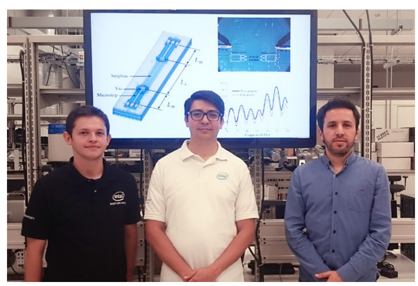
# DEFYING CONVENTION TO ACHIEVE FASTER SIGNAL AND SIMULATION SPEEDS

*Innovative optimization methods combining space mapping algorithms and electromagnetic simulation make it possible to improve signal speed and integrity in package interconnects. Faster simulations ensure the latest high-speed interconnect technology is available in less time.*

By **JENNIFER SEGUI**

**ESTABLISHED AS LEADERS** in the electronics and computer hardware industry, it is easy to assume that the researchers and engineers at Intel rely on powerful computing clusters and servers to efficiently simulate and optimize their designs. While we would be correct in our assumptions, there's much more to their methods. Multiphysics simulation software and an unconventional approach to design optimization developed at the Intel Guadalajara Design Center may be behind the latest high-speed interconnects for electronics packaging.

Take printed circuit boards (PCBs), for example. A mainstay in electronics packaging, PCBs are found in almost every electronic device from handheld computers and cellphones to state-of-the-art satellite communication systems. PCBs have many integrated high-speed interconnects enabling the transfer of electronic signals between components that are attached at the surface. To demonstrate, a PCB research prototype is shown in Figure 1, where probes are in contact with surface traces at each end of a package interconnect.



Engineers from the Intel Guadalajara Design Center, pictured from right to left, are: Juan C. Cervantes-Gonzalez, Carlos A. Lopez, and Isaac G. Farias-Camacho.

In making electronic devices smaller, the size and spacing of package interconnects is scaled down by necessity, which can make computational design optimization to improve signal speed and integrity more time consuming.

Interconnects operating at higher frequencies—or signal speeds—will also consume more power. The geometry and materials of package interconnects have to be redesigned to minimize power consumption and prevent signal loss for a given application, which applies particularly well in the case of PCBs given their range of uses.

"Using simulation to optimize the design of package interconnects is essential, requiring accurate models that capture the non-negligible couplings arising from complex 3D structures," explains Juan C. Cervantes-González, an engineer at Intel. "To make electromagnetic simulations of package interconnects even faster, we have exploited and validated a space mapping optimization algorithm. With this optimized approach to simulation, we can further decrease the length of the design cycle and time to market of the latest, high-speed interconnect technology."

## » MODELING HIGH-SPEED PACKAGE INTERCONNECTS

**FULL-WAVE ELECTROMAGNETIC SIMULATION** is necessary to model signal propagation in package interconnects operating at higher frequencies. By solving the complete set of Maxwell's equations without any simplifying assumptions, simulations can accurately account for non-negligible electromagnetic couplings and impedance mismatch in complex 3D structures, important contributors that cause crosstalk and reflection compromising signal integrity.

Using COMSOL Multiphysics® software, the engineers at Intel developed a model of a single-ended interconnect line embedded in a PCB structure. A cross section of the model geometry is shown at left in Figure 2, and highlights the relevant design parameters that are optimized in their work.

Single-ended interconnects are

> *"With this optimized approach to simulation, we can further decrease the length of the design cycle and time to market of the latest, high-speed interconnect technology."*
>
> **—JUAN C. CERVANTES-GONZALEZ, ENGINEER, INTEL**

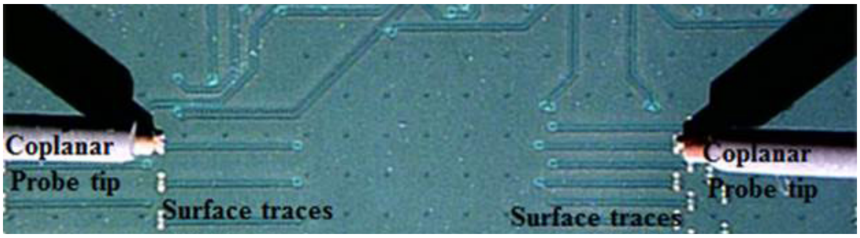



**FIGURE 1:** An Intel PCB research prototype featuring package interconnects.

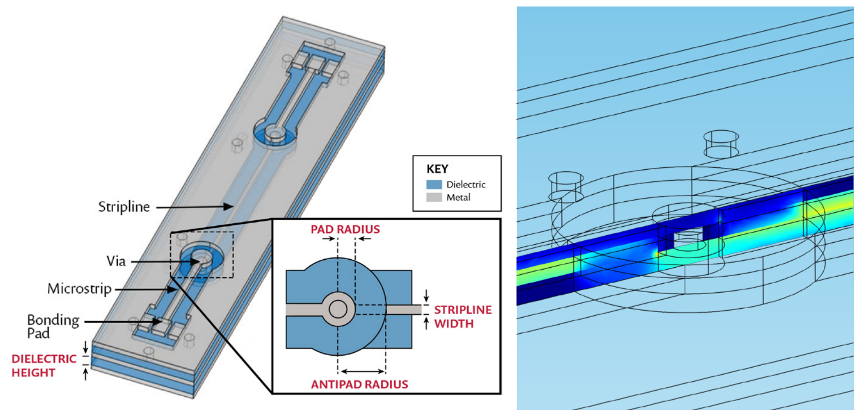



**FIGURE 2:** Left: Model geometry of a single-ended interconnect set up in COMSOL Multiphysics® software. Parameters highlighted in red are optimized using simulation. Right: Electric field distribution through a via in the modeled package interconnect.

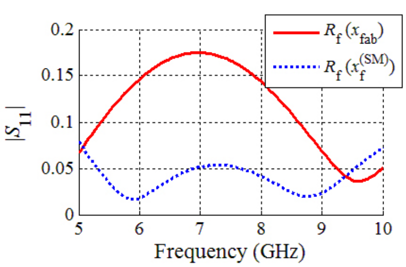



**FIGURE 3:** Magnitude of the reflected signal (|S11|) obtained by solving the fine model. Significant reflection is observed for the design parameters of the fabricated interconnect prototype (red curve) compared with the space-mapped optimized solution (blue curve).

known for their high signal speeds and for taking up less space in electronics packaging, enabling their use in densely packed layouts. Signals propagate laterally through interconnects along metallic microstrips and striplines with ground planes separated by dielectric material. Signals travel vertically through vias, often traversing more than 10 layers of dielectric and metal in a typical PCB, making them the primary culprits contributing to impedance mismatch.

In COMSOL® software, full-wave electromagnetic simulation is used to optimize the geometric parameters of a fabricated prototype in order to minimize impedance mismatch and the resulting signal reflection or return loss. Simulation results showing the electromagnetic field distribution in a single-ended interconnect are presented at right in Figure 2.

## » OPTIMIZING INTERCONNECTS FOR LOW RETURN LOSS

**TO OPTIMIZE THE DESIGN** of high-speed package interconnects and minimize the magnitude of the reflected signal over a range of frequencies, simulations are run on a high-performance server with dual Intel® Xeon® X5670 CPU at 2.93 GHz and 160 GB of RAM. To make simulations run even faster, a Broyden-based input space mapping optimization algorithm was implemented.

The space mapping approach to electromagnetic simulation involves solving two separate interconnect models in COMSOL. The first is a "coarse" model and is a 2D simplification of the model geometry in Figure 2, which neglects electromagnetic losses and is discretized using a very coarse mesh designed to provide a fast result. The second is a "fine" model whose topology is identical to the first, but represents the full 3D geometry shown in Figure 2 and is solved using a much finer mesh, providing greater accuracy at the cost of speed.

The signal response for the optimal 2D model design was determined first using conventional optimization methods, and is an important first step that reduces the overall computation time. The objective of the space mapping algorithm, implemented in MATLAB® software, is to find the 3D model design parameters that make its resulting signal response close to the optimal 2D model response. Using this method, the interconnect design parameters are optimized within just four iterations. The results in Figure 3 were obtained by solving the full 3D model, and show a significant reduction in reflected signal for the optimized design compared with the original fabricated interconnect prototype.

"By using full-wave electromagnetic simulation along with space mapping optimization, a much better interconnect design is achieved with lower return loss, and in far less time than it would take to make and test many different prototypes," says Cervantes.

Although their initial model only solved for electromagnetic wave propagation in order to validate the space mapping optimization method, heat transfer and solid mechanics can also be included in fully coupled multiphysics models providing innovative, if not unconventional, design capabilities. ◎