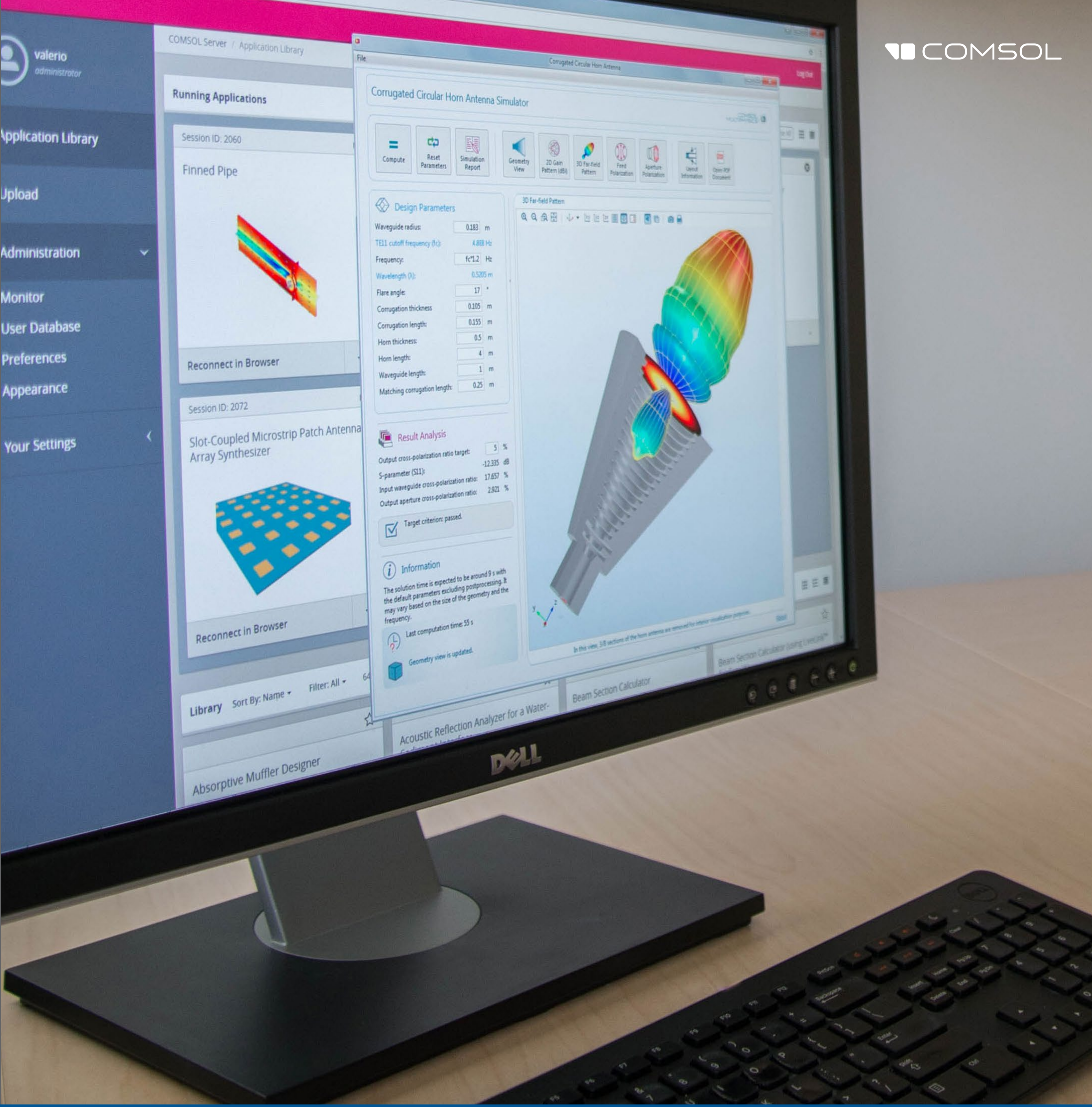


MANAGER'S GUIDE

Accelerate R&D with Multiphysics Simulation

COMSOL® Software

An Integrated Platform for Physics-Based Modeling, Simulation, App Design and Deployment

COMSOL Multiphysics®

Surpass Design Challenges with Numerical Simulation

Product design is a time-sensitive objective requiring the most accurate and comprehensive simulation tools to stay ahead of the competition.

The COMSOL Multiphysics® software is a fully integrated platform for performing powerful simulations and analyses, allowing R&D teams to accelerate development and reduce risk.

Explore your design through a user-friendly interface with a consistent workflow for both single and multiphysics models, regardless of the system of study.

Consider any number or type of physics, including electrical, mechanical, fluid, thermal, acoustic, and chemical effects (Products, p. 18).

Analyze the performance of a product under varied operating conditions, verify and optimize the design prior to prototyping.

Make use of powerful solver technology to deliver accuracy and speed; run on everything from standard desktop hardware to high-performance clusters and clouds (License options, p. 19).

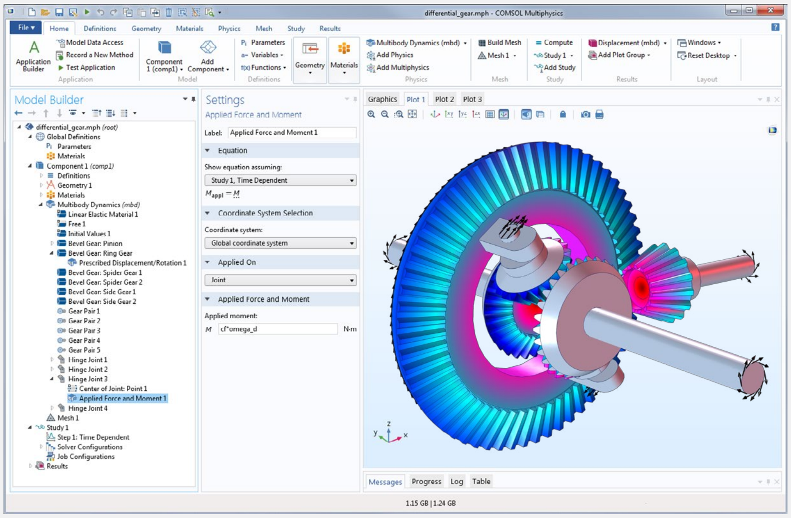
Visualize results with built-in, intuitive post-processing functionality. Interface with industry standard software for technical computing, CAD, and data analysis, and easily share results and collaborate with colleagues in multiple departments.

COMSOL Server™

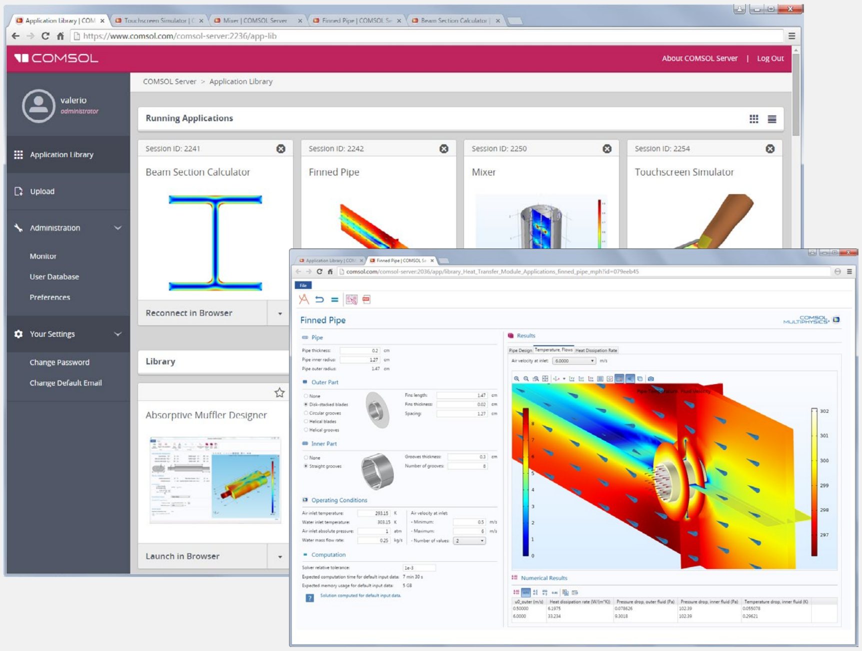
Deploy apps throughout your organization

Generate specialized, user-friendly apps based on your simulations with the Application Builder included with COMSOL Multiphysics®. Extend the power of simulation to colleagues and customers worldwide.

Run apps in COMSOL Multiphysics directly, or use the COMSOL Server™ product to access them from the free-of-charge COMSOL Client for Windows® operating system or major web browsers.



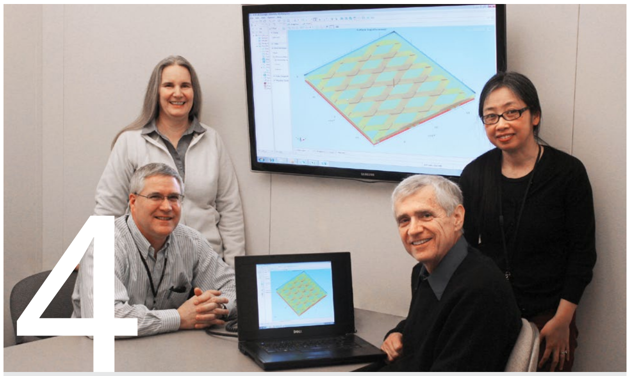
COMSOL DESKTOP® FOR NUMERICAL SIMULATION OF PHYSICS-BASED SYSTEMS
Develop multiphysics models of any system with the Model Builder, then use postprocessing tools to visualize your results. (Image above: Numerical simulation of a differential gear mechanism in the COMSOL® software.)



BRING YOUR SIMULATION TO COLLEAGUES AND CUSTOMERS WITH SIMULATION APPS AND COMSOL SERVER™ Choose which parts of your simulation to share with colleagues, collaborators, and clients. (Image above: COMSOL app of a finned pipe, used to evaluate the thermal performance of various geometries.)

ACCELERATE R&D WITH MULTIPHYSICS SIMULATION

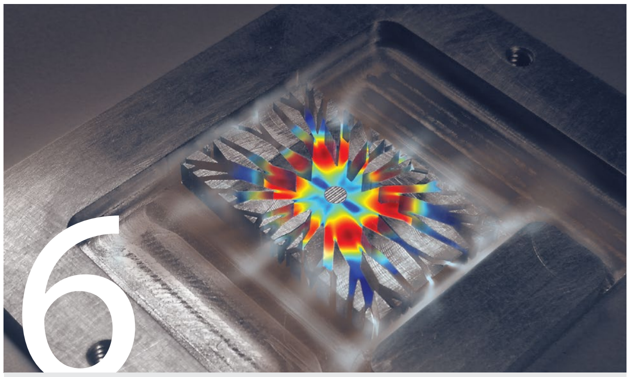
Provide Design Teams, Manufacturing Departments, and Other Colleagues with High-Fidelity Models and Simulation Apps



Boeing

AEROSPACE

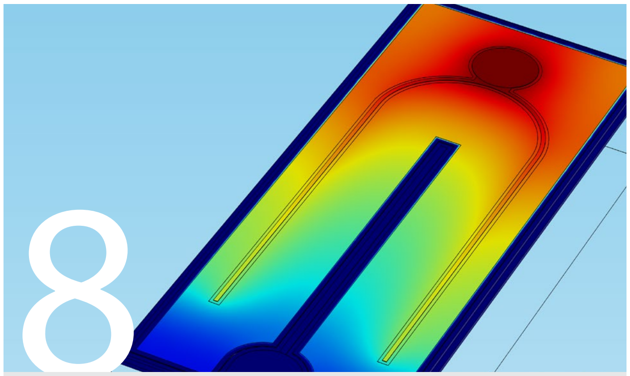
Multiphysics simulation was used to design and evaluate aircraft composite structures containing a protective, electrically-conductive, expanded-metal foil (EMF) layer.



Toyota

AUTOMOTIVE

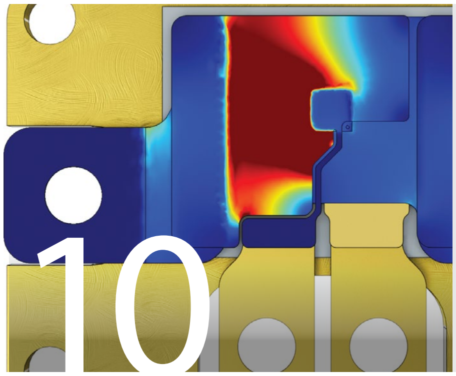
Researchers use simulation to develop optimal thermal management solutions for hybrid vehicles.



Sharp

DISPLAYS & LIGHTING

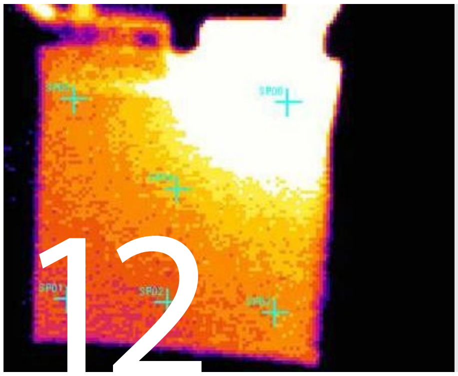
Multiphysics simulation was used to optimize LED designs, and reduce the number of design iterations required.



Wolfspeed

POWER ELECTRONICS

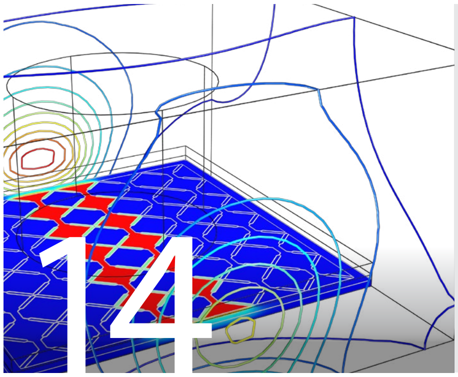
Simulation apps were used to design semiconductor devices that can withstand extreme temperatures.



Fiat

HYBRID VEHICLES

Researchers investigated internal temperature distribution within a battery cell and located problematic hot spots.



Cypress

TOUCHSCREENS

Engineers use simulation apps to improve communication across development teams and streamline touchscreen design.

mieletec

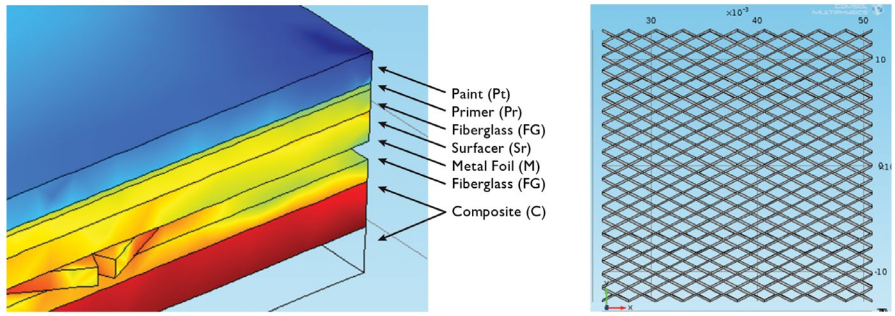
KITCHEN APPLIANCES

Researchers at mieletec used COMSOL® to resolve crucial design challenges.

We welcome your questions and comments.

Contact us at info@comsol.com.

Boeing Simulates Thermal Expansion in Protective Coatings for Aircraft Composites



At left is the composite structure layup from the COMSOL Multiphysics® software model and, at right, the geometry of the expanded metal foil. SWD and LWD correspond to short way dimension and long way dimension. The mesh aspect ratio, SWD/LWD, is one of the parameters varied in the study.

➔LIGHTNING STRIKE PROTECTION OF AIRCRAFT STRUCTURES

The Boeing 787 Dreamliner is innovative in that it is comprised of more than fifty percent carbon fiber reinforced plastic (CFRP) due to the material's light weight and exceptional strength. Although CFRP composites inherently have many advantages, they cannot mitigate the potentially damaging electromagnetic effects from a lightning strike. To solve this problem, electrically conductive expanded metal foil (EMF) can be added to the composite structure layup to rapidly dissipate excessive current and heat for lightning protection of CFRP in aircraft.

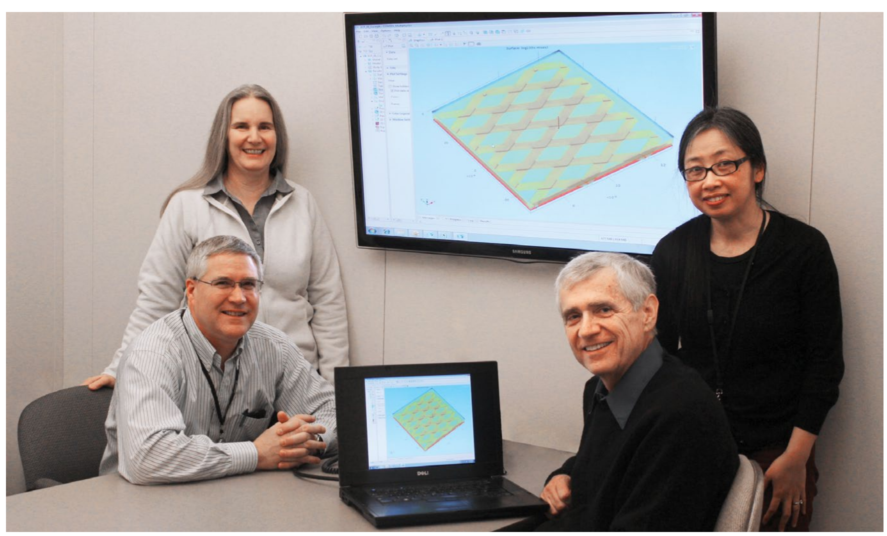
Over time, however, stress accumulates in the protective coating of the composite structure as a result of thermal cycling due to the typical ground-to-air flight cycle. This stress may cause the protective coating to crack providing an entrance for moisture and environmental species that can cause corrosion of the EMF, thereby reducing its electrical conductivity and ability to perform its protective function.

Designing an EMF layer that can perform optimally under these conditions involves realizing a balance between current carrying capacity, displacement due to thermally induced movement of the protective layers, and weight. To better understand the impact of the EMF design on thermal stress and displacement in the protective coating, the engineers at Boeing Research and Technology (BR&T) are using multiphysics simulation in addition to physical measurements. Contributing to the research effort at BR&T are project lead Jeffrey Morgan from Sealants and Electromagnetic Materials, Associate Technical Fellow Robert Greegor from Applied Physics leading the simulation, Dr. Patrice Ackerman from Sealants and Electromagnetic Materials leading the testing, and Technical Fellow Quynhgiao Le from Manufacturing Technology Integration. In their work, the EMF design parameters are varied in order to investigate the relative difference in displacement in each layer of the composite structure layup.

➔REDUCING RISKS AND MAINTENANCE COSTS

The objective at BR&T is to improve overall thermal stability of the protective coating and therefore reduce the risks and maintenance costs associated with damage to the coating or composite system during service.

Greegor and his colleagues qualitatively regard even the smallest projected increase in displacement



Research team at Boeing Research and Technology, from left to right: Patrice Ackerman, Jeffrey Morgan, Robert Greegor, and Quynhgiao Le.

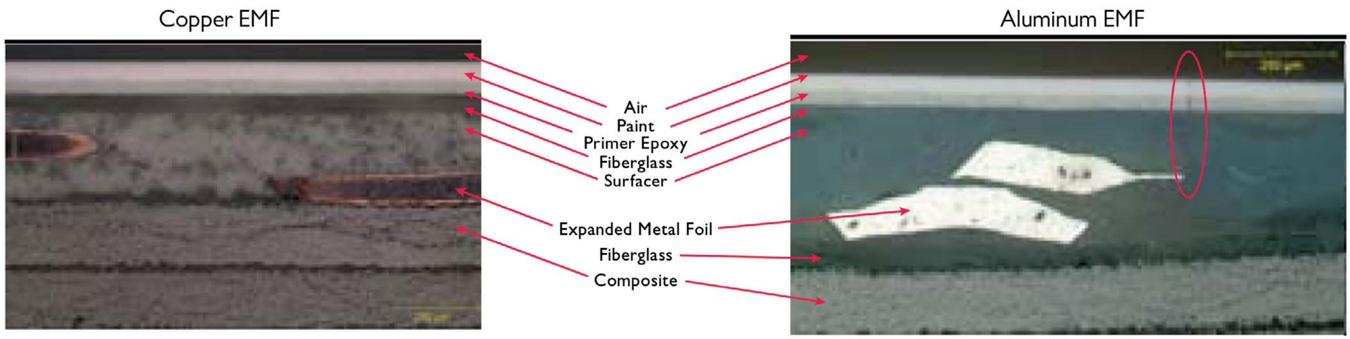


Photo micrographs of the composite structure layups after exposure to moisture and thermal cycling. At left, the results for the copper EMF and at right, the aluminum.

as an increased risk for developing cracks in the protective layers since mechanical stress due to thermal cycling accumulates over time.

Experimental evidence supports this logic as shown in the photo micrograph cross-sections of surface protection schemes with aluminum or copper EMF. The images were acquired after prolonged exposure to moisture and thermal cycling in an environmental test chamber. The layup with the copper EMF shows no cracks, whereas the aluminum EMF led to cracking in the primer, visible edge and surface cracks, and substantial cracking in mesh overlap regions.

Over the same temperature range, the experimental results correlate well with the results from the simulations that consistently show higher displacements in the protective layers for the aluminum EMF. Both simulation and experiment indicate that the layup with copper EMF is a better choice from the durability performance perspective of the protective coating. Multiphysics simulation is therefore a reliable means to evaluate the relative impact of the EMF design parameters on stress and displacement to better understand and reduce the likelihood of crack formation.

➔EVALUATING THERMAL EXPANSION IN AIRCRAFT COMPOSITE STRUCTURES

To evaluate the thermal stress and displacement in each layer of the composite structure layup, a coefficient of thermal expansion (CTE) model was developed by Greegor[1,2] and his colleagues using COMSOL Multiphysics® software. In the surface protection scheme, each layer including the paint, primer, corrosion isolation layer, surfacer, EMF, and the underlying composite structure contribute to the buildup of mechanical stress in the protective coatings over time as they are subject to thermal cycling.

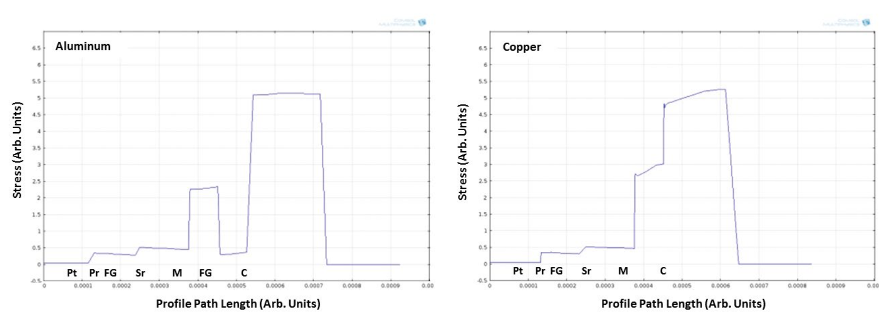
In this study, EMF design parameters including the height, width of the mesh wire, aspect ratio (SWD/LWD), and metallic composition were varied to evaluate their impact on thermal performance throughout the entire structure. The metallic composition of the EMF was either aluminum or copper, where an aluminum EMF requires additional fiberglass between the EMF and the composite to prevent galvanic corrosion.

In the CTE model, the Thermal Stress multiphysics interface couples solid mechanics with heat transfer to simulate thermal expansion and solve for the displacement throughout the structure. The simulations were confined to heating of the composite structure layup as experienced upon descent in an aircraft. Final and initial temperatures were defined in the model to represent the ground and altitude temperatures, respectively.

The results of the COMSOL Multiphysics simulations were analyzed to quantitatively determine the stress and displacement in each layer upon heating and for varied properties of the expanded metal foil. It was found that, due to the lower impact on displacement, increasing the mesh width or decreasing the aspect ratio are better strategies for increasing the current carrying capacity of the EMF for lightning strike protection.❖

References

1. R.B. Greegor, J.D. Morgan, Q.N. Le and P.K. Ackerman, Finite Element Modeling and Testing of Expanded Metal Foils Used for Lightning Protection of Composite Aircraft Structures, Proceedings of the 2013 ICOLSE Conference, Seattle, WA, September 18-20, 2013.
2. J.D. Morgan, R.B. Greegor, P.K. Ackerman and Q.N. Le, Thermal Simulation and Testing of Expanded Metal Foils Used for Lightning Protection of Composite Aircraft Structures, SAE Int. J. Aerospace 6(2), 371-377, 2013, doi:10.4271/2013-01-2132.



Relative stress in arbitrary units was plotted through the depth of the composite structure layups containing either aluminum (left) or copper EMF (right).

Simulation-Led Topology Optimization for Improved Cooling in Toyota Hybrid Vehicles

➔REINVENTING THE ELECTRONICS COOLING SYSTEM

Toyota hybrid vehicles have sophisticated electrical systems comprised of many power semiconductor devices such as diodes and insulated gate bipolar transistors (IGBTs) that are used for power conversion and management. For thermal regulation of the devices, they are mounted on aluminum heat sinks, or cold plates, through which a water/glycol coolant mixture is pumped via cooling channels.

As the technology roadmap for these power components calls for them to shrink to less than half their current size while dissipating the same amount of power, their heat flux will increase. With space already at a premium in the engine compartment, using a larger, more powerful pump to force more coolant through the cold plates is not a viable solution.

Researchers from the Toyota Research Institute of North America (TRI-NA) in Ann Arbor, MI focused on reengineering the cold plate. Dr. Ercan (Eric) Dede, a manager in the Electronics Research Department at TRI-NA explains that, "the goal was to come up with a combination jet-impingement and channel-flow based cold plate with optimally designed branched cooling channels to uniformly remove the most heat and with the least pressure drop." The primary challenge for Dede and his colleagues was to create the branched cooling channel design, where testing the thermal performance of many possible topologies could require a prohibitively large number of prototypes.

➔ACCELERATED WORKFLOW FOR AWARD-WINNING INNOVATION

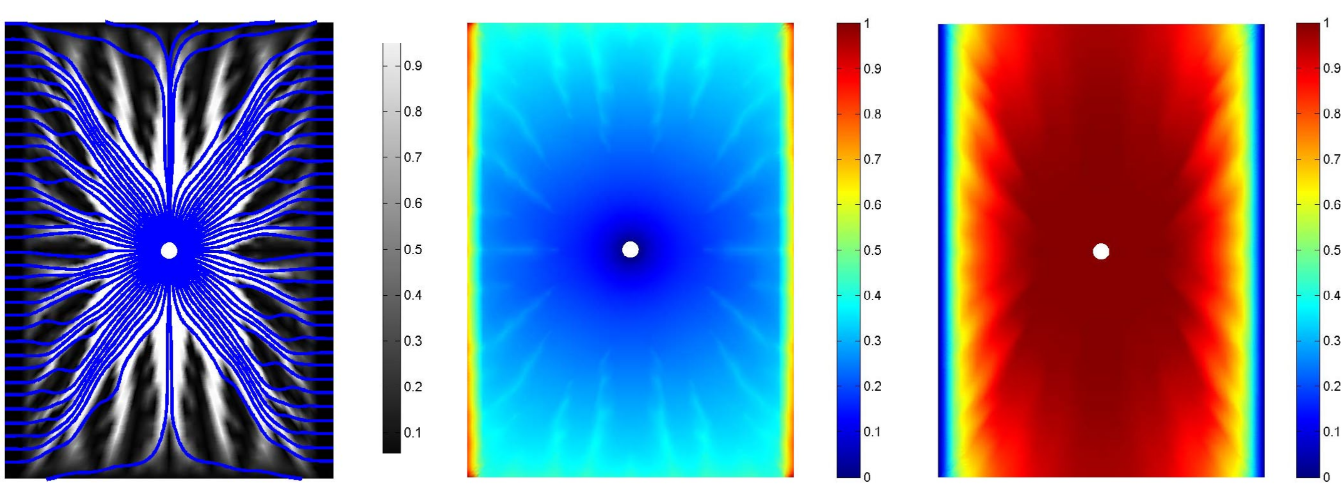
To save the time and expense associated with analytical design methods and trial-and-error physical prototyping, Dede and his colleagues used numerical simulation and multiphysics topology optimization to design and test the possible prototypes of a novel heat sink for future hybrid vehicle generations. Their workflow included simulation in COMSOL Multiphysics® software enabling the efficient design of the branched cooling channel topology for the reengineered cold plate.

Research on the novel heat sink design, which earned the team an R&D 100 award in 2013, was carried out as part of TRI-NA's mission to conduct accelerated advanced research in the areas of energy and environment, safety, and mobility infrastructure.

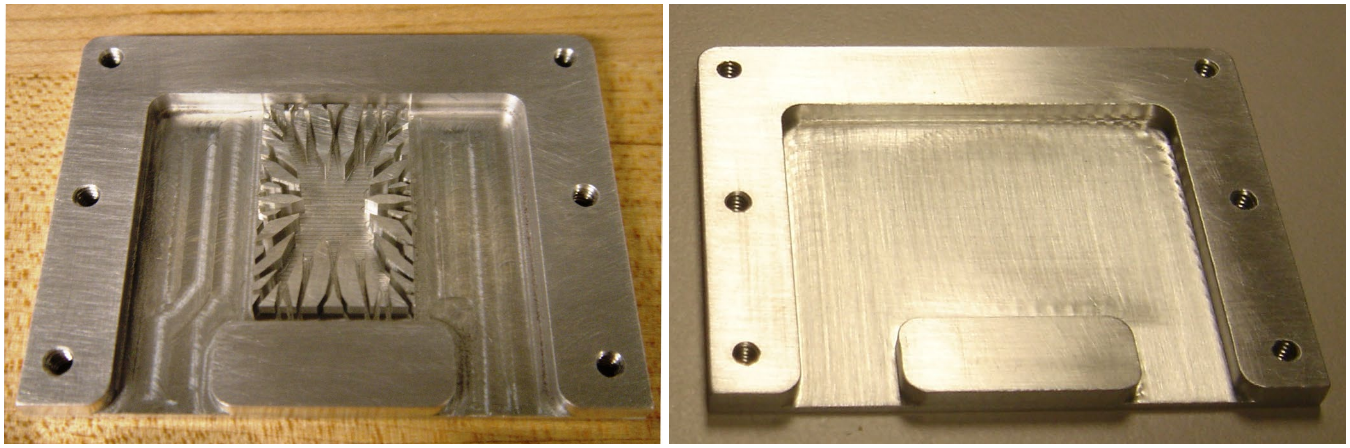
➔COOLING SOLUTION FOR HYBRID VEHICLES

"Many researchers working on diverse applications have identified jet impingement as an attractive way to cool surfaces," said Dede. "But while jet impingement performs well with respect to heat dissipation close to the jet, it's less than optimum as you move away from the orifice." Consequently, their solution combines single-phase jet impingement cooling in the plate's center region with integrated hierarchical branched cooling channels to cool the periphery. "It's in your interest to make those channels short to keep pressure drop to a minimum," Dede explained.

Simulation in COMSOL Multiphysics using the CFD Module and



Representative optimal cooling channel topology with fluid streamlines colored blue (left); normalized temperature contours (center); and normalized pressure contours (right).



Prototype aluminum cold plates with (left) and without (right) a representative hierarchical microchannel topology.

Heat Transfer Module was essential for optimizing the branched cooling channel topology for efficient, uniform heat transfer throughout the cold plate. Additionally, LiveLink™ *for* MATLAB® enabled Dede to run simulations for design optimization from within his MATLAB® software code to examine how the cooling channel topology influenced steady-state convection-diffusion heat transfer and fluid flow, for example.

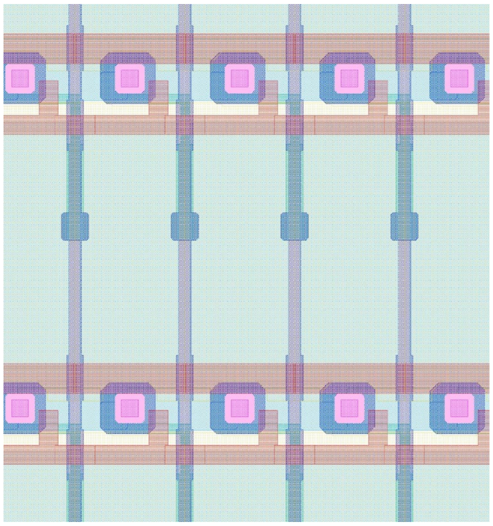
Once an initial channel topology was derived, the height of the fins that separate the cooling channels could be incorporated and was investigated in a separate parametric sizing study. Simulation results demonstrated that the channels efficiently distribute coolant throughout the plate to produce relatively uniform temperature and pressure distributions that are a function of branching complexity. Therefore, this fractal-like topology was used to guide the design of a physical cold plate prototype in SOLIDWORKS® software.

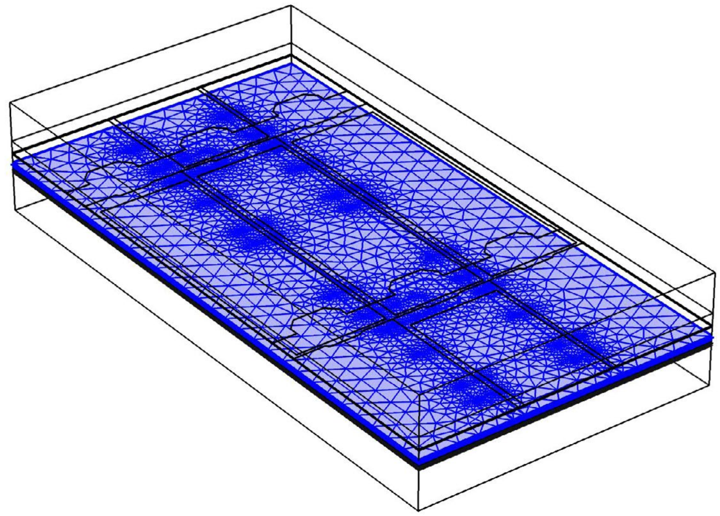
"LiveLink™ *for* SOLIDWORKS® has some nice functionality that allows you to actively link to CAD design tools, and it was easy to import various structures from SOLIDWORKS® software back into COMSOL® software to verify pressure drop and heat transfer," says Dede. "I think this is really the future of simulation, to be able to link your CAD tool to your simulation tool so that you can streamline development through fast, accurate design iterations." Using the designs created in the SOLIDWORKS® software, prototypes were fabricated from aluminum using standard micromachining techniques. The reengineered power electronics cold plate now offers up to 70% better heat transfer and is only one-quarter the size of those currently in use.❖

"...this is really the future of simulation, to be able to link your CAD tool to your simulation tool so that you can streamline development through fast, accurate design iterations."

The Toyota Research Institute of North America's topology optimization team includes (from left) Ercan Dede Ph.D., Manager; Jaewook Lee Ph.D., Assistant Professor at Korea Aerospace University (former TRI-NA researcher); and Tsuyoshi Nomura Ph.D., Sr. Researcher at Toyota Central Research and Development Labs (former TRI-NA researcher).

Multiphysics Software, a Versatile, Cost-Effective R&D Tool at Sharp





Left: The LCD pixel geometry used in Sharp displays was imported from ECAD software into COMSOL Multiphysics® software. Right: Mesh generated for the high aspect ratio structures of the LCD pixels.

➔UNDERSTANDING DIVERSE TECHNOLOGY IN PRODUCT DEVELOPMENT

Today's electronic products are sophisticated, highly integrated systems containing technology such as processors, light and power sources, analog and passive devices, displays, and microelectromechanical systems (MEMS). Understanding the interactions within and among each system component requires that product developers draw on multiple scientific and engineering disciplines right from the outset of a project in order to meet functionality, quality, cost, and time-to-market goals.

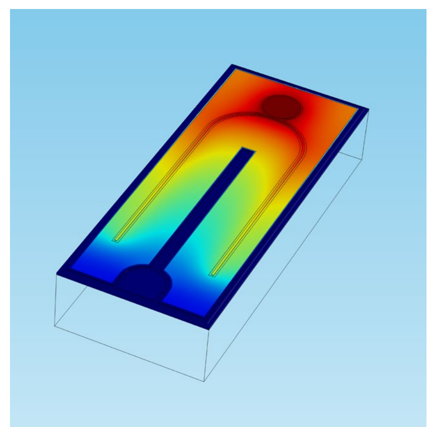
Nowhere has this multidisciplinary approach to product design taken root more firmly than in the R&D laboratories of Osaka, Japan-based Sharp Corporation. At Sharp Laboratories of Europe (SLE), an affiliate of Sharp Corporation, technology for lighting, displays, medical tools, and energy systems is under development.

"A common feature of much of our work is its multidisciplinary nature, as reflected by the broad range of scientific specialties across our research staff, including materials scientists, chemists, physicists, optical designers, electronic engineers, and software developers," says Chris Brown, research manager for SLE's Health & Medical Devices Group.

For product lines such as LED lighting systems, researchers face challenges in optimizing electrode designs to prevent hot spots that can disproportionately reduce the efficiency of the entire device. To improve the image quality and reduce the power consumption of LCD displays, versatile tools are required to extract and analyze the electrical characteristics of individual pixels. Other development initiatives in the healthcare and energy arenas involve understanding the interaction between fluid flow, heat transfer, and electrical properties to design systems that are more accurate and efficient.

➔IMPROVING DEVICE PERFORMANCE, QUALITY, AND TIME TO MARKET

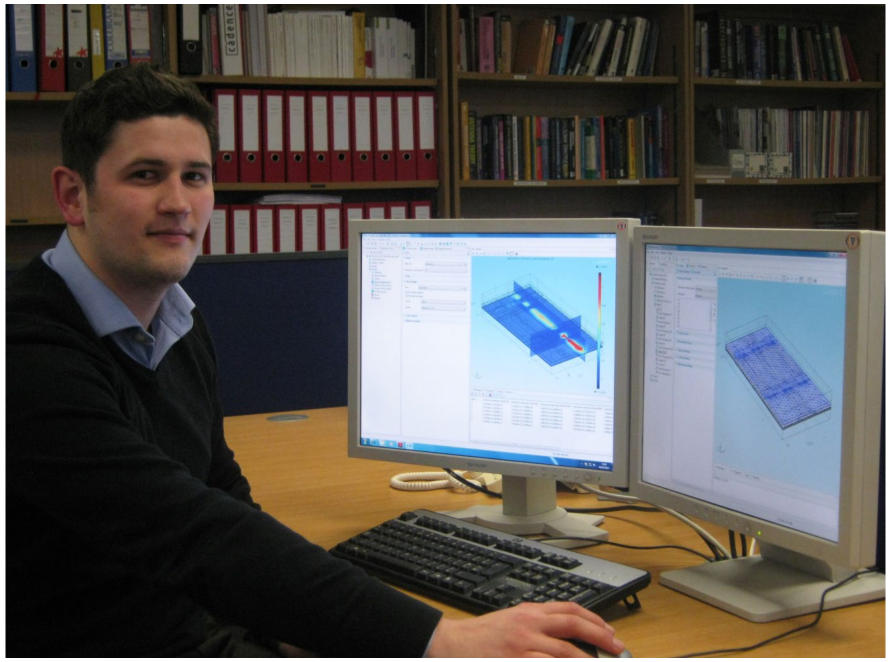
Each application presents unique challenges for the engineers at SLE. Multiphysics simulation offers the



COMSOL® software simulation results showing the surface electric potential in the LED.

toolbox needed to address these challenges, aiding product developers across multiple engineering disciplines in improving device functionality and product design workflow while reducing costs.

In regard to their research in LED systems, the team found that their model incorporating both the electrical and thermal behavior produced an accurate match between simulation and experimental results. Brown explains that with



Researcher Matthew Biginton using COMSOL to simulate LCD pixel capacitances.

multiphysics simulation they "were able to optimize LED designs for improved performance and reduced time to market."

The benefits of using multiphysics simulation to evaluate product design and performance were numerous and varied depending on the application. When it comes to LCDs, "the versatility and degree of control over the meshing procedure in COMSOL® software have allowed us to successfully analyze high-aspect ratio structures for the first time," says Brown. "This modeling ability gives us a more accurate starting point for experiments…reducing the number of design iterations required, which in turn helps us to reduce the R&D prototyping time and cost."

> "This modeling ability gives us a more accurate starting point for experiments…reducing the number of design iterations required, which in turn helps us to reduce the R&D prototyping time and cost."

➔MULTIPHYSICS SIMULATION AS A PRODUCT DESIGN SOLUTION

SLE applies the same rigorous approach to the purchase, configuration, and use of its tools as it does to its R&D explorations with COMSOL software. "SLE's use of COMSOL Multiphysics® software has grown over the last five years, having started out in the LED area and then expanding to the other research themes by way of internal recommendations," says Brown. Each team has a license for COMSOL in addition to relevant application-specific add-on modules.

Multiphysics simulation was used initially to maximize heat dissipation from LEDs to create a uniform temperature distribution and improve device efficiency. For this application, Brown says they "use LiveLink™ *for* SOLIDWORKS® with COMSOL Multiphysics® to simplify the process of design translation and minimize the risk of translation errors."

SLE also provides technical support to Sharp's display business where LCDs are used in products such as smartphones and televisions. As part of SLE's workflow for electronic circuit design, they use the AC/DC Module to extract the electrical characteristics of each pixel in addition to the parasitic resistance and capacitance of the electrical wiring throughout the entire thin film LCD.

For the diverse range of projects at SLE, multiphysics simulation has empowered successful research and development across the company's many engineering disciplines and product lines. Brown expects multidisciplinary research activities to be ongoing at SLE and that "COMSOL Multiphysics will continue to play an important role, both as a research tool and as a product development tool."❖

Chris Brown is the Research Manager of the Health & Medical Devices Group.

LED modules from Sharp (www.sharpleds.com).

High Performance Power Packages and Multiphysics Applications

➔RETHINKING THERMAL MANAGEMENT IN POWER ELECTRONICS

Billions of people use products from the power electronics industry: modern cars, smartphones, tablets, and other wireless devices. Thermal management heavily influences device performance; temperatures higher than the specified operating conditions may cause overheating or increased electrical resistance, lower switching frequencies, and threshold drifts. These effects diminish efficiency and controllability and can eventually lead to failure. With the current trend toward minimizing the size and weight of electronics products, thermal management becomes even more challenging.

There is a growing need, therefore, for power packaging to control heat transfer and current so that electronics can operate stably at high frequencies and temperatures. Engineers at Wolfspeed, A Cree Company have begun designing new power packages that offer more robustness and flexibility than those currently on the market. Their greatest challenges are to minimize thermal resistance and the parasitic inductances that cause voltage spikes. Their power packages, aimed at improving thermal management and device lifespan, contain the die (device), contacts, interconnects, surrounding housing, and base components.

➔SAVING TIME AND MONEY WITH SIMULATION

For Brice McPherson, a Sr. Staff Engineer at Wolfspeed, COMSOL Multiphysics® software simulations proved especially helpful for saving time and money during the design stage. He based his new designs on two wide-bandgap semiconductors, gallium nitride (GaN) and silicon carbide (SiC), which operate stably at high frequencies and temperatures. Simulation was integral to finding the best combination of geometric and material properties to optimize weight, switching frequency, and power density in the new power modules. "Wolfspeed specializes in high power density products, which need a lot of precise testing before they're perfected. It's very valuable to be able to simulate something before you invest money and time into prototyping and building it," he commented.

In the COMSOL® software, McPherson was able to model Joule heating, analyze the heat generated in the conductors, and study the effects of changing geometric aspects such as the substrate and base plate thickness. He also set up parametric sweeps to show how thermal resistance changed according to substrate conductivity and device size: "With parametric modeling, you can find out exactly what's influencing the system the most and get the best compromise among performance, complexity, and cost," he added.

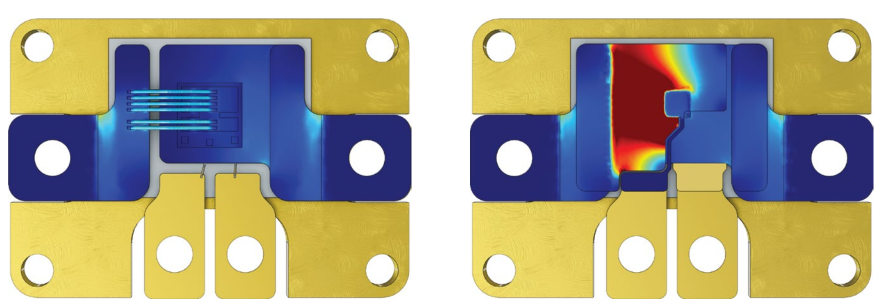
The new Wolfspeed power package is slightly larger than a quarter.

➔SIMULATION RESULTS DRIVE SEMICONDUCTOR SOLUTIONS

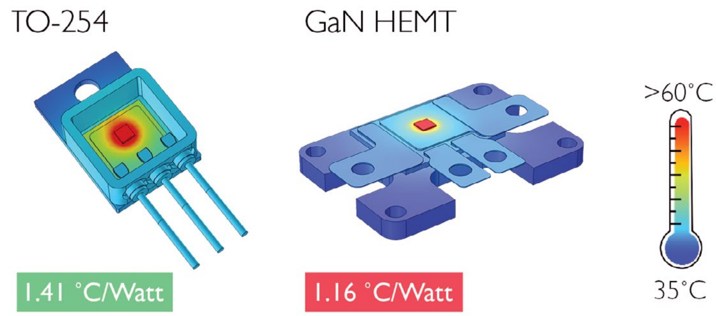
McPherson successfully optimized the thermal and electrical performance of his power packages; his COMSOL results showed that the two new designs exhibited lower inductance and lower thermal resistance than the TO-254, a common commercial transistor. After applying boundary conditions for temperature and voltage and examining the resulting inductance, thermal resistance, and current density, he made design adjustments to optimize current-carrying capacity and footprint. The final Wolfspeed packages designed using multiphysics simulation have greatly improved thermal management and can operate under much more extreme conditions than before—including temperatures over 225° C.

➔DISTRIBUTING SIMULATION THROUGHOUT THE ORGANIZATION

COMSOL is also an application design environment. By using the Application Builder in



Simulation results show the current densities in the SiC (left) and GaN (right) power modules. The SiC package has a lower current density (preferable for high currents), with the greatest current shown in the wire bonds. The GaN module shows a higher average current density, but has more available area for conduction (preferable for lower inductance).

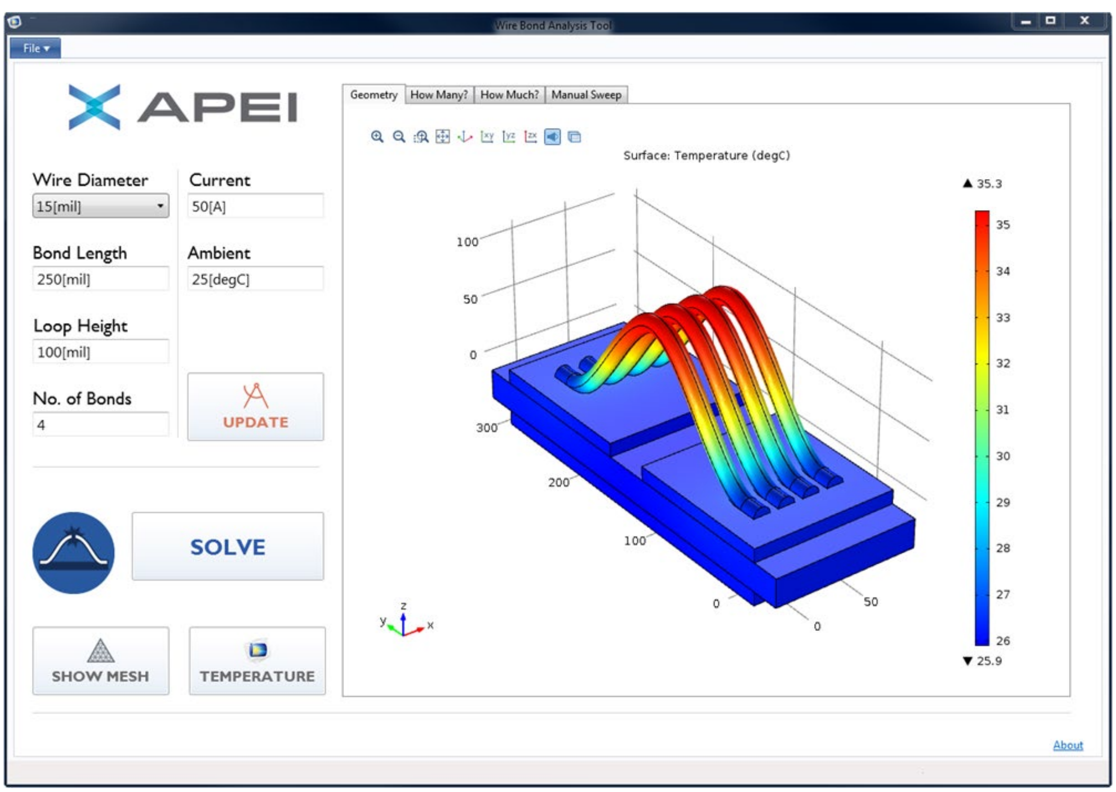


Simulation results comparing the thermal resistance of the TO-254 package to McPherson's SiC (left) and GaN (right) packages.

COMSOL Multiphysics, McPherson was able to extend his simulations to applications—making it easy to share models and results among colleagues, including those without an engineering background. His latest app studies the ampacity and fusing current of wire bonds, used to connect semiconductor devices with packages like the new SiC and GaN modules. "We constantly have to be mindful of how much current we can transfer through these wires…it's heavily driven by the geometry of the wire and the loop," McPherson explained. "Now we can have a clean, simple application to get the necessary data without requiring an engineer." He also expects the Application Builder to expedite their design process in other ways. "We write many grant proposals that typically require an engineer to spend a day running first pass analyses… the Application Builder will be hugely important there as well."

> "It's very valuable to be able to simulate something before you invest money and time into prototyping and building it."

McPherson's application can be run in any major web browser by using the COMSOL Server™ license. Users of McPherson's application can easily determine the maximum allowable current, see how the peak temperature is influenced by the number of wires, and determine the number of bonds of a given diameter required for specific current inputs, temperatures, and geometric setup. By using multiphysics simulation and applications created from his models, McPherson has successfully and easily redesigned the thermal management in Wolfspeed's power electronics packaging.❖



The application showing the temperature change in the wire bonds. The end user chooses the bond length, loop height, current level, and number of bonds.

Fiat Improves Thermal Management of Li-Ion Battery Packs

➔DESIGNING FOR MAXIMUM EFFICIENCY AND SAFETY

Given the long development cycle for vehicles, automobile manufacturers must plan their upcoming lines far in advance. And with growing emission regulations and the rising cost of gas, full electric and hybrid vehicles are expected to become more attractive and grow in market share.

At the Fiat Research Center in Orbassano, Italy, researchers develop electric and hybrid vehicles using lithium and lead-acid batteries as well as supercapacitors. Fiat currently has several light trucks that run on electric drives in addition to an electric version of the Fiat 500 that is presently available to the US market.

While Fiat Research Center does not manufacture the individual lithium-ion battery pouch cells, they are responsible for combining as many as 100 of them into battery packs that generate the requisite 350 volts. Sufficient cooling is necessary while keeping the packs as small and light as possible. Because the cells are wired in series, if one cell doesn't work well due to problems with heat, then it has a negative impact on the entire pack.

> “We estimate that instead of needing 1000 hours for the design of a battery pack, we could cut it down to roughly 300 hours.”

It is important that the maximum temperature differential does not exceed 5 °C across all cells in a pack. In addition, if the temperature of the pack as a whole is too low, it limits the amount of charge extracted. If the temperature is too high, there is the risk of thermal runaway, which can mean a jump directly to electrolyte emission, smoke, or in the worst case, fire.

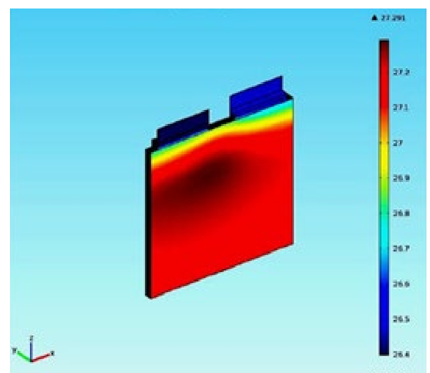
➔SIMULATION PROVIDES CRITICAL ANSWERS AND REDUCES COSTS

By developing a model using COMSOL Multiphysics® software, the researchers at Fiat were able to find the hot spots on a cell and also investigate its internal temperature distribution. This provided invaluable information that cannot be achieved via other methods due to the difficulty involved in embedding thermocouples in battery pouches and attaining reliable results from them.

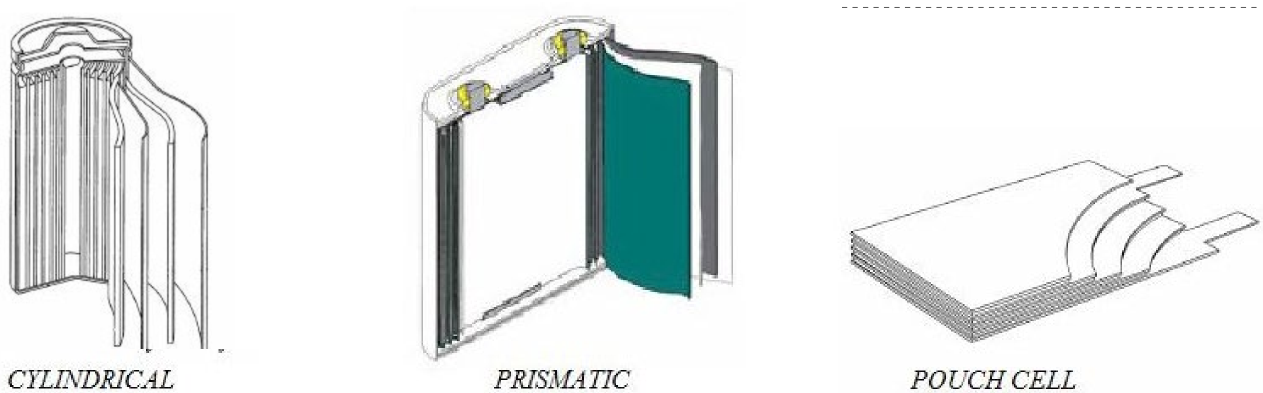
Additionally, by simulating their design, they determined that a less powerful fan was required, which helped reduce costs. “With the help of the model, we were able to cut our design time by 70%. We estimate that instead of needing 1000 hours for the design of a battery pack, we could cut it down to roughly 300 hours,” says Michele Gosso, a researcher with Fiat.

➔BATTERY PACK DESIGN FOR HYBRID VEHICLES

In Li-ion batteries, heat is produced through both Joule heating and chemical reactions, which was



Surface temperature of a pouch cell from a lithium ion battery pack – the uniform distribution is an important parameter.



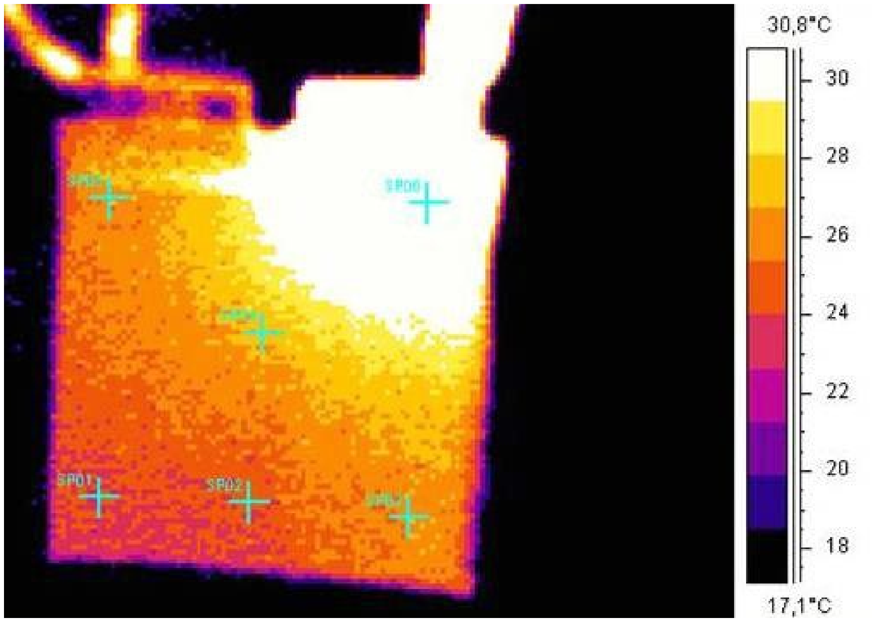
Three types of lithium-ion batteries. Fiat uses a series of 100 or so of the pouch cells to power their vehicles.

evaluated from an expression dependent on the current density. In their designs, Gosso and his colleagues opted for convective cooling and used multiphysics simulation to study the resulting temperature distribution on the cell surface.

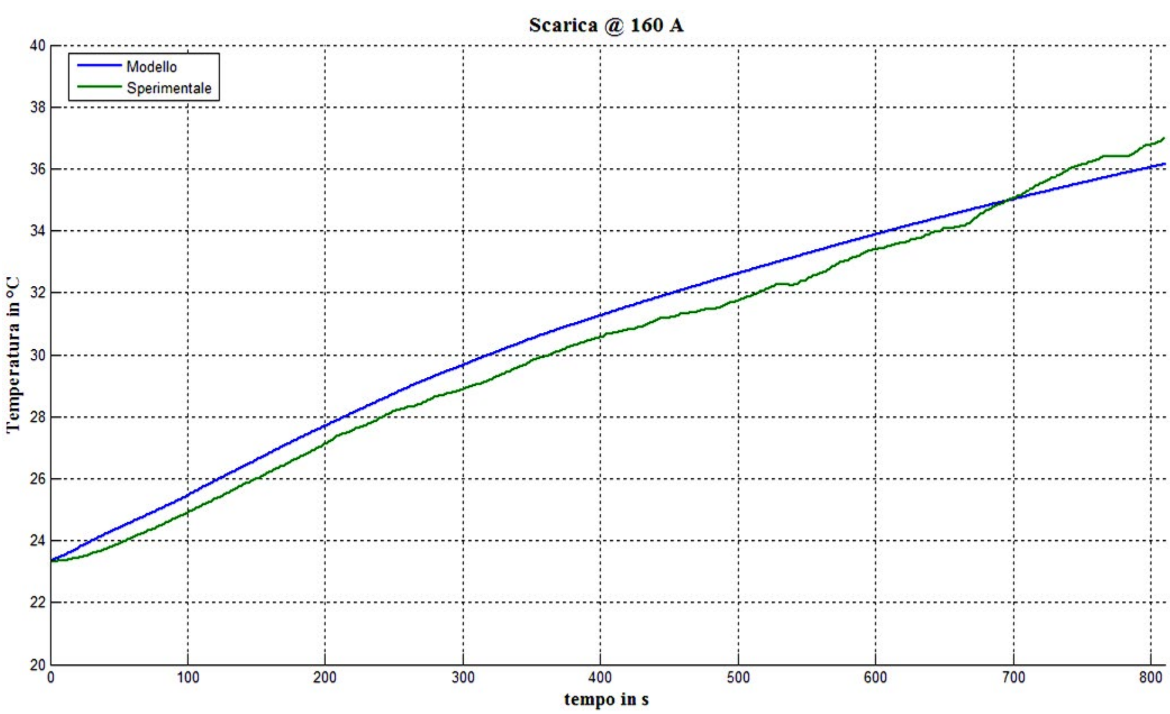
The model divides each surface of the pouch cell into nine areas that correspond to the thermocouples on the cell itself. The temperature distribution was examined at several charge/discharge rates to verify that the model was consistent with reality, as measured by thermocouples and infrared heat cameras. Here, they found that the results were within 1 °C of the measurements.

With the knowledge gained from the model, they were able to reduce the size of the physical channels between the cells. Doing this reduces space and also cuts weight because a smaller frame can be used. This makes it easier to insert the battery pack into a larger variety of vehicles, which is important in order to adapt battery powertrains to vehicles already on the market.

A future project will look at the other extreme conditions for Li-ion battery packs, particularly at temperatures below freezing where it can be difficult to charge these types of batteries. But by leveraging the Joule heating effect and through innovative design, it may be possible to solve this problem as well.❖



Results from using an infrared camera and thermocouples to measure the temperature on the surface of a pouch cell.



A comparison of model and experimental results for one of the thermocouples on the surface of the lithium cell. The results show a maximum difference of 1°C between the two.

Improving Production Processes for Customized Touchscreens

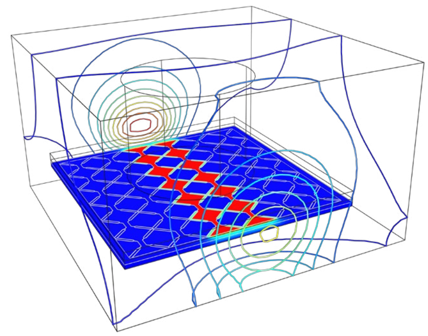
➔DEVELOPING AN EFFICIENT TOUCHSCREEN DESIGN PROCESS

In many of today's technologies, touchscreens are becoming more and more ubiquitous. Cypress Semiconductor, the leading supplier of capacitive touchscreen technologies, designs and manufactures touchscreens for a variety of applications, including smartphones, mp3 devices, laptops, automotive environments, industrial applications, home appliances, and more. Because of the diverse uses of touchscreens and the nature of the products in which they are used, many of the designs Cypress produces must be created individually on a case-by-case basis.

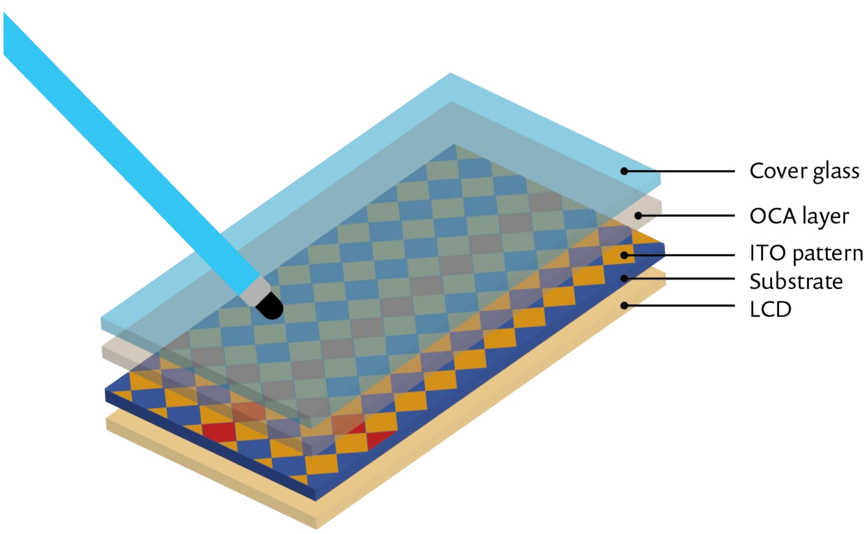
Capacitive touchscreens consist of varying layers of transparent lenses, substrates, adhesives, and horizontally and vertically aligned indium-tin-oxide (ITO) electrodes. Together, these elements are known as touchscreen panels (TSPs) or stack-ups.

Depending on the type of product in which it is used, each touchscreen stack-up and electrode pattern must be customized for its intended environment. This requires studying a variety of environmental conditions and ways in which a consumer will interact with a touchscreen. Peter Vavaroutsos, a member of the modeling group at Cypress, designs TSPs for different consumer products. "For these designs, I must take into account such factors as how interactions with a horizontally mounted GPS, for example, will differ from a smartphone, which can be held and interacted with in a myriad of different ways."

In addition to consumer products, an automotive group at Cypress designs touchscreens for use in applications such as an automobile's center console or rear seat and overhead entertainment systems. "In the automotive group, our designs are more customer-driven and are often created on a case-by-case basis for a specific product," says Nathan Thomas, an R&D engineer on the automotive team.



Example design box showing a touch sensor with electric field lines modeled using the AC/DC Module, an add-on product to COMSOL Multiphysics® software.



Typical touchscreen sensor stack-up, which contains an LCD layer followed by a substrate, a pattern of horizontally and vertically aligned diamond-shaped ITO electrodes, and finally an optically clear adhesive layer that bonds the glass cover onto the screen.

Because of the challenges involved in creating so many custom designs, multiphysics simulation and simulation apps have emerged as key tools at Cypress for ensuring effective product development.

➔DESIGN CAPABILITIES FOR THE ENTIRE ORGANIZATION

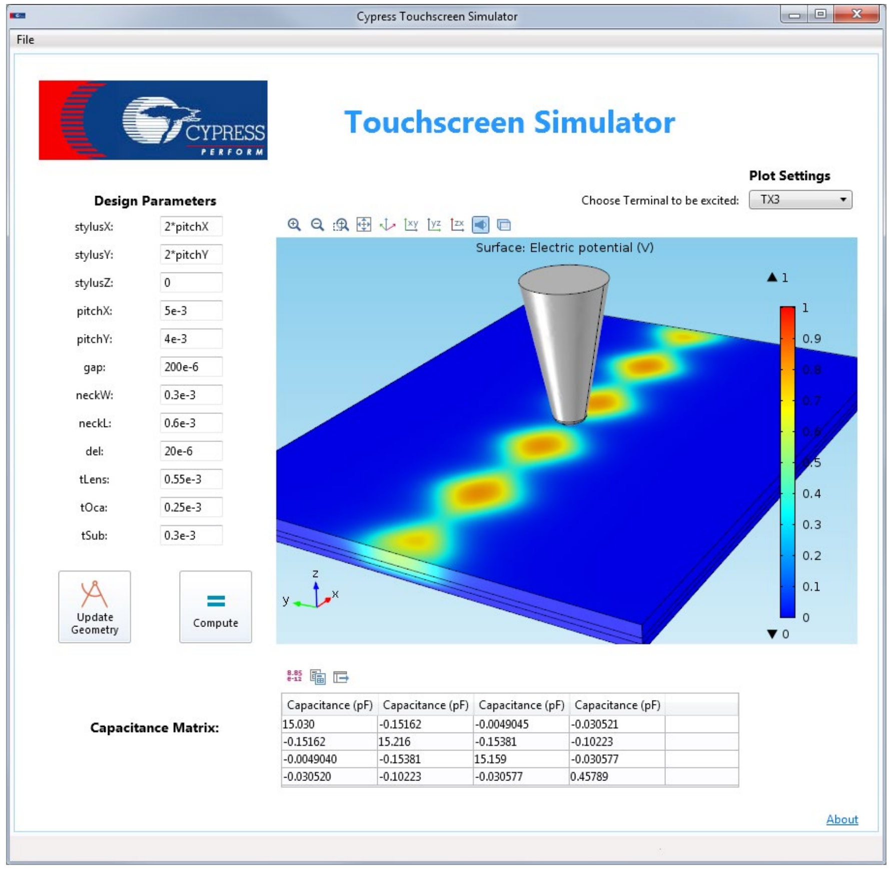
Multiphysics modeling allows designers to predict and optimize numerous device designs without the need to build multiple physical prototypes. The Cypress R&D engineers create multiple electrostatic simulations using the COMSOL Multiphysics® software in order to study the performance of different device geometries, which are referred to as "design boxes".

Recently, Cypress R&D engineers have been using the Application Builder in COMSOL Multiphysics to create simulation apps based on their models. Whether for smartphone designs, automotive applications, or other industrial processes, these simulation apps allow their support engineers, sales teams, and others to experiment with designs that would otherwise have required the expertise of an R&D engineer.

Simulation apps have been particularly valuable for designing customer-specific products. “We’re using the Application Builder to build simplified user interfaces over our models, which allows us to communicate more effectively with our customer support teams,” says Vavaroutsos. “Before we started using simulation apps, any time a customer wanted a design that was slightly outside of the standard design box, we’d have to be involved again to run simulations for minor parameter changes. A lot of times, a sales engineer might try to run the simulations themselves, even though they had little experience using the COMSOL® software. Not only would we have to check the simulations, but they also took up a seat on the software license as well.”

Using the apps, sales engineers, field technicians, and others are able to quickly recalculate a model based on a customer’s specific needs. This gives them the ability to provide timely support for their customers, even for cases that would have previously fallen outside the range of a design box.

“We’re finding that letting our support teams have access to multiphysics simulation results is hugely helpful,” says Vavaroutsos. “We can control which parameters are accessible to the app user so that we know the apps are delivering accurate results, while also letting our support engineers experiment with thousands of different design options without the need to involve an R&D engineer—or use a seat up on our COMSOL Multiphysics license.”



Simulation app based on a COMSOL® software model used to support the design of touch-based capacitive sensors. The app user can change design parameters ranging from the finger location to the thickness of different layers in the sensor. A drop-down list can be used to select a solution corresponding to the excitation of different sensor traces.

➔USER-FRIENDLY SOLUTION FOR DEVICE DESIGN

Each design space—and its multiphysics model—will vary depending on the intended application. Different designs might include, for example, multiple electrode layers, layers in different orders, or varying thicknesses or patterns for each layer. Each will also cover a variety of parameter ranges in order to enable the precise analysis of a certain system, and allows the engineer to predict and optimize the electrical performance of the device.

One app created at Cypress, based on such a simulation, allows the user to change various geometric parameters such as the thickness of layers or the location of a virtual finger touching the screen. The app then calculates the electric field distribution and the capacitance matrix, an integral piece of information for capacitive sensor design, and can generate a detailed report on the study. Simulation apps are shared using a COMSOL Server™ license, which makes the apps accessible through either a Windows®-native client or a web browser.

“We’ve been creating simulation apps that our field engineers can apply directly to the task at hand without having to go through us to create the simulation for them,” says Thomas. “While this is still a new technology for us, I can foresee simulation apps becoming the primary tool used by our field engineers in the automotive group in the near future.”❖

> “I can foresee simulation apps becoming the primary tool used by our field engineers in the automotive group in the near future.”

Multiphysics Simulation Helps Miele to Optimize Induction Stove Designs

➔DEVELOPING AN EFFICIENT DESIGN PROCESS

Induction stoves have several advantages over traditional ones: they provide faster heating and are known for extremely high efficiency, where over 90% of the energy goes directly into heating food. Induction heating is used to heat a pot placed on the stove, rather than heating the stove itself, by passing an alternating current through copper coils to generate a magnetic field. This induces currents in the metal of the pot, causing Joule heating.

> "...they saved development time and reduced the number of experiments needed to finalize their designs by 80%."

However, the process for designing an induction stove was, until recently, quite demanding. It required trial and error for estimating parameters such as the ideal frequency, coil size, and power output. Designers also tackled more unusual challenges, such as silencing the high-pitched noise produced by electric currents flowing through the metal, or the side effect of pots moving around on the stovetop because of magnetic forces.

Researchers at mieletec FH Bielefeld, a joint research laboratory between Miele & Cie. KG and the University of Applied Sciences Bielefeld, Germany, have used computer simulation to close the gap between the concept and production stages of building induction stoves. With the help of COMSOL Multiphysics® software, they have created a breakthrough cooktop for Miele, a world leader in domestic appliances and commercial machines.

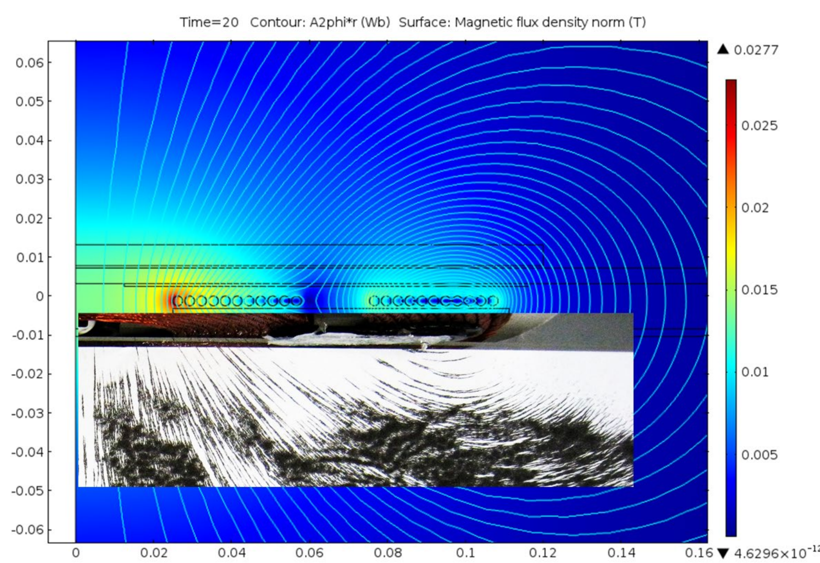
➔REDUCED DEVELOPMENT TIME WITH FEWER PROTOTYPES

At mieletec, engineers relied on simulation and the multiphysics approach to improve, verify, and optimize their induction stove designs. Because their simulations in COMSOL® software accurately demonstrated how the prototypes would perform, they saved development time and reduced the number of experiments needed to finalize their designs by 80%. They were able to simulate the entire system, improving the energy efficiency of the stove and optimizing their results so that when the first prototypes were built, they already had a clear idea of how they would perform. Tests that in practice last for a few days took only a few hours to achieve when simulated.

➔SIMULATION-LED OPTIMIZATION FOR HIGH-QUALITY STOVE DESIGN

Simulating the induction heating process involved solving heat transfer simultaneously with electromagnetics to optimize and determine the best operating conditions. Using COMSOL allowed researchers at mieletec to optimize

The stovetop remains cool; in fact, the ice cubes are hardly melting, while the water inside the pot is boiling.

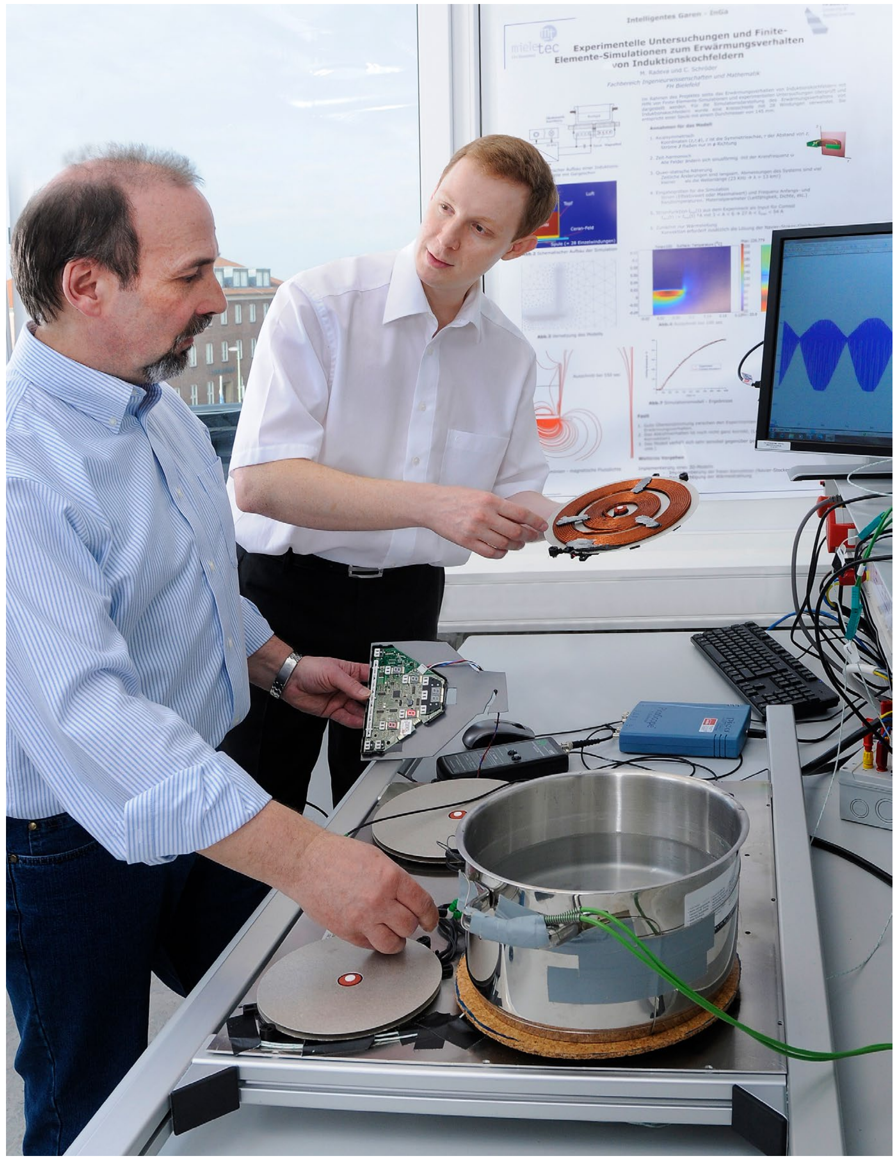


Comparison between results from COMSOL Multiphysics® software (magnetic flux density norm) and experimental field lines can be used to test other coil designs before building a prototype.

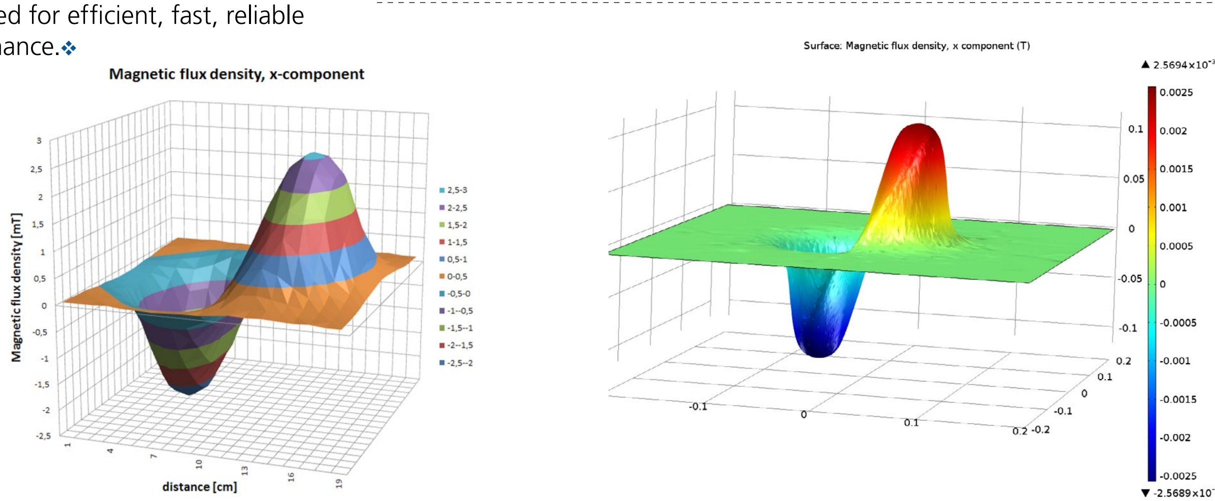
the coil setup, settling on a combination of current frequency and coil geometry that would produce noise at a frequency higher than the human ear can pick up — silencing the high-pitched squeal created by the eddy currents.

To prevent pots from moving across the stovetop, they used simulation to analyze how the properties of different materials used in cookware respond to thermal and electromagnetic effects. Eddy currents in the paramagnetic metals that induction pots are made of produce a magnetic field when they interact with the magnetic field generated by the coil. This creates the magnetic forces that can cause the pot to move. From their results, the team optimized the coil design to ensure that pots would stay put, would provide the right amount of power for cooking, and would not produce noise audible to the human ear, all while retaining the high efficiency characteristic of induction stoves.

The result? A development process aided and hastened by multiphysics simulation, and a high-quality stove created and optimized for efficient, fast, reliable performance.❖



Setup of a test campaign performed by staff scientists Werner Klose (left) and Mikhail Tolstykh (right). The stovetop has been removed, showing the internal workings of the stove.



Experimental results (left) and simulation results (right) showing the x-component of the magnetic flux density for a special coil design.

ADDITIONAL RESOURCES

EVENTS & ONLINE MEETINGS

Check out our many events that provide attendees with opportunities to learn more about the COMSOL Multiphysics® software and its capabilities.

- **Webinars** – Learn about how others in your industry are using COMSOL Multiphysics in a live or archived webinar. Browse the full list at comsol.com/webinars.
- **Web Workshops** – Learn to build a multiphysics model while you follow along from your own computer. Contact us to schedule a demo and download a free trial.
- **COMSOL Days** – Take part in regional 1-day training events featuring hands-on courses and invited talks by experienced COMSOL users, product managers, and applications engineers.
- **COMSOL Conference** – Attend these 2 and 3 day annual events featuring as many as thirty minicourses, poster and oral presentation sessions, keynote presentations, exhibition, and social events.
- **Training courses** – Advance your skills and boost your productivity at our 2-day COMSOL Multiphysics Intensive Training Course, or one of our topic-specific courses.

SUPPORT

Support engineers at COMSOL answer questions and offer suggestions. The online discussion forum provides you with a widespread network of users modeling a diverse range of applications.

PUBLICATIONS & PRODUCT DOCUMENTATION

Get to know the powerful simulation tools COMSOL offers, and read how simulation experts across many industries use COMSOL® software to resolve design challenges.

- COMSOL News, Multiphysics Simulation
- Introductory books to COMSOL Multiphysics and Application Builder
- Handbooks
- Whitepapers

VIDEOS

Watch step-by-step tutorials, user presentations, and topic-specific videos to learn how to model your system with COMSOL.

BLOG

Browse our blog to get inspiration and guidance for your own simulation work. You will find:

- Tutorials and how-tos
- Simulation best practices
- User research

PRODUCTS

› COMSOL Multiphysics®
› COMSOL Server™

ELECTROMAGNETICS
› AC/DC Module
› RF Module
› Wave Optics Module
› Ray Optics Module
› Plasma Module
› Semiconductor Module
› MEMS Module

STRUCTURAL & ACOUSTICS
› Structural Mechanics Module
› Nonlinear Structural Materials Module
› Geomechanics Module
› Fatigue Module
› Multibody Dynamics Module
› Rotordynamics Module
› Acoustics Module

FLUID & HEAT
› CFD Module
› Mixer Module
› Subsurface Flow Module
› Pipe Flow Module
› Microfluidics Module
› Molecular Flow Module
› Heat Transfer Module

CHEMICAL
› Chemical Reaction Engineering Module
› Batteries & Fuel Cells Module
› Electrodeposition Module
› Corrosion Module
› Electrochemistry Module

MULTIPURPOSE
› Optimization Module
› Material Library
› Particle Tracing Module

INTERFACING
› LiveLink™ *for* MATLAB®
› LiveLink™ *for* Excel®
› CAD Import Module
› Design Module
› ECAD Import Module
› LiveLink™ *for* SOLIDWORKS®
› LiveLink™ *for* Inventor®
› LiveLink™ *for* AutoCAD®
› LiveLink™ *for* Revit®
› LiveLink™ *for* PTC® Creo® Parametric™
› LiveLink™ *for* PTC® Pro/ENGINEER®
› LiveLink™ *for* Solid Edge®
› File Import *for* CATIA® V5

PRODUCT FAQ

What is the COMSOL Multiphysics® software?

- An integrated software environment for creating physics-based models and simulation apps.
- A particular strength is its ability to account for coupled or multiphysics phenomena.
- Add-on products expand the software environment for electrical, mechanical, acoustic, fluid flow, thermal, and chemical simulations.
- Interfacing tools enable the integration of COMSOL® simulations with all major technical computing and CAD tools on the market.

What are the advantages to COMSOL Multiphysics®?

- Powerful and extensive multiphysics functionality enables high-fidelity modeling of real world systems.
- A consistent, easy-to-learn interface across all application modules means a shorter learning curve, and enhanced productivity.
- Increase everyone's productivity by converting your COMSOL model into an easy-to-use custom simulation app with the Application Builder tool.

What are the advantages of custom simulation apps?

- App users do not need any experience in numerical simulation to benefit from the power of multiphysics analysis.
- Simulation apps can be deployed to colleagues and customers with a local installation of the COMSOL Server™ product for seamless collaboration.

What is COMSOL Server™?

- A software product for running apps built with COMSOL Multiphysics and the Application Builder.
- It is like COMSOL Multiphysics, but…
  - » With a web interface for running applications from a web browser.
  - » With administrator tools for creating and managing user accounts.
  - » Without the builder tools: Model Builder, Application Builder, and Physics Builder.

What are the advantages to COMSOL Server™?

- Run apps in a web browser (or COMSOL Client for Windows® operating system) from anywhere in the world, sharing application libraries.
- Administrator tools for user accounts, privileges, and user sessions.
- Much lower license fee (a cost-effective way of running apps built with COMSOL).
- Install anywhere – on a server, cluster within an organization, on a laptop, or on a desktop computer for offline use.
- The web browser or COMSOL Client running on the user's device does not do any computations. All computations are done on your server computer(s).

LICENSE OPTIONS

The table below is a summary of the different license types available.

License Type	Multiple Computers	Multiple Users	Client/ Server	Cluster Computing	Network Access	World-wide
Named Single User License (NSL)	✓*					
CPU-Locked Single User License (CPU)		✓				
Floating Network License (FNL)	✓	✓**	✓	✓	✓	
COMSOL Server License (CSL)	✓	✓**	✓	✓	✓	✓

* The software may be installed on 4 machines at one time, and may be run on 2 of those 4 machines at any given time.

** Pay per concurrent user.