VoxCap: An FFT-Accelerated Capacitance Extractor for Voxelized Structures

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Capacitance extractors are of great importance for designers to obtain accurate equivalent circuit models of interconnects on chips, boards, or packages. Among a plethora of capacitance extractors developed so far, those that are accelerated by fast multipole method (FMM) (Nabors and White, *IEEE Trans. Comput.-Aided Design Integr. Circuits Syst.*, 10(11), 1991, pp. 1447-1459) and precorrected-fast Fourier transform (FFT) (Phillips and White, *IEEE Trans. Comput.-Aided Design Integr. Circuits Syst.*, 16(10), 1997, pp. 1059-1072) have sustained their popularity over more than a decade. It has been shown that the is more memory and CPU efficient than the FMM accelerated one for the electrostatic analysis of three dimensional (3D) complex and dense interconnect structures discretized by unstructured meshes. However, many of virtual fabrication environments make use of voxelized geometries since their use in unit process steps of the iterative design explorations is significantly easier. In the case of a voxelized geometry, projection and interpolation operations of the precorrected-FFT accelerated extractor becomes redundant (voxels naturally reside on a 3D uniform grid). To this end, a efficient and accurate capacitance extractor capable of working directly with voxelized geometries would be highly useful in design processes. Additionally, such extractor would be straightforward to use in conjunction with the VoxHenry inductance extractor (Yucel *et.al*, *Progress In Electromagnetics Research Symposium*, 2017) to build simulators for electro-magneto-quasi-static and full-wave analyses of complex and dense interconnect structures.

In this work, an FFT-accelerated capacitance extractor for voxelized structures, called VoxCap, is proposed for this purpose. The VoxCap solves a first kind integral equation in charge density induced on conductor-dielectric and dielectric-dielectric interfaces. The charge density is expanded using pulse basis functions; inserting this expansion into the integral equation and applying Galerkin testing to the resulting equation yield a matrix system in unknown expansion coefficients. This matrix system is solved iteratively, where FFTs are used to accelerate the matrix-vector multiplications. The accuracy and efficiency of the proposed VoxCap will be demonstrated through its application to the capacitance extraction of various voxelized structures including concentric spheres, parallel buses, parallel plates, comb drive, SRAM, and vowen bus structures. In the talk, several preconditioning strategies to ensure the rapid convergence of the matrix system's iterative solution will be discussed.