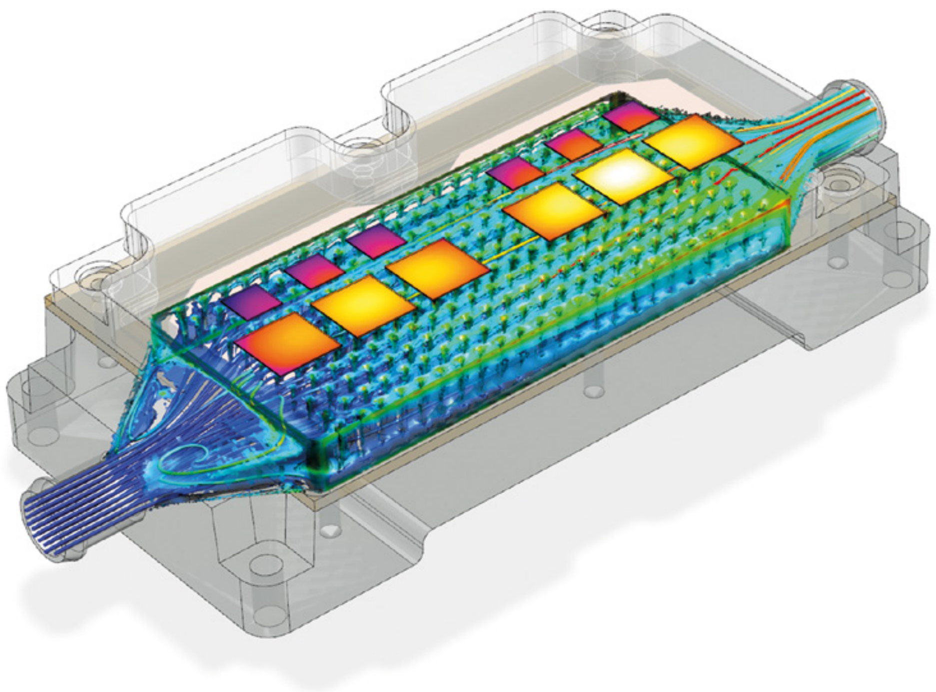
How to....

Optimize an IGBT Cold Plate

By Anton Saratov, Application Engineer, DATADVANCE and Mike Gruetzmacher, Technical Marketing Engineer, Mentor, a Siemens Business

Insulated Gate Bipolar Transistor (IGBT) modules, are used in a wide range of industries. In electronics, IGBTs are used for Variable-Frequency Drives (VFD), for electric vehicle induction furnaces, in wind power applications and also in refrigerators, to give just a few examples.

An increase of the cooling fluid velocity increases the heat transfer coefficient. This leads to a higher heat flow rate, which leads to lower IGBT chip temperatures. However, at the same time, higher velocities also cause an increased pressure drop. The heat exchanging surface area, in this case, the cold plate surface, can be modified by pins or fins in several variants and arrangements (Figure 1). A shifted arrangement for example, usually leads to a higher heat flow rate compared to an aligned arrangement, but it leads to an increasing pressure drop, which increases the energy consumption for pumps.



The factors Size, Weight, Power, and Cost (SWaP-C) play an important role for the product competitiveness. Figures 2a and 2b show an overview of the example model.

Parametric Studies

Parametric studies in FloEFD can lead to the following results:

Figure 3 depicts the results of five variants. On the x-axis is the pressure drop, the y-axis the maximum IGBT temperature and the bubble size illustrates the weight. The larger the bubble the heavier the cold plate. The smooth cold plate has the lowest pressure drop while also being the lightest in size, but the IGBT temperatures are the highest of the group. The cold plate with the shifted fins ensures the lowest temperatures but it results in the highest pressure drop and is the heaviest variant.

The operating curve in Figure 4 shows the results of a parametric study in which the volume flow rate is varied from 0.1 to 5 liters per minute.

DoE Study in FloEFD

A DoE study can be conducted in FloEFD with the settings shown in Figure 7:

The number of experiments is defined automatically according to the previously defined variations and simulated. The results and the response surface are shown in Figure 8. The response surface illustrates the CAD volume of the cold plate, the maximum IGBT temperatures and the pressure drop, with the varied parameters on the x and y axis as well as the corresponding result parameter on the z-axis.

Additional objective functions for the “Find Optimum” function are defined. For this example a maximum pressure drop and a maximum IGBT temperature are applied, which might be defined by a customer’s project specifications (Figure 9).

The optimal design point is now searched on the response surfaces and created as an

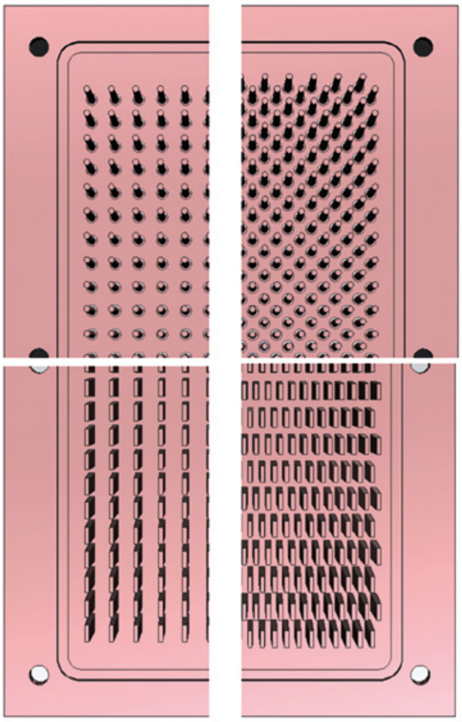


Figure 1. Various versions of the cold plate

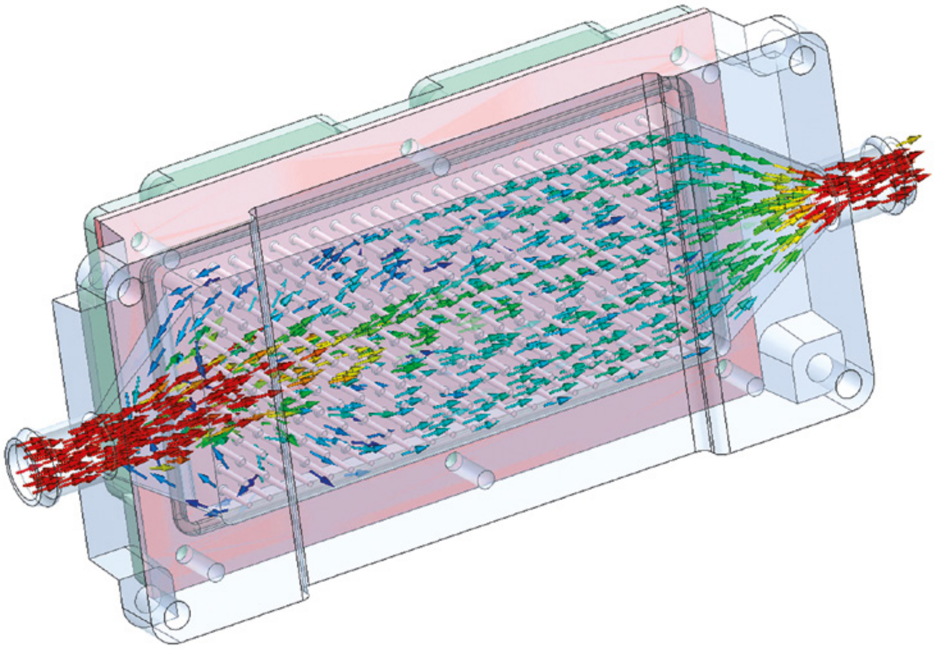


Figure 2a. Overview

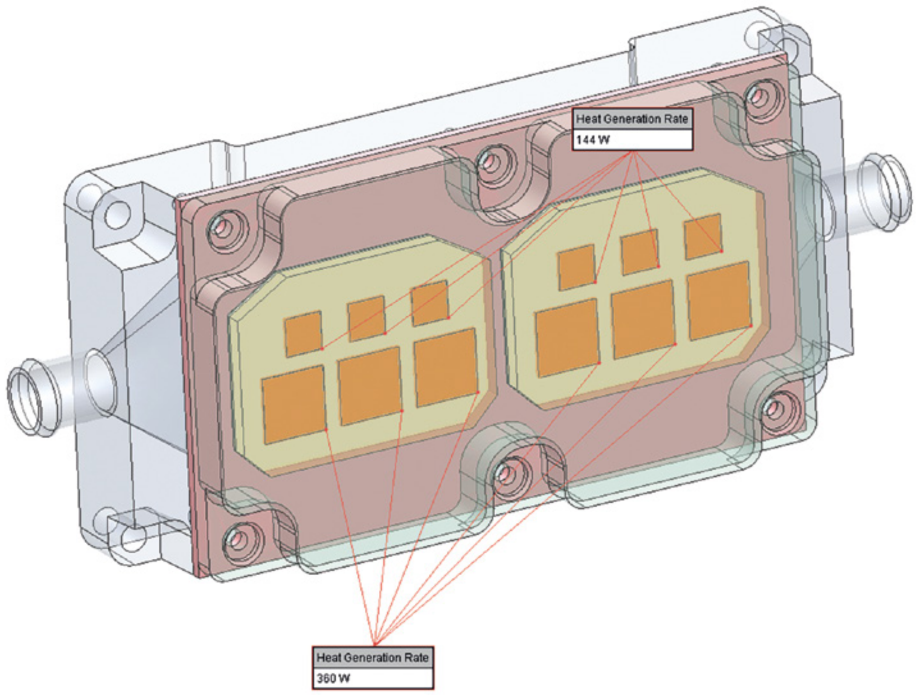


Figure 2b. Overview

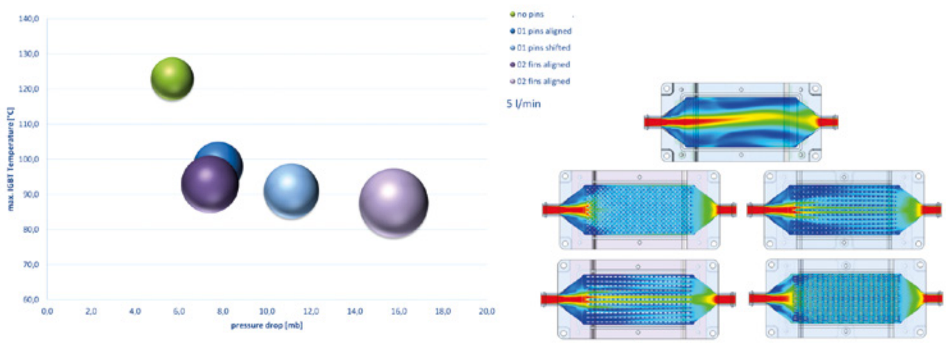


Figure 3. Comparison of the five variants

optimum design point in this scenario. Figure 10 shows the optimized cold plate variant resulting from the DOE.

pSeven and FloEFD

Built-in tools for design exploration like Parametric Study are very useful for a better understanding of the model and preliminary optimization studies. However, in many cases, the problem is too complicated to be solved with such tools and that is where external tools come to play.

pSeven by DATADVANCE is such a platform for the automation of the simulation process and design space exploration. A graphical interface allows users to create workflows with different CAE tools and sophisticated optimization algorithms enable efficient solving times for high-dimensional multi-objective constrained problems. Additional tools for dependencies and correlation studies and approximation building can also be useful for a deeper understanding of the model.

How to control FloEFD

To perform the optimization study in an external tool, one needs a way to control the FloEFD project. There are two possible solutions – a dedicated Parametric Study mode, and via FloEFD API.

Parametric Study in FloEFD has an External Optimizer mode that allows the user to pass the project parameters in xml files and run a simulation from a command line.

Once the parametric study is created, an input xml file needs to be prepared, then placed in the proper place in FloEFD project, run a starter from command line, wait until the simulation ends and then grab the output file and extract results.

API interface is another option. It allows users to change the project inputs and boundary conditions, simulation settings, rebuild and run simulations and retrieve results.

pSeven has a special direct integration block for FloEFD versions for major CAD systems. It combines the flexibility of the API-based approach and an easy-to-use graphical interface. Once the model is specified, the user can select geometrical and simulation inputs and outputs from a dependencies tree as variables for optimization or other studies.

FloEFD block can be connected to an Optimizer or DoE block to act as a simulation driver in the study.

Two-objective optimization problems are considered in order to minimize the temperature of electronic modules and decrease the pressure drop in the system. Moreover, a maximal temperature difference is constrained by 10% to provide equal aging of the electronics.

Six geometry parameters are varied: pin elliptic cross section widths, the distance in a row and between rows, shift between rows and conic angle of the pins. Optimizer settings are shown in Figure 15.

pSeven has SmartSelection heuristics to select the proper algorithm and its settings from a long list.

In this case, a surrogate-based optimization algorithm is used. It allows for setting an explicit budget of evaluations. Number of model runs is set to 120 for this problem.

The result of two-objective optimization is Pareto-frontier. The optimization history in drag versus maximum temperature axis is shown in Figure 16.

Pareto-frontier is useful for trade-off studies but the final decision as to which of the configurations is best is up to the expert.

Automated simulation also allows the user to perform DoE study and create

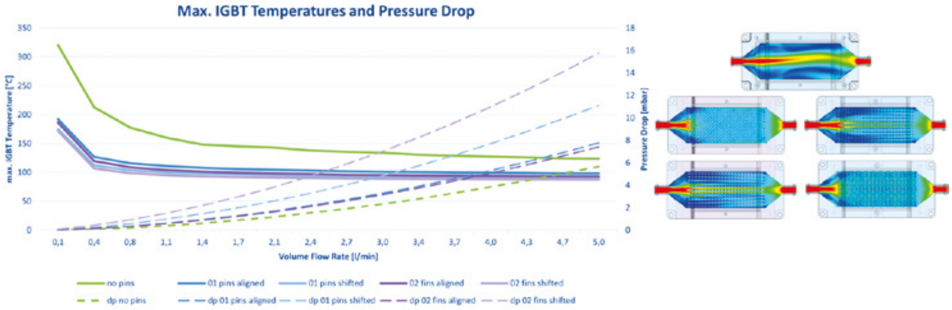


Figure 4. Operating curve

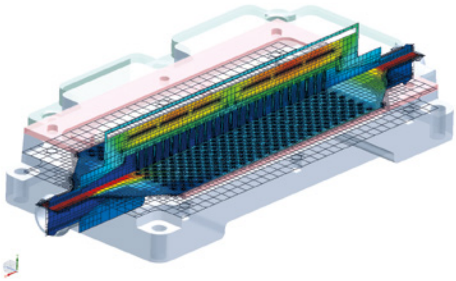


Figure 5. FloEFD simulation

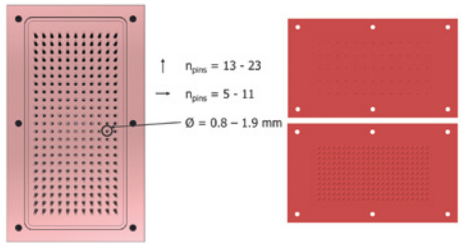


Figure 6. Variation parameters and limits

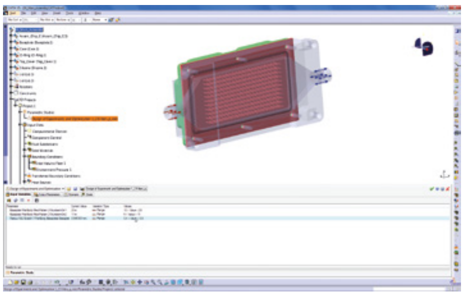


Figure 7. Settings DoE study

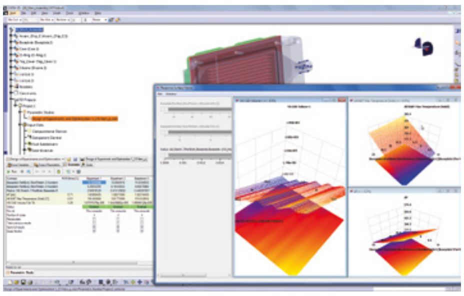


Figure 8. Results and response surface

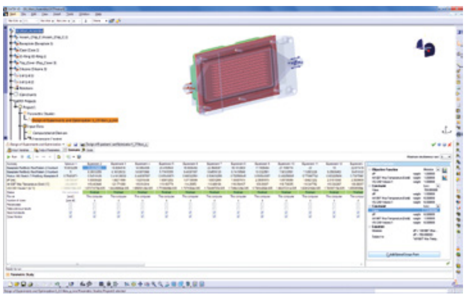


Figure 9. Find optimum function

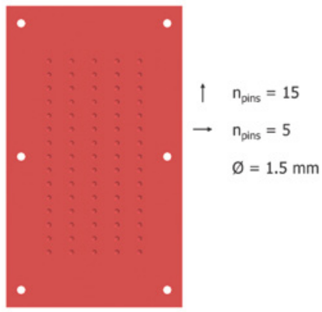


Figure 10. Optimized variant

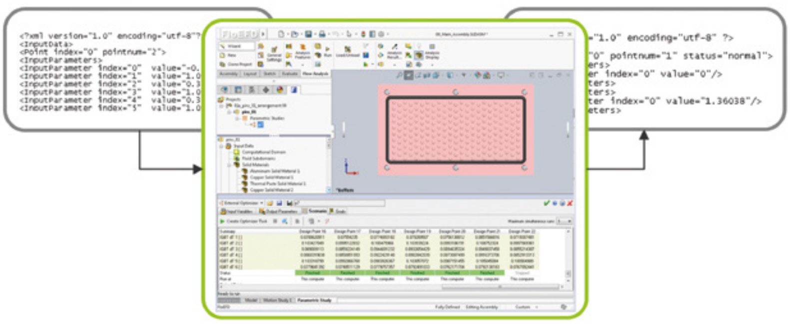


Figure 11. Parametric Study run with xml files

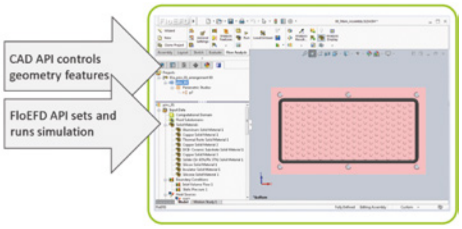


Figure 12. Simulation run by API

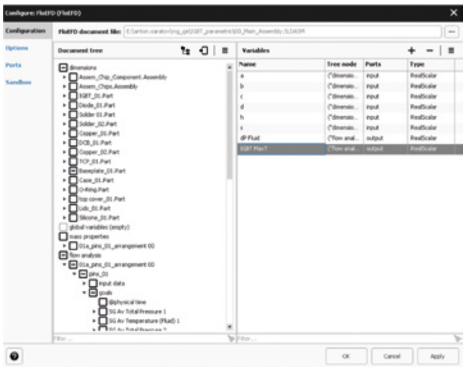


Figure 13. pSeven direct integration block for FloEFD

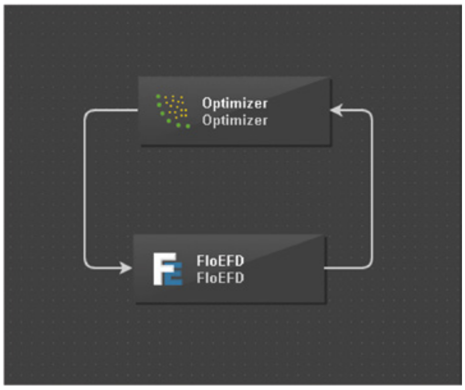


Figure 14. FloEFD block connected to Optimizer

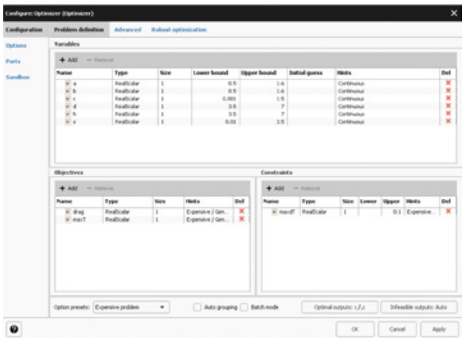


Figure 15. Optimizer settings

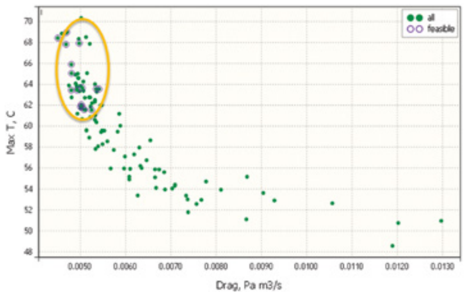


Figure 16. Optimization history drag versus maximum temperature

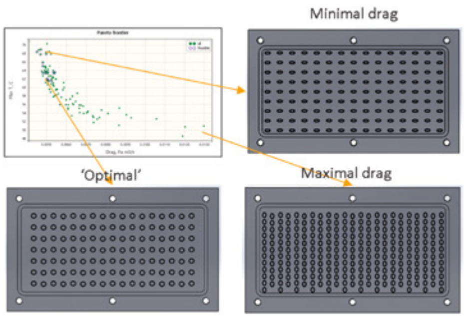


Figure 17. Optimization solution

approximation models of the responses. They can be further used in system level analysis or for solving optimization problem at almost no cost.

To create the approximation model for an IGBT cold plate performance, a 150 points sample was generated with optimal Latin hypercube design of experiment plan. The model was built with the Gaussian Processes (GP) algorithm. It was automatically selected by SmartSelection heuristics. GP algorithm is stable to noise and by nature, provides information about errors at a given point.

As an example, it is possible to determine geometry with the minimal drag for “normal” duty and limited maximum temperature in “burn” mode (+10% heat rate). Moreover, this optimization problem can be solved for different values of the temperature limit.

The result is on the plot (Figure 17) in temperature limit versus drag axis. Despite the significant scatter due to approximation inaccuracies, the general slope of dependency can be seen. Note that approximation models can be exported to executable, Matlab function, FMI unit or Excel.

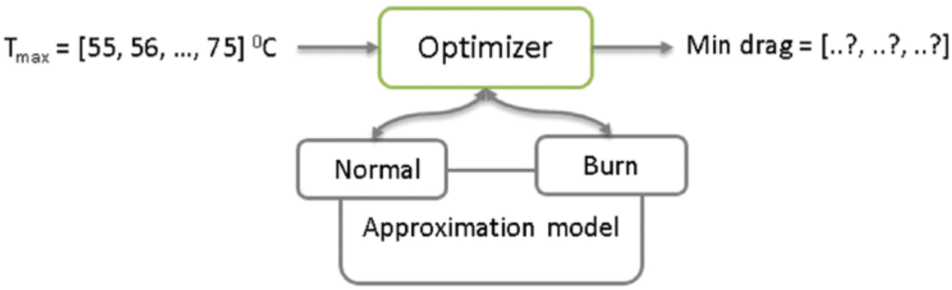


Figure 18. Problem variations

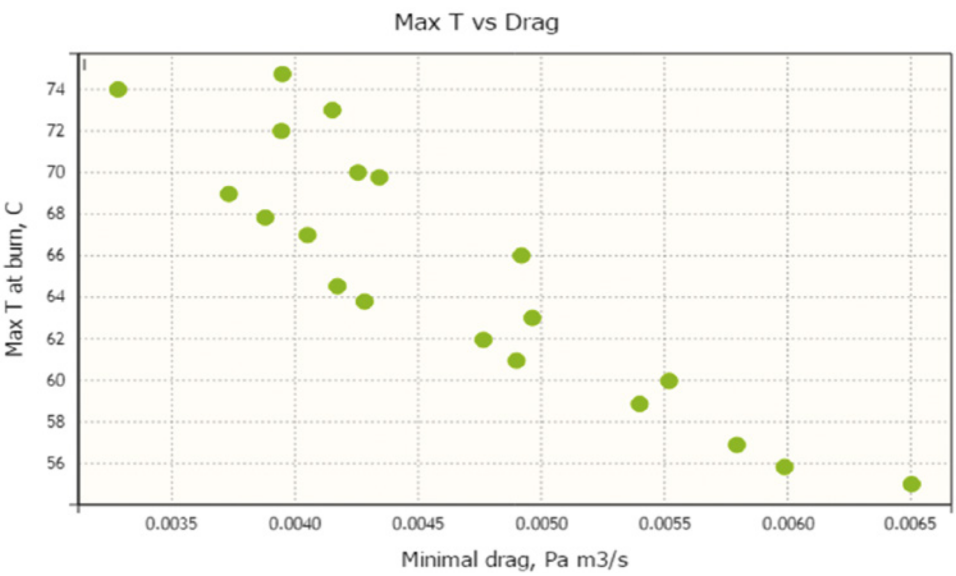


Figure 19. Results for temperature limit versus drag