Moore meets Maxwell

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*Abstract***— Moore's Law has driven the semiconductor revolution enabling over four decades of scaling in frequency, size, complexity, and power. However, the limits of physics are preventing further scaling of speed, forcing a paradigm shift towards multicore computing and parallelization. In effect, the system is taking over the role that the single CPU was playing: high-speed signals running through chips but also packages and boards connect ever more complex systems.**

High-speed signals making their way through the entire system cause new challenges in the design of computing hardware. Inductance, phase shifts and velocity of light effects, material resonances, and wave behavior become not only prevalent but need to be calculated accurately and rapidly to enable short design cycle times. In essence, to continue scaling with Moore's Law requires the incorporation of Maxwell's equations in the design process. Incorporating Maxwell's equations into the design flow is only possible through the combined power that new algorithms, parallelization and high-speed computing provide. At the same time, incorporation of Maxwell-based models into circuit and system-level simulation presents a massive accuracy, passivity, and scalability challenge.

In this tutorial, we navigate through the often confusing terminology and concepts behind field solvers, show how advances in field solvers enable integration into EDA flows, present novel methods for model generation and passivity assurance in large systems, and demonstrate the power of cloud computing in enabling the next generation of scalable Maxwell solvers and the next generation of Moore's Law scaling of systems. We intend to show the truly symbiotic growing relationship between Maxwell and Moore!

Keywords - Maxwell's equations, electromagnetic field solvers, electromagnetic integrity, 2.5D solvers, 3D solvers, finite element, finite difference, method of moments, boundary element method, cloud computing, multicore parallelism, MPI, reduced order equivalent circuit, circuit extraction, passive macro modeling, circuit simulation.

I. NAVIGATING FIELD SOLVERS FOR EDA

There are a myriad of electromagnetic solvers of varying accuracy, scale, and speed with different applicability. Static, quasi-static, full-wave regimes are distinct, as are 2D, so-called 2.5D (layered) and 3D solvers. While static solvers suffice for digital on-chip capacitance and resistance extraction, system-level parasitic extraction necessitates a range of solvers. At higher frequencies, quasi-static solvers produce coupled inductance and capacitance matrices for chip, package and board structures. For handling the complete frequency range of many state-of the-art electronic systems, full-wave solvers are necessary. Different dimensionalities of solvers are also applicable in different scenarios. Efficient and simple two-dimensional solvers work well for cross sections, transmission lines, and cables. So-called 2.5D solvers use layered medium approximations to simplify material media. Such approaches work well for embedded passives in analog chips but have challenges when used for package or board structures. Another class of so-called 2.5D solvers uses symmetric or differential current flow assumptions to simplify the problems and ease computational time and memory. Such methods work well at low frequencies and with conservative designs, but fail for low-cost systems such as memory interfaces. 3D solvers can handle the complete generality of systems but have challenges in scalability unless fast algorithms and parallel methods can be developed. This talk clarifies how to choose the right electromagnetic solver for the right task in electronic design for a variety of challenging applications including: Parasitic extraction, inductive noise, power integrity, high-speed signal integrity, electromagnetic interferences, integrated antennas and radiators, and integrated passives in analog and RF circuits. This talk also focuses on the powerful finite element, finite difference, and method of moments class of solvers, and introduce novel algorithms for high-accuracy solution with dramatic acceleration and scalability. In the context of differential and integral equation methods, concepts such as boundary conditions, equivalent surfaces, source types, iterative and direct solvers, time stepping methods, and S-parameter generation and equivalent circuit generation are discussed.

II. PARALLELIZED, MULTICORE, AND CLOUD ALGORITHMS FOR FIELD SOLVERS

Boundary Element Method (BEM) based electromagnetic field solvers typically involve solving a dense matrix which present a time and memory bottleneck. Over the last two decades, linear scaling iterative solver algorithms have emerged to alleviate the problem to an extent. These methods typically employ matrix compression followed by fast matrix-vector products in a Krylov subspace iterative solution framework. However, analysis of large scale structures such as those encountered in systems-in-package (SiP) entail the solution of large number of basis-functions and many right-hand-sides

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(RHS), and present significant challenges in terms of memory capacity to fit the compressed matrix, and quick turnaround time required for early design optimization.

The emergence of cloud computing and the corresponding on-demand availability of custom computing instances, presents a unique opportunity to meet the time-memory requirements. In order to harness the true potential of the cloud infrastructure, a multilevel parallelization scheme is adopted. The selection of the type of parallelism employed at each different phase in the hybrid framework depends on a scalability study of the individual components and is guided by Amdahl's law and the serial content of the underlying algorithms. In this talk, scalable algorithms for boundary element methods are discussed in the context of parallelism. Hierarchies of parallelism including OpenMP-based multicore parallelism, MPI-based multi-CPU parallelism, and distributed computing are examined. Latency challenges endemic in cloud computing are also presented, including solutions to these issues.

It is shown that the combination of scalable fast solvers and multi-scale parallelism allows electromagnetic simulation of complex high-frequency systems in a manner that enables parametric design, variability analysis, and system optimization.

III. FROM FIELDS TO CIRCUIT SIMULATION THROUGH PASSIVE MACROMODELING

This talk provides a bridge between electromagnetic simulation and circuit-oriented system verification flows. As discussed during previous talks, an accurate electromagnetic analysis of complex signal and power distribution networks at chip, package, and board level is essential for the assessment of all those parasitic effects that might compromise the performance of the system. However, the results of such analyses must be cast in a form that is useable from the designers within their EDA flows, the latter being almost invariably based on circuit simulators of the SPICE class.

In this talk, we discuss various alternatives for casting the results of an electromagnetic analysis as reduced-order equivalent circuits that naturally fit in a circuit-oriented verification flow. Various alternatives for circuit extraction are discussed, including model order reduction and black-box rational approximation/identification with passivity constraints. The state of the art in passive macromodeling is reviewed and discussed, with emphasis on scalability to large-scale systems having massive port counts and large dynamic orders. Algorithm partitioning and parallelization solutions are presented and illustrated in the context of a cloud computing environment. Future challenges are also discussed, with emphasis on verification flow optimization via tool integration.

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