Abstract

The Perfectly Matched Layer (PML) absorbing boundary condition was introduced by Berenger (1993) and Chew and Weedon (1994) as a means for truncating Finite-Difference Time-Domain (FDTD) and Finite-Difference Frequency Domain (FDFD) lattices in order to accurately simulate electromagnetic antenna and scattering problems in isotropic media. In the ionosphere and magnetosphere, where the dominant medium is a magnetized plasma, numerous interesting electromagnetic wave phenomena occur. Many of these would be well suited for analysis by the FDTD and/or FDFD methods, however, until recent developments, including contributions in this dissertation, the PML had not been efficiently extended nor capable, in some cases, to truncate domains containing magnetized plasma. In this dissertation, we develop two methods for extending Chew's formulation to robustly and efficiently truncate any linear magnetized plasma as well as any linear media.

The first PML method developed in this dissertation is a novel approach to the general time domain representation of the Chew and Weedon (1994) PML. This new approach mathematically operates on the spatial field derivatives by convolving them with causal decaying exponential functions. The approach allows the PML update equations to be trivially derived from any set of general linear medium update equations.

The development of the second PML method in this dissertation is motivated by shortcomings of the Perfectly Matched Layer in certain cases involving propagation in anisotropic media, such as whistler-mode propagation in a magnetized plasma, for which the vector component normal to the PML of the group velocity vector and the k-vector are anti-parallel with each other. This new type of PML utilizes information on the k-vector direction by applying relevant spatial derivatives to the PML update equations. We demonstrate the numerical stability and performance of the new PML for whistler-mode propagation in a magnetized plasma with respect to the traditional PML.

A method for calculating the numerical reflection coefficient for the PMLs introduced in this dissertation is developed for general linear media. The derived expressions for the numerical reflection coefficient are used to quantify the performance of the PML for incident plane waves at any incident angle, frequency and polarization. Two and three dimensional numerical test results, which validate the calculation of the numerical reflection coefficient, are presented. For the case of the PML truncating free space, values of up to -100 dB for the numerical reflection coefficient are realized. For the case of the PML truncating a magnetized plasma, values from -40 dB up to -90 dB are realized, depending on the orientation of the ambient magnetic field.

Finally, a technique is developed for the efficient modeling of propagation over long paths (hundreds of wavelengths) by breaking the path up into segments and appropriately applying the PML and the total-field/scattered-field method. For FDTD simulations the new technique is well suited to model both slow and fast wave modes as well as scattering inhomogeneities along the path. In addition, the new technique is directly applicable to FDFD simulations. Both FDTD and FDFD numerical simulations of propagation within the Earth-ionosphere waveguide are performed to validate the new technique.