A UNIVERSAL METHOD OF ACCURATE S-PARAMETER EXTRACTION FROM FD-TD SIMULATIONS APPLICABLE TO OBLIQUE PORTS

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ABSTRACT

A differential method for accurate extraction of the complete S-parameters from FD-TD simulations is proposed. In reciprocal circuits no *a priori* knowledge of reference impedances or field distribution in the ports is needed. The method is directly applicable to arbitrarily shaped and inhomogeneous transmission lines, oblique to the FD-TD grid.

INTRODUCTION

The accuracy of extraction of S-parameters from FD-TD simulations is an important problem which sometimes has decisive influence on the accuracy of the entire process of electromagnetic modelling. Although various approaches have been reported so far [1]..[9], all assume that:

- we should have some knowledge about the transverse field distribution of the modes considered in the ports,
- each port consists of a transmission line parallel to the FD-TD grid.

The first requirement is difficult to meet if the distribution of the considered mode changes with frequency which is the case in all inhomogeneous lines such as microstrip or image guide. The other assumption entails that to consider circuits such as a three-port circulator or a waveguide bend with angle not equal to 90^0 , we must add to the circuit additional bends which adjust the ports to the axes of the grid, but obviously change the original characteristics of the device.

In this paper we introduce a new system of the complete S-parameter extraction. The only assumption required is monomode transmission in a chosen reference plane. The system includes compensation of the influence of imperfect absorbing boundaries and permits direct calculation of the S-parameters in transmission lines oblique to the FD-TD grid, further referred to as oblique ports.

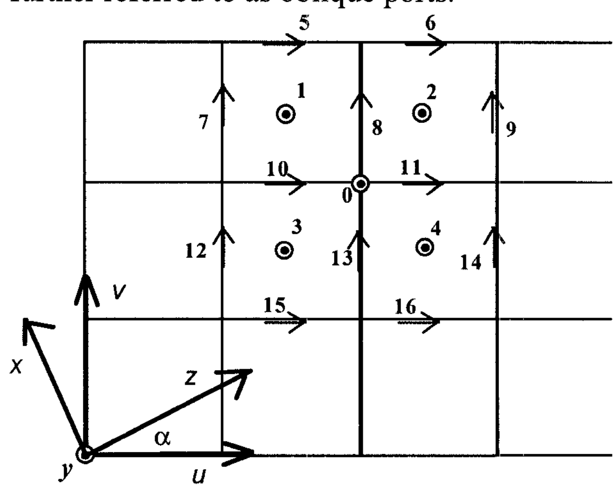

Fig.1. Field component positions used to extract reflection coefficient on oblique grid.

A DIFFERENTIAL METHOD ON OBLIQUE PORTS

In [10] we have introduced a differential method of reflection coefficient extraction

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which uses only the values of an arbitrary tangential E- and H-field components, and their derivatives with respect to the longitudinal direction at one selected point in each port. For ports parallel to the z-axis, the reflection coefficient Γ is obtained from (1):

$$\frac{(1+\Gamma)^2}{(1-\Gamma)^2} = \frac{E_t(x_e, y_e, z)\,\dfrac{\partial H_t(x_h, y_h, z)}{\partial z}}{H_t(x_h, y_h, z)\,\dfrac{\partial E_t(x_e, y_e, z)}{\partial z}} \tag{1}$$

We now extend this approach to oblique ports as shown in Fig.1. The FD-TD grid follows the u and v axes while the propagation in the port line is parallel to the z-axis forming angle α with the axis u. We further assume that the considered port is situated in the xy plane containing point 0 and that we will extract the reflection coefficient from the components E_y and H_x and their derivatives with respect to z, probed at point 0. Referring to Fig.1, we calculate the Fourier transforms of the required tangential E-field and its derivative as:

$$E_t(z_0, \omega) = 0.25 \;\mathbf{F}\begin{Bmatrix} E_{y1}(t) + E_{y2}(t) + \\ E_{y3}(t) + E_{y4}(t) \end{Bmatrix} \tag{2}$$

$$\frac{\partial E_t(z_0, \omega)}{\partial z} = 0.5 / d \;\mathbf{F}\{\Delta E(t)\} \tag{3}$$

with

$$\Delta E(t) = \begin{Bmatrix} (E_{y2}(t) - E_{y1}(t) + E_{y4}(t) - E_{y3}(t))\cos(\alpha) + \\ (E_{y1}(t) - E_{y3}(t) + E_{y2}(t) - E_{y4}(t))\sin(\alpha) \end{Bmatrix}$$

where **F** denotes a Fourier transform and d is the FD-TD cell size.

The Fourier transforms of the H_x serving as the tangential component and of its derivative are calculated in a similar way with the following differences:

- Since the H_x components are not explicitly available they are calculated form H_u and H_v components, for example:

$$H_{x1}(t) = 0.5\;\{(H_{v7}(t) + H_{v8}(t))\cos(\alpha) - (H_{u10}(t) + H_{u5}(t))\sin(\alpha)\} \tag{4}$$

- The calculated Fourier transform of H_x must be multiplied by $\exp(-0.5\ \omega\ \Delta t)$ to take into account the shift in time between the H- and E- field components.

EXTRACTION OF S-PARAMETERS

For clarity, let us consider a two-port circuit. The equations for scattering parameters are:

$$S_{11}\frac{a_1}{b_1} + S_{12}\frac{a_2}{b_1} = 1 \tag{5}$$

$$S_{21}\frac{a_1}{b_2} + S_{22}\frac{a_2}{b_2} = 1 \tag{6}$$

The amplitudes of waves incident on input (a_1) and output (a_2), and reflected from input (b_1) and output (b_2) are proportional to the square root of transmitted power. They are also proportional to the amplitudes of electric field at the probing point:

$$a_1 = C_1 E_{t1}^{+}(\omega) \tag{7}$$
$$b_1 = \Gamma_1 C_1 E_{t1}^{+}(\omega) \tag{8}$$
$$a_2 = C_2 E_{t2}^{+}(\omega) \tag{9}$$
$$b_2 = \Gamma_2 C_2 E_{t2}^{+}(\omega) \tag{10}$$

To extract the **S**-parameters by (5) and (6) we need the value of $C = C_1 / C_2$. Note that $C=1$ if the input and output ports are identical, and the input and output probing points are analogously located in the cross-section of the line. Otherwise, in reciprocal circuits, we apply equations (5) and (6) twice for consecutive excitations from ports 1 and 2. With the reciprocity condition $S_{12}=S_{21}$ we solve the system of four equations with four variables including C.

EXAMPLES OF APPLICATION

Let us consider a structure of Fig.2. It is based on an inhomogeneous parallel-plate waveguide and it has dispersive properties similar to other quasi-TEM lines such as microstrip or coplanar. We analyse the structure up to 9GHz while the cut-off frequency of the first non-TEM mode is about 11GHz. We will show that the S11 parameter can be extracted on oblique ports, practically independently of:

- angle α between the port line and the grid,
- quality of absorbing terminations.

To calculate S11 we apply the differential method in one probing point of the input line and one probing point of the output line (see Fig.2). Then we use equation (5) which after taking advantage of the reciprocity of the circuit ($S_{12} = S_{21} \cong b_2 / a_1$) transforms to:

$$S_{11} = \frac{b_1}{a_1} + \frac{a_2 b_2}{a_1^2} \qquad (11)$$

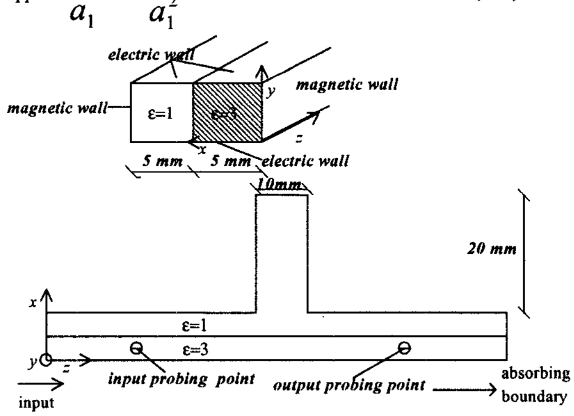

Fig.2. The structure used in example of application

We run the simulation three times with different angles α (see Fig.3). The results of Fig.4 show that the errors practically do not depend on angle α which confirms the method's accuracy on oblique ports. Let us stress that the six field components on oblique metal boundary have been approximated with non-rectangular cells (see Fig.3) using the combination of the techniques described in [7] and [11]. Thus the results also indirectly confirm the accuracy of our method of boundary approximation.

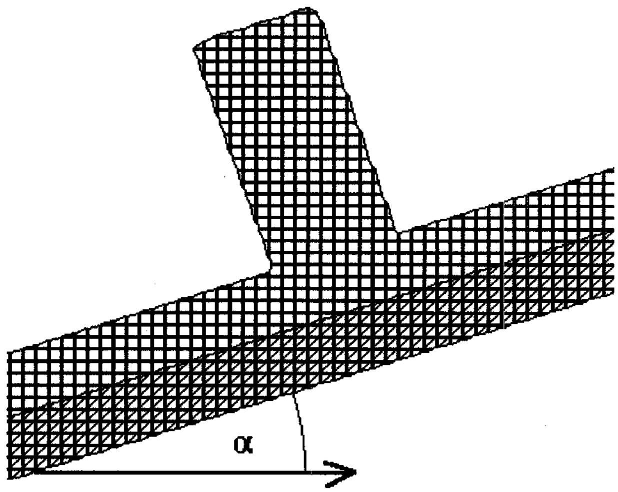

Fig.3. FD-TD grid used in analysis of the structure of Fig.2 assuming α=18.4°.

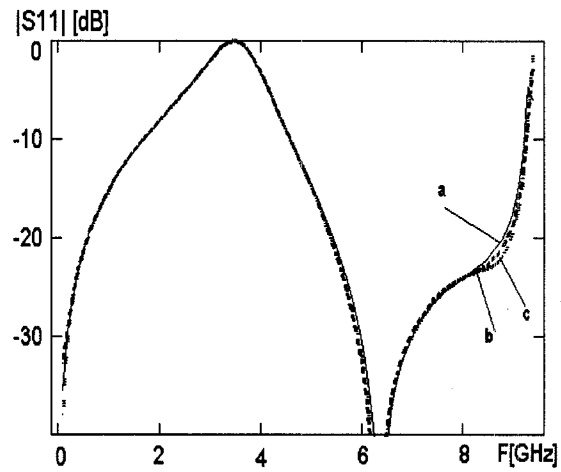

Fig.4. |S11| of the structure of Fig. 2 analysed assuming non-oblique grid (***a***) and oblique grids with α=18.4° (***b***) and α=33.7° (***c***)

We repeat calculations with α=0, in two cases:

- with reflection coefficient at the output at the level of about -30 dB,
- with reflection coefficient at the output at the level of about -16 dB.

Even such a poor absorbing boundary does not significantly deteriorate the accuracy of S11 analysis. This is seen on Fig.5 where the results of |S11| calculation represented by curves *c* and *d* are practically the same.

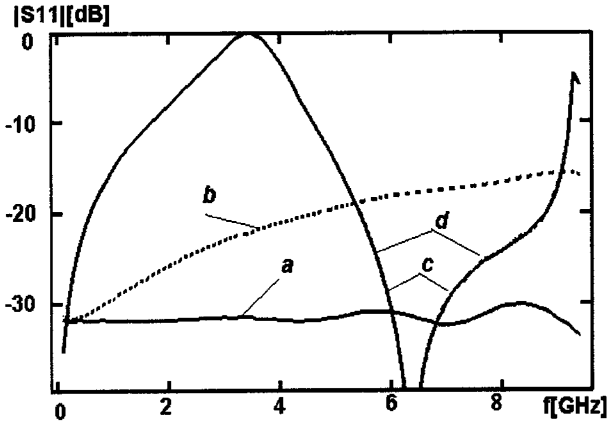

Fig.5.Small influence of the quality of absorbing boundaries: curves ***a*** and ***b*** show the reflection coefficient on absorbing output in two cases, and curves ***c*** and ***d*** the corresponding values of |S11| calculated at the input by the present method.

CONCLUSIONS

The proposed method for S-parameter extraction proved to be simple, universal and very accurate providing that monomode transmission is assured in the considered probing plane. In reciprocal microwave circuits no knowledge of the modal field distribution in the port is needed. This is very important in the analysis of inhomogeneous transmission lines when the field distribution of the mode changes with frequency. Furthermore, we have demonstrated that the method is applicable to oblique ports, and highly immune to the quality of absorbing terminations.

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