Simulation for Flat-plate Bounded Wave EMP Simulator with Distributed Terminator and Plane Source

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Abstract— Parallelized finite-difference time-domain (FDTD) method for simulating the near-fields of flat-plate bounded wave electromagnetic pulse (EMP) simulator with distributed terminator and plane source is presented. The effect of some simulator's model-parameters to the vertical electric fields of the test points at the half-height in the simulator is simulated and analyzed.

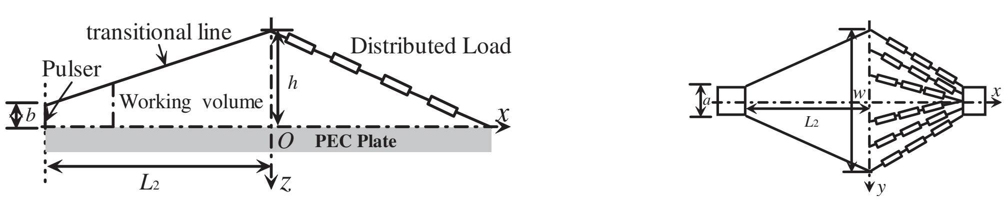
1. INTRODUCTION

Bounded wave electromagnetic pulse (EMP) simulators, which can produce transverse electromagnetic (TEM) waves, have been widely applied to effect experiments of electromagnetic compatibility, interference and damage of complicated electronic systems. Flat-plate bounded wave EMP simulator with distributed terminator has been widely adopted because it can afford EMP with fast rise-time [1–4]. On the other hand, the size of the simulator becomes larger and larger in order to satisfy the need of general systematic experiments. So it's necessary to simulate the time-domain fields of the medium-sized or large flat-plate bounded wave EMP simulator with distributed terminator.

Parallelized finite-difference time-domain (FDTD) method has been used for simulating the near-fields of flat-plate bounded wave EMP simulator (whose height is 22 m) with distributed terminator and some different model-parameters as the simulator is fed by coaxial transmission line [5]. Considering the near-fields of the simulator fed by plane source are different with those of the simulator fed by coaxial transmission line, the effects of some simulator's model-parameters to the fields of the simulator with distributed terminator and plane source, which got by parallelized FDTD method, are presented and analyzed in this paper.

2. MODEL AND METHOD

The model of a flat-plate bounded wave EMP simulator with distributed terminator is shown in Fig. 1. The simulator includes transitional line, below perfect electric conductor(PEC) plate and distributed load. The working volume of the simulator is under the transmission line.



(a) front view (b) top view

Figure 1: Configuration of flat-plate bounded wave EMP simulator with distributed terminator.

The near fields of the simulator are computed by Parallelized FDTD [6, 7]. The uniaxial perfectly matched layer (UPML) absorbing boundary is used in FDTD computing in this paper. Considering the distributed terminator at the simulator's end is used to absorb the electromagnetic waves for assuring no reflected waves returning to the working volume, the simulator's end is truncated (replaced) by UPML absorbing boundary in FDTD method, as shown in Fig. 2. On the other hand, the source pulse also propagates toward to opposite direction (the left side in Fig. 2) as it does to the direction towards working volume. Thus UPML absorbing boundary is also used in the front of the simulator, as shown in Fig. 2.

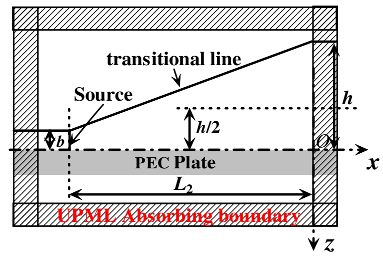


Figure 2: Division of FDTD computing domain in xOz plane.

According to Fig. 2, there are some interfaces between UPML and the simulator's PEC plates. The FDTD expressions of electric field in y direction in UPML for lossy media are [8]

$$\begin{aligned} & P1_y^{n+1}\left(i,j+1/2,k\right) \\ = \; & D_u\left(i,j+1/2,k\right)/C_u\left(i,j+1/2,k\right)P1_y^n(i,j+1/2,k) + ERX(i,j+1/2,k)/C_u(i,j+1/2,k) \\ & \times\left\{\left[H_x^{n+1/2}(i,j+1/2,k+1/2) - H_x^{n+1/2}(i,j_1/2,k-1/2)\right]/\delta_z\right. \\ & \left. - \left[H_z^{n+1/2}\left(i+1/2,j+1/2,k\right) - H_z^{n+1/2}\left(i-1/2,j+1/2,k\right)\right]/\delta_x\right\} \end{aligned} \tag{1}$$

$$\begin{aligned} & P_y^{n+1}\left(i,j+1/2,k\right) = B_z\left(k\right)/A_z\left(k\right)P_y^n\left(i,j+1/2,k\right) \\ & +1/(A_z\left(k\right)\cdot\Delta t)\times\left[P1_y^{n+1}\left(i,j+1/2,k\right) - P1_y^n\left(i,j+1/2,k\right)\right] \end{aligned} \tag{2}$$

$$\begin{aligned} & E_y^{n+1}\left(i,j+1/2,k\right) = B_x\left(i\right)/A_x\left(i\right)E_y^n\left(i,j+1/2,k\right) + 1/A_x\left(i\right) \\ & \times\left[A_y\left(j+1/2\right)P_y^{n+1}\left(i,j+1/2,k\right) - B_y\left(j+1/2\right)P_y^n\left(i,j+1/2,k\right)\right] \end{aligned} \tag{3}$$

where

$$\left\{\begin{array}{l} C_u\left(i,j,k\right) = 1/\Delta t + \sigma\left(i,j,k\right)/(2\varepsilon_0),\;\; D_u\left(i,j,k\right) = 1/\Delta t - \sigma\left(i,j,k\right)/(2\varepsilon_0) \\ A_x\left(i\right) = \kappa_x\left(i\right)/\Delta t + \sigma_x\left(i\right)/(2\varepsilon_0),\;\; B_x\left(i\right) = \kappa_x\left(i\right)/\Delta t - \sigma_x\left(i\right)/(2\varepsilon_0) \\ A_y\left(j\right) = \kappa_y\left(j\right)/\Delta t + \sigma_y\left(j\right)/(2\varepsilon_0),\;\; B_y\left(j\right) = \kappa_y\left(j\right)/\Delta t - \sigma_y\left(j\right)/(2\varepsilon_0) \\ A_z\left(k\right) = \kappa_z\left(k\right)/\Delta t + \sigma_z\left(k\right)/(2\varepsilon_0),\;\; B_z\left(k\right) = \kappa_z\left(k\right)/\Delta t - \sigma_z\left(k\right)/(2\varepsilon_0) \\ ERX\left(i,j,k\right) = 1/\varepsilon_0 \end{array}\right. \tag{4}$$

and $k_v = 1 + (k_{\max} - 1)\left(l_v/d\right)^4$, $\sigma_v = \left(l_v/d\right)^4 \Big/ (30\pi\delta_v)$, $v = x, y, z$, $k_{\max}$ is the maximum number of the layers of the interface about UPML absorbing boundary and perfect electric conductor (PEC), l_v is the distance between the PML and FDTD domain in $v$direction, $d = 4\delta_v$ is the depth of PML media; $\delta_v(v = x, y, z)$ is the FDTD girds' size in three directions, Δt is the time-step, and ε_0 is the dielectric parameter in vacuum. If the UPML contacts the PEC medium, $\varepsilon_r = 1$ and the conductivity $\sigma = 3.75 \times 10^7$ S/m. The FDTD expressions of the other two electric-field components are similar to the above. The FDTD expressions for magnetic fields are as same as the unlossy media.

The simulator's plane source is set at the cross section of the simulator's front-end, as shown in Fig. 2. And each electric field component in z direction (E_z) on the source plane is equal to the excited electric field at each FDTD time-step [9].

3. RESULTS AND ANALYSIS

As shown in Fig. 1 and Fig. 2, $L_2 = 80$ m, $h = 22$ m, $b = 0.4$ m and the ratio of the maximum width (w) to h is 1, 2 and 5 respectively. The width of the below PEC plate (w_d) is w or $2w$. The excited source of the simulator is

$$E_z\left(t\right) = E_0\left(\exp\left(-\alpha t\right) - \exp\left(-\beta t\right)\right) \tag{5}$$

where $E_0 = 2.31 \times 10^6\,\mathrm{V/m}$, $\alpha = 3.46 \times 10^6\,\mathrm{s}^{-1}$, $\beta = 5 \times 10^8\,\mathrm{s}^{-1}$. The rise-time of the source (t_r) is about 4 ns and the FWHM is about 221 ns. All FDTD cell sizes in three directions are 0.1 m and the time-step is $dt = \delta/(2c)$, c is the light's speed in vacuum. The total number of FDTD grids is 636 million. All test points are chosen on $y = 0$ plane and at the half-height in the simulator as shown in Fig. 2. The distance along x-axis from the test point to the source is L.

The rise-time, FWHM and peak-value of E_z changed with L at several test points in the simulator with different w_d and different w/h are shown in Figs. 3(a), (b) and (c) respectively. We can get from Fig. 3(a) that (1) when $w_d = w$ and $w/h = 1$, the rise-time of E_z increases greatly as L increases from 70 m to 80 m; (2) when $w/h = 2$, the rise-time of E_z at each test point can reach the minimum value; (3) when $w/h = 2$ (or 5), the rise-times of E_z at test points in the simulator with $w_d = w$ is almost equal to that in the simulator with $w_d = 2w$.

As shown in Fig. 3(b), when $w_d = w$ and $w/h = 2$, FWHM of E_z at each test point reaches the maximum value, while $w_d = 2w$ and $w/h = 5$, FWHM reaches the minimum value.

As shown in Fig. 3(c), we can obtain that (1) the peak-value of E_z at each test point increases with the distance from the test point to the source along x direction decreases; (2) when $w/h = 2$(or $w/h = 5$), the peak-value of E_z at each test point in the simulator with $w_d = w$ is almost same to that in the simulator with $w_d = 2w$; (3) the peak-value of E_z at each test point as $w/h = 1$ reaches the maximum value, while that as $w/h = 5$ reaches the minimum value.

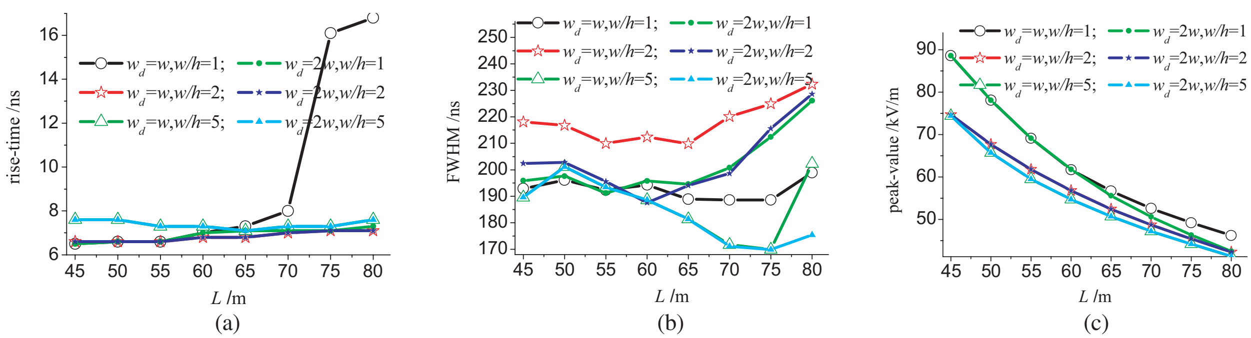


Figure 3: Rise-time, FWHM and peak-value of E_z at several points for various below PEC plate's width and various ratio of the transitional line's maximum width (w) to its maximum height (h).

From above we can get that if the ratio of the transitional line's maximum width to the maximum height (that is the simulator's ratio of width to height) is 2, the smallest rise-times of E_z at test points can be got. Let $w/h = 2$ and the width of below PEC plate is equal to w, $2w$ and infinity respectively. The rise-time, FWHM and peak-value of E_z changed with the distance from the point to the source along x-axis are shown in Figs. 4(a), (b) and (c) respectively. As shown in Fig. 4, the rise-time and peak-value of E_z at each test point are unchanged with the width of below PEC plate, that is, the width of below PEC plate has little effect on the rise-time and peak-value of E_z at each test point when $w/h = 2$, and the design of the width of below PEC plate is decided by the need of FWHM of E_z. The rise-time of E_z at the test point increases with L increased, while the peak-value decreases with L increased. When $w_d = w$, FWHM of E_z at each test point reaches the maximum value.

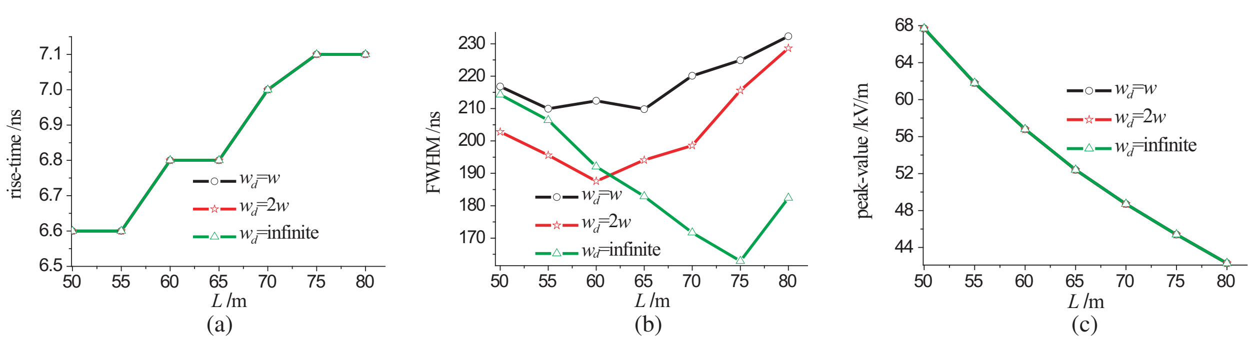
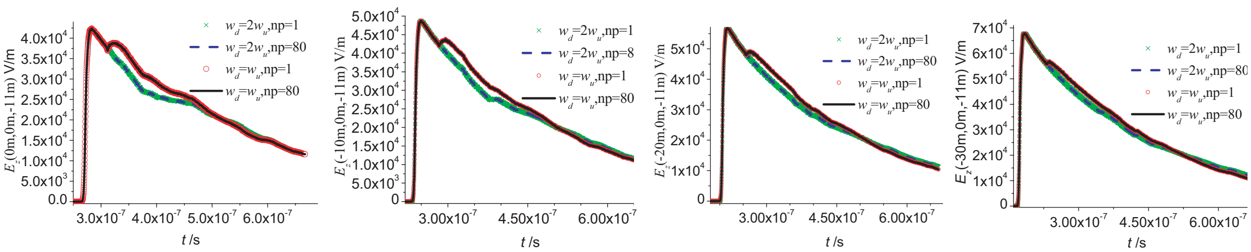


Figure 4: Rise-time, FWHM and peak-value of E_z at several points for various below PEC plate's width as the ratio of the transitional line's maximum width to its maximum height (w/h) is 2.

The electric fields changed with time at several points in the simulator with $w/h = 2$ are shown in Fig. 5. As shown in Fig. 5, the results got by Parallelized FDTD with 80 processors ($np = 80$) are same with those by serial FDTD ($np = 1$). From Fig. 5, we also can get that there's some difference at the rear of the electric field's waveform at the same point in the simulator with $w_d = w$ or $w_d = 2w$. And the more difference, the farther the test point from the source along x-axis. That is due to the accumulation of the effect of the below PEC plate's edge become great as the distance between the point and the source increases.



(a) L=80 m (b) L=70 m (c) L=60 m (d) L=50 m

Figure 5: EMP of E_z at several points for various below PEC's width as w/h is 2.

4. CONCLUSIONS

Parallelized finite-difference time-domain (FDTD) method for flat-plate bounded wave EMP simulator with distributed terminator and plane source is shown in this paper. The distributed terminator is replaced by UPML absorbing boundary at the end of the simulator. The effect of some simulator's model parameters to the fields of several points is analyzed by the method. And the results in this paper can also be used in the design of other large simulators with distributed terminator and plane source.

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