A Fast and Efficient FDTD Algorithm for the Analysis of Planar Microstrip Discontinuities by Using a Simple Source Excitation Scheme

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Abstract—**A fast solution FDTD algorithm with a simple and efficient excitation scheme for the analysis of microstrip circuits is introduced. In this algorithm, the source plane is located several nodes inside the near-end terminal plane and absorbing boundary conditions (ABC's) can be applied on the terminal plane directly, without any special treatment. In addition, with this excitation scheme, no dc source distortions are induced on the source plane and nearby. Consequently, the terminal plane can be moved very close to the discontinuity, even at one-cell beyond the input/output reference planes. Hence, very significant computational savings can be achieved. To demonstrate the validity and efficiency of this algorithm, numerical results for a typical discontinuous microstrip structure are given and compared with those obtained by conventional FDTD method.**

I. Introduction

In RECENT studies [1]–[6], the finite-difference time-domain (FDTD) technique has proven to be one of the most prominent tools for numerical modeling of micorstrip discontinuities. In the application of the FDTD method to the above structures, one of the most difficult problems is how to solve the interaction, in time domain, between the source excitation and the reflected wave on the terminal plane (where the ABC's are applied). In the past, this interaction has been commonly solved by employing a long uniform feeding port between the source plane and the discontinuity [1]–[5]. The length of this uniform feeding port is determined from the separation of the incident and reflected waves on the source plane and the decay of evanescent modes. If only the dominant mode is considered, the condition for the decay of evanescent modes (comparing to the above separation requirement) can be removed. However, to meet the above separation requirement, a rather long uniform feeding port is often needed. This certainly limits applications of the FDTD method because most of the computational volumes are used for calculating this unnecessary long uniform feeding port section. Besides, before the ABC's are allowed to 'switch on' on the terminal plane, a special boundary (i.e., either the electric [1] or the magnetic wall [2]) treatment has to be applied on the source plane, which produces a DC source distortion on this plane and nearby. Alternately, a lumped device model [6] was developed. In this model, however, unrealistic media with constant conductivity (σ) have to be introduced in the excitation and/or terminal regions. The implementation of this approach is more complicated, and most importantly, this approach has difficulties when applied to microstrip structures with lossy media. To overcome the above difficulties, therefore, it is necessary to develop a better excitation scheme that solves the interaction and the dc distortion totally for general microstrip circuits.

In this letter, we introduce a fast and efficient FDTD approach, based on a simple source excitation scheme, for the analysis of general microstrip discontinuities. In this approach, the source plane is separated from the near-end terminal plane by moving this source plane several nodes into the computational volume. With this scheme, the interaction between the source excitation and the reflected wave in time domain as well as the source distortion are totally removed. Therefore, the terminal plane (also the source plane) can be moved very close to the discontinuity and then the computational volume for calculations of S-parameter in strong resonant microstrip circuits can be reduced to its minimum. This certainly saves the computer memory and CPU time. Although similar attentions for reducing the length of the long uniform feeding port section were paid to microwave waveguide problems [7]–[9], to the best knowledge of the authors no similar efforts have been made to microstrip discontinuities.

II. Implementation of the Simple Excitation Scheme

The circuit considered in this letter, as shown in Fig. 1, is the microstrip low-pass filter [2]. The input plane (i.e., source plane) is located several nodes inside the near-end terminal plane. The whole computational region is divided to two sub-region by this input plane. The discontinuity and the far-end terminal plane are suited in region 1, whereas the near-end terminal plane is in region 2. For a given input wave, $E^n_{z,\mathrm{inc}}(i, j_{\mathrm{inp}}, k)$, located at j_{inp}, the new equation on this plane is simply modified as

$$\begin{aligned} E_z^{n+1}&(i, j_{\mathrm{inp}}, k) \\ &= E_z^n(i, j_{\mathrm{inp}}, k) \\ &\quad + \frac{\Delta t}{\varepsilon \Delta x}\left(H_y^{n+1/2}(i+1, j_{\mathrm{inp}}, k) - H_y^{n+1/2}(i, j_{\mathrm{inp}}, k)\right) \\ &\quad - \frac{\Delta t}{\varepsilon \Delta y}\left(H_x^{n+1/2}(i, j_{\mathrm{inp}}+1, k) - H_x^{n+1/2}(i, j_{\mathrm{inp}}, k)\right) \\ &\quad + E^n_{z,\mathrm{inc}}(i, j_{\mathrm{inp}}, k). \end{aligned} \tag{1}$$

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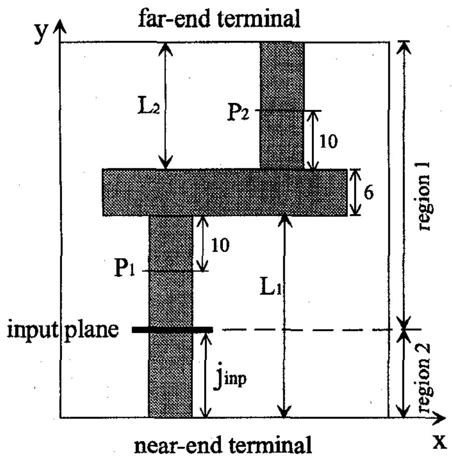

Fig. 1. Top-view of the microstrip low-pass filter.

The definition of the input wave in both time and space is the same as that used in [2]. With the above arrangements, within the first part (i.e., between the input plane and the discontinuity) of region 1 the EM fields contain the incident wave (propagating in $+y$ direction) and the reflected wave; whereas, the EM fields in region 2 contain the incident wave (propagating in $-y$ direction) and the reflected wave and they are immediately absorbed at the near-end terminal plane. The incident wave (within the first part of region 1) propagating in $+y$ direction is used to examine the microstrip structure itself. Moreover, on the source plane, no special treatment is applied to the remaining EM fields. They are calculated from the normal FDTD formulation. Thus, unlike the source excitations considered in the conventional FDTD methods [1], [2], the dc source distortions are not apparent in our excitation scheme. In addition, the Mur's first-order ABC [10] is used on all the open walls.

III. Numerical Results

To confirm the validity of our source excitation scheme, we first chose all parameters are the same as those used in [2], except that the input plane is separated (or moved-in) from the near-end terminal plane. Details are given in Table I. Parameters S_{11} and S_{21} calculated for the input plane at three different positions are given in Fig. 2, respectively. As shown in Fig. 2, the results obtained with our approach are in good agreement with those obtained by the conventional FDTD method [2], even for the case (i.e., case 3) where the input plane is located behind the reference plane P_1. It should be noted that in case 3 the field E^{in} (also E^{total}) for calculating S_{11} (and S_{21}) is obtained from the incident wave propagating in $-y$ direction (i.e., the wave in region 2).

The above results certainly confirm the validity of our excitation scheme. Next, we carry out our calculations by moving the terminal (and keeping the incident plane at 5-cell away from the discontinuity) planes from both end sides, and again details are given in Table I. Numerical results are shown in Fig. 3. It can be seen from Fig. 3 that good results can still be obtained even when the whole computational volume is reduced to $80 \times 28 \times 16$. Thus, for the structure under consideration, extremely significant savings (up to 70%) in both computer memory and CPU time can be achieved with our excitation scheme. In addition, for cases 4 and 5, the geometry rearrangement technique (GRT) [5] for reducing the error in S_{21} is also investigated. As shown in Fig. 3 (comparison is given for case 5 only), no significant improvement is achieved. This is due to the fact that with our excitation scheme the GRT condition can be automatically satisfied by adjusting the distance between the near-end terminal plane and P_1 equals to the distance between the far-end terminal plane and P_2, such as in cases 4 and 5.

TABLE I
Mesh Dimensions Used in the Calculation

	case 1	case 2	case 3	case 4	case 5
j_{inp}	5	25	45	9	6
L_1	50	50	50	14	11
L_2	44	44	44	14	11
size	80x100x16	80x100x16	80x100x16	80x34x16	80x28x16

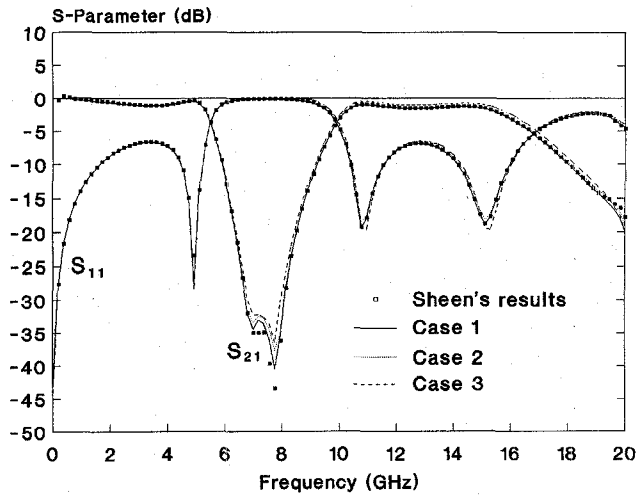

Fig. 2. Magnitude of S-parameter for the low-pass filter, where the total computational size is $80 \times 100 \times 16$, and the input planes are located at three different positions.

IV. Conclusion

A fast and efficient FDTD algorithm combined with a simple source excitation scheme has been developed. In this algorithm, the source plane is separated from the near-end terminal plane. This separation (in space domain) totally solves the interaction between the source excitation and the reflected wave in time domain, and the ABC's can be applied on the terminal plane directly. It has been shown that the implementation of our new excitation scheme is easier than that of the conventional excitation scheme and, also, no dc source distortions are induced. Most importantly, with our excitation scheme, the computational volume can be reduced very significantly by moving the terminal plane close to the reference plane (or discontinuity). This in turn saves computer memory and CPU time. Numerical results obtained from our algorithm confirm the validity and efficiency of this new

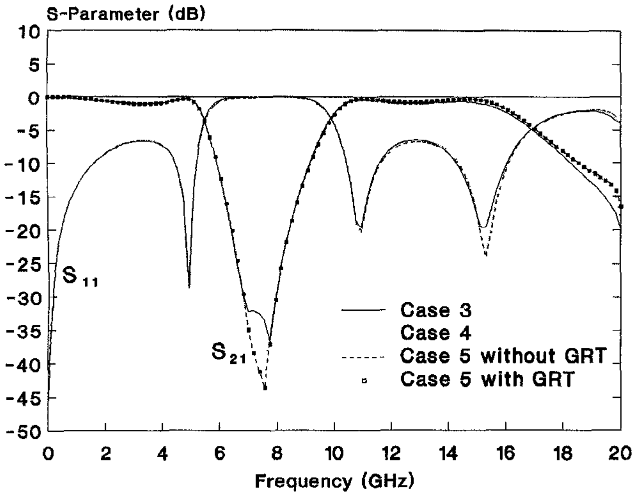

Fig. 3. Magnitude of S-parameter for thelow-pass filter, where the input plane is fixed at 5-cell away from the discontinuity and the total computational sizes are $80 \times 100 \times 16$, $80 \times 34 \times 16$, and $80 \times 28 \times 16$, respectively.

excitation scheme and the approach proposed in this letter should be very useful in computer-aided-design (CAD) of a variety of microstrip and microwave integrated circuits.

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