Efficient transmission conditions in a domain decomposition method for the 3-D scattering problem

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The scattering problem of a time harmonic electromagnetic wave from complex penetrable 3-D objects can be accurately solved by coupling a finite element (FE) method with an exact radiation condition prescribed on the outer boundary of the computational domain. For electrically large objects coated with inhomogeneous materials, the total number of volume unknowns generally reaches several tens of millions. A domain decomposition method (DDM) allows a considerable reduction of the numerical complexity by decomposing the initial problem into coupled subproblems.

The computational domain is partitioned into concentric non-overlapping subdomains with transmission conditions (TCs) on the interfaces. The exact radiation condition is accounted for by an integral representation (IR) prescribed on the outer boundary. The global system obtained after discretization of the finite element formulations is solved via a GMRES iterative method. It is preconditioned in such a way that, essentially, only the solution of the FE subsystems in each subdomain is required. Also, the IR avoids the problematic solution of the full subsystem arising from an integral equation usually employed as an exact radiation condition. The convergence rate of the GMRES depends on the efficiency of the TCs, and some high-order TCs (HOTCs) are proposed here for multilayer coated objects.

The first ones are derived from the exact impedance boundary conditions on the interfaces for an infinite planar multilayer coating. A spectral analysis performed on this structure shows that the eigenvalues of the preconditioned DDM matrix are all equal to unity, thus yielding a super-convergent rate. However they suffer from the following drawbacks. Because these TCs involve pseudo-differential operators, their implementation in a FE formulation necessitates the introduction of additional unknowns on each interface that increase the numerical complexity of the DDM. Also, the equivalence of the DDM with the original Maxwell's problem must be ensured by sufficient conditions (SCs) that degrade the performances of these HOTCs. As a consequence, we propose simplified and well-posed HOTCs that reduce the number of iterations, compared with the local Robin TCs with optimized coefficients proposed in [Stupfel et al., JCP 2016], with the same numerical complexity. Accurate numerical results obtained on various coated objects involving several tens of millions of unknowns are presented that illustrate the efficiency of these HOTCs.