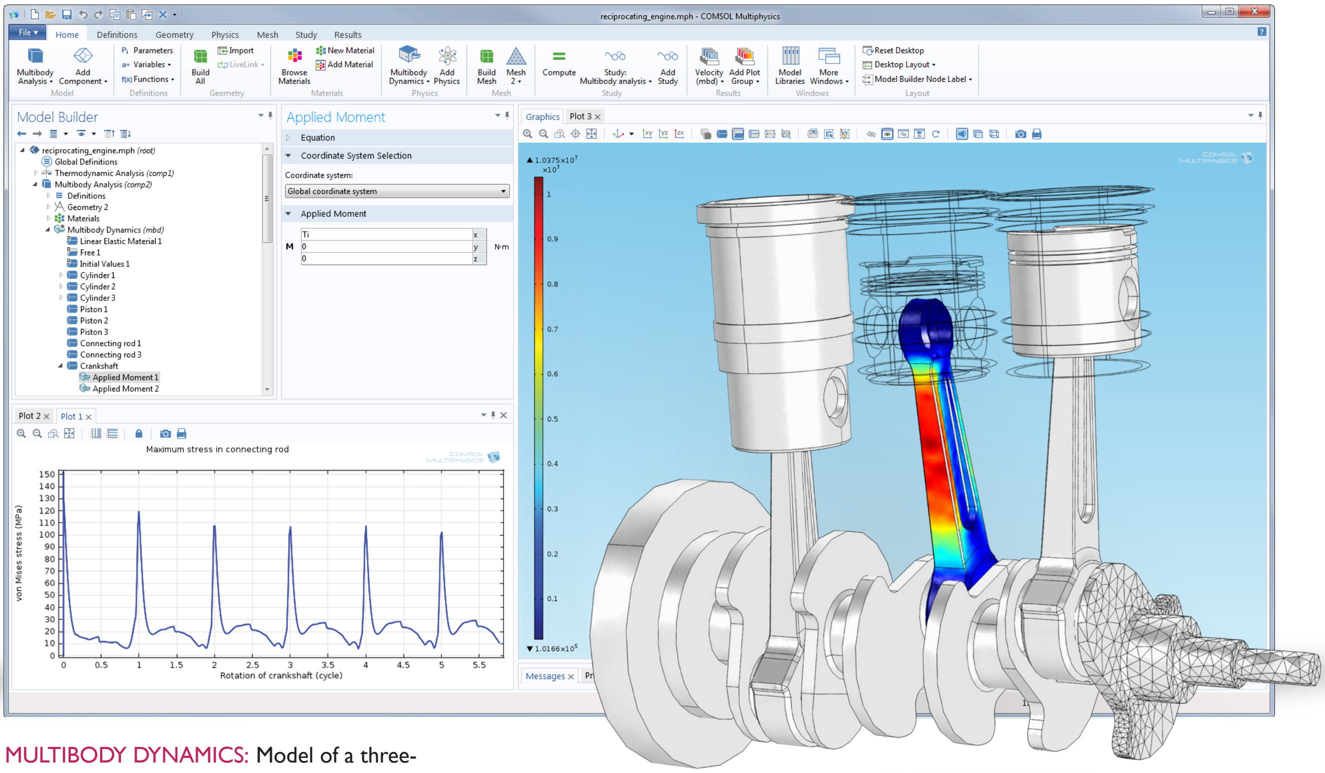
Manager’s Guide 2014

Productivity and Innovation Through Multiphysics Simulation

COMSOL

THE COMSOL DESKTOP® ENVIRONMENT



MULTIBODY DYNAMICS: Model of a three-cylinder reciprocating engine used for the design of structural components.

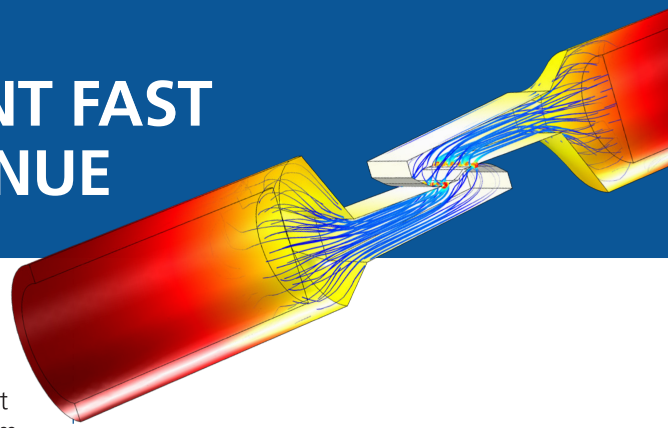
WHAT IS COMSOL MULTIPHYSICS® SOFTWARE?

COMSOL Multiphysics® is an integrated platform for the modeling and simulation of your designs. You can analyze the behavior of your product under varied operating conditions and optimize the design prior to prototyping.

Multiphysics analysis delivers accurate results by coupling multiple physics in a single model that are solved for simultaneously to simulate real-world performance. Simulations can include any number or type of physics including electrical, mechanical, fluid, thermal, acoustical, and chemical effects.

Readily set up and customize your model using the tools available in the COMSOL Desktop® shown above. The user interface delivers a consistent workflow for any application regardless of model complexity.

THE PRODUCT DEVELOPMENT FAST TRACK TO MAXIMUM REVENUE



Simulation is used extensively in all industries and throughout the product development cycle to enable design innovation with shorter time to market and reduced costs. In this guide, see how high-tech companies benefit from incorporating multiphysics simulation in their design workflow.

INNOVATION WITH REDUCED RISK

Innovation is fundamentally a time-sensitive objective requiring the most accurate and complete simulation tools to stay ahead of the competition. "With multiphysics simulation, you can study test cases and physical phenomena that aren't always possible to build or measure, at least not in a realistic or competitive timeframe," says Jeff Hiller, Vice President of Sales for COMSOL.

Consider, as an example, an extended study to evaluate how a device performs over many years and in a harsh environment. Simulating the design in COMSOL Multiphysics® software provides an accurate and efficient method of analysis where a model can include any number of physical effects and their interactions to easily model multiphysics phenomena such as Joule heating, thermal expansion, convective cooling, or fluid-structure interaction. A model can be as simple or complex as is necessary. The results from the simulation can be obtained in a matter of minutes, providing valuable insight into your design long before experimental results are available. The risk of product failure and delays to market can be drastically reduced.

ACCELERATE YOUR WORKFLOW

COMSOL features a simulation environment that's highly customizable and can immediately accelerate your workflow upon integration, making it a worthwhile investment. Through the COMSOL Desktop, shown on page 2, model setup and results visualization are straightforward. The simulation process is the same for any application, which applies to both single and multiphysics models.

"From the start, go with a software that won't require additional training for every type of physics or device that you want to model," says Hiller. "Researchers and engineers trained in using COMSOL Multiphysics are often the most versatile when it comes to simulating multidisciplinary or a diverse range of applications."

The COMSOL Product Suite on page 12 of this guide, features many add-on modules with physics interfaces for simulating chemical, mechanical, fluid flow, and electrical applications. The tools provided can be used together to make it easy to build real-world models that encompass any type of physics and any number of physical effects. Powerful solver technology delivers accuracy and speed, running on everything from standard desktop hardware to high-performance clusters and clouds.

Several add-on products are available to enable interfacing with industry-standard software for technical computing, CAD, and data analysis, making it easy to share results and collaborate with colleagues in multiple departments to improve product design workflow.

Convenient licensing options for COMSOL Multiphysics and the add-on products are presented on page 13.

COMSOL PRODUCTS IN ACTION

This guide features examples demonstrating how high-tech companies have upgraded their workflow with multiphysics simulation. Highlights include:

Read it here first. Then go to comsol.com for full-length articles and more information on multiphysics simulation.

Manager's Guide 2014
Editor: Jennifer Segui
Technical Marketing Engineer, COMSOL, Inc.

We welcome your questions and comments. Contact us at info@comsol.com.

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.

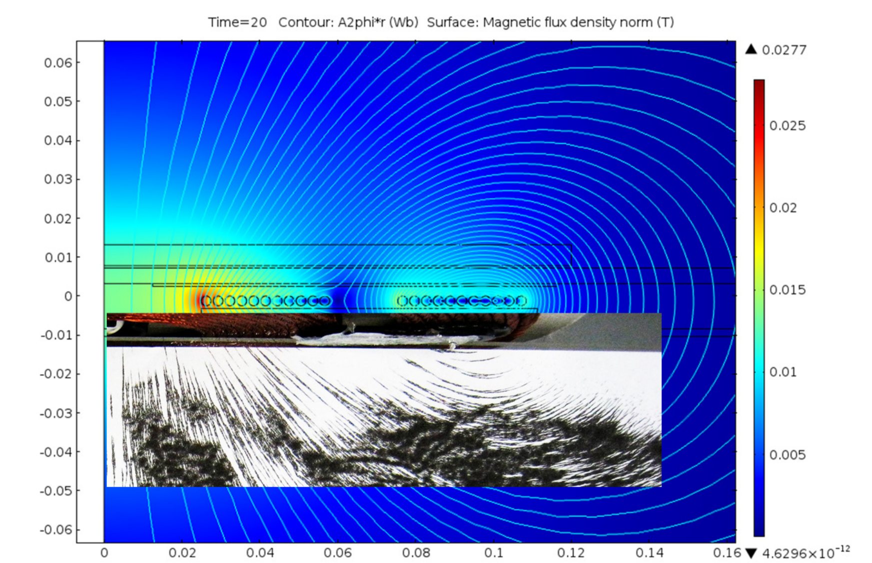
➔REDUCED DEVELOPMENT TIME WITH FEWER PROTOTYPES

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.

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

➔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

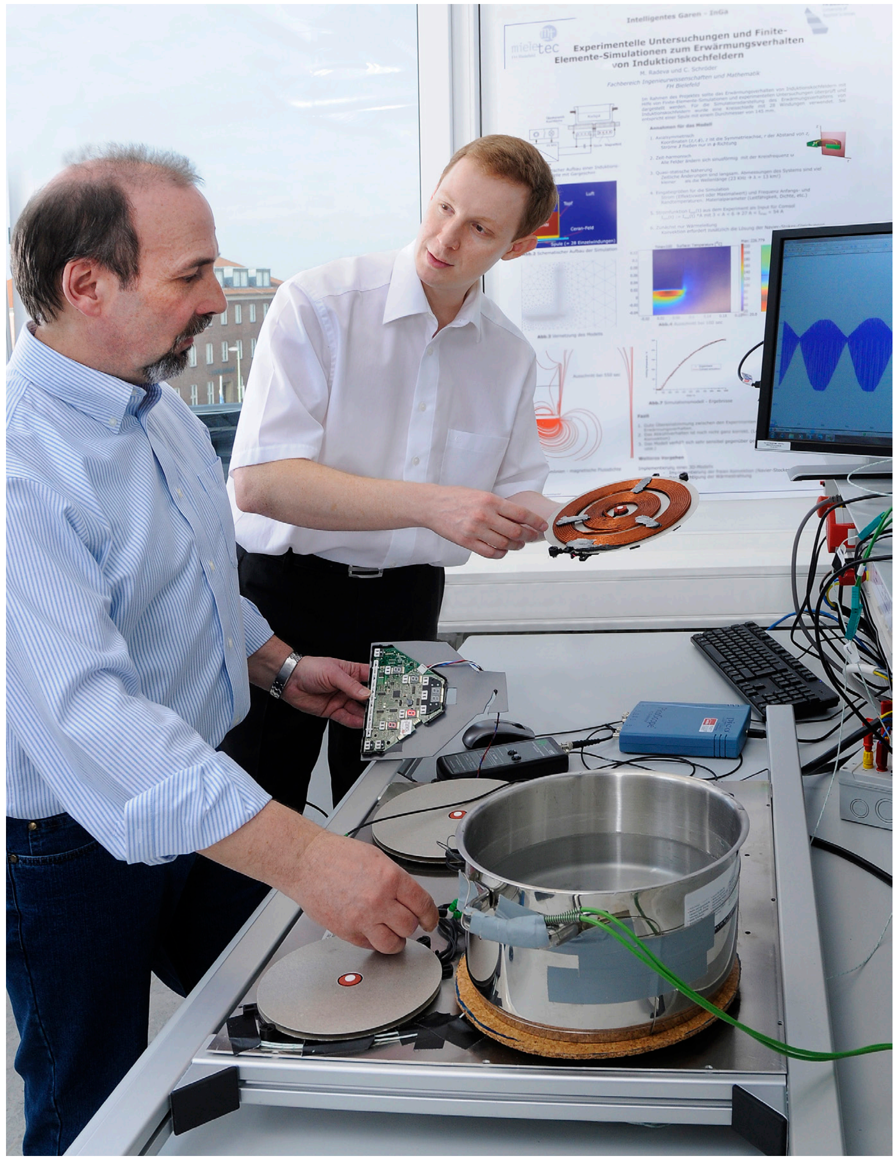


The comparison between COMSOL Multiphysics results (magnetic flux density norm) and experimental field lines can be used to test other coil designs before building a prototype.

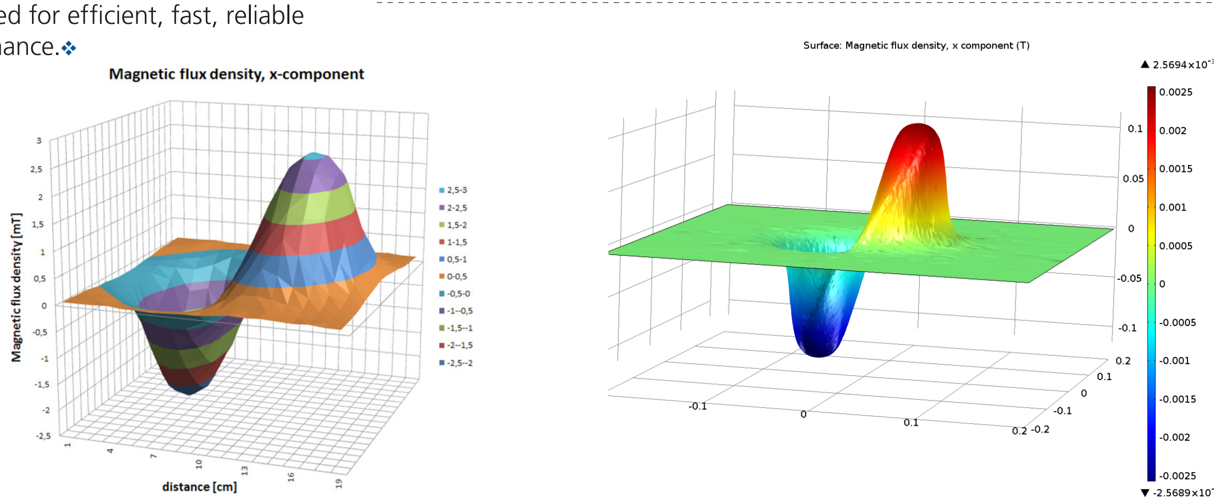
optimize the coil setup, settling on a combination of current frequency and coil geometry that would produce noise at a frequency higher than the human ear can pick up — silencing the high-pitched squeal created by the eddy currents.

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, they 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.

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

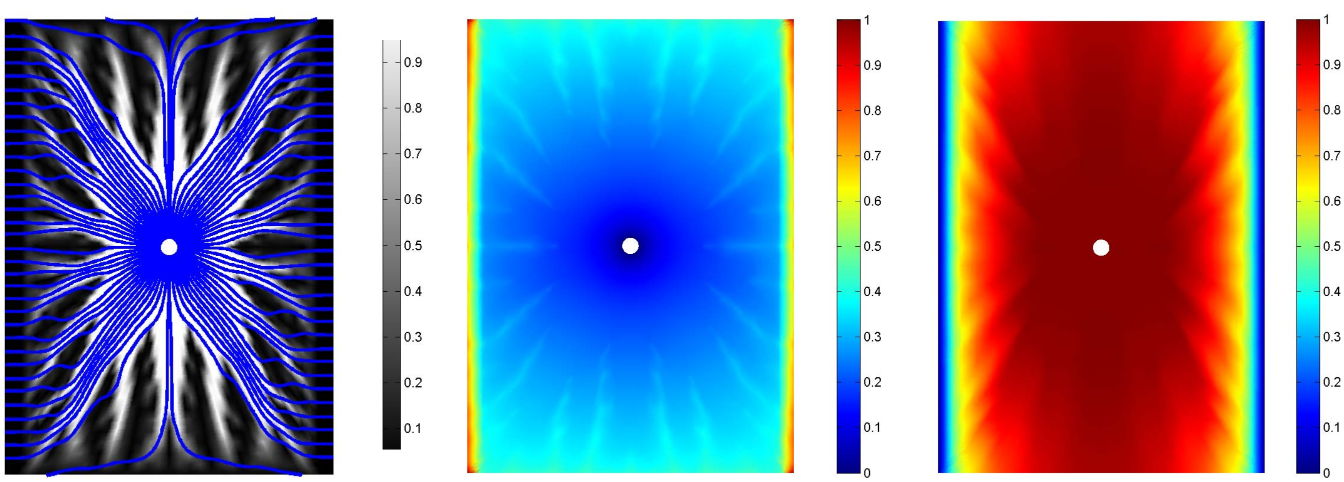
To save the time and expense associated with analytical design methods and trial-and-error physical prototyping, Dede and his colleagues used numerical simulation and multiphysics topology optimization to design and test the possible prototypes of a novel heat sink for future hybrid vehicle generations. 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.

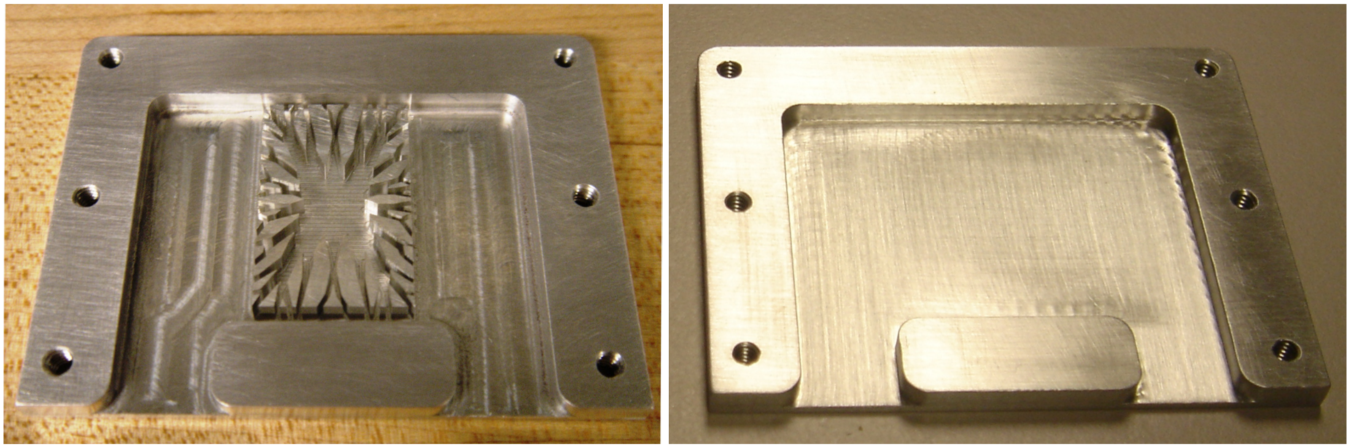
➔COOLING SOLUTION FOR HYBRID VEHICLES

"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.

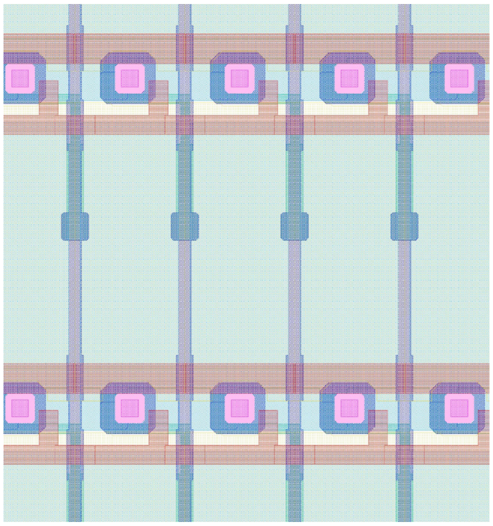
Once an initial channel topology was derived, the height of the fins that separate the cooling channels could be incorporated and was investigated in a separate parametric sizing study. Simulation results demonstrated that the channels efficiently distribute coolant throughout the plate to produce relatively 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.

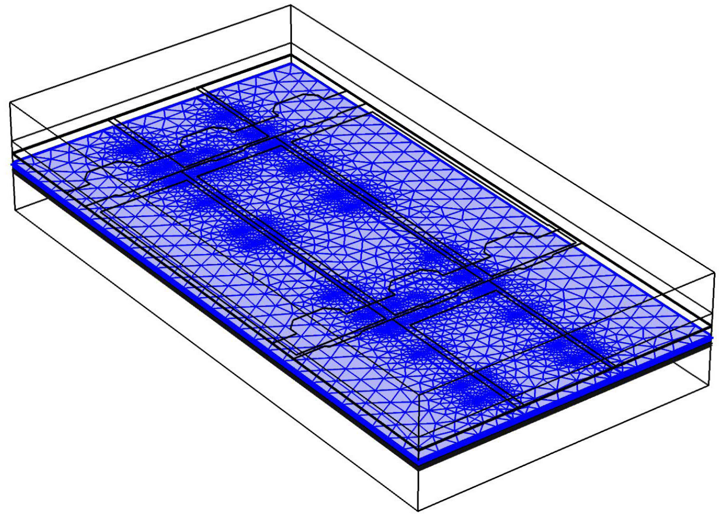
"LiveLink™ *for* SOLIDWORKS® has some nice functionality that allows you to actively link to CAD design tools, and it was easy to import various structures from SOLIDWORKS® software back into COMSOL® software to verify pressure drop and heat transfer," says Dede. "I think this is really the future of 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 SolidWorks® software designs, 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.

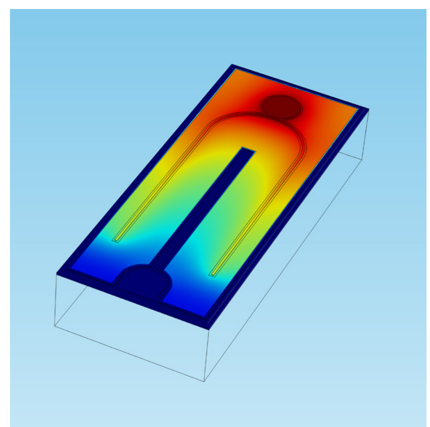
Nowhere has this multidisciplinary approach to product design taken root more firmly than in the R&D laboratories of Osaka, Japan-based Sharp Corporation. At Sharp Laboratories of Europe (SLE), an affiliate of Sharp Corporation, technology for lighting, displays, medical tools, and energy systems is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

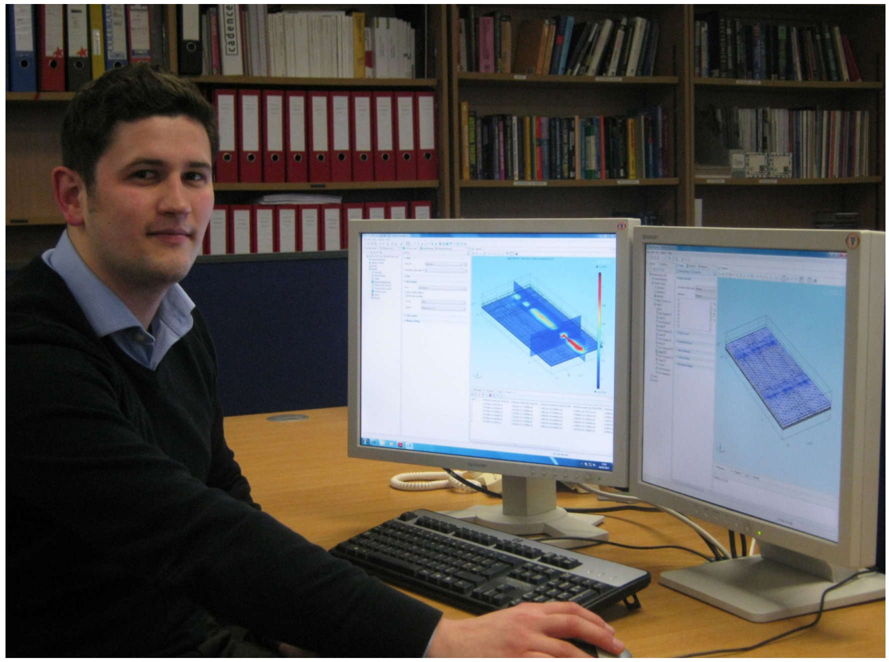
Each application presents unique challenges for the engineers at SLE. Multiphysics simulation offers the



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 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

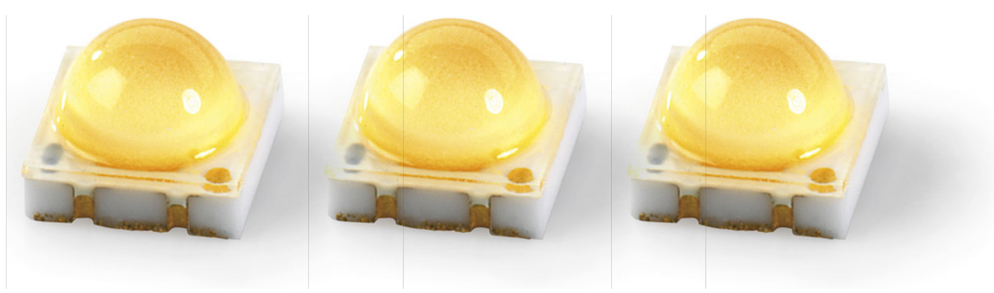
SLE applies the same rigorous approach to the purchase, configuration, and use of its tools as it does to its R&D explorations with COMSOL Multiphysics. "SLE's use of COMSOL has grown over the last five years, having started out in the LED area and then expanding to the other research themes by way of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

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 350V. 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.

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

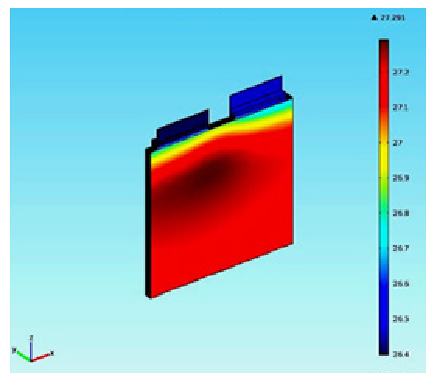
When developing a model using COMSOL Multiphysics® software, the researchers at Fiat were able to find the hot spots on a cell and also investigate its internal temperature distribution. This provided invaluable information that cannot be achieved via other methods due to the difficulty involved in embedding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

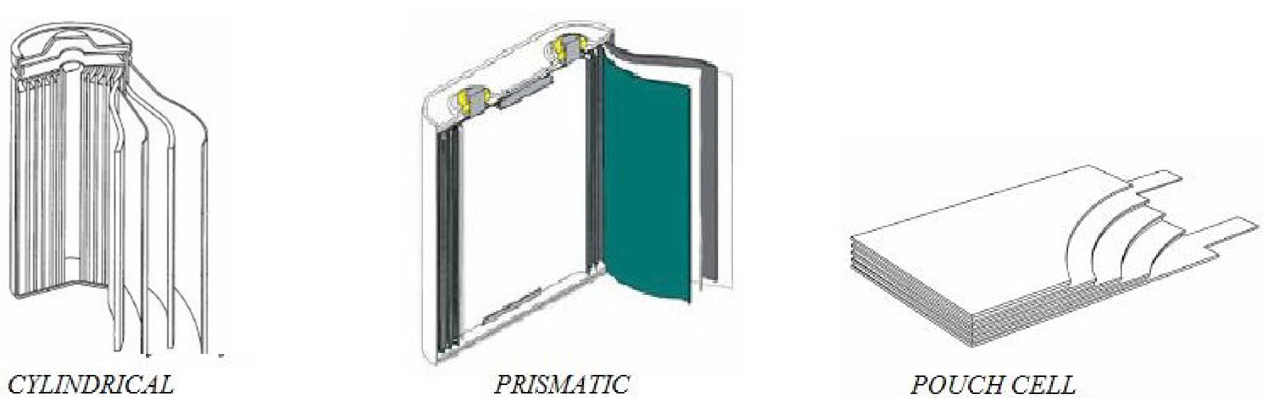
> "We estimate that instead of needing 1000 hours for the design of a battery pack, we could cut it down to roughly 300 hours."

➔BATTERY PACK DESIGN FOR HYBRID VEHICLES

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



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

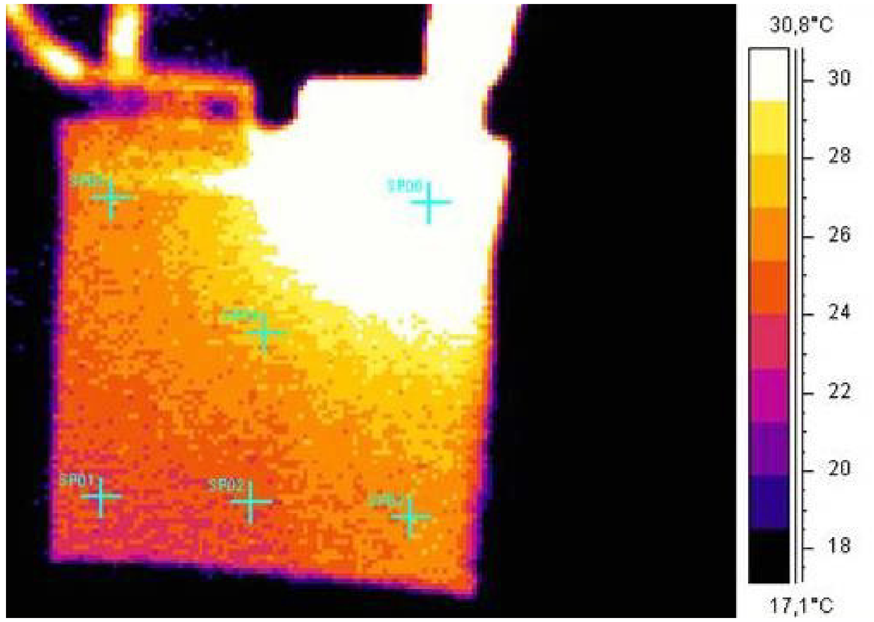


Three types of lithium-ion batteries. Fiat uses a series of 100 or so of the pouch cells to power their vehicles.

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.

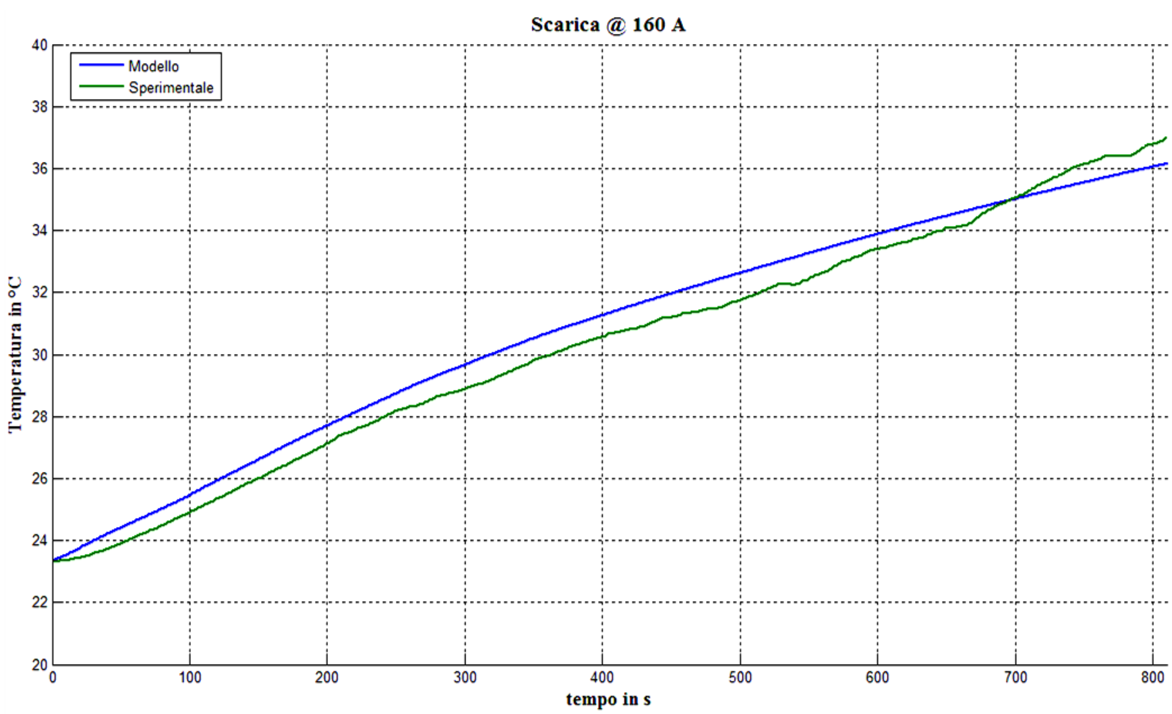
With the knowledge gained from the model, they were able to reduce the size of the physical channels between the cells. Doing this reduces



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

space and also cuts weight because a smaller frame can be used. This makes it easier to insert the battery pack in 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.❖



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.

ADDITIONAL RESOURCES FOR COMSOL MULTIPHYSICS® SOFTWARE

Getting started is easy…
Visit us on the web at www.comsol.com to sign up for courses, workshops, and to download tutorials from the Model Gallery.

Once you've started using COMSOL Multiphysics for simulation…
You'll gain access to a knowledgeable global community including the support engineers at COMSOL and a widespread user base that uses COMSOL Multiphysics for a diverse range of applications.

In addition to the documentation provided for each product, many online resources are available including the COMSOL Blog and Discussion Forum.

Also, make sure to check out our extensive collection of videos, webinars, and user stories.

For further ideas and inspiration...
Browse the 2014 edition of *COMSOL News* to learn more about how engineers and researchers are using COMSOL Multiphysics.

THE COMSOL PRODUCT SUITE

The COMSOL simulation environment facilitates all the steps in the modeling process – defining your geometry, meshing, specifying your physics, solving, and then visualizing your results.

A suite of add-on products expands this multiphysics simulation platform for modeling specific application areas and supports interfacing with different CAD formats, software packages, and programs for data organization and visualization.

Product Suite

COMSOL Multiphysics

ELECTRICAL
AC/DC Module
RF Module
Wave Optics Module
MEMS Module
Plasma Module
Semiconductor Module

MECHANICAL
Heat Transfer Module
Structural Mechanics Module
Nonlinear Structural Materials Module
Geomechanics Module
Fatigue Module
Multibody Dynamics Module
Acoustics Module

FLUID
CFD Module
Mixer Module
Microfluidics Module
Subsurface Flow Module
Pipe Flow Module
Molecular Flow 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
ECAD Import Module
LiveLink™ *for* SolidWorks®
LiveLink™ *for* Inventor®
LiveLink™ *for* AutoCAD®
LiveLink™ *for* Creo™ Parametric
LiveLink™ *for* Pro/ENGINEER®
LiveLink™ *for* Solid Edge®
File Import *for* CATIA® V5

LICENSING OPTIONS

Named Single User License (NSL)

One physical person designated to COMSOL by name can run a session of the software. This designated user may be replaced on a temporary or permanent basis provided that only one individual is designated to COMSOL as the user at any given time. A Named Single User License may not be used or accessed over a network.

CPU-Locked Single User License (CPU)

You can install the software on one computer and different users can take turns using COMSOL on that computer, one session at a time. A CPU-Locked Single User License may not be used or accessed over a network.

Floating Network License (FNL)

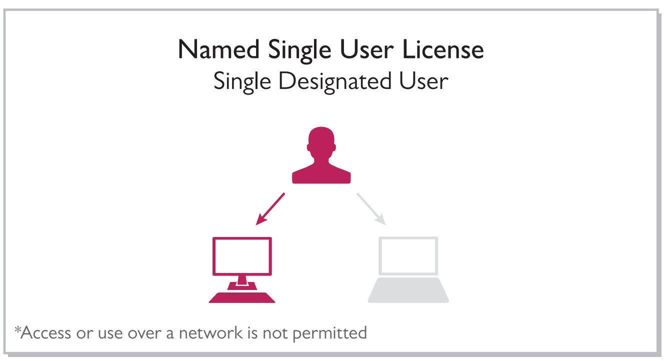
Licensed per concurrent user, you can install the software on as many machines on your network as you want. COMSOL can run on local computers with the network being used only for license authentication, or alternatively you can run COMSOL on a remote computer over your network. Cluster computing is supported on Windows Compute Cluster Server 2003, Windows HPC Server 2008, and Red Hat Enterprise Linux 5. Cloud computing is supported on Amazon Elastic Compute Cloud™ (Amazon EC2™).

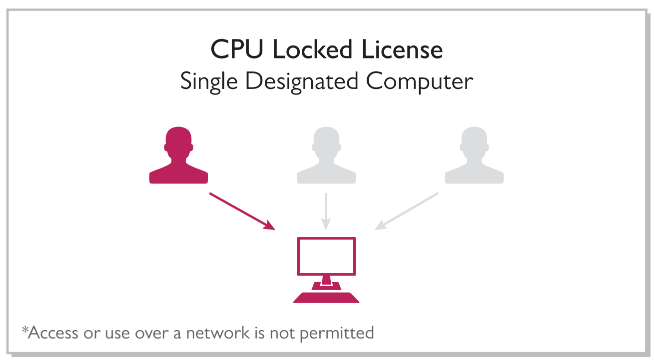
High Performance Computing

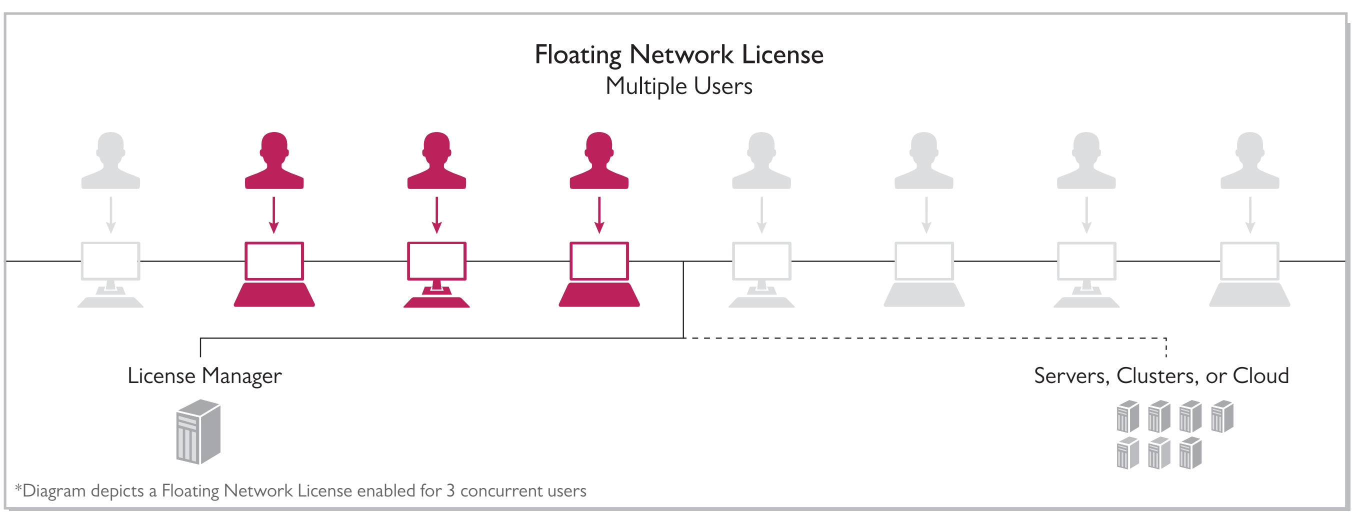
All license options include support for multicore computing with no limit on the number of cores. The Floating Network License includes additional support for cluster and cloud computing with no limit on the number of compute nodes.

License Type	NSL	CPU	FNL
Multiple Computers	✓		✓
Multiple Platforms	✓		✓
Multiple Users		✓	✓
Client/Server			✓
Clusters			✓
Cloud Computing			✓

For detailed license conditions, please refer to the COMSOL Software License Agreement available for download from www.comsol.com/shared/downloads/sla.pdf.







All Licenses Perpetual, 20% yearly support and upgrades

PC, Mac or Linux® compatible