FEM-SIE and VIE-SIE Diakoptic Domain-Decomposition Electromagnetic Scattering Analyses Using Higher Order Numerical Discretizations

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Both the finite element method (FEM) and the volume integral equation (VIE) approach in conjunction with the method of moments (MoM) are especially suitable for modeling and analysis of structures that contain inhomogeneous, complex electromagnetic materials. The surface integral equation (SIE) approach is, on the other hand, particularly well suited for electromagnetic analysis of open-region problems based on the surface equivalence principle. This paper presents FEM-SIE and VIE-SIE diakoptic domain-decomposition analyses of inhomogeneous and complex electromagnetic scatterers using higher order numerical discretizations.

In the FEM-SIE diakoptic method, we wrap each scatterer with a closed surface (diakoptic surface) and place equivalent electric and magnetic surface currents over it (Manić, Olcan, Ilić, Notaroš, “Diakoptic FEM-MoM Analysis Using Explicit Connection between Field and Current Bases,” 2013 IEEE APS International Symposium). Each scatterer, together with the associated equivalent surface currents, is analyzed completely independently, using the higher order FEM-SIE technique, with the objective to find linear relations between coefficients of the equivalent current expansions (diakoptic coefficients). The relations for all scatterers are combined into a system of linear equations, which is solved for diakoptic coefficients. All quantities for the original system are then obtained from these coefficients. Diakoptic electric sources and the magnetic field in FEM subsystems are connected using dual sets of vector basis functions explicitly satisfying the natural relation between surface current and volume field expansions.

In the VIE-SIE diakoptic method, the interior diakoptic subsystems containing inhomogeneous dielectric materials are analyzed completely independently applying the VIE-SIE MoM solver, and the solution to the original problem is again obtained from linear relations between electric and magnetic surface-current diakoptic coefficients on diakoptic surfaces, written in the form of matrices, and a direct solution of the diakoptic linear system of equations is used again (Chobanyan, Olcan, Ilić, Notaroš, “Combining Diakoptic, VIE-MoM, and SIE-MoM Approaches in Analysis of Dielectric Scatters,” 2013 IEEE APS International Symposium). The interior subsystem discretization is based on a Galerkin VIE solution for the equivalent electric displacement vector throughout dielectric domains.

The techniques implement Lagrange-type generalized curved parametric hexahedral VIE-MoM and FEM volume elements and quadrilateral SIE-MoM and diakoptic patches of arbitrary geometrical-mapping orders, and curl-conforming and divergence-conforming hierarchical polynomial vector basis functions of arbitrary field and current expansion orders. The hexahedra can be filled with inhomogeneous materials with continuous spatial variations of the material parameters described by Lagrange interpolation polynomials of arbitrary material-representation orders. In all solutions, special attention is paid to numerical computation of various types of singular and near-singular integrals, which are evaluated using different methods for both the singularity extraction and the singularity cancellation.

Examples include two- and three-dimensional finite arrays of scatterers of various geometries and material inhomogeneities and compositions, and demonstrate computational features and advantages of the diakoptic domain decomposition, as well as of FEM-SIE and VIE-SIE modeling approaches. They also show benefits of using truly higher order geometrical, field/current, and material discretizations.