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Applications of the PSTD Method to Dipole Antenna Analysis

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1. Introduction

One of the most widespread method for analyzing electromagnetic problems is that the Finite-Difference Time-Domain (FDTD) method, and its availability and capability are well recognized. However, some previous works have indicated that a spatial sampling density is needed greater than 10 to 20 cells per minimum wave length to ensure that the FDTD method produces acceptable results even for an electrically small problem. To keep acceptable accuracy for an electrically large problem, it may be necessary to increase the spatial sampling density beyond this range to reduce the cumulative dispersion error.

In order to reduce the numerical dispersion error in FDTD calculations, various techniques have been proposed[1]～[3]. One of which is the PseudoSpectral Time-Domain (PSTD) technique in which the Fast Fourier Transform (FFT) is used to approximate spatial derivatives in PSTD update equations. As a result of using the FFT, spatial sampling rate is required only two cells per minimum wavelength. This is very attractive, and its effectiveness was indicated in the electromagnetic wave propagation problem[3]. However, the PSTD method have never been applied to the antenna problem. In this paper, we apply the PSTD method to analyze a dipole antenna and compare with the FDTD method to confirm its efficiency.

2. PSTD update equations

In this section, we will briefly review the PSTD method in contract to the original FDTD method in order to clarify some features. In the FDTD method, a whole computational space is divided by many staggered grids as cells, and electric and magnetic fields are set on each cell edges as shown in Fig.1(a). On the contrary, all field components are located at the cell center as shown in Fig.1(b). This centered grid provides an important advantage over FDTD in specifying material properties.

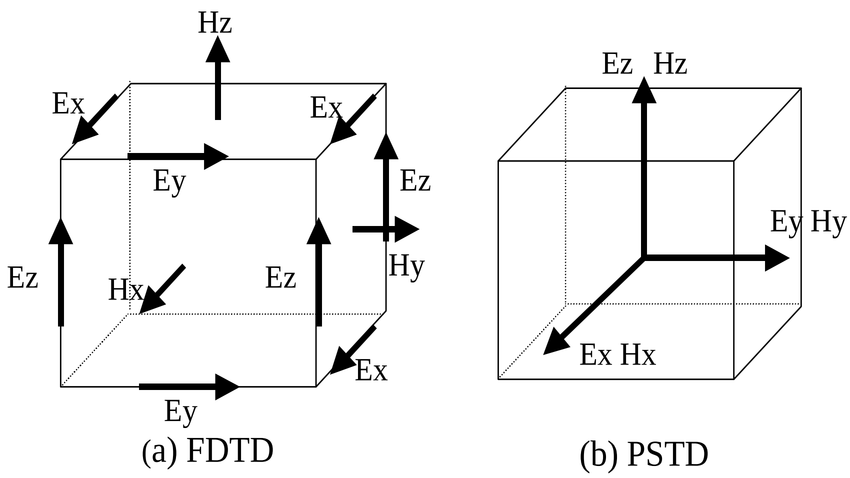

Fig. 1: Arrangement of field components

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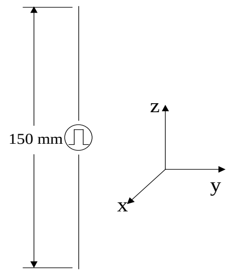

Fig. 2: Dipole antenna

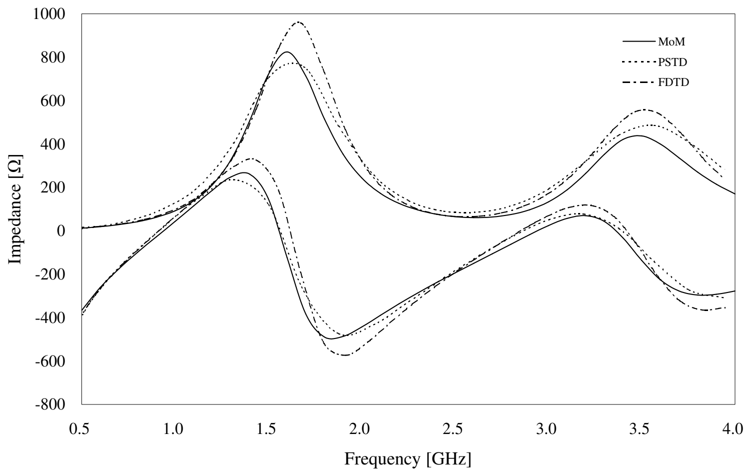

Fig. 3: Input impedance of a dipole antenna

The spatial derivatives of the Maxwell's curl equations are approximated by the FFT so that a periodicity in space has to be assumed inherently in the PSTD method. Thus, the time update solutions could be corrupted by wave propagating from other periods and become distorted. To eliminate this wraparound effect, the perfectly matched layers (PML) are applied to truncate the computational space boundaries. The update equations of E_x and H_x components are described as

$$E_x^{n+1}(i,j,k) = C_1 E_x^n(i,j,k) + C_2(\mathfrak{I}_y^{-1}[jk_y\mathfrak{I}_y[H_z^{n+1/2}]] - \mathfrak{I}_z^{-1}[jk_z\mathfrak{I}_z[H_y^{n+1/2}]]) \quad (1)$$

$$H_x^{n+1/2}(i,j,k) = H_x^{n-1/2}(i,j,k) - C_3(\mathfrak{I}_y^{-1}[jk_y\mathfrak{I}_y[E_z^n]] - \mathfrak{I}_z^{-1}[jk_z\mathfrak{I}_z[E_y^n]]) \quad (2)$$

where

$$C_1 = \frac{1-\sigma(i,j,k)\Delta t/2\epsilon(i,j,k)}{1+\sigma(i,j,k)\Delta t/2\epsilon(i,j,k)}, C_2 = \frac{2\pi\Delta t/\epsilon(i,j,k)}{1+\sigma(i,j,k)\Delta t/2\epsilon(i,j,k)}, C_3 = \frac{2\pi\Delta t}{\mu(i,j,k)} \quad (3)$$

$\mathfrak{I}$ and $\mathfrak{I}^{-1}$ denote the conventional forward and inverse Fourier transforms that are represented using trigonometric functions[3][4].

3. Antenna analysis using the PSTD method

In order to confirm the accuracy and efficiency of the PSTD method, we calculated an input impedance of the dipole antenna as shown in Fig.2. An antenna conductor is modeled by forcing the electric fields along z-axis to zero. A feed voltage is given at the center of antenna conductor. For both FDTD and PSTD calculation, all cell sizes were set $\Delta x = \Delta y = \Delta z = 4.29$mm. Therefore, the antenna is divided by 35 cells. Calculated results of input impedance are shown in Fig.3. The method of moment (MoM) results is also shown. The PSTD seems to agree with the MoM rather than the FDTD in a general view.

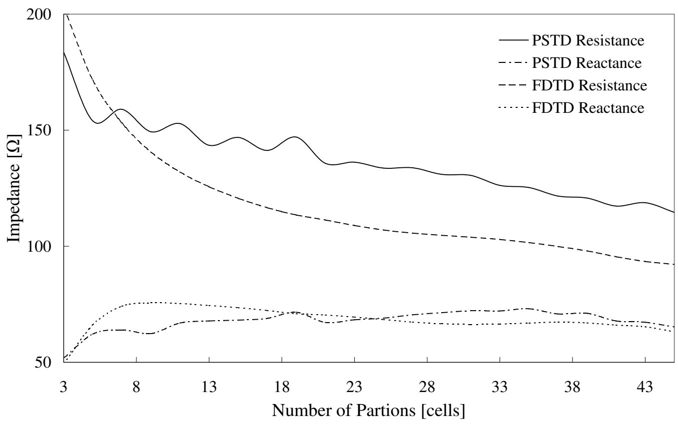

Fig. 4: Input impedance vs number of cells at 1GHz

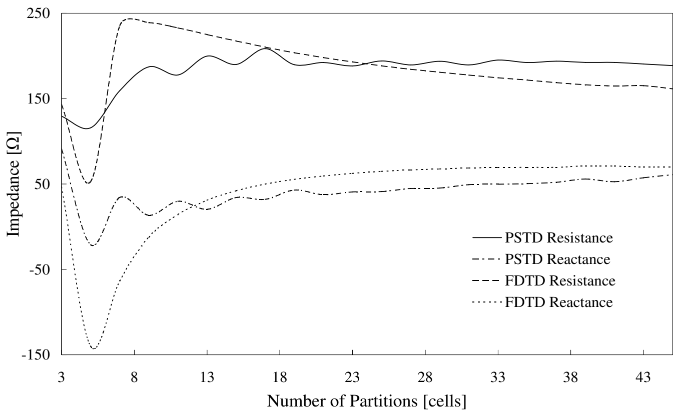

Fig. 5: Input impedance vs number of cells at 3GHz

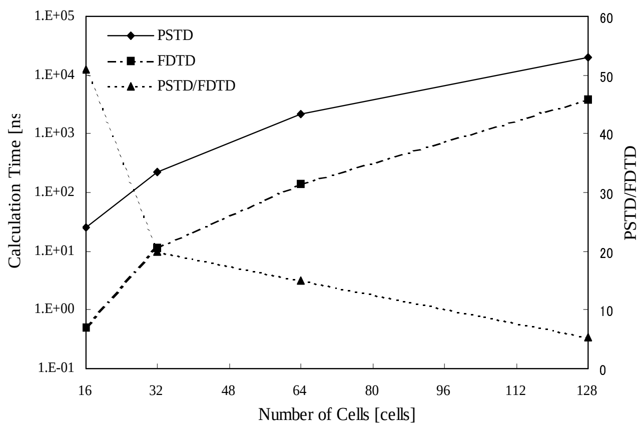

Fig. 6: Turn-around time

In order to discuss the convergency in detail, the impedance at 1GHz and 3GHz when the number of division of the antenna is changed are shown in Fig.4 and Fig.5. From these figures, it can be found that the PSTD method gives relatively good result even if a coarse cell size is need. On the other hand convergency of the FDTD method is slow compared with the PSTD.

The turn-around times of the FDTD and PSTD methods, and its ratio are shown in Fig.6. In this calculations, we used Petinum4 Xeon 2.4GHz processor. The horizontal axis of Fig.6 indicated that number of one side cells of cubic computational region. It is found that the turn-around time of the PSTD method becomes some thirty or forty times as much as the FDTD method depending as the number of cells. It is also shown that the ratio of the turn-around time decrease when the number of cells increases. Therefore the PSTD method is suitable for huge problems rather than small problem in the view point of the computational cost.

4. Conclusion

In this paper, the PSTD method was applied to the impedance calculation of a dipole antenna and compare with FDTD method on its accuracy and the computational costs. It has been shown that the turn-around time becomes some thirty or forty times as much as the FDTD method, but its convergency for the number of cells faster than the FDTD method.

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