A Simple Plane Wave Source for the 3D-FDTD Simulation of Dispersive Layered Media

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Abstract—**In this paper, a simple and efficient plane wave excitation method for 3-D finite-difference time-domain simulation of dispersive layered media is proposed. A 1-D auxiliary simulation and total-field/scattered-field method are used with closed boundary to introduce the plane wave. The total-field/scattered-field simulation with closed boundary makes the near-field to far-field transformation possible. Stored 1-D auxiliary simulation data file can be used in iterative simulations of same geometry without repetition of same 1-D simulations.**

Keywords—total-field/scattered-field, dispersive stratified media, near-field to far-field transformation, 1-D auxiliary grid,

I. INTRODUCTION

Behavior of electromagnetic plane wave in stratified media has widely been studied for its various applications including ground-penetrating radar (GPR), on-body RF devices, through-the-wall radar (TWR), etc. The finite-difference time-domain (FDTD) method is a good candidate for simulation of the applications mentioned above, because the method has advantages on dealing with arbitrary shape and dispersive characteristic of scatterers [1]. Also, the FDTD method can efficiently be used in wide-band simulation by using the Fourier transform.

Among the various researches developed for the FDTD analysis of plane wave behavior in layered media, total-field/scattered-field (TF/SF) method with 1-D auxiliary simulation is one of the most simple and efficient method to use. Many researches on TF/SF method with 1-D auxiliary simulation for layered media have proposed, however, they are restricted to 2-D geometry, non-dispersive media, open-boundary or complex to implement [2-5].

In this paper, a simple and efficient plane wave excitation method is proposed for the 3-D FDTD analysis in dispersive layered media. TF/SF method with 1-D auxiliary simulation is used with closed square-shaped boundary. Closed boundary makes the near-field to far-field transform possible. Stored 1-D simulation data in a file is reusable for same geometry simulation without unnecessary repetition of same 1-D simulations. Zeros are padded in 1-D incident field history, because *past time* (t < 0) is introduced at TF/SF boundaries at early time of simulation. By using the zero-padding, unnecessary *if statements* are avoided in simulation code and the simulation time can be efficiently saved.

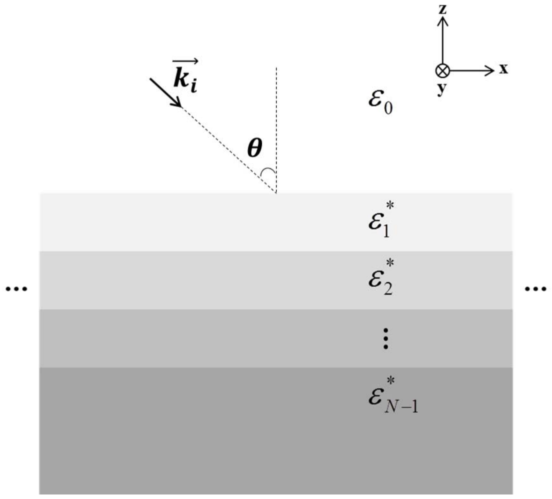

Fig. 1. Schematic of N-layer stratified dispersive media

II. SIMULATION

A. Geometry

We assumed N-layer problem. The incident wave travels from the uppermost region (ε_0) to the lowermost region (ε_{N-1}^*). The uppermost and lowermost regions extend to infinity, respectively. Relative permittivity of dielectric layers use single-pole Debye model. The complex relative permittivity of the single-pole Debye model is [2]

$$\varepsilon_r^* = \varepsilon_\infty + \frac{\varepsilon_s - \varepsilon_\infty}{1 + j\omega\tau} + \frac{\sigma}{j\varepsilon_0\omega} \tag{1}$$

where ε_∞, ε_s, τ and σ are relative optical and static permittivity, relaxation time and conductivity of medium, respectively.

Without loss of generality and for the sake of simplicity, we set the plane of incident xz-plane and the axis of symmetry z-axis. The formulations can be easily extended to arbitrarily oriented plane of incident by using the coordinate transformation.

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B. 1-D Time-domain formulation

Based on phase matching condition, incident field is split into two sets of equations. One is transverse electric (TE) and the other is transverse magnetic (TM). The equations for TE-wave are

$$\frac{\partial H_x}{\partial z} = \sigma E_y + \frac{\partial D_y}{\partial t} - \varepsilon_0 \sin^2 \theta \frac{\partial E_y}{\partial t} \tag{2}$$

$$\frac{\partial E_y}{\partial z} = \mu_0 \frac{\partial H_x}{\partial t} \tag{3}$$

$$H_z = Y_0 \sin \theta E_y \tag{4}$$

where,

$$\varepsilon_0 (\varepsilon_\infty + \frac{\varepsilon_s - \varepsilon_\infty}{1 + j\omega\tau}) E_w = D_w \qquad , w = x, y, z \tag{5}$$

Frequency-domain formulation of Maxwell's equation for TE-wave is converted to time-domain representation for the single-pole Debye model. Time derivative of electric flux density is solved using piecewise linear recursive convolution method [2].

The equations for TM-wave are

$$-\frac{\partial E_x}{\partial z} = \mu_0 \frac{\partial H_y}{\partial t} - \mu_0 \sin^2 \theta \frac{\partial H_y^*}{\partial t} \tag{6}$$

$$-\frac{\partial H_y}{\partial z} = \sigma E_x + \frac{\partial D_x}{\partial t} \tag{7}$$

$$E_z = -Z_0 \sin \theta H_y^* \tag{8}$$

where,

$$H_w^* = \frac{H_w}{\varepsilon_r^*} \qquad , w = x, y, z \tag{9}$$

An auxiliary-H scheme is used to accurate modeling of layer and update equation for H_y and auxiliary equation are solved simultaneously with differencing around the time at t= n-0.5. 1-D array simulation is conducted at x=0 plane. Discretization and update equations for 3-D and 1-D FDTD simulations are well known [1,4].

III. NUMERICAL RESULT

A plane wave injection in a simple half-space layered media is simulated to verify the proposed method. Upper region is free-space and lower region is fat. Relative optical and static permittivity, relaxation time and conductivity of the fat are $\varepsilon_\infty = 3.9870$, $\varepsilon_s = 7.5318$, $\tau = 13.0 \times 10^{-12}$ and $\sigma = 0.08$, respectively. The parameters for the 3D FDTD are problem space size $10\ \mathrm{cm} \times 4\ \mathrm{cm} \times 10\ \mathrm{cm}$, grid spacing $\Delta x = \Delta y = \Delta z = \Delta = 0.5\mathrm{mm}$, and the Courant number 0.98 with 10-cell CPML. Fat layer is from 0 to 5 cm in z-direction. A Gaussian pulse is used as source waveform.

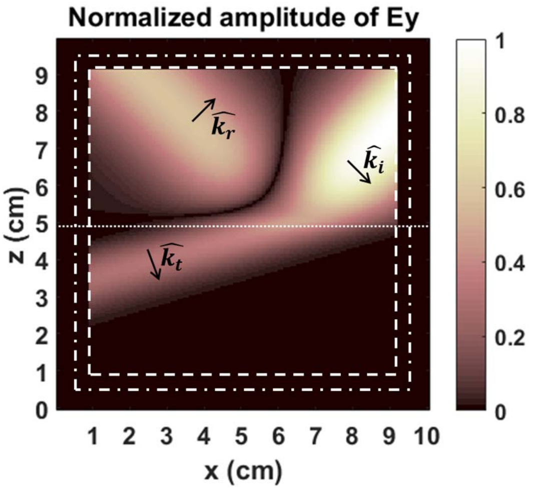

Fig. 2. Simulation result of a plane wave injection to a half-space fat with TF/SF(— — —) and CPML(— · —) boundaries at time t = 1600Δt

Simulation result for E_y component in xz-plane at time t = 1600Δt is shown in Fig. 2. The direction of incident wave, reflected wave and transmitted wave are shown on the plot by using wave vectors with subscript *i*, *r* and *t* respectively. Simulation result shows that the plane wave is well introduced in dispersive layered media and proposed method works well.

IV. CONCLUSION

In this paper, plane wave injection method for 3D-FDTD analysis of dispersive layered media is presented. TF/SF method with 1-D auxiliary simulation array is used with zero-padding for time saving simulation. Closed TF/SF boundary makes the near-field to far-field transformation possible. Proposed method is expected to be applied to wide-band simulation in dispersive layered media including GPR, on-body device, and so on.

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