Simulations with the 3D TLM SCN Using FD-TD Absorbing Boundary Conditions

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Abstract

The FD-TD absorbing boundary conditions for one-dimensional wave propagation are adapted to the 3D SCN (Symmetrical Condensed Node) TLM mesh. The properties of these boundary conditions are characterized for a simple TEM waveguide structure, and their applicability to complex structures is demonstrated by calculating scattering parameters for a microstrip step.

Introduction

Many papers on the TLM method are presenting results evaluated by a resonant cavity formulation using 2D or 3D meshes [1, 2]. Since Johns proposed the use of a 3D SCN [3] for the simulation of electromagnetic fields, the efficiency of the TLM method has steadily approached that of the FD-TD method because of its favorable dispersion characteristics and the yield of all six field components at one point in space. When employed in a transient-type regime this node is very efficient in analyzing complex structures. Therefore it is necessary to formulate free-space boundary conditions to simulate an imaginary extension of the computational domain.

Theoretical Background

There exist several types of absorbing boundary conditions [4, 5, 6], but each of them strives for a solution of Sommerfeld's radiation condition by applying special algorithms. One possibility is to use the properties of the one-dimensional wave propagation.

The wave equation for plane wave propagation in positive x-direction can be solved by

$$E_{tan}(t,x) = E_{tan}(t - \frac{x}{v_{ph}}) \qquad (1)$$

where E_{tan} is the electrical field transversal to the propagation direction (tangential to the boundary) and v_{ph} is the phase velocity. The used absorbing boundary algorithm for the field at the boundary x_b at time t_b assumes that it is the same as just one space step Δl in front of the boundary at an earlier time $t_b - t_0$ which demands

$$E_{tan}(t_b, x_b) \stackrel{!}{=} E_{tan}(t_b - t_0, x_b - \Delta l), \qquad (2)$$

leading to the delay time

$$t_0 = \frac{\Delta l}{v_{ph}} \qquad (3)$$

This means that one can predict the value of the field at the boundary by buffering the fields one space step in front of the boundary for a time t_0. This delay time must be an integer number to fit all discrete conditions of the system, which demands synchronism of pulses because of discrete space and time.

This method can also be applied to the 3D SCN TLM mesh provided that one guaranties that the plane of nodes in front of the boundary supports only TEM field propagation.

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Results

The described algorithm works very well for a free space simulation, but instability occurs when inhomogeneous material fills the computational domain (Fig. 1). This phenomenon is analytically described in [7]. The instability problem can be solved by a modification of the algorithm, meaning that the field values are no longer predicted by buffering. Now a linear interpolation between the two actual values at the boundary and one space step in front of it is used to predict the next field value at the boundary. Thus it is no longer necessary to restrict the delay time t_0 to integer numbers.

To characterize the behavior of this algorithm, a parallel plate waveguide structure has been terminated with such a wall [8]. Its reflection coefficient shown versus normalized frequency $\frac{\Delta l}{\lambda}$ with the relative permittivity as parameter in Fig. 2. This algorithm is stable and leads to acceptable reflections. The reflections are slightly dependent on the relative permittivity.

This modified algorithm has also been applied to the calculation of S-parameters for a microstrip step. The step was arranged on Galliumarsenide substrate of $100\mu m$ height. The width of the conductors were $w_1 = 75\mu m$ (port 1) and $w_2 = 150\mu m$ (port 2). Fig. 3 shows the S-parameters versus frequency for this microstrip step [8] and compares them to the results for a magnetic wall model [9]. The absolute value shows good agreement with the reference calculation while the phase shows larger deviations. Fig. 4 gives the electric field component E_y perpendicular to the upper dielectric surface at different times of the transient type analysis for a microstrip step.

Errors

The introduced TLM absorbing boundary algorithm leads to small reflections which influence the S-parameter calculations. These reflections occur because the algorithm assumes plane wave propagation without dispersion. Therefore the chosen phase velocity is correct only for low frequencies and only for one of the ports. Different ports can be terminated differently except when they are positioned at the same absorbing boundary.

Conclusions

An absorbing boundary condition previously used for FD-TD simulations has been applied to the 3D SCN TLM mesh. Since it led to instability it had to be modified. The modified algorithm is stable and yields to acceptable reflections.

Acknowledgement

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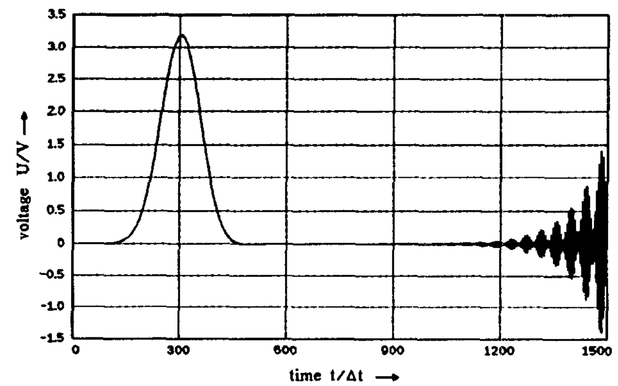
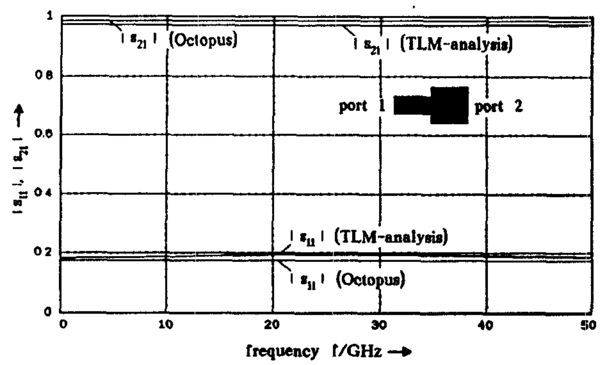


Figure 1: Instability of the absorbing boundary algorithm based on buffering of the fields. The behavior is shown for a Gaussian pulse traveling towards the boundary.[8]



a) absolute values of s_{11} and s_{21} versus frequency.

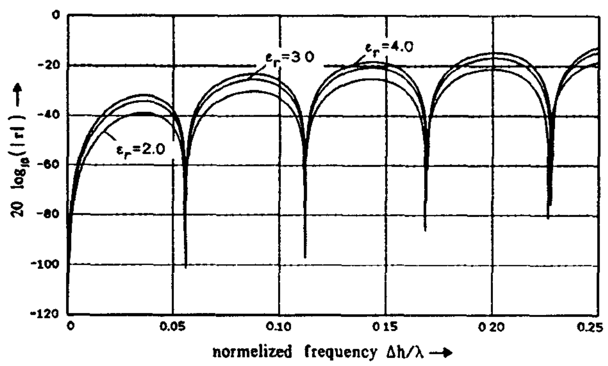
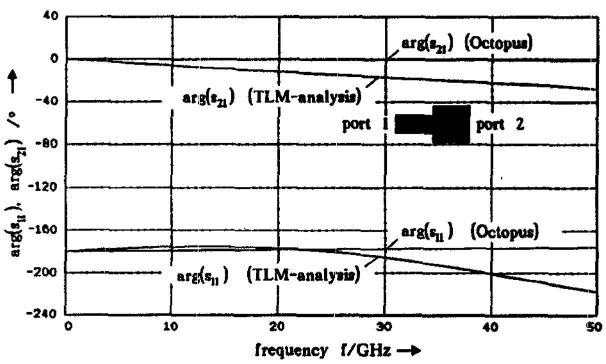
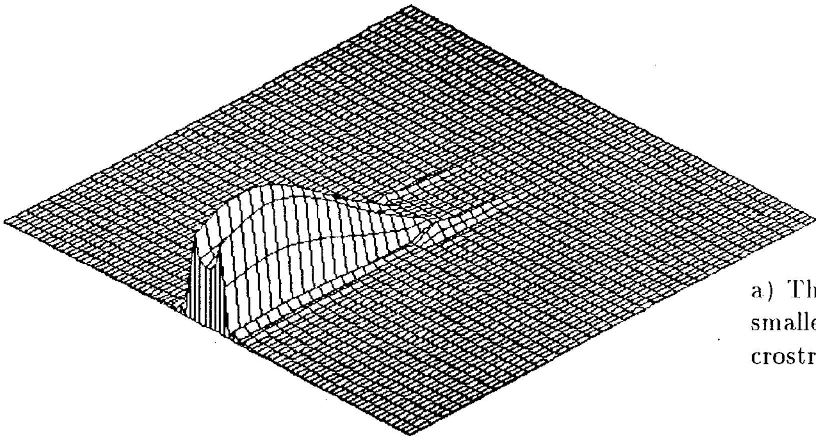


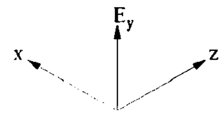
Figure 2: Reflection characteristics of an absorbing boundary using the linear prediction algorithm. The reflection coefficient is given versus normalized frequency $\frac{\Delta l}{\lambda}$ with the relative permittivity as a parameter [8].



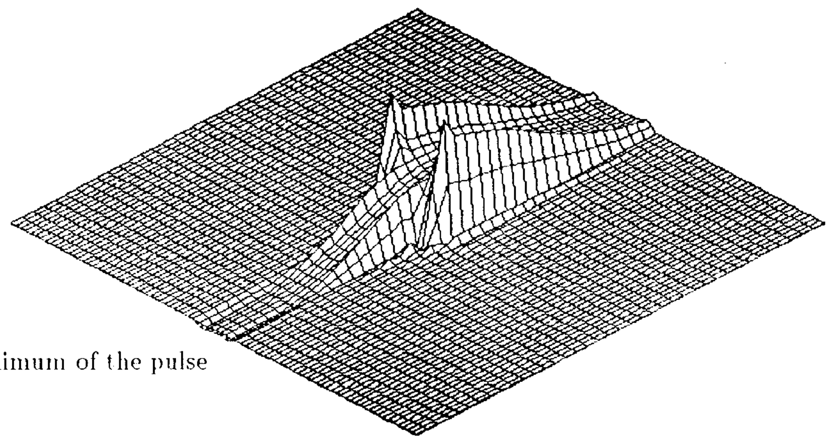
b) angles of s_{11} and s_{21} versus frequency.

Figure 3: Scattering parameters of a microstrip step evaluated by the TLM method [8] in comparison with a magnetic wall model [9].

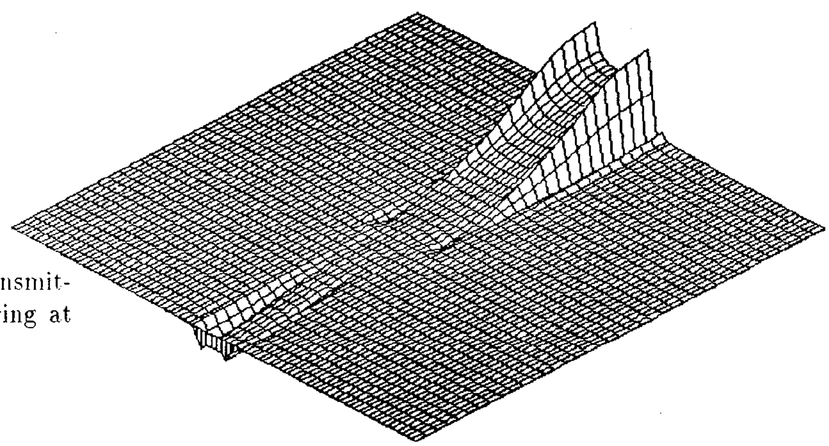




a) The exciting pulse on the smaller line in front of the microstrip step.



b) The maximum of the pulse at the step.



c) The reflected and transmitted pulses after scattering at the step.

Figure 4: a) - c) A transient type analysis at different times: the electric field component E_y perpendicular to the upper dielectric surface of a microstrip step is shown.