EMMC-Workshop

Materials modelling for electronic devices / sensors:
successful translation expertise and modelling aspects

Warsaw

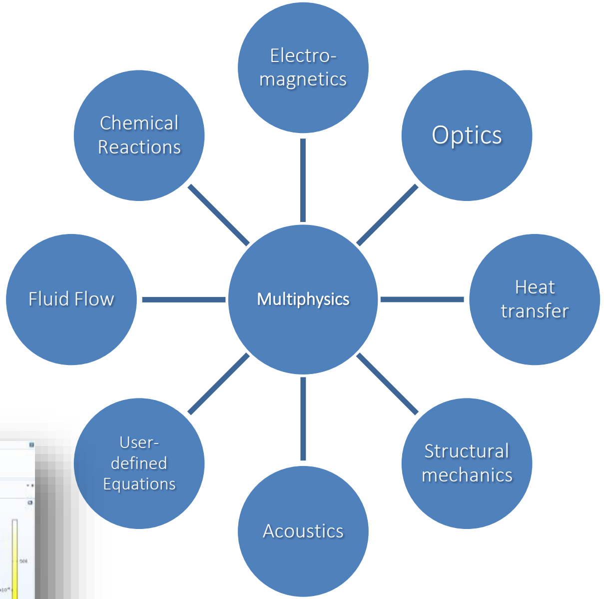
18 September 2017

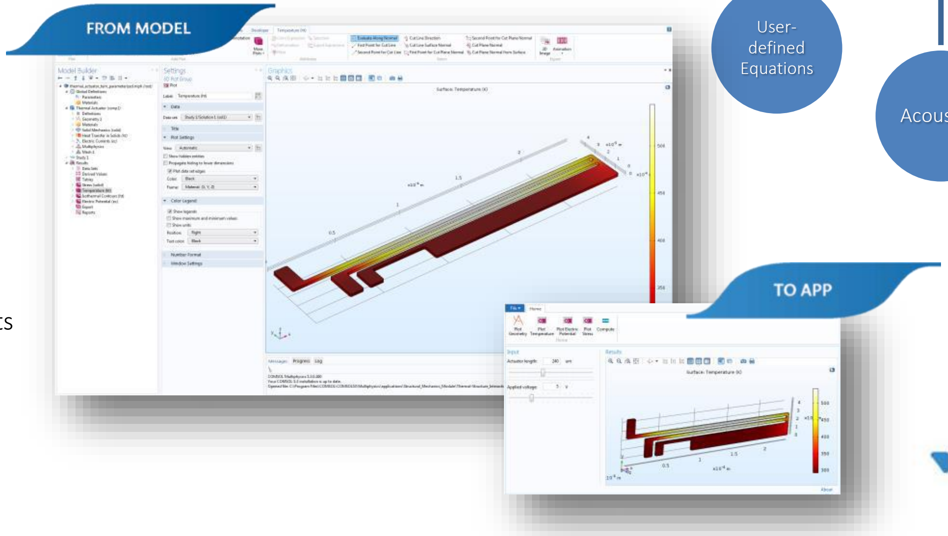
Tomasz Krupicz

Comsol Multiphysics GmbH

COMSOL MULTIPHYSICS

- Modeling and Simulation
  - Ready made physics interfaces
  - General mathematics interfaces
  - Built-in CAD tools
  - Add-on modules with specialized physics interfaces
  - LiveLink™ products to connect with partner software
    - Most major CAD tools
    - MATLAB®
    - Excel®
- Development tools
  - Model Builder
  - Physics Builder
  - Application Builder
- Deploying Apps
  - COMSOL Multiphysics®
  - COMSOL Server™
    - Browser and Windows® clients





COMSOL 2017 – Translation activities

- Translators?
  - Technical sales engineers in offices all around the world
- Activites?
  - We have the ability to analyse the users problem, to estimate the economic advantage of simulation and to propose modelling workflows to solve the problem.
  - We organise on-line meetings, workshops and training courses in order to maximize the utilization of modelling and simulation in COMSOL Multiphysics
  - We also support you in the whole proces of modelling

COMSOL

User Stories

- Convective Cooling of an Electrical Device
- Increasing Lifespans of High-Power Electrical Systems
- Evaluation and Optimization of Custom Capacitor Designs.

Multiphysics HPC-Simulation:

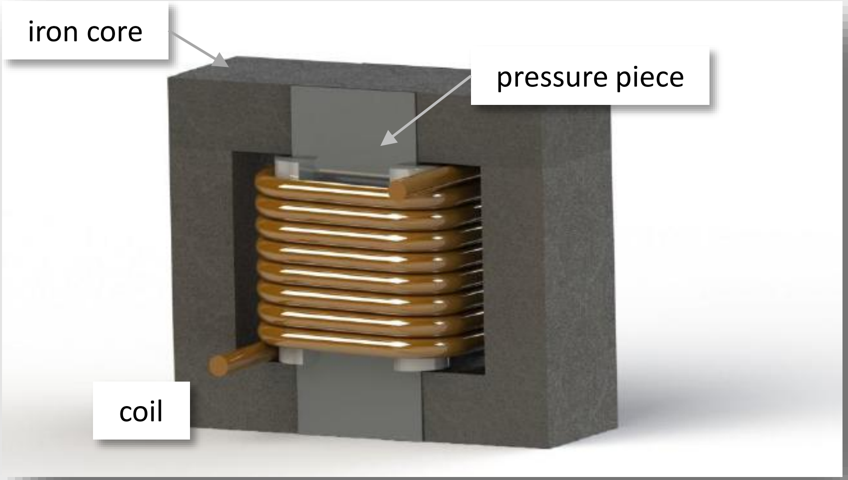
Convective Cooling of an Electrical Device

BLOCK TRANSFORMATOREN-ELEKTRONIK GMBH

VERDEN, GERMANY

The Problem

- Efficient thermal management with high power electrical devices is a necessity:
  - Need to simulate electromagnetic losses as well as the device's interaction with the surrounding environment
- Difficulties in running experiments as well as simulations:
  - Simulations are complex and difficult with standard workstation hardware
  - An aspect ratio of 10,000 between the dimensions of the coil windings and the distance from a cooling fan to the transformer has to be overcome (submodeling)

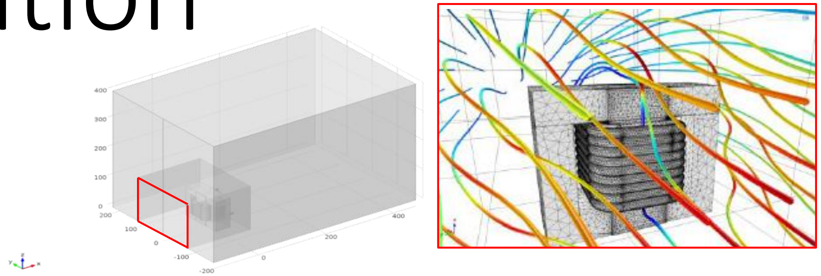


CAD-drawing of a transformer

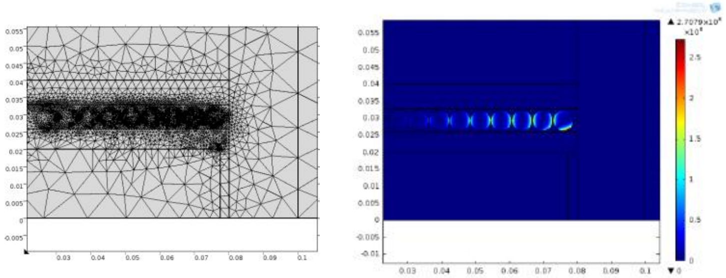
COMSOL

The Solution

- Sophisticated modeling:
  - Use symmetries
  - Use COMSOL's submodeling feature:
    - Split up the fluid-flow problem and use non-isothermal flow only where it is necessary
    - Restrict the electromagnetic computation to the submodel
  - Use adaptive mesh refinement
  - Use homogenized anisotropic material data for the conductivity of the laminated iron core
- Output:
  - Frequency-dependent magnetization losses
  - Current densities in coil and the other metal components
  - Winding-dependent **B**- and **H**-field
  - Temperature and flow field



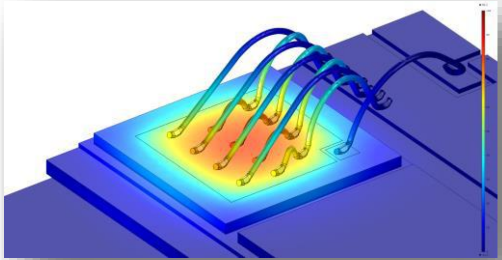
Submodeling



Adaptive mesh refinement

Multiphysics Simulation Story:
Increasing Lifespans of High-Power Electrical Systems

- The goal is to improve the performance of ABB's HiPak power modules, which are composed of many paralleled insulated-gate bipolar transistor (IGBT) chips.
- Gained an explanation via simulation for the stronger performance of IGBT chips with more wire bonds. Verified that mechanical stress was reduced in experimental studies in which reinforced IGBT modules showed a ten-fold improved cycling performance.
- IEEE Spectrum Multiphysics Simulation Insert: Samuel Hartmann*, ABB Semiconductors, Switzerland*



Temperature distribution in the IGBT chip with the stitch-bond layout.

The stitch-bonded layout now used in HiPak power modules.

Multiphysics Simulation Story:

Evaluate and optimize custom capacitor designs.

David Leigh, Sam Parler, Trent Bates, Cornell Dubilier.

Extract from COMSOL News 2017

ACCELERATING CUSTOM CAPACITOR DESIGN WITH SIMULATION APPS

Engineers at Cornell Dubilier Electronics use simulation apps to evaluate and optimize custom capacitor designs. These apps allow design and manufacturing engineers to quickly explore configurations on-site, bypassing the complexity of the underlying computational model.

by SARAH FIELDS

Capacitors are ubiquitous across common electrical devices used today, as well as in applications where extreme conditions must be considered. In each of these applications for which capacitors are necessary, the requirements can vary greatly. A capacitor may require an exact power specification, may need to function within a certain temperature range, or be made of specific materials.

One of the biggest manufacturers of custom capacitors used around the world, Cornell Dubilier Electronics, develops capacitors for some of the most demanding military and aerospace applications, including fighter jets and radar systems, as well as civilian applications such as wind turbines and solar energy. Engineers at Cornell Dubilier use mathematical modeling and custom simulation apps to fine-tune the design of custom capacitors.

"By using COMSOL Multiphysics and its Application Builder I can create high-fidelity multiphysics models and build apps based on them, which allows my colleagues in other departments to test different configurations and pick the best design," comments Sam Parler, research director at Cornell Dubilier.

FIGURE 1. Aluminum electrolytic capacitors. The windings are composed of aluminum foils and cellulosic separators, and exhibit thermal anisotropy.

⇨ WHEN THINGS HEAT UP

Cornell Dubilier's capacitors are specific to the application for which they are designed and can comprise one or more elements, such as electrolytic windings composed of aluminum foils and cellulosic separators; electrostatic windings of offset, metallized dielectric films; or interleaved, stacked plates of metal foils and dielectrics such as mica (Figure 1).

One matter at the forefront of the issues considered by capacitor designers is heat. Passing current through the aluminum foils of the windings results in Joule heating, which must be taken into consideration during the design to gain a full understanding of the thermal profile within the capacitor. Too much heat dramatically shortens the capacitor lifetime, which is cut in half each time the capacitor's temperature is 6-10 degrees higher than the maximum. Engineers at Cornell Dubilier use simulation to minimize heat generation and to optimize dissipation of heat.

In optimizing heat generation and heat dissipation, the complex materials of the capacitor must be accurately represented. One capacitor can easily include as many as six materials, some of which have anisotropic properties. In one design, the winding is composed of cellulosic separators and aluminum foils, and exhibits anisotropy of thermal conductivity over two orders of magnitude higher in the axial than in the radial direction.

Parler is able to accurately capture the thermal profile of capacitors with COMSOL Multiphysics® thanks to the flexibility that allows him to directly input the thermal conductivity tensor. For example, a typical simple capacitor tensor of a z-oriented cylindrical electrolytic winding can be approximated as orthotropic with a diagonal thermal conductivity tensor of {1,1,100} [W/m/K].

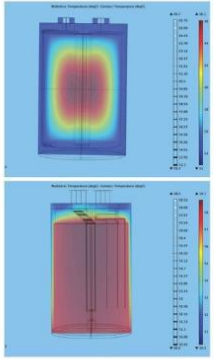


FIGURE 2. A thermal comparison of a metallized polypropylene film capacitor (top) and an aluminum electrolytic capacitor (bottom), both approximately 76x120 mm and dissipating 5 watts in a 45°C environment.

In one case, Parler considered two power capacitors of similar size and ripple current rating, but with entirely different construction: that of a metallized polypropylene (plastic) film capacitor and an aluminum electrolytic capacitor (Figures 1 and 2).

The plastic film capacitor (top) has a much lower axial thermal conductivity than the aluminum electrolytic capacitor (bottom). Using multiphysics simulation, Parler was able to quantify how much hotter the plastic film capacitor becomes compared to the aluminum electrolytic capacitor for a given dissipated wattage.

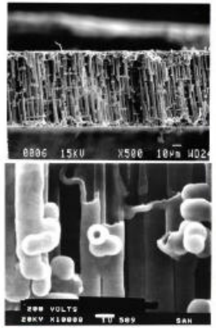


FIGURE 3. Coaxial microstructure of large aluminum electrolytic capacitors. The dielectric is aluminum oxide (Al_2O_3), grown in an anodizing bath on the tortuous surface of highly etched aluminum foil. In the images here, the aluminum surrounding the alumina dielectric tubes has dissolved away.

⇨ DEMYSTIFYING THE MICROSTRUCTURE WITH SHAPE OPTIMIZATION

As the capacitors developed at Cornell Dubilier are often new technological developments, in some cases, it is necessary to characterize the impedance of cutting-edge materials in house. In designing one large aluminum electrolytic capacitor, Parler needed to represent the impedance of an aluminum oxide (Al_2O_3) dielectric with a complex microstructure. This dielectric was produced in an anodizing bath on the tortuous surface of highly etched aluminum foil (Figure 3).

While a zero-dimensional electrical circuit simulation carried out in a different software could reproduce the frequency response, it was not able to perform the transient simulation due to 'noncausality' errors arising from the limitation of its internal inverse-Laplace-transform algorithms.

Using a shape optimization technique with the COMSOL software, Parler was able to calculate the correct transient solution for a customer. He began with a single cylindrical, electrolyte-filled capacitive pore, applied a known excitation at the opening, and used the sparse nonlinear optimizer solver (SNOPT) available in the software to find the solution to his nonlinear optimization problem where the shape of the axisymmetric pore wall needed to be varied until the experimental impedance data was fitted.

The resulting geometry (Figure 4) demonstrated that the software could accurately reproduce the time-dependent pulse-current response that was measured experimentally, allowing further design work based on a validated mathematical model.

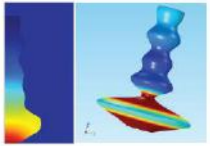


FIGURE 4. An alternative approach to capturing the electrical behavior of the coaxial microstructure of the dielectric material is to use shape-optimization techniques. Optimized microstructure is shown.

> "Using COMSOL Multiphysics® and its Application Builder I can create high fidelity multiphysics models and build apps based on them, which allows my colleagues in other departments to test different configurations and pick the best design."
> — SAM PARLER, RESEARCH DIRECTOR, CORNELL DUBILIER

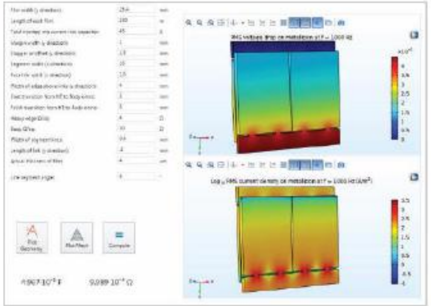


FIGURE 5. A design app for a power film capacitor used to determine capacitance and resistance.

COMSOL

Thank you for your Attention!