i-FDTD: A New Stencil for Enhanced Isotropy in the FDTD Simulation of Electromagnetic Wave Phenomena

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When the Finite-Difference Time-Domain (FDTD) method is used to simulate electromagnetic wave interactions in electrically large computational domains extra care is needed with containing or mitigating numerical dispersion and numerical anisotropy errors. This can be achieved in one of two ways, namely, increasing the number of cells per minimum wavelength (spatial over-sampling) or increasing the order of the finite-difference approximation of the derivatives (K. L. Shlager and J. B. Schneider, IEEE Trans. Antennas Propagat., vol. 51, Aug. 2003). Both result in an increase in the computational time needed to update the fields everywhere in the computational domain by one time step. The former comes at the additional cost of increased memory resources. The latter, assuming that one is interested in maintaining the higher-order accuracy in the approximation of the derivatives everywhere in the grid, raises the complexity of the equations used to update field components located at material interfaces or adjacent to them. The reality of practical applications tends to favor a mix of the two approaches.

In this presentation we introduce a new stencil for the approximation of the curl operators in Maxwell's equations on the staggered FDTD grid. The new stencil is based on a modified central difference approximation of the first-order derivatives on a rectangular grid which, while second-order accurate, results in improved isotropy (A. Kumar, J. Comp. Phys., vol. 201, 2004). More specifically, for a given phase velocity anisotropy error, the new stencil requires a much coarser grid than the one required by the standard, second-order accurate FDTD stencil. This, in turn, amounts to gains in computational resources when transient electromagnetic interactions in electrically-large domains are being modeled.

The numerical attributes of the proposed stencil, namely, its numerical stability properties, and its dispersion and anisotropy, are presented and contrasted to those of the standard, second-order accurate FDTD stencil. Results from our experience with its application to the electromagnetic analysis of wave interactions in inhomogeneous domains will be presented to facilitate the discussion of its implementation in the vicinity of material interfaces and the quantitative assessment of the numerical error and computational cost associated with its use.