ABSTRACT

Computational analysis of electromagnetic systems finds applications in a many areas ranging from military communication systems and stealth technology to commercial wireless networks and biomedical imaging technologies. This analysis entails the numerical solution of Maxwell's equations for the radiation radar scattering or transmission of electromagnetic waves through complex structures. By and large, the finite element and moment method (integral) approaches have been the preferred numerical approaches for solving Maxwell's equations. Among them, the finite element method is a partial differential equation-based method necessitating use of mesh truncation operators for solving open domain problems. One truncation technique is to hybridize the finite element method with a boundary integral equation leading to the, so-called, finite element-boundary integral method. Although this method is quite efficient and can be easily generalized to model arbitrary inhomogeneous objects, it encompasses the inherent drawback that the entire computational domain must be discretized even for large regions of homogeneous material. The latter can be attentively modeled more efficiently via other methods, including surface integral equation techniques incorporating an appropriate Green's function. It is therefore of interest to combine finite element and integral equation methods to permit a more efficient implementation of hybrid frequency domain methodologies. With this goal in mind, we propose herewith a hybrid volume-surface integral equation formulation that can

also be coupled with finite element implementations to have a rather versatile formulation for a variety of applications where multi-scale details can be modeled efficiently. The advantage of the volume integral equation within this general approach is the ease and robustness of implementing high contrast inhomogeneous dielectrics in the presence of surface boundary conditions, such as PEC, PMC, impedance, sheet, etc. Essential, to our formulation is a novel material factorization technique that causes the volume integral equation to contribute as a perturbation so that objects consisting of high contrast inhomogeneous materials can be efficiently modeled. Thus, volume discretizations only need to be considered in regions where material properties vary smoothly or where material anisotropies exist.

Both, 2-D and 3-D implementations of the hybrid methods are considered and high order hierarchical functions are integrated into the implementation. A key feature of the implementation is a unique testing for the volume integral equation solution which ensures its accuracy over curved geometries. This formulation is also extended to infinite periodic structures for modeling frequency selective devices and metamaterial structures. A p-refinement strategy is implemented to exploit the hierarchical nature of the proposed basis functions and to achieve additional efficiencies when performing electromagnetic simulations of periodic structures.