IMPROVED EXCITATION OF 3D SCN TLM BASED ON VOLTAGE SOURCES

J. L. Herring and W. J. R. Hoefer

NSERC/MPR Teltech Research Chair in RF Engineering, Department of Electrical & Computer Engineering, University of Victoria, P.O. Box 3055, Victoria, B.C., Canada, V8W 3P6.

ABSTRACT

The implementation of voltage, current, electric field and magnetic field sources is described. The correct voltage pulses that must be injected into a TLM network to produce a given temporal and spatial field distribution are obtained by placing voltage sources in a reference structure. This gives a field of known amplitude in which transients decay more rapidly than with the conventional approach. The method is applied to a waveguide.

INTRODUCTION

The transmission-line matrix (TLM) method of numerical electromagnetic analysis in three dimensions with the symmetrical condensed node is well established [1]. Voltage pulses are introduced into the system and the time evolution of the fields is observed at appropriate output points. An impulse excitation can be used to obtain information at all frequencies within the working frequency range of the mesh. However, it is often necessary to use a band-limited excitation, for example, to avoid instabilities with certain kinds of absorbing boundary conditions, or to reduce signal processing problems. For such a continuous waveform, the usual approach is to assume that the voltage pulses that must be added to the pre-existing pulses are simply proportional to the desired incident field at each instant in time. In this paper, it will be shown how "hard" sources may be introduced at a node. In structures such as waveguides, the transients due to the highly dispersive impedance are reduced by strictly imposing the input waveform. By making use of a reference structure excited by voltage sources to obtain the voltage pulses introduced by the sources, and then injecting these pulses into the structure under study, the advantages of rapidly decaying transients and absorption of reflected waves can be combined.

SOURCES IN TLM

In TLM there is considerable flexibility in the choice of where elements such as sources are introduced, for example, they may be placed at a node or at the mid-point of the *link-lines* connecting adjacent nodes. Simple circuit theory can be used to introduce voltage or current sources on the link-lines. Here, sources are placed at a node. To do this, use is made of the fact that the pulses scattered from a node can be written as [2]:

$$V^r_{inj} = \phi_j + \psi_k - V^i_{ipj} \qquad V^r_{ipj} = \phi_j - \psi_k - V^i_{inj}$$

where i, j, k subscripts are the directions (x, y, z), Z_0 is the link-line characteristic impedance and the three voltage pulse subscripts denote the direction of the link-line, 'n' or 'p' for the negative or positive side of the node (taking the centre as the origin), and the link-line polarization. For normal scattering ϕ_j and ψ_k are obtained from the incident pulses. To impose an electric or magnetic field, ϕ_j or ψ_k are set to one of the following values

$$\phi_j = -E_j \Delta l \qquad \psi_k = H_k Z_0 \Delta l$$

For the general case of a voltage source with finite series resistance, the imposed voltage can be obtained from the Thévenin equivalent circuit, as shown in fig.1 for the hybrid node [3]. Here, three distinct values of characteristic impedance are used for the twelve link-lines on each node and these are associated with the three components of the magnetic field. For each electric field component there are incident pulses V^i_1 and V^i_2 from link-lines with normalized admittance $\hat{Y}_a$, pulses V^i_3 and V^i_4

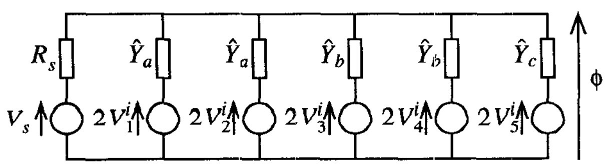
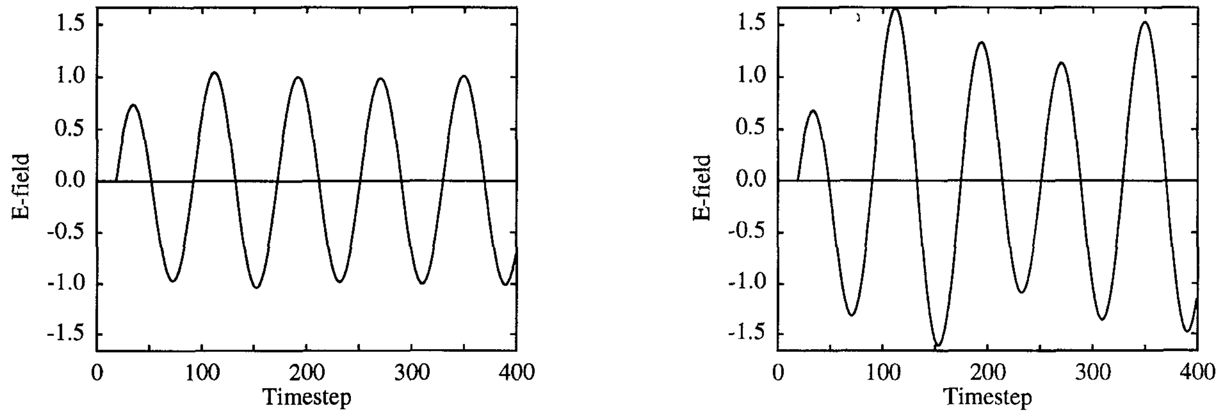


Fig. 1 – Calculation of total voltage

0-7803-3246-6/96/$5.00 © IEEE



(a) hard voltage source

(b) conventional additive excitation

Fig. 2 – Response of a waveguide to the onset of a sinusoidal waveform excitation

from link-lines $\hat{Y}_b$ and pulse V_5^i from stub $\hat{Y}_c$. The source V_s has series resistance R_s.

$$\phi = \frac{1}{k_1}\left(\frac{Z_o V_s}{R_s} + 2\left[\hat{Y}_a(V_1^i + V_2^i) + \hat{Y}_b(V_3^i + V_4^i) + \hat{Y}_c V_5^i\right]\right)$$

$$\text{where} \qquad k_1 = \frac{Z_0}{R_s} + 2(\hat{Y}_a + \hat{Y}_b) + \hat{Y}_c$$

A similar expression may be obtained for the stub-loaded node by setting $\hat{Y}_a$ and $\hat{Y}_b$ to unity. For the standard 12-port node $\hat{Y}_c$ is set to zero. Current sources can be included by replacing the voltage source and series resistance with the equivalent current source and shunt conductance.

A voltage source can be applied between two nodes separated by an arbitrary distance using the procedure described by *Al-Asadi et. al.*[4]. For the hybrid node, the total voltage and the total normalized impedance between the two nodes are given by

$$V_{tot} = \sum \frac{2\left[\hat{Y}_a(V_1^i + V_2^i) + \hat{Y}_b(V_3^i + V_4^i) + \hat{Y}_c V_5^i\right]}{2(\hat{Y}_a + \hat{Y}_b) + \hat{Y}_c}$$

$$\hat{Z}_{tot} = \sum \frac{1}{2(\hat{Y}_a + \hat{Y}_b) + \hat{Y}_c}$$

A current source of value

$$I_s = \frac{V_s - V_{tot}}{R_s + Z_0 \hat{Z}_{tot}}$$

is then placed on all nodes over which the voltage source is applied.

IMPLEMENTATION

Sources can be implemented by substituting a new scattering procedure. Alternatively, the same effect can be achieved by modifying the incident pulses so that the correct scattered pulses are obtained after a standard scattering event. In matrix notation, the scattering process can be written as

$$[V^r] = [S]\,[V^i]$$

The modified incident pulses, $V^{i'}$, are obtained by solving the equation

$$[S_{std}]\,[V^{i'}] = [S_{source}]\,[V^i]$$

where S_{std} is the standard scattering matrix and S_{source} is the scattering matrix with sources present. Only the voltage pulses associated with the same field component as the source are affected. After suitable manipulation it can be shown that application of a source can be accomplished by adding a quantity ΔV to each of the four link-lines and the stub. For an electric field source with the hybrid node

$$\Delta V = \phi - \frac{2}{k_2}\left[\hat{Y}_a(V_1^i + V_2^i) + \hat{Y}_b(V_3^i + V_4^i) + \hat{Y}_c V_5^i\right]$$

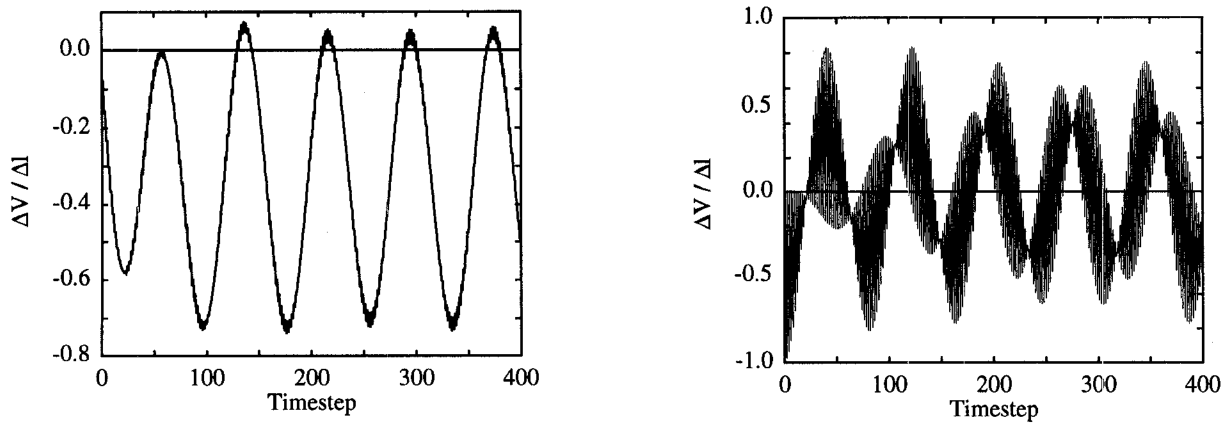
$$\text{where} \qquad k_2 = 2(\hat{Y}_a + \hat{Y}_b) + \hat{Y}_c$$

$$V_n^{i'} = V_n^i + \Delta V \qquad n = 1, 2, 3, 4, 5$$

A similar procedure can be adopted for a magnetic field source. For the stub-loaded node

$$\Delta V = \psi - \frac{2}{4 + \hat{Z}_s}(V_1^i - V_2^i - V_3^i + V_4^i - V_5^i)$$

$$V_n^{i'} = V_n^i + \Delta V \qquad n = 1, 4$$



(a) sine wave (b) cosine wave

Fig. 3 – Pulses injected by sources to maintain the desired waveform

$$V_n^{i'} = V_n^i - \Delta V \qquad n = 2, 3$$

$$V_5^{i'} = V_5^i - \hat{Z}_s \Delta V$$

Here, V_1^i to V_5^i are the incident pulses from the link-lines and stub contributing to the magnetic field and $\hat{Z}_s$ is the normalized short-circuit stub impedance.

APPLICATION TO A WAVEGUIDE

The difference between applying a sinusoidal voltage source and just adding pulses with magnitude proportional to a sinusoid is shown in fig. 2 for a waveguide cross-section of 30x15 nodes. The excitation is applied over a plane with the spatial distribution of the dominant mode. In the second case, the amplitude is somewhat indeterminate and steady-state is not achieved quickly. The excitation introduces local non-propagating modes that impose a slowly decaying modulation on the desired propagating mode. For the additive type excitation, a more satisfactory electric field can be obtained by exciting the magnetic field.

The pulses injected by the voltage sources in order to maintain the desired input waveform are shown in fig. 3 for the cases of sine and cosine functions. The voltage pulses have been normalized with respect to the node spacing.

CALCULATION OF S-PARAMETERS

With a conventional additive excitation, one method of calculating S-parameters is to place the same excitation in a reference structure as in the structure under study. The incident wave is then obtained directly from the reference structure (in which there is no reflected wave). The reflected wave is obtained from the total field in the main simulation by subtracting the incident wave. This accounts for the fact that the amplitude, and in general the shape, of the incident wave cannot be predicted.

A hard source cannot be used directly to obtain S-parameters since it will not absorb the wave reflected from the input port. However, hard sources can be placed in a reference structure and, for each node in the cross-section, the pulses injected by the source, ΔV, can be obtained and then these can be added in to the structure under study. The reflected wave is again obtained by subtracting the incident wave from the total field but in this case the incident wave is exactly that specified as the excitation waveform.

In both cases a reference structure is required but this need only be a single node thick if the ends are terminated with Johns matrix boundaries [5]. In cases where the field must be obtained at the same points as the excitation, it must be calculated from both the incident and reflected pulses since the usual condition, that the charge due to the incident pulses is the same as the charge due to the scattered pulses, does not hold. For example, for the 12-port node the E_x field must be calculated as

$$E_x = \frac{1}{4\Delta l}(\Sigma V^i + \Sigma V^r)$$

where $\Sigma V^i = (V^i_{ynx} + V^i_{ypx} + V^i_{znx} + V^i_{zpx})$

and $\Sigma V^r = (V^r_{ynx} + V^r_{ypx} + V^r_{znx} + V^r_{zpx})$

As an example, a typical discontinuity consisting of a non-touching axial strip has been analyzed with a modulated Gaussian input waveform [6]. The geometry is shown in fig. 4. With conventional excitation the waveform that is actually introduced is distorted and the peak is shifted down in frequency by 0.2GHz. The incident waves are compared in fig. 5a in the frequency domain. The incident and reflected waves obtained with the new scheme are shown in fig. 5b in the time domain. This graph would be difficult to reproduce exactly with conventional additive excitation.

CONCLUSIONS

Hard voltage and current sources, as well as electric and magnetic field sources can be easily incorporated into the TLM node. Such sources can be used to obtain the voltage pulses that must be injected to give the desired temporal and spatial field distribution. This allows excitation with a field of known amplitude in which the transients decay more rapidly than in the conventional approach. This is important for visualization purposes and is essential if the amplitude must be known in advance, for example, when modeling non-linear systems.

REFERENCES

1. P. B. Johns, "A symmetrical condensed node for the TLM method", *IEEE Trans. MTT*, vol. 35, no. 4, pp 370–377, Apr 1987.
2. P. Naylor and R. Ait-Sadi, "Simple method for determining 3-D TLM nodal scattering in nonscalar problems", *Electronics Letters*, vol. 28, no. 25, pp 2253–2354, 3 Dec 1992.
3. R. Scaramuzza and A. J. Lowery, "Hybrid symmetrical condensed node for the TLM method", *Electronics Letters*, vol. 26, no. 23, pp 1947–1948, Nov 1990.
4. M. Al-Asadi, T. M. Benson and C. Christopoulos, "Interfacing field problems modelling by TLM to lumped circuits", *Electronics Letters*, vol. 30, no. 4, pp 290–291, Feb 1994.
5. C. Eswarappa, G. J. Costache and W. J. R. Hoefer, "Transmission line matrix modeling of dispersive wide-band absorbing boundaries with time domain diakoptics for S parameter extraction", *IEEE Trans. MTT*, vol. 38, pp 370–386, Apr 1990.
6. J. L. Herring and W. J. R. Hoefer, "Accurate modelling of zero thickness septa with the symmetrical condensed node", *1st International TLM Workshop*, Victoria, Canada, pp 237–240, 1–3 Aug 1995.

ACKNOWLEDGEMENTS

This research has been funded by the Natural Sciences and Engineering Research Council of Canada, the Science Council of British Columbia, MPR Teltech Inc. of Burnaby, B.C., and the University of Victoria.

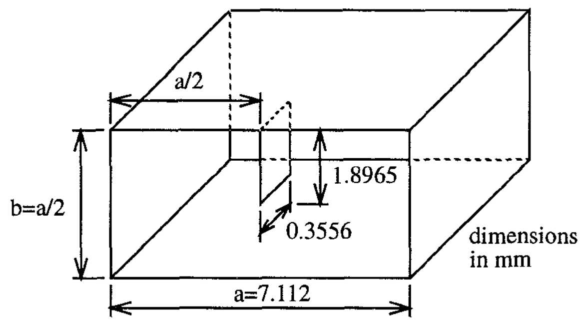
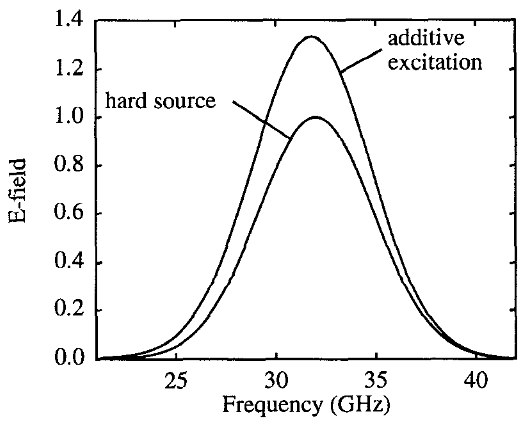
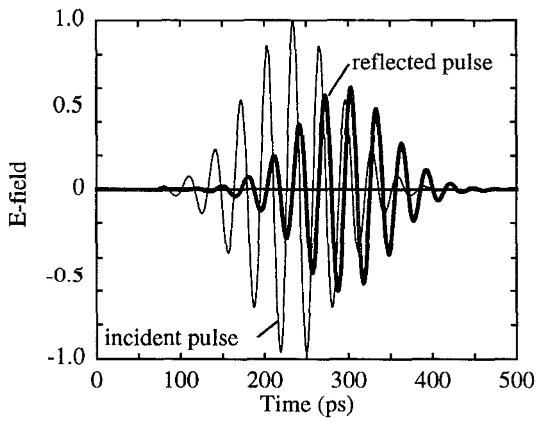


Fig. 4 – Geometry of non-touching axial strip



(a) incident pulses in the frequency domain



(b) incident and reflected pulses in the time-domain (voltage source)

Fig. 5 – Electric field on the input plane of a rectangular waveguide containing a non-touching axial strip