AN ALTERNATIVE WAY OF COMPUTING S-PARAMETERS VIA IMPULSIVE TLM ANALYSIS WITHOUT USING ABSORBING BOUNDARY CONDITIONS.

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ABSTRACT

This paper presents a transmission line matrix (TLM) procedure to compute wideband scattering parameters of microwave structures from a single time domain simulation without using matched loads or absorbing boundary conditions (ABCs) in the main propagating direction. This is done by computing the admittance parameters in the time domain through an impulsive excitation and short-circuit boundary conditions (SBCs). Results presented for both lossy and lossless cases agree well with available data. Also, this procedure does not require the prior knowledge of the propagation characteristics (such as incidence angle or effective dielectric constant) of the guide.

INTRODUCTION

The two major advantages of time domain numerical methods such as the Transmission Line Matrix (TLM) [1] and Finite Difference-Time Domain (FDTD) [2] method are the ability to analyze complex structures with arbitrary geometry, and obtain the frequency characteristics over a wide frequency spectrum with a single time domain simulation. In particular, the TLM method has the capability of impulsive excitation and is stable under this condition. However, the impulsive excitation is avoided for practical structures for various reasons: strong dispersion at high frequencies, excitation of spurious modes in the TLM mesh, longer convergence time, and most importantly the lack of high quality (broadband and stable) absorbing boundary conditions. Higher-order absorbing boundary operators may be used to increase the bandwidth of absorption [3], but long time stability may be difficult to achieve. To overcome this problem, we propose to compute the scattering parameters via admittance parameters. Computation of admittance parameters does not require matched loads (or absorbing boundary conditions). Impulsive voltage excitation and short circuit conditions at the ports enable the computation of admittance parameters directly in the time domain. Moreover, the Y parameters provide an easy way of extracting the lumped element equivalent circuits through Foster synthesis [4].

THEORY

If a one-port linear circuit is excited with a voltage source v(t), the response current i(t) can be obtained by convolving the voltage source v(t) and the input admittance y(t):

$$i(t) = \int y(t_1 - t)\, v(t_1)\, dt \qquad (1)$$

If v(t) is an impulse excitation, the current i(t) at the same port becomes equal to the input admittance of the circuit. If v(t) is not an impulse excitation, a numerical deconvolution [5] of i(t) with v(t) must be performed in order to obtain the input admittance in the time domain. Since the TLM method allows impulse excitation, the admittance in time can be directly computed by recording the stream of current pulses at the input port. This procedure can be easily extended to multiport circuits by applying a multiport version of equation (1).

We have implemented the above procedure for the 3D-Symmetrical Condensed Node (SCN) (Fig. 1) TLM algorithm [6-7]. Impulse voltage excitation is applied by injecting a unit voltage on the branch 2 of the first node at t=0 traveling in x-direction. Short circuit conditions are placed at both the input and output ports of the structure immediately after the excitation. The impulse values on the branch 1 of the first node and on the branch 2 of the last node are recorded. The response currents at the input and output ports can be obtained by dividing these impulse streams by the characteristic impedance of the link lines.

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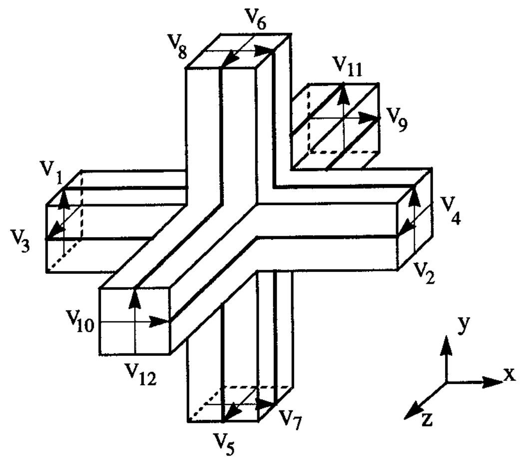

Fig. 1 3D Symmetrical Condensed Node (SCN)

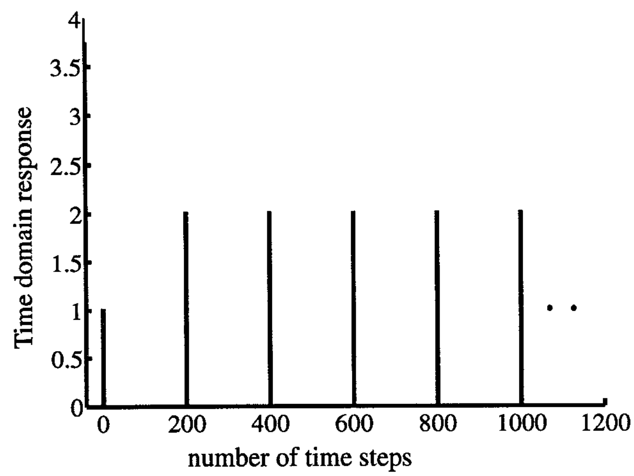

Fig. 2 Time domain response current obtained at the short-circuited reference plane of a plane wave stub

These correspond to the admittance parameters y_{11} and y_{21} in the time domain. Similarly, by exciting the other port, the admittance parameters y_{22} and y_{12} in the time domain can be obtained. These time domain admittance parameters are then Fourier transformed to obtain the frequency domain admittances. The frequency domain scattering parameters are then easily obtained by standard transformations.

The above procedure has first been verified by applying it to a parallel plate waveguide stub carrying a TEM wave, short-circuited at 50 Δl from the reference plane. The time domain current obtained on the reference plane in response to the impulsive voltage excitation (equivalent to the time domain admittance of the stub) is shown in Fig. 2. This time domain signal can be represented by the following series:

$$y(t) = \delta(t) + 2\sum_{n=1}^{\infty} \delta(t-2nk) \qquad (2)$$

where $\delta(t)$ represents a Dirac delta function and $k=100\ \Delta t$. The Laplace transform of (2) can be analytically performed [8]:

$$\begin{aligned} Y(s) &= L[y(t)] = 1 + \sum_{n=1}^{\infty} e^{-2kns} = \\ &= \frac{2e^{2ks}}{e^{2ks}-1} - 1 = \frac{\cosh(ks)}{\sinh(ks)} = \coth(ks) \end{aligned} \qquad (3)$$

The admittance obtained, $Y(s)=\coth(ks)$, is the analytical input admittance of the stub. Note that the TLM algorithm gives the results that are exactly equal to the analytical time domain values since the SCN presents no dispersion for waves travelling in the axial direction.

NUMERICAL RESULTS

Having verified the procedure in case of a TEM stub, we have applied it to a WR-28 waveguide lossy stub. It was discretized with SCN TLM nodes with 48 nodes along the width of the waveguide and 50 nodes along its length. The loss tangent ($\tan\delta$) of the medium was 0.1. To account for this dielectric loss in the TLM analysis, loss stubs of characteristic admittance $g = \frac{\omega\varepsilon_r \Delta l \tan\delta}{c}$ were added.

The stub was excited at the input port along the branches with voltage impulses whose magnitudes were spatially distributed according to the dominant mode field distribution. Because the response current obtained is an infinite series, windowing of the series must be done in order to reduce the truncation error in the Fourier transform performed on a finite number of time steps. In this case a triangular window has been used although other windows such as Hamming, Hanning, etc., can be employed. The real and the imaginary part of the admittance have been compared with analytical results in Fig. 3. They agree well in the entire operating frequency range of the waveguide.

Next, a two-port circuit has been considered. A thick inductive iris with aperture $a/2$ and thickness $a/6$ in a WR-28 waveguide has been analyzed. Because of symmetry, only one half of the structure was discretized with

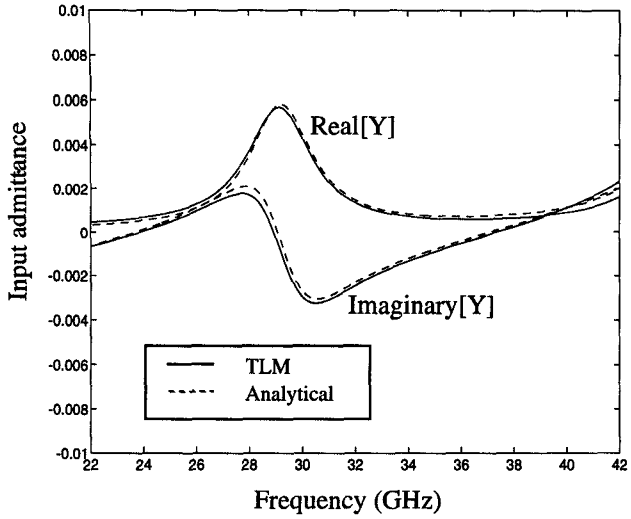

Fig. 3 Comparison of the analytical and TLM input admittance for a lossy waveguide stub

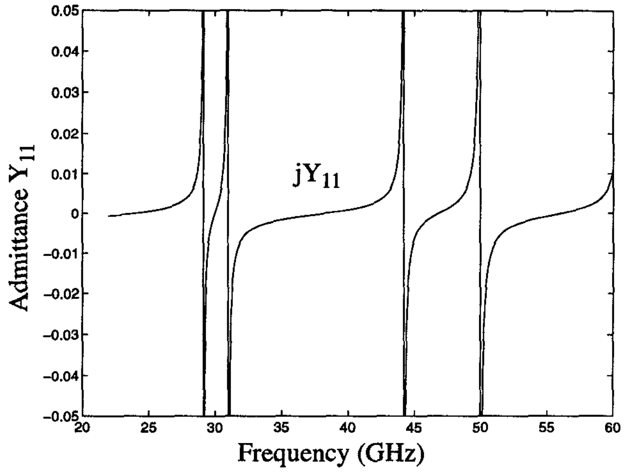

Fig. 4 Admittance Y_{11} for the iris in a WR-28 waveguide computed from the TLM time admittance

space resolution Δl=a/48. The reference planes have been placed at a distance of 7a/8 from the discontinuity for a total mesh size of 92*1*24 cells.

The admittance computed in the time domain under impulsive excitation and transformed into the frequency domain are shown in Figs. 4 and 5.

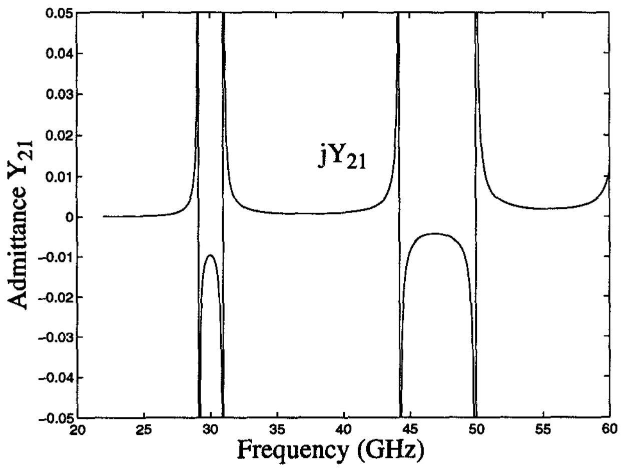

Fig. 5 Admittance Y_{21} for the iris in a WR-28 waveguide computed from the TLM time admittance

A comparison of S-parameters computed with three different methods, namely via admittance parameters (SBC), via direct computation using matched loads (ABC [9]) and via Marcuvitz's equivalent circuit model [10] are plotted in Fig. 6.

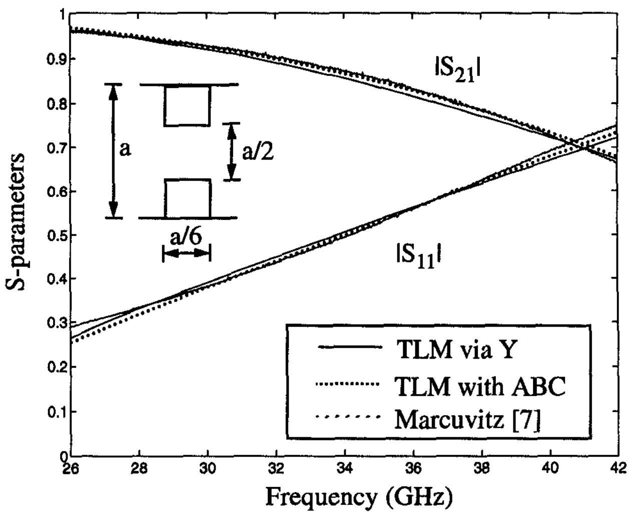

Fig. 6 Comparison of S-parameters for a thick inductive iris in a WR-28 waveguide computed via admittance parameters, with ABC and Marcuvitz [10].

DISCUSSION AND CONCLUSIONS

A new procedure for the TLM characterization of microwave structures has been presented which yields the admittance matrices directly in the time domain. It allows extraction of scattering parameters of closed structures such as waveguide components and quasi-planar circuits without the need for matched loads (ABC in the propagation direction). However, for open structures, ABCs on the side and top walls are still required.

It should be noted that this procedure requires a larger number of time steps than the analysis with ABCs because of the impulsive excitation and resonant behaviour due to the short circuit conditions. Time can be reduced by exciting with band-limited pulses and performing a numerical deconvolution. However, for structures for which the knowledge of the propagation characteristics of the guide (such as direction of the propagation vector, effective dielectric constant) is not known, this time domain admittance procedure represents an attractive alternative approach.

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