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Rising to Meet the Thermal Challenge

Electrical-Thermal Interaction

Thermal effects on electrical performance have always existed; processor speed limits are set by thermal limits, and power has been a key concern for the mobile and datacenter markets for a decade. Increased electrical content logically generates more heat, which affects system performance. For example, in the automotive market, ADAS and infotainment systems are drastically increasing automotive electronics content, leaving the problem of thermal effects yet to be solved.

With higher data rates, too, comes more heat generated. 400G and 800G Ethernet are supported by 100G ports, which create heat. The PCIe® roadmap is predicting 64GT/s, and 5G promises data rates of up to 10Gb/s.

Tech companies are promising a lot from 5G. While 4G tops out at a theoretical 100Mbps, 5G tops out at 10Gbps. That means 5G is a hundred times faster than the current 4G technology.[1]

All electronic technology improvements magnify the effects of the thermal problem. Advances in IC packaging create heat dissipation challenges, and within ICs, tighter geometries and smaller voltage swings increase susceptibility to thermal effects.

The Multiphysics Problem

The thermal analysis of electronic systems is made more complex by interconnected electrical and thermal effects. IC heat generation is mainly a function of switching frequencies and operating conditions, and how the heat generated is dissipated/transferred out of the system depends on the environmental conditions. These two problems must be solved together.

System heat dissipation almost always involves both conduction and convection. The IC/package/board/enclosure interface is primarily a conduction problem best handled by finite element analysis (FEA). The enclosure/environment (air or liquid) interface is a computational fluid dynamics (CFD) problem. So not only must electrical and thermal physics domains be analyzed together, but the thermal component requires both FEA and CFD approaches.

Scaling Up While Drilling Down

Traditional approaches to solving FEA problems have been unsuccessful in scaling up to the analysis requirements of today's advanced systems because of speed, capacity, and compute limitations. Speed limits were imposed by tools that were unable to distribute simulations over more than a dozen or so servers without running into the scaling limits typical of traditional simulation methods. Capacity limits were hit when the tools required too large of a memory footprint, so objects in a system had to be simulated separately to fit into server memory. Compute limits were imposed by the financial impracticality of purchasing enough superfast servers with vast amounts of RAM to run these traditional tools.

At the same time, complex interactions found in electrical-thermal co-simulation require that components in the system be analyzed in more detail, not less. For instance, simple models of 3D-IC assemblies do not provide the precision needed to represent their impact on system-level simulations. Instead, true FEA is required, further stressing the limits described above.

An Architecture for the Future

While systems were becoming more complex over the past decade, Cadence has been developing new approaches to traditional electronic design problems in the SoC domain. It has become increasingly clear that to meet the needs of designs of 10nm and below, new algorithms and approaches would be needed to scale up necessary steps, like parasitic extraction, timing analysis, power grid analysis, and physical verification.

To meet these needs, Cadence has drawn upon its expertise in computational software development to create a new software architecture that enables massive scalability in a cloud-optimized computing environment. This architecture underpins the Cadence® SoC implementation platform and is the foundation for the Cadence Clarity™ 3D Solver, which performs finite element extraction and simulation for electromagnetic analysis. This same architecture has now been implemented for electrical-thermal co-simulation with dramatic benefits for electronic systems developers.

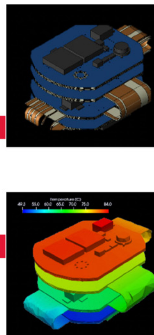
Overcoming Limitations

With the launch of the Cadence Celsius™ Thermal Solver, electronic system developers can sidestep the usual limitations. Compared with traditional solutions, the Celsius Thermal Solver:

- Breaks the speed limits with 5 to 10X cycle time improvements
- Overcomes capacity limits with up to 10X memory reduction
- Eliminates the compute limits imposed by dependency on super high-end servers with a solution optimized for execution on public cloud environments

In use by beta customers for two years before the Celsius Thermal Solver was released, it has already generated impressive results. Figure 1 shows actual results for an device in an automotive application, in which the Celsius Thermal Solver delivered a 7X cycle time improvement, using 11X less memory than a traditional tool.

Parameters	Legacy Solution	Celsius Thermal Solver
Mesh Generation	10:23:44	1:14:17
Simulation	1:37:29	0:19:45
Total Time	12:01:03	1:34:02 -7X
CPU Cores	40	128
Number of Nodes	14,750,070	14,750,070
Number of Elements	98,910,040	98,910,040
Memory/Machine	450G	41G -11X



Advantages:
7X faster
11X less memory/machine

Figure 1: Combination rigid/flex PCB assembly for a prototype in an automotive application.

A Complete Solution

With the Celsius Thermal Solver, design teams now have access to the electronic industry's first complete electrical-thermal co-simulation solution, which:

- Combines FEA with CFD for total system analysis
- Performs transient as well as steady-state analysis for accurate electrical-thermal co-simulation
- Delivers massively parallel execution to achieve up to 10X faster performance than existing solutions
- Integrates with Cadence IC and PCB implementation platforms for quick iterations

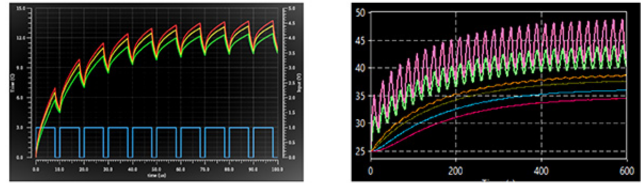


Figure 2: The Celsius Thermal Solver provides transient as well as steady-state analyses.

Advanced Features

Massive parallel computational solver

In performing computational simulation, traditionally large structures are either greatly simplified or cut up into smaller structures for analysis using the largest and most powerful computing resources. On the contrary, the massive parallel computational solver equipped in the Celsius Thermal Solver is designed from the ground up to take advantage of your multi-core compute resources by parallelizing the mathematical tasks required to solve for 3D structures. The tasks can be parallelized within one computer's cores or across multiple computers, cutting the time to solve for complex structures up to 10X and even more.

This industry-leading parallelization technology ensures that both meshing and physical structures can be partitioned and parallelized across as many computers, computer configurations, and cores as are available. The amount of time required to solve is scalable based on the number of computer cores. If a user can double the number of computer cores, performance will be nearly doubled as well. In addition, the memory usage per machine for computing is accordingly scaled down with the increase of the number of computer cores.

3D FEA field solver

The 3D FEA field solver provides accurate thermal conduction analysis and electrical simulation for arbitrary 3D structures, such as complicated packages with bumps or bondwires, connectors, and transitions of connectors to the PCB. Powerful 3D thermal distribution analysis is combined with 3D electrical simulation in an automated environment for true electrical-thermal co-simulation that iterates on the vital interactions between temperature and current flow. This maximizes accuracy and fully considers effects such as the increasing electrical resistance that occurs at higher operating temperatures.

This unified environment makes it easy to confirm that your design has met specified temperature, voltage, thermal stress, geometrical deformation, and current density thresholds. The 3D structures can also be extracted into equivalent thermal models for fast thermal simulations.

2.5D FEA Field Solver

The 2.5D FEA field solver is a great option to quickly and accurately simulate thermal conduction in 3D planar layered structures, such as in packages and PCBs with multiple layers and interconnect vias. Thermal results, such as temperature, heat flux, conductivity, fusion current density, and mean time to failure, are graphically displayed in 2D plots to quickly identify problem areas. 3D distribution plots for temperature and heat flux are also available with *x*, *y*, and *z* slice plane options to provide further insight into the thermal response of the system. These 3D planar structures can also be extracted into equivalent thermal models for fast thermal simulations.

CFD Solver

CFD is a powerful analysis tool used to analyze fluid flow convection, conduction, and radiation heat transfer in systems. Systems with chassis and ventilation hole openings are easily simulated in natural convection or forced convection environments. Heat transfer coefficients can be extracted from the CFD simulations and used in the FEA field solvers to account for air and other fluid flow effects over solid surfaces.

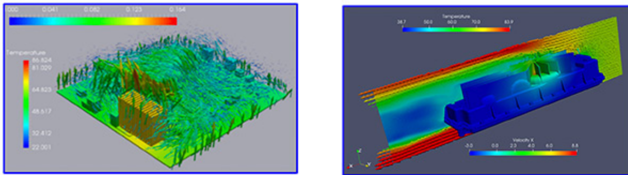


Figure 3: The Celsius Thermal Solver models the impact of convection and forced airflow around an electronic system.

3D Workbench

The Celsius Thermal Solver environment incorporates a 3D mechanical CAD GUI for creating, editing, and importing 3D solid models for electrical-thermal analysis. You can bring in design data from popular MCAD formats, such as Acis, IGES, and STEP, as well as Cadence Allegro® and Sigrity™ formats. 3D components are easily created with parameterization and equation expressions to allow for modeling flexibility and simulation optimization. Geometrical problems and misalignment errors happening in a 3D CAD model can be quickly repaired with 3D Workbench's model clean-up functions. The advanced adaptive meshing algorithms allow you to automatically generate accurate meshes for small intricate 3D components to large complex electronic systems with enclosures.

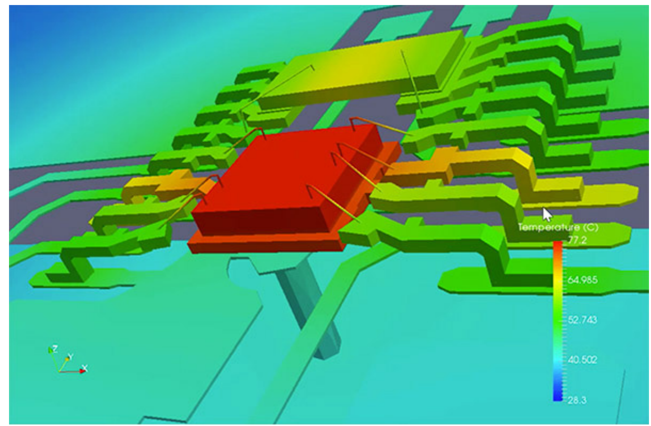


Figure 4: Example of 3D visualization capabilities.

Conclusion

Analysis and mitigation of thermal effects have now become a key development concern for electronic systems spanning a wide variety of markets. Proper analysis requires a multiphysics approach, combining electrical-thermal co-simulation with FEA and CFD analyses. Traditional solutions have speed, capacity, and compute parameters that limit productivity and extend project timelines; the Celsius Thermal Solver, with its advanced architecture and deep feature set enables electronic system developers to meet today's thermal challenges.

References

1. C. Hoffman, "What is 5G, and How Fast Will It Be?," How-To Geek, 15 March 2019. [Online]. Available: https://www.howtogeek.com/340002/what-is-5g-and-how-fast-will-it-be/. [Accessed 15 August 2019].

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