On the Solution of FEM Problems with Massive Number of Ports

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Phased array characterization, and electromagnetic (EM) and circuit (CKT) co-simulation of packaging, components and PCBs both involve large number of ports. As such, obtaining their transfer (system) function matrix requires multiple simulations, each with a different port excitation. Even fast methodologies such as the model order reduction (MOR) and other fast CEM methods, experience severe slow-down attributed to the large number of ports. This is due to the fact that the transfer (system) function matrix, i.e. s-matrix or Y or Z-matrix is dense ($P \times P$, P is number of ports), and traditionally each row or column is obtained through a full-wave solution of the model at hand.

Traditionally such problems are best tractable with direct factorization matrix methods such as the multifrontal LU decomposition, where after the factorization stage, the transfer matrix is rapidly obtained through P^2 forward/backward substitutions. Alternatively block Krylov iterative methods (Y. Saad, Iterative Methods for Sparse Linear Systems, 2003) or multiple right-hand-side Krylov methods (C. Smith et al., IEEE Trans Antenna Propag, Nov 1989) could be used. This work will exploit the inherent rank-deficiency of such transfer matrices, to reduce the computational cost. Randomized singular value decomposition (SVD) algorithms (N. Halko et al., SIAM Review, pp.217-288, 2011) will be used to compute rank-deficient representations of such transfer matrices or sub-blocks. These methods use random projections along with low complexity, often out-of-core, linear algebra operations to find the dominant subspace of a matrix. As a result, the randomized SVD of an $m \times n$ dense matrix requires $O(mnlog(k))$ ($k \ll min(m,n)$) floating-point operations instead of the $O(mn^2)$ of the standard full SVD. To extract the frequency dependence of such transfer function matrices, these randomized SVD-based methods will be combined with deterministic, robust and error controllable model order reduction methods as well as direct factorization schemes appropriately tailored to expedite the computation of selective inverse matrix entries.

The talk will first outline the importance of fast many-port device CEM solvers, and highlight their computational challenges. Then, it will present the proposed computational framework that combines the randomized SVD, model order reduction method and fast selective inverse direct solvers. To verify the accuracy and efficiency of the proposed framework, problems ranging from antenna array, signal integrity and the computation of the Dirichlet-to-Neumann map will be considered.