Numerical Analysis on Electromagnetic Wave Propagation in VLF/LF Earth-Ionosphere Waveguide by 3D FDTD Method in the Spherical Coordinates

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Electromagnetic waves in the very low frequency (VLF)/low frequency (LF) bands can propagate in the Earth-ionosphere waveguide. Because one boundary of the waveguide is the D-layer of ionosphere, the VLF/LF wave can be used to monitor directly electron density distribution in the D-layer. For the monitoring, it is of importance to model precisely VLF/LF wave propagation by numerical analyses. The finite difference type of numerical method is appropriate as computation of VLF/LF waves because of inhomogeneous electron density of the ionosphere. In this study, the finite-difference time-domain (FDTD) method are utilized for this reason. We formulate the update equations in the spherical coordinate system, taking into account curvature of the Earth's surface. The objective of this study is to establish numerical method to simulate EM wave propagation in VLF/LF Earth-Ionosphere Waveguide by 3D FDTD method in the spherical coordinates. A VLF/LF transmitter is supposed as a current source. The ionosphere consisting of magnetized plasma can be modeled as an anisotropically conductive medium. The magnetized plasma is also dispersive, but we use constant values at a frequency used by the transmitter. The ionosphere have much wider extent in space than regions of interest, so that absorbing boundary conditions (ABCs) are necessary to truncate computational grids. In this study we develop the ABC utilizing the complex coordinate stretching and formulating update equations with respect to electric flux density. The Earth's crust is a relatively highly conducting medium and is excluded from computation by adopting the surface impedance method. The surface impedance is also dependent of frequency, but again we use a constant impedance at a transmitter frequency. In this study we investigate the effects of parameters on the VLF/LF propagation. The direction and the magnitude of geomagnetic field can be set arbitrarily in the developed simulator. But, it is found that for thousands kilometer propagation in the middle latitude, there are no significant effect on the propagation, and we can use spherically symmetric geomagnetic field with small errors. It is also found that the conductivity of the Earth's surface have considerable influence on the propagation.

Keywords: Very low frequency/Low frequency, FDTD method, Ionosphere, Ground conducticity, Absorbing boundary conditions

