TIME-DOMAIN METHOD OF LINES APPLIED TO THE UNIFORM MICROSTRIP LINE AND ITS STEP DISCONTINUITY

S. Nam, H. Ling and T. Itoh

Dept. of Electrical and Computer Engineering
The University of Texas at Austin
Austin, TX 78712
U.S.A.

ABSTRACT

The general formulation and the procedure of the time-domain method of lines for the analysis of wave scattering and propagation properties in planar circuit are described. The results of the time-domain data and the derived frequency domain characteristics for the uniform microstrip line and its step discontinuity are presented.

INTRODUCTION

The time-domain analysis of microwave planar transmission structures provides an alternative to the frequency domain approach. It is also useful for studying the behavior of pulsed signals in structures such as high speed digital circuits. A typical time-domain analysis requires discretization of a three-dimensional space into a three-dimensional mesh [1]. Usually, large computer storage and long computation time are required.

The time-domain method of lines (TDML) originates from the fact that most of the discontinuities appearing in the planar transmission structures are located on the substrate surface and the space below and above this surface is uniform and homogeneous. We wish to solve the problem by discretizing only in a two dimensional surface on the substrate where the discontinuity is located. This is possible if the wave scattering information in the direction perpendicular to the substrate surface is available analytically. The TDML actually incoporates this process and reduces the dimension of the problem by one.

Previously, the TDML has been applied only to two-dimensional problems to obtain the scattering data of the input pulse in the time domain and the cutoff characteristics in the frequency domain for planar transmission structures[2]. In this paper, it is shown that the TDML can be extended to three-dimensional problems. The time-domain data for a planar transmission line and its discontinuities can be obtained by TDML. From the time-domain results, the frequency domain characteristics can be found by Fourier transform. The results for the uniform microstrip line and the step discontinuity are presented and compared with the available published data.

The present method is different from [3] in which the time domain data were calculated from the frequency domain results based on the method of lines [4]. In that method[3], the S-parameters of a discontinuity were obtained at a given frequency by finding three resonant structures (tangent method). This process is repeated for a wide range of frequency points and then the inverse Fourier transform is invoked to find the time domain data. The method presented here works with a fixed geometry. The time signal at any time is found directly by this method. The frequency response can be found by invoking the Fourier transform.

FORMULATION AND PROCEDURE OF THE METHOD

Let us consider a general planar transmission line with discontinuity shown in Fig. 1. In order to apply the TDML, electric walls or magnetic walls should be placed at both ends of the waveguide so that a resonant structure results. Figure 2 shows the top view of the structure with discretization points for the y component of electric field, E_y. It is assumed that the structure has spatial symmetry in x-direction so that the problem can be reduced by the factor of two.

(i) Discretization

As shown in Fig. 2, the structure is discretized by field lines which are properly placed to satisfy the boundary conditions on the side walls and the end walls. For example, since the Neumann boundary condition for E_y is applied along side wall A and the Dirichlet condition at side wall B, the E_y points are located away from the side wall A by one half of Δx and away from side wall B by one Δx.

(ii) Expansion of Input Pulse

In the structure shown in Fig.1 with end walls, a field distribution at any time t, $[E_y(y)]_t$, can be expanded by modal field distributions, $[E_{yn}(y)]$ as follows;

$$[E_y(y)]_t = \Sigma_n (A_n \cos \omega_n t + B_n \sin \omega_n t) [E_{yn}(y)] \qquad (1)$$

where [ ] denotes a column vector whose i-th component represents the field value at the i-th discretization line. Also the subscripts t and n denote the time and the mode number respectively.

In the expansion (1), the coefficients A_n can be determined by the input field distribution, $[E_y(y)]_{t=0}$ and the orthogonal property of the modal fields.

$$A_n=\int[E_y(y)]_{t=0}[E_{yn}(y)]dy \,/ \int[E_{yn}(y)]^t[E_{yn}(y)]dy \qquad (2)$$

Also, the B_n can be found by the causality condition used in

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the time iteration method[5]

$$B_n = A_n \tan(\omega_n \Delta t / 2) \qquad (3)$$

$$\text{where } \Delta t \le \min(\Delta x, \Delta z) / C_{max}\sqrt{3} \qquad (4)$$

and C_{max} is the maximum wave phase velocity within the structure.

In order to find the engenfrequencies and eigenmodes of the structure, we borrow the technique in frequency domain method of lines[4]. In this technique, the characteristic equation is obtained from the application of the metallic boundary condition to the metalization on the dielectric boundary. The equation is given by

$$\begin{bmatrix} E_z \\ E_x \end{bmatrix}_{red} \begin{bmatrix} [Z_{11}] & [Z_{12}] \\ [Z_{21}] & [Z_{22}] \end{bmatrix}_{red} \begin{bmatrix} J_z \\ J_x \end{bmatrix}_{red} \qquad (5)$$

$$\det [Z(f)]_{red} = 0 \qquad (6)$$

where the subscript "red" represents the reduced matrices corresponding to the discretization points on the metalization

After the eigenfrequencies are found, equation (5) can be used to obtain the current density distribution $[[J_z],[J_x]]^t$ which determines the modal field distributions,$[E_{yn}(y)]$. One thing to be noticed in this step is that the system of equations (5) should be solved by the QR method to ensure stability of the result.

(iii) Time-Domain Data and Frequency Domain Characteristics

Once procedures (i) and (ii) are carried out, all the constants in Eq.(1) are determined. Therefore, the field value at any point at any time can be calculated by Eq.(1). If the field variation in the time domain at two different observation points z=0 and z=L are found, the frequency domain transfer characteristics can be obtained by taking the Fourier transform of the time signal.

In this paper, we tested two structures ; a uniform microstrip line and a step discontinuity.

(a) Uniform Microstrip line

In this case, the transfer function can be found by

$$\exp[-\gamma(\omega)L] = V_y(\omega,z{=}L) / V_y(\omega,z{=}0) \qquad (7)$$

where $\gamma(\omega) = \alpha(\omega)+j\beta(\omega)$

$V_y(\omega,z{=}0)$ = Fourier transform of $[V_y(t,z{=}0)]$ at a fixed x.

Vy(w,z=L) = Fourier transform of [Vy(t,z=L)] at a fixed x.

V_y (t,z) is a voltage defined as the line integral of E_y from the microstrip to the ground plane.

In the actual application, we can obtain stable data by using this choice of voltage definition for the calculation of frequency domain characteristics.

We use the current-voltage definition for the impedance calculation where the current is found by a line integral of the H-field around the microstrip line at z=0. Hence, the characteristic impedance of the line can be obtained by

$$Z(\omega) = V_y(\omega,z{=}0) / I_z(\omega,z{=}0) \qquad (8)$$

(b) Step discontinuity

The scattering parameters are defined as

$$S_{11} = V_{1,ref}(\omega) / V_{1,inc}(\omega) \qquad (9)$$

$$S_{21} = V_{2,trans}(\omega)\sqrt{Z_{01}(\omega)} / V_{1,inc}(\omega)\sqrt{Z_{02}(\omega)} \qquad (10)$$

RESULTS AND DISCUSSION

Figure 3 shows the pulse propagation along the uniform microstrip in the time domain. Figures 4 shows the propagation constant (β) obtained by using the Fourier transform of the time-domain data shown in Fig. 3. The results agree well with those from the curve-fit formula [6]. The calculated transmission coefficients shown in Fig.5 show that the deviation from the exact value is less than 1 %. Figure 6 shows the characteristic impedance (Z_0) of the structure with the data from the closed form formula given in reference [6]. The difference between the two results is about 6 % and it is believed to be caused by the side wall and top wall effect which was known to reduce the characteristic impedance[7].

Figure 7 shows the scattering of the pulse at a microstrip step discontinuity in the time domain. Using Eqs.(11) and (12), the frequency domain characteristics can be extracted from the time-domain data. Figure 8 shows the frequency dependent scattering parameters of the given structure with the available published data[8].

CONCLUSION

It has been demonstrated that the time-domain method of lines is a reliable and efficient method capable of dealing with pulse propagation and discontinuity problems in planar transmission lines. This is an extension of two-dimensional results reported earlier. The frequency domain characteristics obtained from the time-domain data has been made more stable by applying the QR algorithm in the eigenmode determination and by using integrated field quantities in the extraction of frequency domain parameters. The method can be applied to various planar structures.

Acknowledgments

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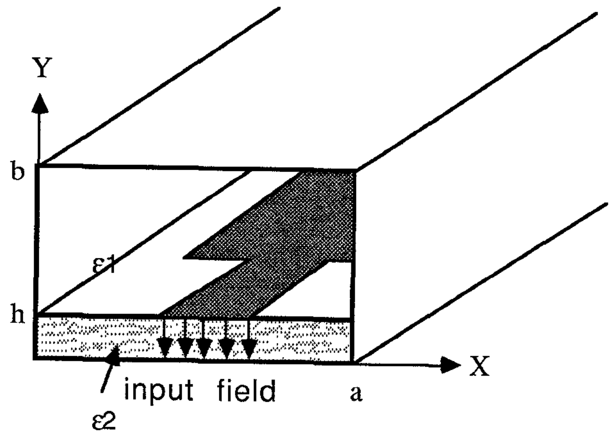

Fig. 1 A general planar transmission line with discontinuity in a shielded rectangular waveguide

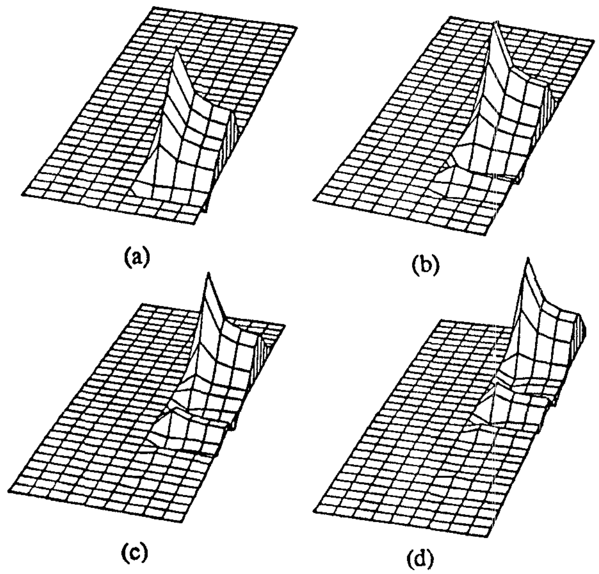

Fig. 3 Ey configuration beneath a uniform microstrip line. (a=2, b=10,w1=w2=.635, and h=.635[mm]) (a) t=0, (b) t=40, (c) t=80, and (d) t=120 [p-sec]

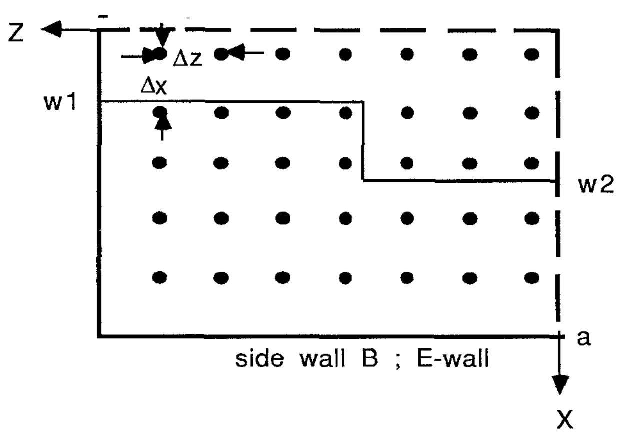

Fig. 2 Top view of the structure shown in Fig.1 with the proper discretization points for Ey component

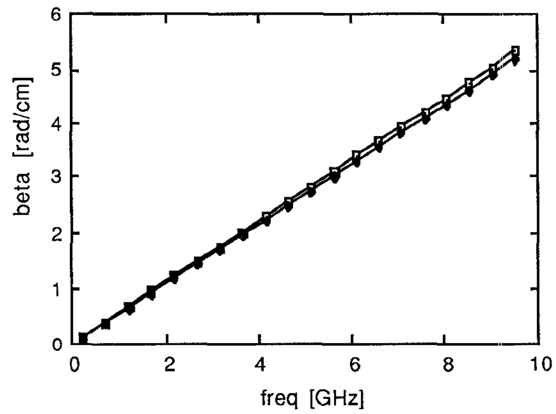

Fig. 4 Dispersion relation for the uniform microstrip line (a=2, b=10, h=.635 [mm], e1=1, and e2=9.6) obtained by TDML.

TDML, curve-fit formula [7] (open structure)

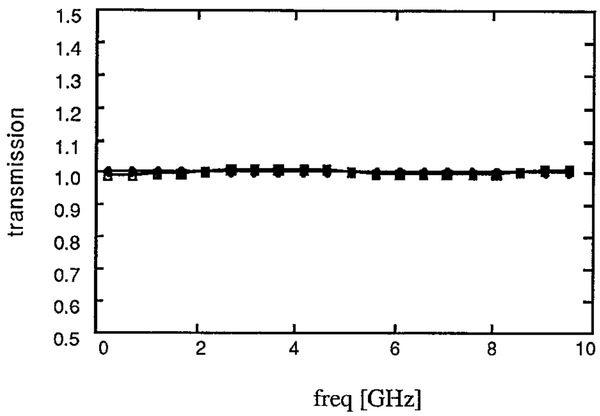

Fig. 5 The transmission coefficient (T) of the uniform microstrip line obtained by TDML

—□— TDML, —■— exact

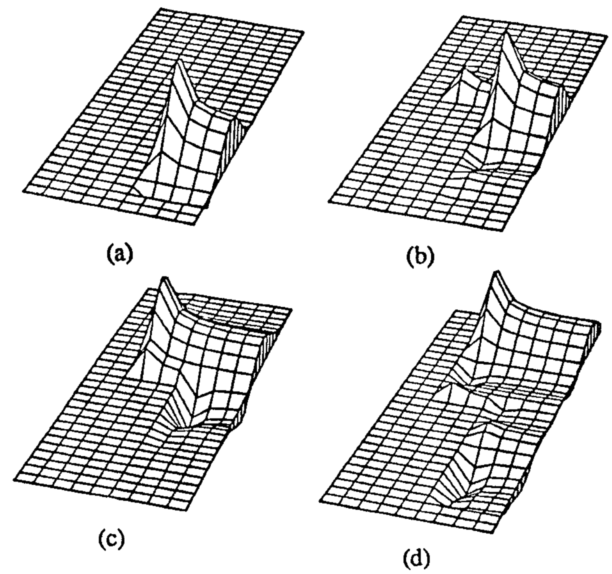

Fig. 7 Ey configuration beneath a step discontinuity..
(a=2, b=10,w1=w2=.635, and h=.635[mm])
(a) t=0, (b) t=40, (c) t=80, and (d) t=120 [p-sec]

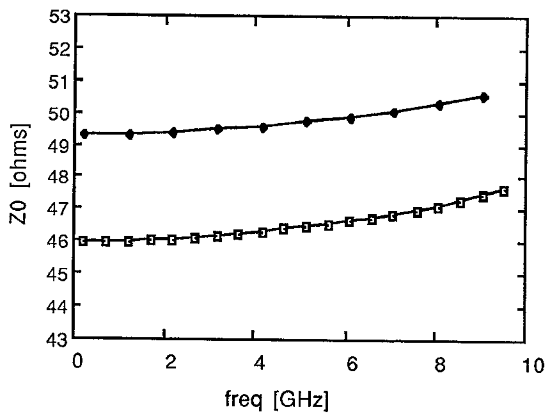

Fig. 6 Characteristic impedance for the uniform microstripline shown in Fig. 1.
(a=2, b=10,h=.635 [mm], e1=1, and e2=9.6)

—□— TDML, —◆— curve-fit formula [7] (open structure)

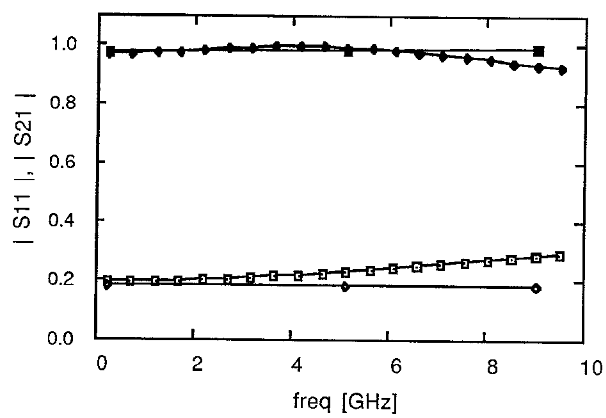

Fig. 8 Scattering parameters(S11, S12) for the symmetric step discontinuity shown in Fig. 2.
(a=2, w1=.3175, w2=.635 [mm], e1=1, e2=9.6)

—□— S11, —◆— S21 TDML, —■— S11, —◇— S21 ref. [9]