An Internally Combined Volume-Surface Integral Equation for 3D Plasma Scatterers

Abdulkadir C. Yücel, Luis J. Gomez*, and Eric Michielssen
Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI 48109, USA

Plasmas drive many different technologies ranging from fluorescent/luminescent lighting to microelectronic device etching and medicine. To accelerate the pace of innovation and development in plasma science and engineering, fast and accurate electromagnetic simulators are called for. Unfortunately, the application of standard differential equation and volume integral equation (VIE) techniques to the analysis of fields inside highly-heterogeneous plasmas containing regions of negative permittivity often results in ill-conditioned system of equations that converge very slowly when solved iteratively.

To address this problem, we recently proposed a 2D volume-surface combined field integral equation (VSCFIE) technique (Gomez et al., *USNC/URSI Nat. Radio Sci. Meeting*, 2014). This technique relies on (i) subdividing the plasma into regions with strictly positive and negative permittivities, (ii) wrapping negative permittivity regions with equivalent surfaces and artificially changing the sign of the permittivity of the "background medium" by exploiting surface equivalence principles, and (iii) judiciously coupling Muller combined field integral equation (CFIE) for equivalent surfaces with a VIE to assemble a well-conditioned system of VSCFIEs that can be solved rapidly by iterative solvers. The technique was shown to yield well-conditioned systems of equations when used to analyze TE scattering from highly-heterogeneous negative permittivity cylinders. However, the technique suffers from low-frequency (LF) breakdown: when the mesh that discretizes the plasma scatterer contains elements with dimensions that are much smaller than the wavelength, discretization of the VSIE results in ill-conditioned systems of equations.

Here a 3D internally combined volume-surface integral equation (ICVSIE) technique that does not suffer from LF breakdown when applied to the analysis of electromagnetic scattering from highly heterogeneous plasmas containing regions with negative permittivity is proposed. The technique leverages the same principles used by above referenced 2D VSCFIE technique with one slight change: in the ICVSIE, the volume equations are modified by adding the electric field due to exterior surface currents on the equivalent surface of each region. This addition renders the equations low-frequency stable. Numerical results obtained by applying the solver to the analysis of electromagnetic scattering from 3D highly-heterogeneous negative permittivity media suggests that discretization of the proposed ICVSIE yields well-conditioned systems of equations that can be solved rapidly by iterative solvers, irrespective of the sign of the permittivity of scatterer.