On Efficient Combination of the Calderon Multiplicative Preconditioner with the Adaptive Integral Method

Yi-Ru Jeong and Ali E. Yilmaz
The University of Texas at Austin, Austin, TX, 78712

The electric field integral equation (EFIE), which is widely used for analyzing scattering from arbitrarily shaped structures modeled as perfect electrical conductors, suffers from a variety of limitations including low-frequency and dense-discretization breakdowns. Among the various possible remedies, the Calderon multiplicative preconditioner (CMP) using Buffa-Christiansen basis functions (F. P. Andriulli *et al.*, IEEE Trans. Antennas Propag., 56, 8, 2398–2412, 2008) has been shown to be effective in improving the condition number and iterative solution convergence of the EFIE solution. The reduction in the number of iterations is offset, however, by the more expensive matrix-fill and matrix-vector multiplication costs of the CMP (F. P. Andriulli *et al.*, IEEE Trans. Antennas Propag., 61, 4, 2077-2087, 2013) causing the total CMP simulation time to be slower than that for other EFIE solution methods in many practical scenarios. This is because the CMP method forms an impedance matrix from basis functions defined on the barycentric mesh, which causes the matrix dimensions to increase 6 times and the matrix-fill time and per-iteration cost of the traditional method-of-moments computation to increase ~36 times.

To enhance its computational efficiency, CMP has been combined with various fast matrix-compression algorithm, including the adaptive integral method (AIM), multi-level fast multipole method (MLFMM), and adaptive cross approximation (ACA). The way these acceleration techniques are combined with the CMP affects the overall computational cost; in particular, the various parameters of acceleration techniques must be carefully chosen. This relation is often ignored or mentioned in a cursory manner in the literature. In this article, a highly-scalable parallel implementation of the AIM is used to reduce the computational costs (F. Wei and A. E. Yilmaz, Parallel Comp., 37, 279-301, 2011) and the impact of AIM auxiliary grid spacing, near-zone size, and moment-matching order on the performance of the CMP-AIM is analyzed.

Let N_{near} and N_{C} denote the number of AIM near-zone interactions and auxiliary grid points. Then, the AIM requires $\mathcal{O}(N_{\mathrm{near}}^{\mathrm{o}})$ and $\mathcal{O}(N_{\mathrm{C}}\log N_{\mathrm{C}} + N_{\mathrm{near}}^{o})$ operations to fill the near-zone correction matrix and compute the matrix-vector multiplications per iteration, respectively, when the original structure is analyzed (without any preconditioner). On the one hand, if the same auxiliary grid is used without any other parameter changes in the CMP-AIM, these computational costs will increase roughly to $\mathcal{O}(36N_{\mathrm{near}}^{\mathrm{o}})$ and $\mathcal{O}(N_{\mathrm{C}}\log N_{\mathrm{C}} + 36N_{\mathrm{near}}^{\mathrm{o}})$, respectively. On the other hand, if the spacing of the auxiliary grids in CMP-AIM is reduced by half, the method will require $\mathcal{O}(36N_{\mathrm{near}}^{\mathrm{o}}/8)$ and $\mathcal{O}(8N_{\mathrm{C}}\log(8N_{\mathrm{C}}) + 36N_{\mathrm{near}}^{\mathrm{o}}/8)$ operations, respectively. The optimal choice of the grid spacing depends on the relative costs of the FFT computations and near-zone operations, will change depending on the structure shape and size, and will generally be in between these two extremes. At the conference, we will discuss the efficient combination and parallelization of CMP with AIM and analyze the effect of AIM parameters on the CMP-AIM computational cost and accuracy.