Hybrid Time Domain Integral Equation – Physical Optics – Adaptive Integral Method for Transient Electromagnetic Analysis of Large Scale Structures

Wei Luo [1], Eric Michielssen[2], Jian-Yao Zhao* [3], and Wen-Yan Yin[3,1]

(1) Key Lab of Ministry of Education of Design and EMC of High-Speed Electronic Systems, Shanghai Jiao Tong University Shanghai 200240, CHINA
(2) Department of ECE, University of Michigan, USA
(3) Centre for Optical and EM Research (COER), State Key Lab of MOI, Zhejiang University Hangzhou 310058, CHINA

Time-domain electric field integral equations (TD-EFIE) are widely used for analyzing transient scattering from perfect electrically conducting surfaces. These equations often are solved via marching-on-in-time (MOT) methods. Unfortunately, the computational cost of classically formulated MOT-based TD-EFIE solvers scales as $O(N_t N_s^2)$ where N_t and N_s are the number of time steps and spatial surface unknowns, respectively. This cost prevents these solvers from being used to study high-frequency phenomena involving large-scale structures.

In the past, a variety of methods for accelerating MOT-based TD-EFIE solvers have been developed; they include, but are not limited to, hybrid TD-EFIE and time domain physical optics (TDPO) methods, and fast summation schemes such as the time-domain adaptive integral method (TD-AIM). In the hybrid TD-EFIE-PO method, structures are partitioned into EFIE and PO regions. In the EFIE region, surface currents are updated by MOT; incident fields comprise those produced by external sources and currents in the PO region. In the PO region, currents are updated using incident fields produced by external sources and currents in the EFIE region (W. Luo, W. Y. Yin, M. D. Zhu, J. Y. Zhao, and J. F. Mao, IEEE Trans. Electromagn. Compat., 54, 1006-1016, 2012). The asymptotic computational complexity of the TD-EFIE-PO scheme scales like that of the TD-EFIE scheme albeit with a far smaller leading constant, enabling the solution of much larger problems. The TD-AIM constitutes the extension of the frequency domain adaptive integral method to the time domain, and reduces the computational complexity of a TD-EFIE solver from $O(N_t N_s^2)$ to $O(N_t N_s^{3/2} \log^2 N_s)$ without any (high-frequency) assumptions on the current (A. E. Yılmaz, J. M. Jin, and E. Michielssen, IEEE Trans. Antennas Propag., 52, 2692–2708, 2004).

This paper presents a solver that hybridizes the TD-EFIE-PO and TD-AIM methods. In the hybrid scheme, the TD-AIM is used to propagate fields within the EFIE region as well as from the EFIE to the PO region, and back. The hybrid scheme is computationally far more efficient than its standalone constituents. Depending on the nature of the structure considered, the TD-AIM method uses a single grid that covers both the EFIE and PO regions, or separate and nonoverlapping grids for both regions. We apply the proposed scheme to the analysis of interactions of high-power electromagnetic pulses (HP-EMP) with large-scale platforms. Numerical results demonstrate the efficiency, accuracy, and stability of the proposed method.