FAST IMPLICIT TIME-DOMAIN SIMULATION OF COMPLEX 3D SLOW-WAVE STRUCTURES*

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The Courant—Friedrichs—Lewy (CFL) stability condition limits the size of time step that may be used by conventional explicit finite-difference time-domain particle-in-cell (FDTD-PIC) codes in proportion to the grid cell size. In slow-wave vacuum electronic devices with non-relativistic electron beams, the typical scale length for fields in the beam region is $L \cong \beta\lambda << \lambda$, where $\beta = v_b/c$ is the normalized beam velocity and λ is the vacuum wavelength. This dictates a very small cell size $h << L << \lambda$ for PIC simulation which via the CFL condition imposes extremely small time steps compared to the RF period. Consequently explicit methods require long simulation times to model slow-wave devices.

To circumvent this problem we use an alternating direction implicit (ADI) FDTD algorithm that is not subject to the CFL limit. We have formulated a new efficient scheme using a complex-envelope (CE) representation of fields [1,2] for use in our code NEPTUNE. We demonstrate stable, accurate 3D RF simulation of narrow-bandwidth signals using time steps exceeding the CFL criterion by more than two orders of magnitude, and in some cases exceeding even the RF period. Although originally developed to model only the vacuum fields in the beam tunnel region, we have recently extended the algorithm to allow full 3D modeling of complex geometries directly, represented as metallic, dielectric and permeable materials in the cells of the mesh. Simulation results for a number of slow-wave devices undergoing development at NRL will be presented.

1. S. J. Cooke, M. Botton, T. M. Antonsen, Jr., and B. Levush, “A Leapfrog Formulation of the 3-D ADI-FDTD Algorithm,” International Journal of Numerical Modeling, vol. 22, pp. 187-200, 2009.

2. M. Botton, S. J. Cooke, T. M. Antonsen, Jr., I.A. Chernyavskiy, A. N. Vlasov, and B. Levush, "Compact 3D Envelope ADI-FDTD Algorithm for Simulations of Coherent Radiation Sources." Submitted to IEEE Trans. Plasma Sci., 2010 Special Issue on High Power Microwave Generation.

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