BETA SIMULATION SOLUTIONS

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White paper

Simulation enabling technologies

Power Electronics pre- & post-processing with BETA CAE Systems tools

Power electronics in traction inverters are crucial to the automotive industry's shift toward zero emissions. Their increased efficiency and reduced size improve electric vehicle range but generate significant heat. Efficient cooling with heatsinks and Conjugate Heat Transfer (CHT) modeling ensures thermal regulation and performance.
The solutions offered by BETA CAE Systems empower engineers to successfully model and handle CHT cases.

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Power electronics drive the zero-emission transformation

Power electronics within inverters play a key role in the automotive industry's transformation towards the zero-emission goal. By increasing their efficiency and reducing their size, they offer a higher range for battery electric vehicles and more packaging options. However, the downside of these design changes in power electronics results in a considerable amount of heat, which needs to be continuously dissipated to guarantee a hassle-free propulsion system. Therefore, efficient power electronics cooling requires heatsinks to dissipate the heat to a continuously flowing fluid.

The power module (Figure 1) is in contact with at least one heatsink, which is responsible for keeping semiconductors within their thermal requirements limits, while a tiny fraction of the heat is dissipated to the air via natural convection. All these phenomena could be accurately simulated by utilizing the capabilities of Conjugate Heat Transfer (CHT) modelling, a discipline of Computational Fluid Dynamics (CFD).

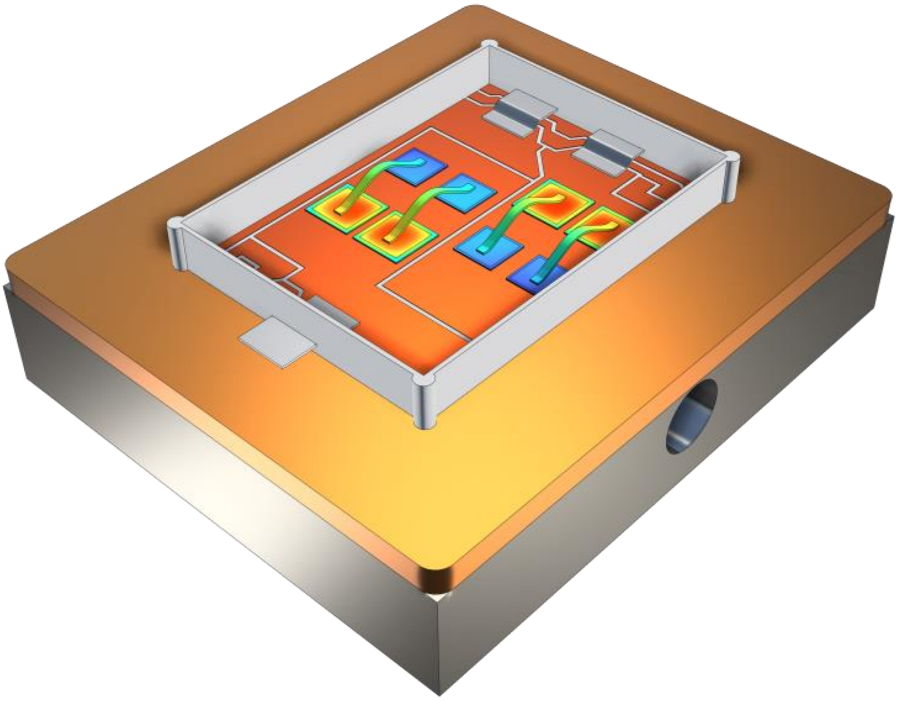

Figure 1: Power module, single phase, laying on top of a heatsink

The presence of both fluids and solids in a simulation scenario requires valid interfaces which efficiently transfer the heat fluxes across the different domains. Even if it is challenging, the generation of conformal interfaces is suggested since it ensures both contact existence and node-to-node matching (Figure 2), minimizing numerical errors. Furthermore, the accurate domain discretization with effective and robust mesh generators enhances further the simulation stability, speed, and fidelity.

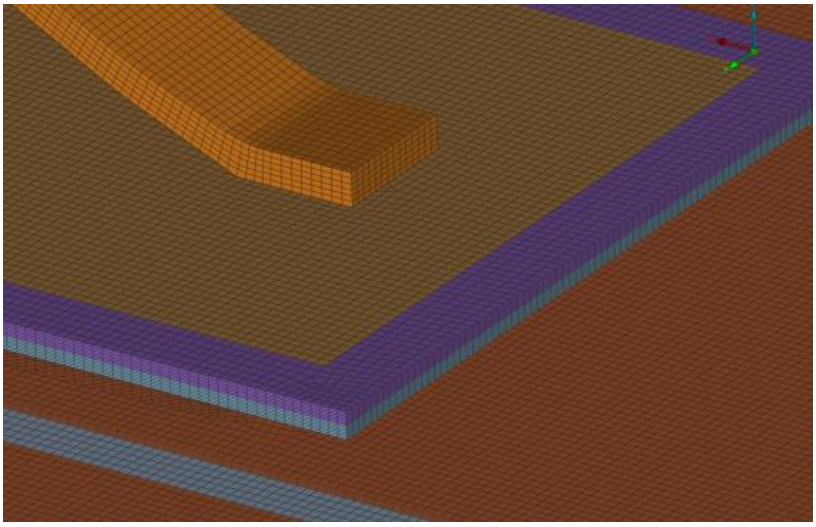

Figure 2: Ribbon, IGBT die and DCB conformally connected

BETA CAE Systems, with its advanced preprocessor ANSA, enables engineers to easily define contacts between different parts and domains, which results in the desired conformal interfaces. Additionally, the continuous development of versatile mesh generation algorithms has led to the creation of a powerful new mesh generator for thin solids and narrow fluid passages, features that are commonly found within a traction inverter. Furthermore, engineers can benefit from the legacy mesh algorithms, such as HexaInterior for accelerating the numerical solution.

Model set up

The preprocessing is necessary to ensure that the geometry is watertight and meets the requirements for adequate meshing. The heatsink is placed on top of the cooling bed which may yield areas with high proximity. Those areas can affect the quality and coverage of boundary layers. These areas can be handled and automatically manipulated in ANSA so that the boundary layers are properly generated, as shown in Figure 3.

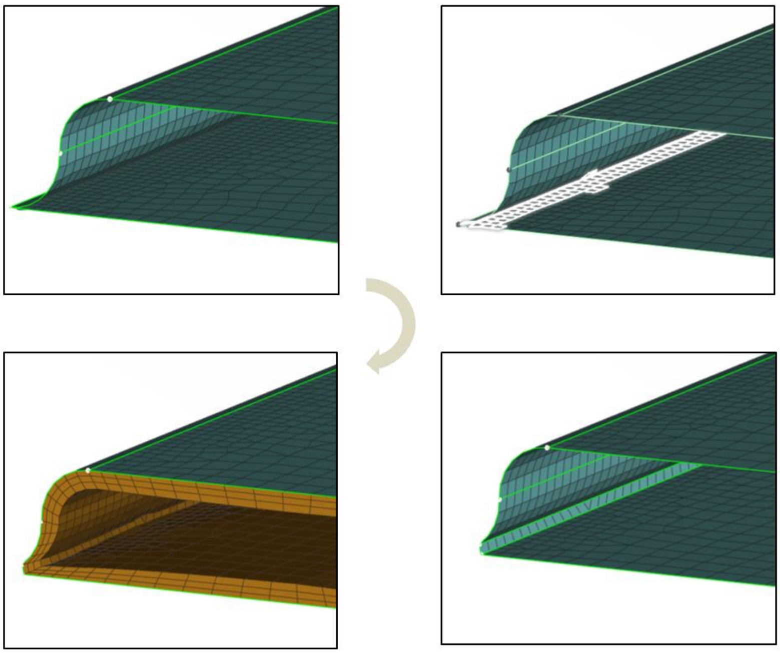

Figure 3: Identification of the concave area and auto-fix

Once those areas are identified, the different regions of solids and fluids should be conformally connected before applying the surface mesh. ANSA provides an advanced tool, the Flanges Compatible, which can automatically identify parts in proximity, and based on a user defined threshold, the connection of the regions is achieved (Figure 4). It's an intuitive and effortless function, which ensures that different regions are in contact, and a conformal interface will be generated later in the process.

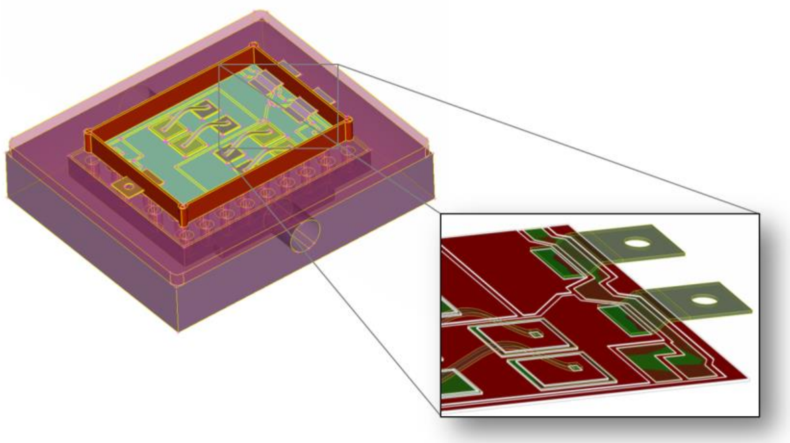

Figure 4: Flanges Compatible identifies the sides of parts in contact and highlights them with red and green colors.

Before applying the surface mesh to the regions, it is important to detect and define a dedicated element length for convex and concave areas, as well as regions in close proximity, such as the space between the heat pins and the cooling bed (Figure 5). The surface element length is locally refined in these areas. These features and proximities can be easily identified using the Feature Manager, an integrated tool in ANSA that quickly identifies and illustrates the different features, allowing the user to apply specific rules to them.

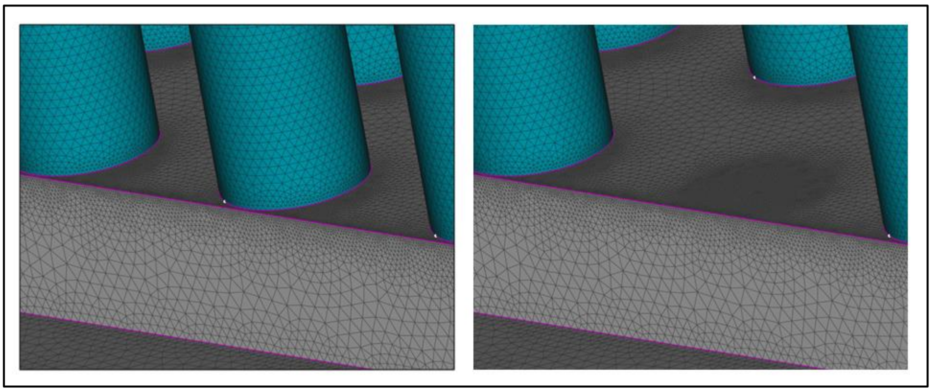

Figure 5: Feature recognition identifies sharp edges (marked in purple
Proximity refinement is applied under the heat pin.

Volume mesh for solids and fluids

In CHT modeling, the fluid and solid domains coexist (Figure 6). The fluid domains can be further divided into several regions, such as air and coolant. A similar approach is applied to the solid domains, which are divided into different regions based on material and boundary condition properties. Furthermore, all regions are connected node-to-node, showcasing a powerful capability of ANSA.

In the simplified power module, the bulk solids and the air are meshed using the Hexa Interior algorithm (Figure 6), a multi thread algorithm which creates hexahedral elements in the bulk volume and uses tetrahedral or polyhedral elements near the boundaries. The main advantage of this type of mesh is the control of the hexahedral element in the bulk volume, resulting in accurate domain discretization with low cell count.

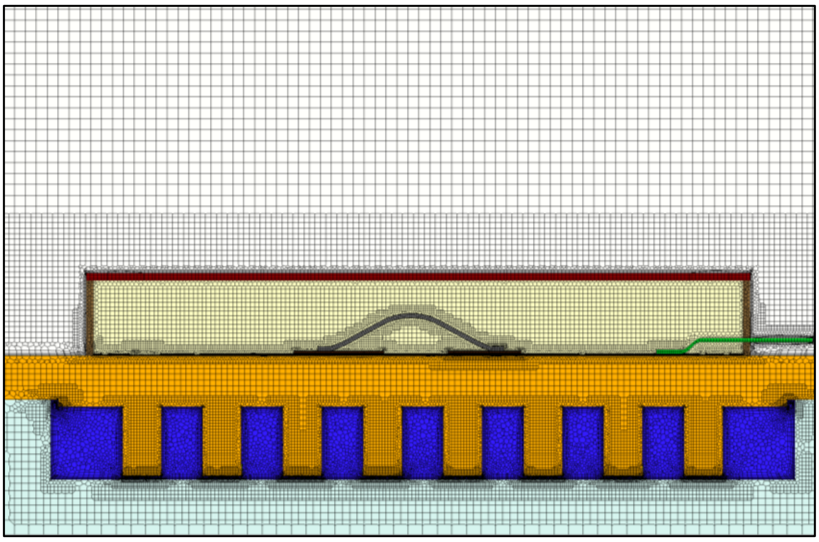

Figure 6: The white areas represent air, the blue areas represent coolant, and the remaining regions are solids.

The thin solids are meshed automatically by using the powerful Thin Mesh algorithm, which creates a structured-like mesh in thin areas by generating hexas or prisms, depending on the surface mesh type.

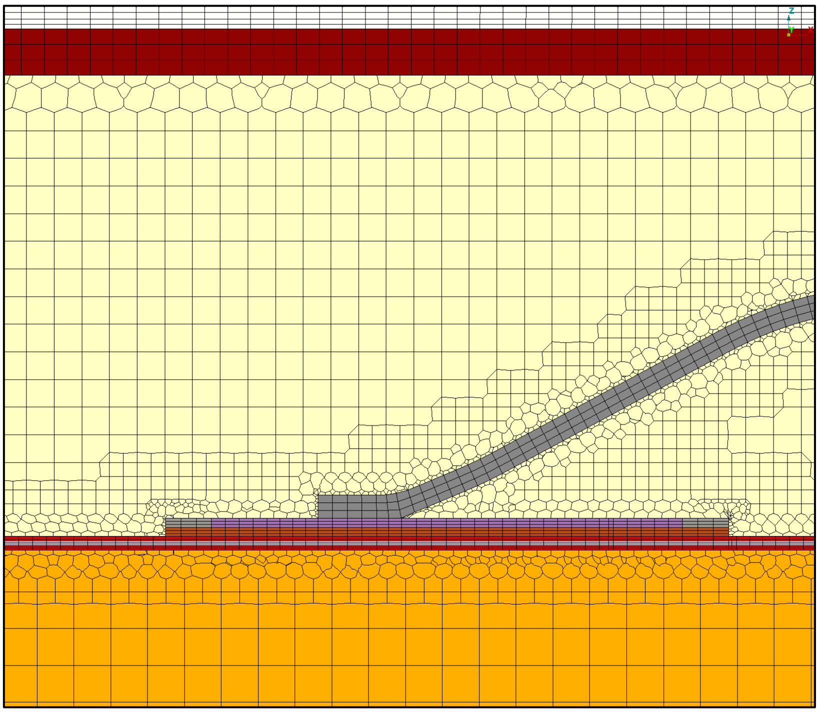

Figure 7: Thin mesh is applied to the ribbon, IGBT dies, and DBC.

The polyhedral mesh is well suited for complex geometries and flow paths (Figure 8). Even if the current flow path is not complex, the use of polyhedral meshes is demonstrated since, in a realistic inverter case, there is geometrical complexity before, after, or even within the heatsink. The greatest advantage of the polyhedral mesh is the presence of many faces per cell element which results in better gradient capturing and solver stability.

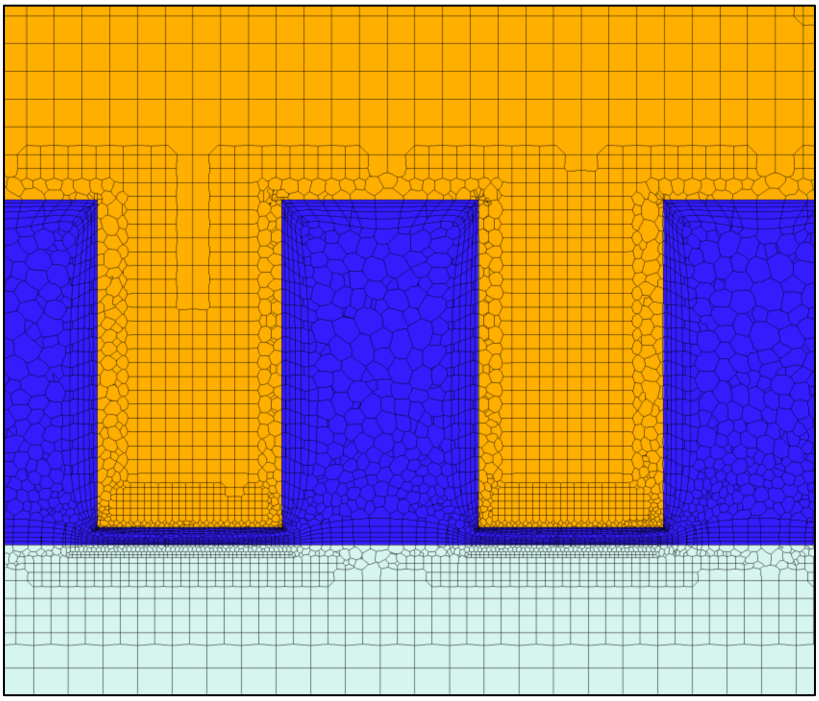

Figure 8: Polyhedral cell elements are used in the coolant region.

The natural convection phenomena occurring in the air domain are driven by the buoyancy effect and the density difference between cold and hot air. While most of the heat is dissipated to the coolant, a small fraction of it is also dissipated to the air. The airflow is predominantly directional in the Z-axis (Figure 9), making a hexahedral dominant mesh, such as Hexa Interior mesh in ANSA, a relevant choice.

Hexa Interior combines the advantages of hexahedral elements with the flexibility of polyhedral or tetrahedral elements close to surface in an automated manner. Engineers can benefit from the Hexa Interior mesh in the air domain since it reduces the solution time significantly, without sacrificing fidelity.

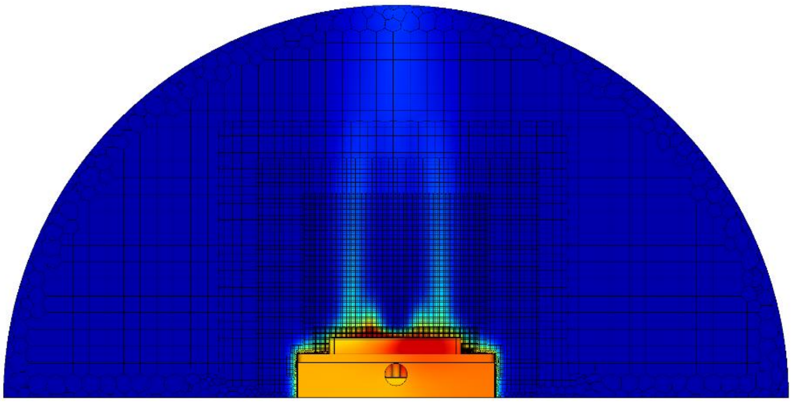

Figure 8: The temperature contour is displayed on the air and solid regions.
Hot air rises due to buoyancy-driven flow.

BETA CAE Systems, with its versatile ANSA preprocessor and META postprocessor, enables engineers to tackle complex and time-consuming tasks in an automated and consistent manner, while easily assessing simulation results via the dynamic preprocessor. Thermal modeling of complex electric drive components, such as traction motors, inverters, and high-voltage batteries, has never been easier.

BETA CAE Systems is a leading provider of engineering simulation solutions, dedicated to developing advanced software and delivering exceptional services. For over 30 years, we have helped industry leaders across sectors tackle complex challenges.
BETA CAE Systems is now part of Cadence Design Systems.
For more information on BETA, our products, and our services, visit www.beta-cae.com.

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