

# Accelerating Hybrid Integral-Equation and Physical-Optics Solutions with MLFMA

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We propose an algorithm for the solution of electromagnetic scattering and radiation problems by hybridizing integral-equation (IE) and physical-optics (PO) formulations. The goal is to combine the efficiency of PO solutions with the accuracy of IE solutions. The hybrid IE-PO method can provide fast and accurate solutions for problems involving electrically-large geometries with small details, such as the case of resonant antennas mounted on very large platforms that are hundreds/thousands of wavelengths in size.

Traditionally, the method of moments (MoM) is employed with  $O(N^2)$  complexity for calculating the interactions of the testing and basis functions. The high complexity of MoM constitutes a bottleneck, not only for the size of the IE region, but also for the size of the overall problem, in terms of both time and memory requirements of the solution. In order to reduce the computational requirements, we employ the multilevel fast multipole algorithm (MLFMA) with  $O(N \log N)$  complexity. MLFMA accelerates the calculation of necessary interactions and reduces the required memory. MLFMA performs the matrix-vector multiplication (MVM) related to the near-field interactions directly, while other interactions, i.e., far-field interactions, are calculated on-the-fly through aggregation, translation, and disaggregation steps within a tree structure. In a MoM scheme, the resulting matrix is rectangular when the basis and testing domains are distinct. This calls for a special treatment of the MVMs implemented with MLFMA. As the surface of the geometry is divided into IE and PO domains, the overall tree structure is also divided into IE and PO trees, one of which is used as the basis tree and the other as the testing tree. The fields of the basis clusters are aggregated using the basis tree and translated to the testing tree. Then, the translated fields are disaggregated down to the lowest-level testing clusters using the testing tree.

The hybrid method divides the geometry surface into IE and PO domains and solves the surface current on each domain with the corresponding formulation. Discretization of the surface current yields  $N = N_{IE} + N_{PO}$  basis functions, where  $N_{IE}$  and  $N_{PO}$  are the numbers of basis functions in the IE and PO domains, respectively. The selection of IE and PO domains is a matter of choice. For both open and closed geometries, we choose the regions near the shadow boundary (i.e., the boundary that divides the illuminated and dark surfaces), in the vicinity of the sources (e.g., antennas), and near the edges/corners as part of the IE domain. The rest of the surface is taken as the PO domain; the current on the illuminated regions is calculated by expanding the tested incident field on the basis functions and the dark regions are simply not treated at all.