ELECTROMAGNETIC SIMULATION FOR ELECTRONIC SYSTEMS

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WHITEPAPER

HIGH SPEED DESIGN

THE NEED FOR ELECTROMAGNETIC SIMULATION

Packages and boards are playing an increasing role as a way to increase speed and density while reducing power and form factor of electronic systems. This is part of a trend called sometimes "more than Moore", to refer to factors in addition to scaling ICs. Packages and boards both represent sizeable industries, even compared to the $300 billion semiconductor industry[1]. Packaging is estimated to be an approximately $24 billion of revenue industry, while boards are estimated at approximately $60 billion of yearly revenue[2]. This paper focuses on the simulation of the package-board system, which is becoming increasingly more complex and often requires solving the electromagnetic fields.

Electromagnetic simulation consists of solving Maxwell's equations to calculate the electric and magnetic fields. In electronic systems, electromagnetic simulation is used to characterize the behavior of interconnect accurately. Stated in a simplified way, this becomes necessary when a signal travels a distance comparable to its wavelength and needs to be modeled as a wave. In practice, electromagnetic simulation is used for "fast" packages and boards, less frequently for dies because they are smaller. For example, at 1 GHz, the wavelength in air (very similar to vacuum) is 30 cm or about one foot, so signals that travel several centimeters require electromagnetic simulation; packages and boards exhibit these dimensions.

Electromagnetic fields are of course only one of many ways to model electric systems. Other common ways, in increasing order of accuracy, include: register transfer level (RTL), logic, analog circuit and device physics. In this scale of "levels" (figure 1), electromagnetic simulation; which uses fundamental physics (Maxwell's equations) is more accurate than analog circuit simulation, which uses R, C, L, G and lumped transistor models. It simulates a different case than device physics used for example in technology computer aided design (TCAD) to model the behavior of a semiconductor device.

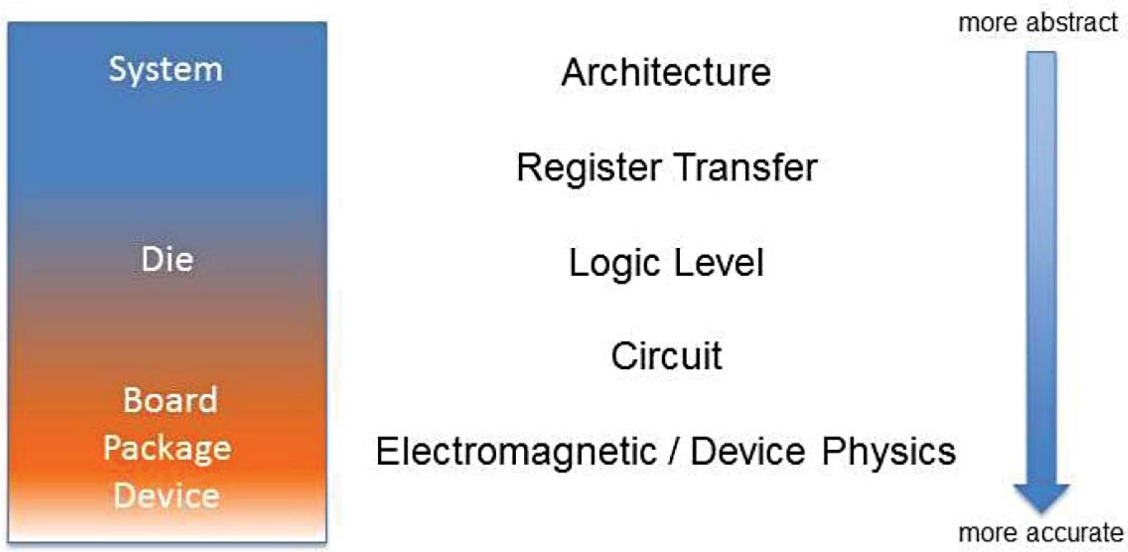

Figure 1: Modeling levels of electronic systems.

The market for electromagnetic simulation is expected to continue increasing. The main technology drivers include:

HIGHER FREQUENCIES

In the next ten years, the frequency from chip to board is expected to double for memory, to increase perhaps fivefold for for high-performance systems with high-speed serial links and to slightly increase for mobile systems.

DECREASING VOLTAGE

Even though voltage is expected to decrease only slightly from typically 0.5-1 V today to 0.4-0.8 V in the next ten years, lower voltages mean progressively smaller margins for device switching and higher susceptibility to noise, requiring more accurate analysis.

INCREASING DENSITY

High-performance packages will increase their pin count, substrates will reduce line width and spacing and via diameter and pitches. Wafer level chip scale packages are increasingly common. Increased density means increased electromagnetic coupling and interference. Referencing (localized current return paths) is also likely to become poorer, creating more common mode current and increased radiation.

3DIC PACKAGING (3DIC)

Advanced technologies for board-package systems, often referred to as 3DIC, are becoming an important contributor to reducing power, increasing speed and allowing compact form factors of electronic systems. Numerous 3D techniques are being developed, such as mounting ICs on a silicon interposer, stacked dies and package on package (PoP). Through silicon vias (TSVs) are used to connect the different levels in several of these technologies. These 3D structures are large compared to a standard chip and need to be modeled accurately electromagnetically.

ELECTROMAGNETIC SIMULATION IN THE DESIGN FLOW

Electromagnetic simulation consists in solving Maxwell's equations. The inputs are the geometry and material characteristics of the system, e.g. a board, a package or a package-board system, and the excitation at so called ports, e.g. pins or ball grid array (BGA) of a package. The outputs are the electric and the magnetic fields. These fields allow calculating electric potentials, current densities, impedances, s-parameters, etc., and are ultimately used for signal integrity, power integrity and electromagnetic interference. The point is that electromagnetic simulation is necessary for accuracy; simplifications such as lumped parameters do not capture the behavior of signals that behave like waves.

In the most general case, a solver has to be able to accept any 3D geometry and any frequency range; these solvers are referred to as "full wave 3D". The solution can happen in the time domain or in the frequency domain. In the time domain the formulation is typically of finite differences and these solvers are called "finite difference time domain" (FDTD) solvers. In the frequency domain two formulations are common: finite elements (finite element analysis, FEA, solvers) and boundary element solvers (BEM), also known as method of moments (MoM).

The solver can be simplified by restricting the geometries and/or the frequency range they apply to. A "2D" solver solves a two-dimensional cross section of a problem, for example of a transmission line, using the simplifying assumption that the third dimension is infinite. Such a 2D solution can be used on a "per unit length" basis to generate the approximate impedance of the transmission line. Similarly, for layered structures such as packages, boards or on chip inductors, simplifications can be done, particularly if the design contains well-defined reference planes (power, ground); such solvers are called 2.5D. If the frequency range is limited to specific frequencies that are low enough to allow solving Maxwell's equations, ignoring the explicit time derivatives, the solver is called (electro/magneto) "quasistatic". The trade-offs between a full-wave 3D solver and the different simplified versions are run-time/memory vs. accuracy. Electromagnetic simulation is used in the design flow as indicated in figure 2.

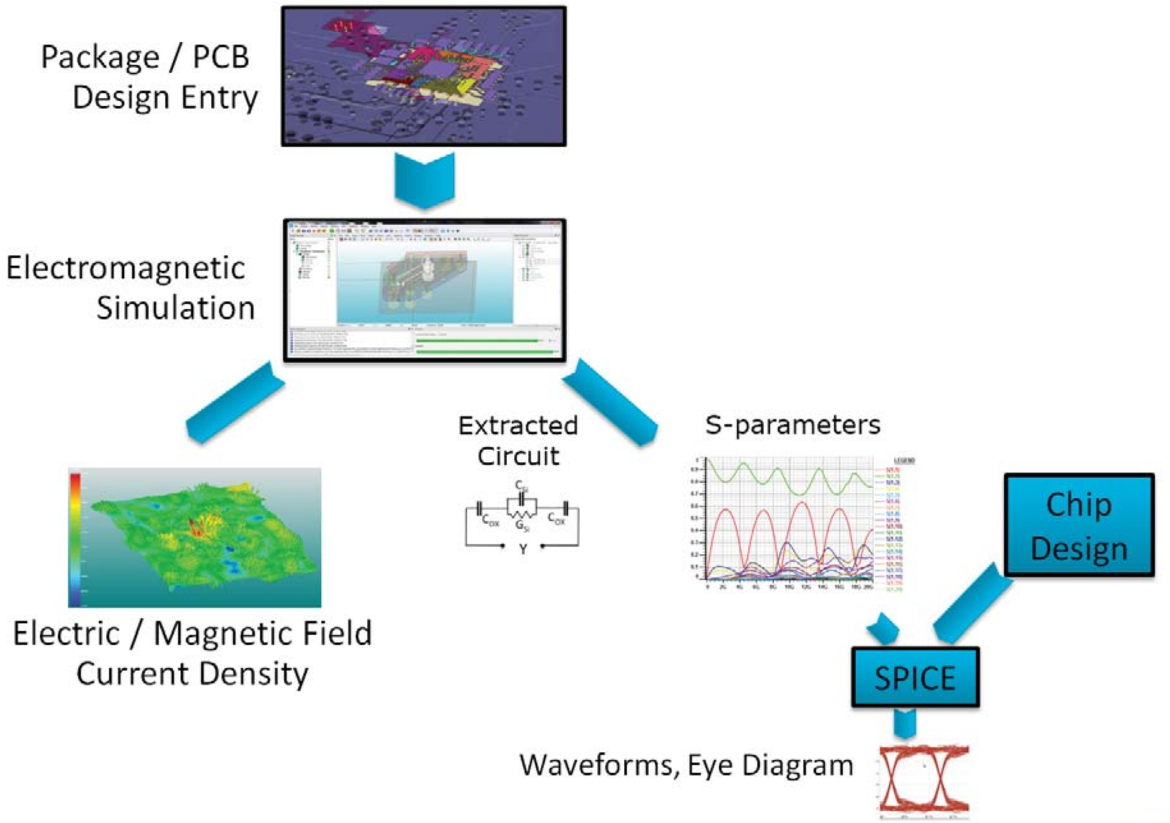

Figure 2: Electronic simulation in the design flow.

The fields are used for electromagnetic compatibility (EMC) and electromagnetic interference (EMI), such as FCC compliance. The extracted parasitics can be given as an equivalent RCLG circuit, e.g. at a given frequency; but in the more general case, are given as so-called scattering parameters (s-parameters). Without getting into details, s-parameters are given as an nxn matrix for n ports and describe how a signal on a given port i "scatters" and exits on all n ports, including reflection on the same port i, transmission to the ports connected to it and coupling to all the other ports. S-parameters are frequency dependent and are complex numbers that affect magnitude and phase. Circuit simulators read s-parameters, allowing accurate time domain simulations to obtain for example, the familiar "eye-diagrams" to judge the quality of a high-speed digital channel. In such a simulation, a circuit model of the transmitter/receiver typically represents the die and the package-board system is represented by the s-parameters.

SUMMARY

Electromagnetic simulation is an integral part of the design flow for high-speed electronic systems such as computers, mobile systems, networking, etc. Its adoption is being driven mainly by higher frequencies and by more sophisticated packaging techniques. Electronic system designers use electromagnetic simulation to extract the parasitics of the package-board system and to compute the electromagnetic fields for EMC/EMI. Semiconductor and IP designers need to be increasingly aware of the electromagnetic environment that their chips will work in, just as radio frequency (RF) designers are aware.

REFERENCES

1 "A Changing Packaging Materials Market", www.semi.org/en/node/41966

2 "IPC World PCB Production Report for the Year 2011", www.ipc.org

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