NMM Simulation of Electromagnetic Waves in Cylindrical Geometries with an Extremely Thin Vertical Layer

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Abstract—The numerical mode matching (NMM) method is widely employed in the simulation of electromagnetic (EM) problems with cylindrical geometries. Its significant reduction of the computational cost is achieved by transforming the original 2.5D problem to a 1D eigenvalue problem in the radial direction, which is usually treated with the finite element method (FEM), and a semi-analytical problem in the $z$ direction, which can be easily tackled with the mode matching strategy. However, when an extremely thin vertical layer is encountered, such as the steel casing in well logging, the conventional NMM method will be challenged as in the finite element method. The extremely thin layer will cause the mesh for the FEM to be tremendously dense, thus greatly lowering its efficiency. Moreover, if the thin layer is extremely conductive, the matrices for the eigenvalue problem are highly ill-conditioned, making the solution of the eigenvalue/eigenvector inaccurate. To overcome these problems, we propose to apply the surface current boundary condition (SCBC) to substitute the extremely thin vertical layer in the NMM method. To employ the NMM-SCBC method, the mixed-order FEM is first implemented to treat the 1D eigenvalue problem, and the capability of the corresponding mixed-order NMM method is shown in the paper. Furthermore, the expression of the SCBC is derived and applied to the mixed-order NMM method. Several numerical examples have shown the accuracy and efficiency of the mixed-order NMM-SCBC method.