Passive Cooling of Power Electronics: Heat in the Box

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Abstract

Power Electronics is often employed in vehicles in a more or less closed environment and without a suitable cooling loop or device. Thus, opportunities to get rid of power losses are very limited. The project we are reporting about dealt with a 5kVA-DC-AC-converter for applications in forklifts. A successful design (power MOS chip, circuit, electromechanical construction, cooling, and certification with world class 96% of overall energy efficiency) has been made from scratch in a concurrent engineering way within 2 years by a group of some 10 engineers. Simulation was crucial to evaluate different approaches in advance. The project has been supported by the Fraunhofer-Gesellschaft and local authorities [1]. COMSOL has been heavily used within the project for (1) estimating the size of the heat sinks; (2) improving thermal insulation of power devices from the control unit; (3) modeling of heat sinks under extreme thermal conditions; (4) optimizing the placement of power chips on the substrate; (5) forecast of the life time of solder bumps. Structures to be resolved within one simulation setup range from 1 micron to 1 meter in 3D with more than 200 essential construction details (Figure 1). Zth-curves were extracted to enable coupled lumped element circuit simulation (Figure 2). Different forklift driving scenarios had to be applied to make sure that no overheating will take place under any practical circumstances (Figure 3). Furthermore, in the context of heat sinks in closed boxes free convection problems had to be solved and turned out to be a basic research topic of unexpected complexity bringing COMSOL close to its limits. It turned out that heat transport by mass flow will never come to a stationary solution within closed boxes due to internal turbulences. There are no mathematical proofs for unique solutions. However, the engineering problem was urgent. Several simulation experiments were made to show stability, reproducibility and meaningfulness of the results gained (Figure 4). Finally, a 2D model problem called "heat in the box" was defined to get rid of too many parameters. Engineering problems had and some still have to be solved like: Where is the practical limit between closed box and open space in order to choose suitable heat sinks? Is there a quasi-stationary solution after a long time and what does this mean for maximum temperature at the heat source? Do the turbulences really influence the overall behavior? A lot of questions for the model problem are still open as well, as the maybe-solutions turn out to be very diverse (and even of some beauty) depending on the position of the heat source and the size of the surrounding box or other details. Numerous videos can be shown to illustrate this "zoo". We have just started to sort them into boxes of patterns, try to figure out their practical importance and find simplified models.

Reference

[1] www.klsh.de.

Figures used in the abstract

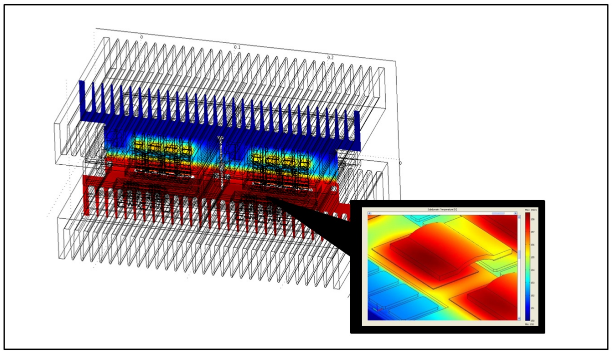

Figure 1: DC-AC-converter simulation model with details inserted.

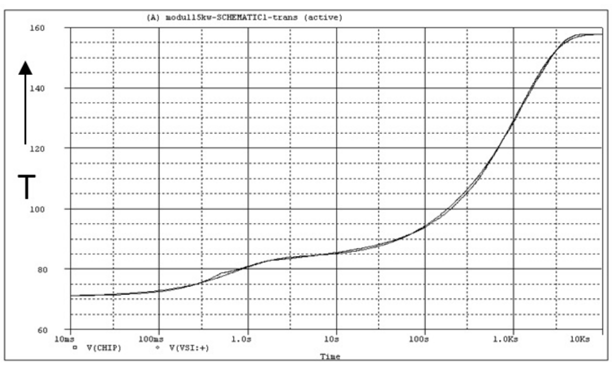

Figure 2: Zth-curves extracted and used in electrical network simulation.

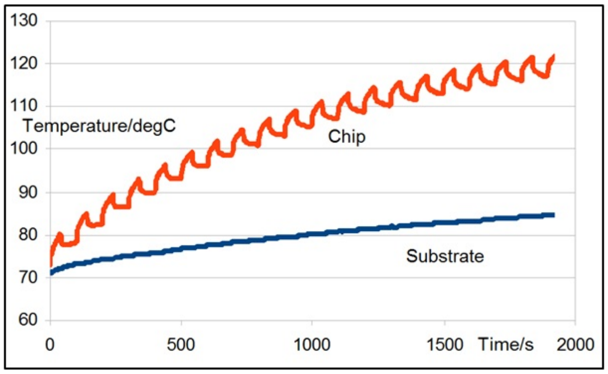

Figure 3: Dynamical behavior of converter in forklift driving scenario.

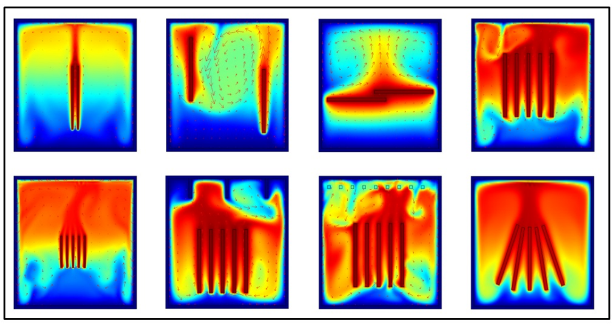

Figure 4: Some simulation experiments to prove plausibility of results for heat-in-the-box problem.