VoxHenry: FFT-Accelerated Inductance Extraction for Voxelized Geometries

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Post-layout parasitic extraction plays a key role in almost every digital design flow, and is used in functional verification, timing loop closure, power estimation, and electrical fault checking (e.g. IR drop). Existing extraction tools are fast enough to be used in iterative digital design exploration, and are even accurate enough for some analog applications. But these tools were not designed to handle the far more stringent needs of high-performance mixed signal designs, which usually include high-accuracy ADC's and and near-terahertz circuits. To address the needs of these mixed signal designers, extractors are being dramatically enhanced; they are using much more accurate 3-D geometries (often generated by process-simulation), and are extracting dense coupling due to longer-range inductive effects. Of course these enhanced extractors are much slower, usually too slow to use in iterative exploration of a complete design.

A fortuitous confluence of technological developments is ushering in a new breed of extraction tools, ones that are fast and accurate enough to be used in high-performance mixed-signal design exploration. By borrowing ideas from computer graphics, a new breed of voxel-based process emulation tools are emerging, ones that use the simplicity of manipulating cubes to quickly, reliably, and automatically generate accurate 3-D structures from layout and process descriptions. These tools, initially designed for visualization, generate billion-cube representations that challenge most extraction algorithms. But, such representations are an excellent match to recently developed FFT-accelerated volume integral equation methods.

In this paper, we describe VoxHenry, an FFT-accelerated inductance extraction simulator that shares many features with the popular FastHenry inductance extractor, while also exploiting the voxelized geometries generated by process emulation. VoxHenry solves the same combination of electric-field-volume-integral and current-conservation equations as FastHenry, but with two essential differences: (i) VoxHenry uses three piecewise-constant and two piecewise-linear basis functions in every voxel, to preserve translation invariance, and (ii) uses explicit conservation equations resolved using a sparse preconditioner, to avoid forming invariance-dissembling meshes. As we will show in a full paper, these differences allow VoxHenry to exploit the FFT on voxelized geometries, and make it fast and accurate enough to extract inductances from large scale and arbitrarily shaped structures generated by process emulation, with only a desktop computer. The VoxHenry simulator will be demonstrated through its application to the inductance analysis of various structures, such as square and circular coils (situated over ground planes) and arrays of RF inductors.