Modeling of Massively Coupled Electromagnetic Interactions in Microelectronic Systems Using A Parallel Multilevel Oct-tree Based Low-Rank Decomposition Algorithm

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State of the art high performance system design is featured by high speed signal transfer, low power consumption and high functionality integration. Those features bring the necessity of accurate behavior characterization of the sub-circuit where distributed electromagnetic effects are important, which may be computationally expensive. Surface integral equation based methods have been gaining popularity owing to requirement of less number of unknowns and recent breakthroughs in near-linear complexity algorithms, like the fast multipole methods, FFT-based techniques, and multilevel low-rank decomposition. However, for the modeling of complex real world 3D circuit layouts containing massively coupled electromagnetic components and tens of dielectric layers and many thousand interconnects, parallel implementations of the fast algorithms are the only viable options.

Performance of a parallel algorithm is determined mainly by the cost of parallelization, work-load distribution and inter-processor communication. A good candidate algoirhtm should attain near perfect load-balancing. A recently-developed low-rank decomposition based algorithm, PILOT [D.Gope and V.Jandhyala, APS, 53, 3324-3333, 2005] relies on a regular multilevel oct-tree structure. Far field interactions of each level are compressed into independent merged interaction list (MIL), and matrix generation and product across different level are parallel to each other. This makes PILOT an ideal candidate for parallelization.

In our work, PILOT is parallelized through a high performance load-balancing scheme and minimized inter-processor communication. The overall computational workload for PILOT includes the near field Method of Moments (MoM) matrix set up, far field interaction decomposition--Q and R matrices set up, and matrix-vector multiplication. The overall workload on MoM matrix setup can be exactly calculated by extracting source and observer information from the neighbor list and evenly distributed to each processor. However for far field Q and R matrices set up, it is not possible to predetermine the exact workload on each QR list node since the Q and R matrices have to be created before the rank of each node can be known. However, a good estimate for each processor's workload can be obtained by utilizing the predetermined rank map in the MIL based on the oct-tree structure. Given the fact that workload of matrix set up on each processor is proportional to the workload of matrix-vector multiplication, the distribution scheme applied to matrix set up can also be used for matrix-vector multiplication. To speed up the convergence rate of the iterative solution, a three-stage preconditioner involving loop-tree decomposition, basis rearrangement and a parallel sparse approximate inverse is developed. This algorithm has been applied to capacitance, inductance extraction and full-wave simulation.