Double-Higher-Order Finite Element Modeling of a Conformal Perfectly Matched Layer for Electromagnetic Scattering Simulation

Aaron P. Smull, Ana B. Manić, Sanja B. Manić, Branislav M. Notaroš
Electrical & Computer Engineering Department, Colorado State University, Fort Collins, CO
asmull@rams.colostate.edu, anamanic@engr.colostate.edu, smanic@engr.colostate.edu,
notaros@colostate.edu

The Perfectly Matched Layer (PML) method has been a key component in the simulation of electromagnetic scattering problems using the Finite Element Method (FEM) since the early 90's (Berenger, Journal of Comp. Phys., 114, 185-200, 1994), providing means to effectively terminate otherwise infinite computational domain. The PML, unlike many other absorbing boundary conditions, is advantageous in that the solutions accuracy is not dependent on the distance the absorbing layer is placed from the scatterer.

In recent years, the emphasis in literature has been on extending Berenger's original rectangular PML to more arbitrary coordinate systems in an attempt to reduce the number of unknowns. In other words, the focus of PML-related research is following the computational trend of minimizing the memory requirement for solving given electromagnetic problem. Over the years, Berenger's PML framework has been extended first to spherical, followed by cylindrical geometries, and eventually to conformal mappings (Ozgun, O. and Kuzulogu, M., IEEE Transactions on Antennas and Propagation, 55, 931-937, 2007). Each of these innovations further decreases the memory requirement and computational cost of scattering simulations.

This paper presents a reformulation of the locally-conformal PML scheme as an anisotropic medium modeled with the previously developed Anisotropic Double-Higher-Order (DHO) Finite Element Method (Manic et al., Microwave and Optical Technology Letters, 54, 1644-1649, 2012). The anisotropic DHO FEM couples large, continuously inhomogeneous, anisotropic curvilinear hexahedral elements with a hierarchical set of higher-order curl-conforming basis functions leading to reduction in the size of the linear system of equations to be solved and an increase in overall computational efficiency. Reformulation of the vector wave equation into separate incident and scattered field parts was a major barrier to implementation. In the new formulation, the field for which we are solving is the scattered component, unlike previous implementations, in which the total electric field was solved for.

The focus of this presentation is not just on the reduction in size of the final matrix equation by double higher-order modeling, but the attribute of anisotropic curved higher-order geometrical elements ability to effectively conform to required geometric and material constraints of the perfectly matched layer. Curved geometries provide the means to automatically generate the required material parameters of the PML and are able to more accurately conform to the desired geometry than low order geometrical elements. Continuously inhomogeneous material parameters provide even better approximation to the exact reflectionless layer – more accurate than what would be obtained with piecewise material approximations.