Meanwhile, many of the highest-growth applications for electronics involve control of illumination. New technology for flat-panel displays, LED lighting, solar energy, and high-speed interconnect requires analysis of the physics involved in electro-optical behavior.

**Multiphysics Simulation Enhances Electronics System Design**

By Mike Demler • Technical Editor

Simulation of electronic circuits and systems has long focused on the analysis of electrical signals: voltage or current waveforms for analog engineers and binary bit patterns for digital engineers. Now that IC density has grown into the billions of transistors, however, on-chip management of power dissipation has become more critical. You must also consider the physics of how that power converts into performance-degrading heat. Verification of system performance and reliability requires analysis of both thermal and electrical conduction, involving modeling of materials that you previously may have ignored, and the physical interaction from a chip to its package and surrounding environment.

**Divide and Conquer**

Multiphysics simulation is a tool for analyzing systems with disparate physical behaviors that disparate mathematical models describe. The physical behaviors may be intentional components of a design, such as in electromechanical or electro-optical systems, or they may be an unavoidable aspect of the physical realization, as is the case for most electrothermal behavior. Approaches to simulation also vary—from co-simulation of tightly coupled systems...
SOFTWARE MODELS DRIVE NEXT-GENERATION CARS

Martin Rowe and Jennae Cohen, Test & Measurement World

Software lets engineers model and simulate everything from silicon to sheet metal. The EcoCar team at RHIT (Rose-Hulman Institute of Technology) is learning how to model an entire vehicle with The MathWorks’ Matlab and Simulink as part of the EcoCar competition.

In the three-year competition, now in its final year, students from 16 colleges compete to design an environmentally friendly car (Reference A). Students spent the first year developing a software model that lets them evaluate the impact of their proposed modifications to a General Motors vehicle.

The system model comprises mathematical models of the vehicle’s components that the students purchase, modify, or adapt to improve fuel efficiency. To get the students started on the model, GM supplied data on the vehicle’s parts and systems. “We took an approach of a system integrator, and we selected components that would get the job done,” says Professor Zac Chambers, one of the RHIT project advisors.

From Matlab models that connect through Simulink, team members roughly calculated the size and power characteristics of the components for their hybrid vehicle. Students and faculty ran cases in which they compared architectures to see how they performed for the competition metrics. For example, they examined the amount of power an engine required to meet the vehicle’s unassisted towing requirement should the battery fail.

Figure A shows the software hierarchy of the vehicle model. This simplified diagram follows the path from the overall vehicle model to the models that simulate the engine. Students wrote the simulation code with Matlab and used Simulink to tie the models together into a system. From the Simulink model, team members narrowed down the choices of engines that GM had available for them.

They first tried a 1.3-liter diesel engine, the smallest, in their model. GM had available for us. We then used the NX software to determine whether it would mechanically fit into the vehicle when connected to the vehicle’s automatic transmission.

The Matlab/Simulink system model runs in a National Instruments PXI instrument chassis. Analog, digital, and communications I/O cards in the chassis connect to external controls that simulate control signals, such as the gas and the brake. Instruments also collect data from the ECU (engine-control unit) from sensors in the vehicle.

“In choosing the 1.3-liter turbo diesel, we used Siemens NX CAD [computer-aided-design] software to make sure the parts we designed would fit inside the vehicle,” says Chambers. “From the Simulink model, we can figure out the rough power requirements for the engine and then, from that figure, narrow down the choices of engines that students use the model to predict how the actual car will run. Software components of the model started as simple equations. Along with the plant model, they have a model of the overall vehicle supervisor and the competition metrics they must log and a model of how the driver will drive the vehicle based on a driving cycle. They have also incorporated CAN (controller-area-network) interfacing so the components can model working on the vehicle network.

“We started with the high-level plant model and made incredibly simple mathematical models,” says Chambers. “For example, our first model of the vehicle’s engine [an electric motor] was a constant torque source that put out the maximum torque and had no rpm limits. With a simple motor like that, you can start hooking that motor up to the vehicle. From these simple models, you can get a feel for how the vehicle should respond. Then, you can develop a control strategy and verify that the response is what you expect.”

With its measurement and signal-generation cards, the PXI system let students collect 45 minutes of data, compare test data with the model, and refine the model. “We have a graduate student who is developing sophisticated optimization tools,” Chambers says. “Graduate students will use the model to teach undergraduate students about modeling-system design.”

Figure A The path proceeds from the overall vehicle model to the models that simulate the engine.

Reference


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to a divide-and-conquer approach that uses specialized tools and languages for each domain and APIs (application-programming interfaces) to pass data between the various models.

With everything from toothbrushes to our cars now using embedded electronics, multiphysics is a hot topic. Multidomain simulators, on the other hand, have been around for a long time. The earliest commercial multidomain tool is Analogy's Mast language, which debuted in 1986 and still finds use in Synopsys' Saber simulator.

Lee Johnson, business-development manager at Synopsys' Saber unit, sees an increasing emphasis on total system design with a focus on the components that surround the chip. Multiphysics simulation is gaining most of its traction, Johnson says, because of the many bidirectional interdependencies and interactions that occur in such systems. With electronic actuation replacing hydraulics in many vehicles, multiphysics simulation is necessary for modeling the interaction between controllers and their loads.

The trend toward the development of “green” energy is also creating new applications for multiphysics simulation, requiring sophisticated models to incorporate solar arrays and new battery technologies. The ability to integrate high-voltage components, combining electrical and electromagnetic behavior with electrothermal characteristics, thus becomes a necessity in high-power systems.

Darrell Teegarden, business-unit director at Mentor Graphics, says that system complexity is making it more difficult for his customers to design products. A complete system design commonly involves embedded software, an RTOS, sensors, actuators, a DSP, and energy sources. Teegarden, co-author of The System Designer's Guide to VHDL-AMS (Reference 1), sees accelerating interest in system-modeling languages because of the need to describe behavior across multiple disciplines.

Modeling remains the biggest challenge, however, relying on experts in each domain to choose the language that best fits their piece of the overall system. The divide-and-conquer approach may involve executable UML (unified modeling language) to generate C code, Spice for analog components, or data-driven models from engineering tests of prototypes. The Mentor SVX (SystemVision X) client environment eases the job by providing an interface to National Instruments LabView software for test-program development and execution throughout the design cycle.

The SVX virtual-execution environment dynamically connects domain-specific modeling and software tools over a secure, managed signal channel. A C/C++ API makes it easy for embedded application software to interact with models of control systems, multiphysics subsystems, sensors and actuators, and analog and digital electronics.

Figure 1 A thermal profile for an RF-antenna switch demonstrates the range of temperature variation within a cell-phone IC (courtesy Gradient).
TEMPERATURE VARIATION

Engineers have routinely limited the analysis of the impact of temperature variation on an IC design to corner analysis, which entails varying the simulated temperature for the whole chip or function block from nominal to the hot/cold extremes of a device’s operating range. Corner simulation operates on the assumption that the chip substrate is an isothermal surface and that there is no variation in either the lateral or the vertical directions through the various insulating and conductive materials. With the higher levels of integration in today’s SOCs (systems on chips), especially the increasing number of RF and analog- and mixed-signal functions, that assumption no longer holds.

Adi Srinivasan, vice president of engineering for EDA start-up Gradient, points out that on-chip temperature variations can often be 25°C or greater. These temperature effects disturb device-matching assumptions in sensitive analog circuits, introducing another variable for designers who struggle to account for on-chip statistical variations in nanometer-device characteristics. Failure to properly account for these temperature excursions can also lead to device failure. Accurate simulation of IC-temperature variations requires coupling the physics of thermal conduction to the models of dynamic electrical conduction, adding 3-D models of the materials that compose the insulating layers around active devices, and conductive paths to the device package.

Gradient’s HeatWave 3-D electrothermal simulator for chips and stacked-die SIPs (systems in packages) computes the temperature profile inside a die, allowing annotation of the data into a standard circuit simulator to make results more accurate (Figure 1). For most SOCs that rely on dynamic on-chip power management, HeatWave can compute a transient-temperature map, showing variations over time as a function of circuit operation. HeatWave integrates with industry-standard custom and analog IC design flows, taking as its inputs the chip’s layout geometry, power sources from the circuit netlist, package specifications, and a file that describes the materials in the semiconductor-manufacturing process. The interactive GUI (graphical-user-interface) mode lets users navigate a chip both horizontally and vertically to examine the temperatures and heat-conduction paths throughout various device layers.

Gradient also offers HeatWave 3DIC for steady-state analysis of heterogeneous stacked-die packages (Reference 2), which are increasingly extending Moore’s Law into the vertical dimension. The thinning of chips, necessary for such packaging, and the addition of interdie insulators and
molding compounds, which can negatively affect heat-conduction paths, further complicate the electrothermal physics of stacked-die configurations.

A COMPLETE APPROACH

For complete system optimization, the analysis of electrothermal effects that begin on-chip at the nanometer scale continues outward to the millimeter scale of the package and the PCB (printed-circuit board). At this stage, overdesign of heat sinks and cooling systems can add unnecessary cost, whereas inaccurate modeling of the physics of heating in copper traces can result in reliability problems. Electromechanical effects also enter the picture as a result of the thermal stress of electronic components and the interfaces between dissimilar materials in the chip/package/board stack.

Ansys’ Icepak optimizes the design of cooling systems by analyzing heat transfer and fluid flow in IC packages, PCBs, and complete electronic systems. Steve Scampoli, lead product manager for Ansys’ multiphysics, describes Icepak as a unique approach that can analyze electronic cooling at multiple levels—from chip packages to PCBs to systems for data centers. Icepak imports electronic and mechanical CAD (computer-aided-design) data from EDA software, such as Cadence’s Allegro PCB-design tool and APD (Advanced Package Designer). A connection to the Ansys S1wave (signal-integrity-wave) and power-integrity-analysis tool enables developers to import dc-power-distribution profiles for thermal analysis of heating in the conductors of PCBs and packages.

CRTs have gone the way of the dinosaurs, and energy-efficient options, such as LEDs, are replacing incandescent bulbs, so electronics systems for lighting control are growing in importance. The recent “Designing with LEDs Workshop,” which EDN sponsored, devoted a day to topics such as power and thermal management, optics and light measurement, and LEDs and solar power. Along with electrothermal behavior, the electro-optical interfaces in lighting systems require a multiphysics approach for system optimization.

To examine trade-offs in lighting-system design, National Semiconductor is providing its LED-simulation tool free online (Reference 3). The Webench LED Architect allows users to select models for LEDs, passive components, and heat sinks from a variety of manufacturers, aiding in the selection of the appropriate National Semiconductor PowerWise LED driver.

EDA vendors have also moved deeper into optical design. For example, Synopsys recently acquired the 47-year-old ORA (Optical Research Associates), whose LightTools 3-D design tool provides virtual prototyping, simulation, and illumination applications for optical design (Figure 2). According to Tom Walker, R&D director in the Optical Solutions Group at Synopsys, LightTools addresses the physics of phosphors and applications in which designers must “coerce photons.” LightTools finds use in LED design, backlighting for LCDs in cell phones, and modeling and analysis of solar-collection systems. Synopsys has added ORA’s products to the TCAD (technology-computer-aided-design) product portfolio, which also includes the Sentaurus device simulator. Sentaurus simulates the electrical, thermal, and optical characteristics of semiconductor devices.

REFERENCES