Higher Order Volume and Surface Integral Equation Modeling of 3-D Scattering and Radiation Problems

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The method of moments (MoM), as one of the most powerful and versatile general numerical tools for electromagnetic-field computations based on discretizing integral equations in electromagnetics, has been especially effectively used for full-wave three-dimensional (3-D) solutions to open-region (e.g., scattering and radiation) problems in the frequency domain. In the MoM analysis in conjunction with the volume integral equation (VIE) approach, the volume equivalence principle is invoked to represent a scattering or radiation structure containing linear dielectric materials of arbitrary inhomogeneity and complexity by a distribution of volume electric (polarization and conduction) currents (the real currents) radiating in free space, and the resulting VIE, with the total volume current density vector, or another vector proportional to it, as unknown quantity, is discretized by the MoM. The analysis of composite dielectric and metallic radiation/scattering structures can be performed combining the VIE for dielectric parts and the surface integral equation (SIE) based on the boundary condition for the electric field intensity vector for metallic parts, with surface electric currents (again, the actual currents) treated as an unknown quantity. This gives rise to a hybrid VIE-SIE or VSIE formulation, which solves simultaneously for the volume currents throughout the dielectric domains and the surface currents over the metallic surfaces.

This paper presents VIE-SIE modeling of scattering and radiation problems based on a higher order Galerkin MoM using Lagrange-type interpolation generalized hexahedral volume elements and quadrilateral patches of arbitrary geometrical-mapping orders and hierarchical divergence-conforming 3-D and 2-D polynomial vector basis functions of arbitrary current-approximation orders. The volume and surface MoM techniques enable excellent curvature modeling and excellent current-distribution modeling, using large curved hexahedra and quadrilaterals that are on the order of a wavelength in each dimension as building blocks for modeling of dielectric and metallic objects (i.e., the volume and surface elements can be by an order of magnitude larger in each direction than traditional low-order elements).

Numerical examples include structures composed of homogeneous and inhomogeneous, lossless and lossy dielectric materials and metallic parts, with diverse shapes. Applications include a large variety of scatterers, antennas, and photonic materials. Results demonstrate excellent numerical properties of VIE-SIE solutions, using current expansions of very high orders and large-domain VIE and SIE meshes with a very small number of large conformal curved hexahedral and quadrilateral elements, which results in solutions with minimal total numbers of unknowns. In addition, the VIE-SIE technique is compared to the pure SIE technique, where both electric and magnetic equivalent (artificial) surface currents are introduced over boundary surfaces between homogeneous regions of the structure, and surface integral equations based on boundary conditions for both electric and magnetic field intensity vectors are solved with current densities as unknowns. These results serve to cross-validate the two techniques against each other, and to evaluate their numerical properties, advantages, and deficiencies.