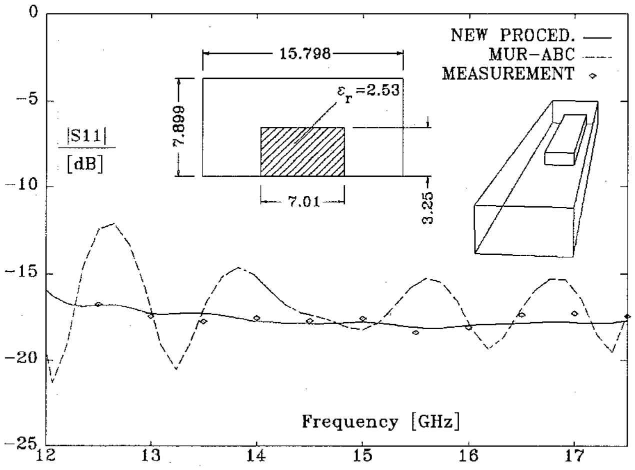

Fig. 4: Transition from a waveguide to a shielded dielectric image guide. Return loss calculated by the new procedure (solid curve) and the standard procedure using MURs ABC's (dashed curve); measurement data (⋄,⋄,⋄). Applied discretization 22 × 22 × 80 cells, 16384 time iterations.

IV. CONCLUSION

A new and very efficient technique for the wide-band extraction of scattering parameters using time domain methods (e.g. FDTD, TLM) is introduced. The accuracy of the technique and its wide applicability makes the usage of computation time and memory consuming wide-band absorbing boundaries for the time domain analysis of generalized 3D microwave circuits unnecessary. The technique achieves even with standard non-dispersive Mur's absorbing boundaries excellent and reliable results also for dispersive microwave structures and inhomogeneous input and output ports. To demonstrate the accuracy and efficiency of the proposed technique in combination with the finite difference time domain (FDTD) method, the scattering parameters of some typical examples are calculated where measurements or reference values are available. The proposed method is verified by excellent agreement with measurements or with mode-matching results.

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