Solving Maxwell's equations without projection in CELESTE3D, an implicit PIC plasma simulation code

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We apply the second-order formulation of Maxwell's equations proposed by Jiang *et al.* (1996, *J. Comp. Phys*. **125**, 104) to the solution of the three-dimensional, time-dependent Vlasov-Maxwell's system through an implicit Particle-in-Cell (PIC) method.
Implicit PIC methods are useful for the study of low-frequency phenomena and realistic electron-ion mass ratios because they eliminate many numerical stability constraints on the time and space, which strongly affect explicit PIC methods, while they retain the full kinetic plasma model.
In the present work, an implicit finite difference algorithm is developed to solve the Maxwell's equations in a bounded domain with physical boundary conditions comprising electrically conducting walls (perfect conductors), constant magnetic flux walls, and periodic conditions.
The new formulation of Maxwell's equations eliminates the need for a separate projection step, which required the troublesome solution of a Poisson's equations with non-constant coefficients. In particular, we formulate the boundary conditions for Maxwell's equations in order to satisfy the divergence condition (Gauss theorem) throughout the domain by solving it only on the boundary. The zero divergence condition on the magnetic field is also automatically satisfied.
We compare numerical results with analytical solutions for electromagnetic waves *in vacuo*, and using the implicit particle-in-cell code CELESTE3D, we test the new solver on the Geospace Environment Modeling (GEM) magnetic reconnection challenge. Finally, we present results on three-dimensional reconnection.