A Stochastic FDTD Model of Electromagnetic Wave Propagation in Magnetized Ionospheric Plasma

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Communications, surveillance, and navigation capabilities rely heavily on accurate knowledge of electromagnetic (EM) signal propagation characteristics through and reflected by the Earth's ionosphere. Satellite communications, over-the-horizon radar, and target direction finding are a few example applications. Poor understanding of either the ionospheric state or the complete signal propagation characteristics through the ionosphere can negatively affect the performance of these applications. For example, inaccurate signal predictions may lead to erroneous target identification and coordinate estimation.

Numerical EM techniques typically use average (mean) values of the constitutive parameters of the materials and then solve for expected (mean) electric and magnetic fields. The ionosphere, however, exhibits considerable variability that renders many propagation problems too complex to be solved using a deterministic formulation. The structure of the ionosphere depends not only on the altitude, time of day, and season, but also on the latitude (and longitude), sun spot cycle, and occurrence of major space weather events. The ability to determine not only the mean values of the EM fields but also their variance will, for example, provide a means of determining the confidence level that a communications / remote sensing / radar system will operate as expected under abnormal ionospheric conditions.

A useful approach to a highly complex problem such as EM wave propagation in the ionosphere is to consider it as a random medium problem. The Monte Carlo method is a well-established and widely used brute force technique for evaluating random medium problems via multiple realizations. Depending on the nature of the statistical correlation, however, a random medium problem may require tens or hundreds of thousands of realizations. This yields an extremely inefficient brute force approach, particularly for two-dimensional and three-dimensional problems, and is therefore rarely used in electrodynamics modeling.

Here we will describe the development of an efficient, single-realization stochastic FDTD magnetized plasma model for EM wave propagation in the ionosphere. The governing equations are Maxwell's equations coupled to the Lorentz equation of motion. This work is based on the recently reported stochastic FDTD (S-FDTD) method that solves purely Maxwell's equations [Smith and Furse, *TAP*, 60(7), 2012] and has been applied to biomedical applications.