3-D FDTD Modeling of Electromagnetic Wave Propagation in Magnetized Cold Plasma

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We report a three-dimensional (3-D) finite-difference time-domain (FDTD) model (A. Taflove and S. C. Hagness, *Computational Electrodynamics: The Finite-Difference Time- Domain Method*, 3rd. ed., Norwood, MA: Artech House, 2005) of electromagnetic wave propagation in anisotropic cold plasma. This model is based upon the two-dimensional (2-D) cylindrical-coordinate FDTD model published by Hu and Cummer (*IEEE Trans. Antennas Propag.*, vol.54, No.5, May 2006). In this work, we expand their 2-D, tightly coupled electric field (E) – current density (J) collocation plasma method to the fully 3-D case. As a result, taking into account all three particle species (electrons, positive ions, and negative ions), our whole 3-D iteration system consists of 15 linear equations with 15 state variables. We use an equivalent set of explicit iteration equations to derive the FDTD iteration coefficients for these 15 linear equations (rather than deriving them analytically).

Hu and Cummer's 2-D FDTD model was used to simulate lightning-generated electromagnetic wave propagation in the ionosphere. Their results showed strong correlation with experimental data and mode theory at both high altitudes and over long distances. Using our newly developed 3-D FDTD anisotropic plasma model, we expect similar accuracy to their 2-D results, but with the additional capability of modeling such effects as Faraday rotation and including fully 3-D spatial variation in the magnetization of the cold plasma.

To validate our new 3-D FDTD plasma algorithm, we generate a Gaussian-pulsed plane wave propagating along the externally applied magnetic field. We first observe the slow whistler mode below the plasma gyrofrequency with a resonance at the gyrofrequency. Above the stop band extending between the gyrofrequency and the plasma frequency, we also observe the effects of the two circularly polarized modes. Finally, for the case of no externally applied magnetic field, the propagation modes only show a cutoff at the plasma frequency. These numerical results of our 3-D FDTD model agree very well with the plasma theory.