

Correction of Numerical Errors at Current Sources in Explicit Finite-Difference Time-Domain Method with Higher-Order Accuracy

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This study proposes a correction of numerical errors at current sources in the Finite-Difference Time-Domain (FDTD) method with the time-development equations using higher-order differences. The FDTD method (Yee 1966) is a numerical method for solving the time development of electromagnetic fields by approximating Maxwell's equations in both time and space with the finite difference of the second-order accuracy. A staggered grid system is used in the FDTD method, in which Gauss' law is always satisfied. Owing to this advantage, the FDTD method is used for more than a half century and applied into plasma kinetic simulations. In the FDTD method, however, numerical oscillations occur due to the error between the numerical phase velocity and the theoretical phase velocity. The FDTD(2,4) method (Fang 1989; Petropoulos 1994), which uses the fourth-order spatial difference, is proposed for reduction of the numerical errors. However, the Courant condition becomes more restricted by using higher-order finite differences in space and a larger number of dimensions. Recently, numerical methods have been developed by adding one-dimensional odd-degree difference terms to the time-development equations of FDTD (Sekido & Umeda, IEEE TAP, 2023; EPS, 2024; PIER M, 2024), which relaxes the Courant condition and reduce numerical errors in phase velocity. With those methods, computational time is reduced significantly, since longer time steps can be used. However, it has been found that there arise large numerical errors in the charge conservation law if the time-development equations including current sources are discretized with higher-order finite differences in space. The numerical errors in the charge conservation law have a negative impact in plasma kinetic simulations. Therefore, corrections of the input current densities are necessary. In the present study, the numerical errors are suppressed by adding correction terms to the time-development equations of the FDTD methods with higher-order differences.

Keywords: FDTD, Courant condition, dispersion relation, charge conservation law, numerical errors, higher-order difference