Non-uniform Grid Time Domain Approach for Fast Multilevel Evaluation of Transient Fields

Amir Boag[†*], Eric Michielssen[‡], Vitaliy Lomakin[‡], and Ehud Heyman[†]
[†] Department of Physical Electronics, Tel Aviv University, Tel Aviv 69978, Israel
[‡] Electrical and Computer Engineering Dept., University of Illinois at Urbana-Champaign, 1406 W. Green Street, Urbana, IL 61801, USA

We consider the problem of analyzing scattering from an open three-dimensional perfectly conducting surface through the Marching On in Time (MOT) based solution of a time domain electric field integral equation. Each MOT step requires evaluation of the electric field generated by all historic surface currents. The number of field and current sampling points on the surface is proportional to its electrical dimensions, i.e., of $O(N)$ where $N=(kR)^2$, where R denotes the radius of the smallest sphere circumscribing the scatterer and k is the wavenumber at the highest frequency present in the incident field. The straightforward evaluation of the instantaneous field at $O(N)$ spatial observation points by surface integration, which requires the summation of $O(N)$ partial fields for each observer, amounts to $O(N^2)$ operations. This high computational burden underscores the need for using fast field evaluation techniques.

In this paper, we develop a novel non-uniform grid time domain (NGTD) technique that facilitates the numerically efficient evaluation of the field produced by a given current distribution. The algorithm is based on the observation that, locally, the delay compensated field radiated by a finite size source is an essentially bandlimited function of the angular and radial coordinates of the source centered spherical coordinate system. The angular bandwidth is proportional to the linear dimensions of the source, while the local bandwidth with respect to the radial distance decreases rapidly with the distance. Therefore, the radiated field can be sampled on a non-uniform spherical grid with radial density decreasing with the distance from the source. The total number of grid points is proportional to the source region dimensions.

With this in mind, we introduce a multilevel algorithm based upon a hierarchical decomposition of the scatterer surface into subdomains. At each level, the domain decomposition proceeds by subdividing each parent domain into a number of subdomains. At the finest level, for each small subdomain, radiated fields are computed directly at a small number of points of a very coarse non-uniform spherical grid. Next, the fields of each group of adjacent subdomains are aggregated into those of the parent subdomain and defined over a finer non-uniform grid. Transition from coarse to fine grids is effected by interpolation. The time delay common to all source points in a given subdomain is removed from the field prior to interpolation, thus rendering the field a slowly varying function of the spatial variables in the retarded time domain. Following the interpolation step, delays are restored and partial fields aggregated. At the highest level, the fields are interpolated to the scatterer surface. The proposed multilevel algorithm attains an asymptotic complexity of $O(N\log N)$.

A high-order accurate multilevel implementation of the NGTD scheme will be presented. Its performance will be compared to that of the established plane wave time domain algorithm in terms of both CPU time and memory consumption.