A Well-Conditioned Volume-Surface Combined Field Integral Equation (VSCFIE) for Inhomogeneous Scatterers with Negative Permittivities

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Plasmas have numerous applications ranging from microelectronic device manufacturing to the development of military stealth systems. To facilitate the design of new technologies that leverage plasmas, novel fast electromagnetic simulators are called for. Indeed, plasmas often are highly inhomogeneous and contain regions of negative permittivity. Unfortunately, the application of standard differential and volume integral equation (VIE) techniques to the analysis of fields inside such media yields ill-conditioned systems of equations that converge slowly. Here we propose a novel volume-surface combined field integral equation (VSCFIE) that alleviates this problem.

Recently, it was shown that the application of a combined field integral equation (CFIE) to the study of electromagnetic phenomena in homogenous media of negative permittivity results in relatively well-conditioned systems of equations (Liu and Chew, *IET Microw. Antenna P.*, vol.1, no.1, pp. 84-88, 2007). Here we extend these results to highly-heterogeneous media by combining a VIE and CFIE in the following manner:

1) Subdivide the object into regions each having a strictly positive or negative permittivity.
2) Wrap each of the negative permittivity sub-regions with equivalent electric and magnetic surface currents and invoke surface equivalence principles to artificially change the sign of the permittivity of the "background medium" in which their volume polarization currents radiate.
3) Simultaneously obtain all surface and volume currents by numerically solving a system of VSCFIE equations composed of coupled CFIEs and new combined VIEs. For each region, the new combined VIEs are constructed by judiciously adding contributions due to the surface currents residing in its exterior and propagating in the appropriate "background medium".

Numerical data obtained by analyzing time-harmonic TE scattering from various 2D layered cylinders suggests that discretization of the new VSCFIE yields well-conditioned matrices even when used to analyze scattering from highly-heterogeneous objects having negative permittivities. The method therefore will be useful to model electromagnetic phenomena occurring inside plasmas.