Fast Computation of Electromagnetic Fields in Anisotropic Media Layered Both Vertically and Cylindrically Using the Numerical Mode Matching (NMM) Method

Junwen Dai* and Qing Huo Liu
Department of Electrical and Computer Engineering, Duke University

A structure layered both vertically and horizontal cylindrically is a special 3D inhomogeneous medium with axial symmetry and has many engineering applications. An off-axis source will generate full three-dimensional electromagnetic fields in such a medium. Typical applications of such electromagnetic simulation include geophysical exploration, optical fiber communications and integrated optics. For example, in geophysical exploration, the induction well-logging tool consisting triaxial coils will produce nonaxisymmetric electromagnetic waves in a heterogeneous formation.

Numerical mode matching (NMM) method is a powerful semi-analytical solver that can reduce a higher dimensional problem into a series of lower dimensional problems through numerical computation of eigenmodes and their reflection and transmission. Here the NMM method is applied to solve the 2.5D problem of an off-axis source radiating in the inhomogeneous medium layered vertically and cylindrically. The eigenmodes in each horizontal layer can be easily obtained by the 1D FEM. The discrete eigenmodes will be found if the structure is finite whereas continuous modes, i.e. radiation modes, will be observed for unbounded structure. The reflection and transmission matrices due to the multiple junction discontinuities can be found by matching boundary condition of tangential components of electric and magnetic fields. The excited total fields can be expressed in terms of summation of eigenmodes with different coefficients.

The NMM method has previously been shown to be a fast and robust semi-analytical solver for this 2.5D inhomogeneous medium. In this work, we have improved the NMM method with new capabilities: (1) The method has been extended to anisotropic media to expand its application range. (2) The perfectly matched layer (PML) has been added as an absorbing boundary condition in cylindrical coordinate system to make NMM more accurate in low conductivity media and applicable to lossless media. (3) Instead of using small radius to approach origin, this paper manipulates weak form of Maxwell’s equation and impose the boundary condition to yield exact fields at origin. It is crucial in borehole well-logging system, which frequently measures the field along the Z-axis. (4) This work offers formulations for fields excited by both electric and magnetic dipole with arbitrary orientations. Numerical results will be shown to demonstrate the efficacy of this method.