SAND2018-0700C

Massively Parallel Frequency Domain Electromagnetic Simulation Codes

William L. Langston, Joseph Kotulski, Rebecca Coats, Roy Jorgenson, S. Adam Blake, Salvatore Campione, Aaron Pung, and Brian Zinser
Department of Electromagnetic Theory
Sandia National Laboratories
Albuquerque, USA
{wllangs, jdkotul, rscoats, rejorge, sablake, sncampi, ajpung, bzinser}@sandia.gov

***Abstract*—This paper provides an overview of the electromagnetic frequency domain simulation capabilities of the Electromagnetic Theory department at Sandia National Laboratories via a description of two of its codes. EIGER is a Method of Moments code for electromagnetic simulations, but it only runs on traditional CPUs, not on new architectures. Gemma is in development to replace EIGER and will run on many architectures, including CPUs, GPUs, and MICs, by leveraging the Kokkos library.**

Keywords—electromagnetics, GPU, Kokkos, MIC, moment method, performance portability.

I. Introduction

The Electromagnetic (EM) Theory department at Sandia National Laboratories (SNL) requires several codes to support its analysists. The ideal code returns results quickly, handles a wide variety of problems across an extreme band of frequencies, and produces high accuracy results. The Boundary Element Method (BEM) version of the Method of Moments (MoM) for solving integral equations satisfies these criteria by reducing the dimensionality of the problem to be solved while producing high accuracy results on the boundary, which yeilds accurate results elsewhere with post processing. Next generation platforms (NGPs) promise the ability to reduce the turnaround time without degrading the accuracy. As such, the present production code EIGER is being rewritten into a new code Gemma to leverage the computational efficiency of the NGPs [1]. The rewrite will include the development of new algorithms that leverage the NGPs and better analytic models.

II. EIGER

EIGER (Electromagnetic Interactions GenERalized) is a massively parallel EM simulation code that uses MoM to solve electrodynamic and electrostatic problems. EIGER was originally written in FORTRAN 90 and underwent a partial rewrite in the early 2000's to leverage MPI for intra- and internode parallelism.

EIGER supports a wide variety of problems, including scattering, coupling, layered media, and 1D and 2D periodic problems [2]. Excitations can be from plane wave or voltage sources. Geometries can be made up of wires and/or bodies, which can be perfect electrical conductors (PECs) or dielectrics, following the PMCHWT formulation for dielectrics [3-6]. Specific examples where these features are used include modeling metamaterials and antennas as well as aircraft bodies [7].

EIGER utilizes RWG basis functions in filling a dense, complex-valued matrix for the electric field integral equation (EFIE), magnetic field integral equation (MFIE), or combined field integral equation (CFIE) where the CFIE avoids the internal resonance problems of the EFIE and MFIE. Singular and near-singular integrals are handled by a radial-angular transformation [8]. EIGER then solves the matrix via LU factorization, GMRES, or conjugate gradient. Simulation geometry is typically meshed using at least 10 elements per wavelength. Each element contributes to a dense, complex-value matrix. The storage requirement for this matrix is the limiting favtor for simulating high frequencies.

III. Gemma

Gemma is a C++ rewrite of EIGER for NGPs. Using the Kokkos library for performance portability, it can be compiled for CPU, GPU, or MIC by changing a single flag [9]. Kokkos is a lightweight wrapper around OpenMP, CUDA, and other back-ends that implement thread level parallelism. It also provides a multidimensional array that is indexed layout left (column major) for GPUs or layout right (row major) for CPUs to ensure proper coalesced memory access and caching, respectively. Algorithms written with Kokkos can take advantage of multiple levels of parallelism and memory as well as utilize several different types of execution resources at the same time. While Kokkos manages parallel threads on a single node, MPI will be used for internode parallelism.

Currently, Gemma solves the dense, complex-valued matrix equation using LU factorization or an iterative solver, such as GMRES, from Trilinos's Belos library [10]. For the iterative solve, Gemma uses a Sparse Approximate Inverse (SpAI) preconditioner [11]. The sparse approximation is constructed using an octree based on distance between unknowns; the matrix entries decay exponentially with distance. The relationships between octree leaf sizes, the frequency, and internal resonance have not been studied extensively. Calculating the inverse of the sparse approximation yields a suitable preconditioner for the linear system.

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA-0003525.

Gemma can presently perform scattering calculations from an incident plane wave. An example is discussed below. Developing Gemma will continue by first implementing the MFIE, CFIE, dielectrics, and wire and slot subcell models needed for electromagnetic coupling problems. Broadly, Gemma will include all the features in EIGER, though the algorithms will be modified where performance gains can be obtained for the new architectures. In addition, new features will be developed for Gemma. These include interfacing with a circuit solver Xyce [12] and advanced solver technologies such as hybrid methods, fast multipole methods, and adaptive cross approximation.

IV. Validation

The Electromagnetic Code Consortium (EMCC) provides a set of measurement data for specific geometries and incident plane waves for code validation [13]. The EMCC problems are run with EIGER, Gemma, and FEKO's MoM solver, FEKO being used for comparison when agreement with EMCC data is poor. Being a partial reimplementation of EIGER, EIGER and Gemma produce indistinguishable results, up to a prescribed level of numerical accuracy.

As an example, Fig. 1 shows the measured and calculated radar cross section (RCS) for a cone-sphere with the mesh pictured at the center of the figure. For all three codes, the geometry was meshed with 10 elements per wavelength; FEKO was allowed to refine the mesh as it deemed necessary while EIGER and Gemma used a mesh produced by the CUBIT meshing software and have no adaptive refinement capabilities [14]. Further refining the mesh did not change the character of the results. Fig. 1 shows EIGER and Gemma obtaining excellent agreement with FEKO and good agreement with experiment.

V. Summary

While EIGER meets the current needs of the EM theory department at SNL, it cannot run efficiently on MICs and it cannot run on GPUs. Gemma meets future needs by utilizing the Kokkos library to run well on all desired high-performance computing (HPC) architectures. By using Kokkos, Gemma will be low maintenance. First, it will be written once for all platforms. Second, Kokkos, not Gemma, will implement any new architectures as a new backend that can be selected at compile time. In short, Gemma will provide analysts with high accuracy results quickly on a variety of HPC architectures for a minimal amount of programming effort.

Acknowledgment

We thank Rafael Schleder for his work projecting the RCS results on to a polar coordinate system.

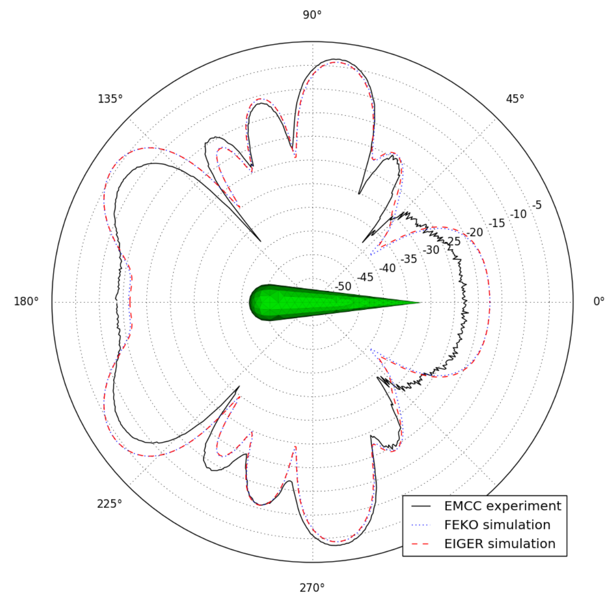

Fig. 2. Monostatic RCS (dB per square meter) of a cone-sphere from multiple angles due to an incident plane wave of 869 MHz. Being indistinguishable in this plot, EIGER and Gemma are both represented by the dashed red line.

References

[1] D. R. Wilton, W. A. Johnson, R. Jorgenson, R. Sharpe, and J. Rockway, "EIGER: A new generation of computational electromagnetics tools," ElectroSft: Software for EE Analysis and Design, Miniato, Italy, pp. 28-30, May 1996.

[2] C. Lertsirimit, D. R. Jackson, and D. R. Wilton, "An efficient hybrid method for calculating the EMC coupling to a device on a printed circuit board inside a cavity by a wire penetrating an aperture," Electromagnetics, vol. 25, iss. 7-8, 2005.

[3] J. Poggio and E. K. Miller, "Integral equation solutions of three-dimensional scattering problems," in R. Mittra (ed.), Computer Techniques for Electromagnetics, Oxford, UK, Pergamon Press, 1973.

[4] Y. Chang, R. F. Harrington, "A surface formulation for characteristic modes of material bodies", *IEEE Trans. Antennas Propag.*, vol. 25, no. 6, pp. 789-795, Nov. 1977.

[5] T.-K. Wu, L. L. Tsai, "Scattering from arbitrarily-shaped lossy dielectric bodies of revolution", *Radio Sci.*, vol. 12, no. 5, pp. 709-718, Sep./Oct. 1977.

[6] J. R. Mautz and R. F. Harrington, "Electromagnetic Scattering from a Homogeneous Material Body of Revolution," Archiv fur Elektronik und Ubertragungstechnik, vol. 33, pp. 71-80, 1979.

[7] L. I. Basilio, W. L. Langston, L. K. Warne, W. A. Johnson, and M. B. Sinclair, "Full-wave simulation of a three-dimensional metamaterial prism," Microw. Opt. Technol. Lett., vol. 57, pp. 537–540, March 2015.

[8] M. A. Khayat, D. R. Wilton, and P. W. Fink, "An improved transformation and optimized sampling scheme for the numerical evaluation of singular and near-singular potentials," IEEE Antennas Wireless Propag. Lett., vol. 7, pp. 377–380, 2008.

[9] H. Edwards, C. Trott, and D. Sunderland, "Kokkos: Enabling manycore performance portability through polymorphic memory access patterns," J. Parallel Distrib. Comput., vol. 74, no. 12, pp. 3202-3216, 2014.

[10] E. Bavier, M. Hoemmen, S. Rajamanickam, and H. Thornquist, "Amesos2 and Belos: Direct and iterative solvers for large sparse systems," Scientific Programming, vol. 20, iss. 3, 2012.

[11] M. Bettencourt, B. Zinser, R. Jorgenson, and J. Kotulski, "Performance portable sparse approximate inverse preconditioner for EFIE equations," CEM, 2017, in press.

[12] E. Keiter, et al., "Xyce parallel electronic simulator users' guide, version 6.7," Albuquerque, NM: Sandia National Laboratories, 2017.

[13] A. Woo, H. Wang, M. Schuh, and M. Sanders, "Benchmark radar targets for the validation of computational electromagnetics programs," IEEE Antennas and Propag. Mag., vol. 35, no. 1, pp. 84-89, February 1993.

[14] "CUBIT Geometry and Mesh Generation Toolkit 15.3 User Documentation", Sandia report SAND2017-6895, 2017.