TAKE COMMAND OF THERMAL OPTIMIZATION DURING PCB DESIGN

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As published in EETimes

EE Times

Mentor Graphics®

MECHANICAL ANALYSIS

WHITEPAPER

Computational fluid dynamics software tools can be useful in considering the effect on a printed circuit board of such things as package selection, board layout and structure as well as enclosure design.

In the traditional industries in which computational fluid dynamics (CFD) has been used to investigate product performance, such as aerospace, nuclear, and automotive, design times are relatively long, and safety and reliability have been prioritized over cost and performance.

Thermal design of electronics in these industries is also influenced by these issues. The focus is more on reducing component temperatures by some safety margin to well below their rated value to increase their lifetime. Effort is expended on building redundancy into the cooling system, so that if a fan fails, the system can still operate well within specification and that the fan can be replaced while the system is in operation.

In high-volume consumer electronics, cost and performance are the key drivers. The pace of change is such that design times are compressed to just a few months from conceptual design to production. Minimizing product unit cost is a key part of the design activity.

This translates into a need to explore the design space to ensure the most cost-effective cooling solution is chosen by considering the effect of all aspects of the design such as package selection, PCB layout, board structure, and enclosure design including fan size, location, and vent positioning for example.

This unique and overriding requirement of rapid analysis and design space exploration has given rise to the development of electronics-cooling?specific CFD software from the late 1980s to the present day. These solutions leverage different CFD technology to that of traditional body-fitted CFD to deliver a first result faster, as well as much faster turnaround for subsequent design iterations.

With the latest CFD technology, modifications to the thermal model, including geometric changes, meshing, solution, and result post-processing can be automated, freeing up valuable engineering time for higher value activities. This technology can be used to optimize functionality by allowing engineers to run multiple scenarios early in the design process.

For example, the command center in the CFD 3D simulation software enables engineers to run a design of experiment (DOE). They can run different variables at the same time to run many simulations, and the software will mathematically figure out the best distribution of input variables to consider, greatly reducing the number of required simulations.

Response surface optimization (RSO) uses the results of the DOE to mathematically estimate the optimum values of input variables that minimize a cost function, such as junction temperature of a component. In addition to providing the optimal design inputs, RSO provides information on the sensitivity of the design inputs to the design goal, allowing the engineer to focus only on the parameters that effect the thermal design.

HEATSINK OPTIMIZATION FOR CPCI CARD

The following is an example of how to construct and analyze a CFD model of a cPCI card with two components that have heatsinks. CompactPCI is a very high-performance industrial bus based on the standard PCI electrical specification in rugged 3U or 6U Eurocard packaging. The goal is to optimize the heatsinks for components with reference designators U7 (upstream) and U8 (downstream) subject to the following three separate cost functions:

- Case 1: Minimize the mass of heatsink, affects their cost, smaller and lighter are better.
- Case 2: How low can component temperatures go?
- Case 3: How can differences between components minimized because electrical function works better if operating at same temperature?

We will simulate the PCB with the following environmental parameters. The orientation with respect to flow is shown in Figure 1.

- Elevation: Sea level
- Ambient Temperature: 55 °C
- Upstream Velocity: 400 ft/min
- Slot Pitch: 0.8 in

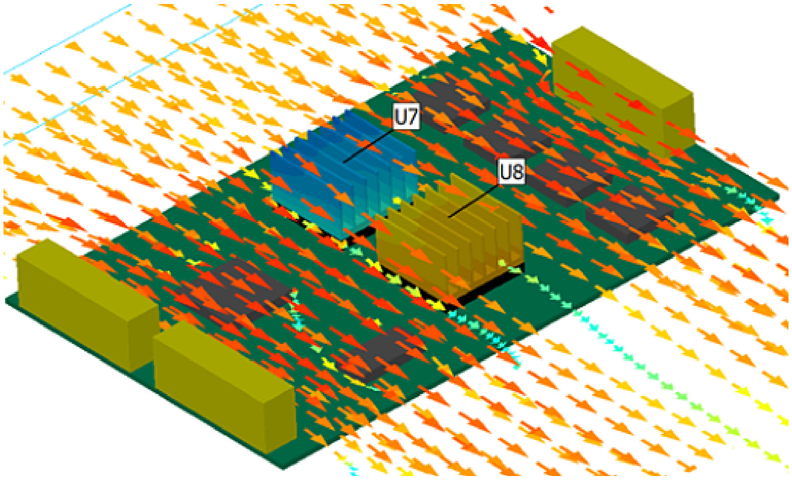


Figure 1

With a board layout as shown in Figure 2, the PCB is defined as:

- Stack Up: 2S2P
- PCB Dimensions: 100 mm x 160 mm
- PCB Thickness: 1.6 mm
- Total Power: 22.5 W

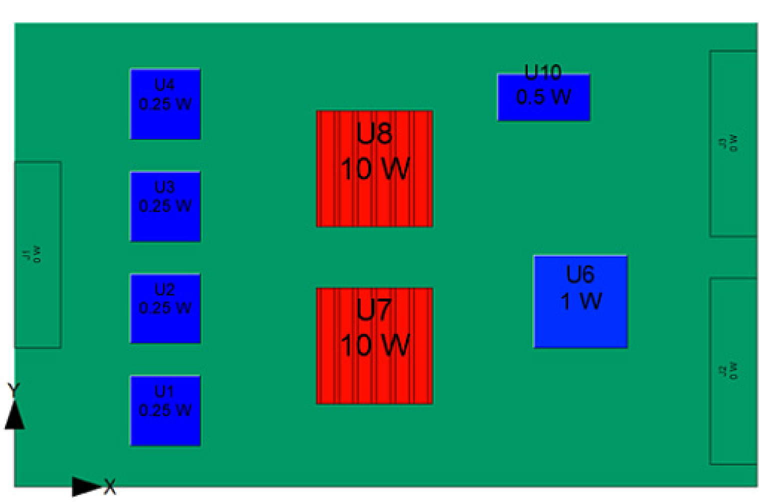


Figure 2

U7 (upstream) and U8 (downstream) are modeled as 2R compact thermal models, and the other components are modeled as lumped blocks with distributed heat. The specific parameters relevant to the cooling design are:

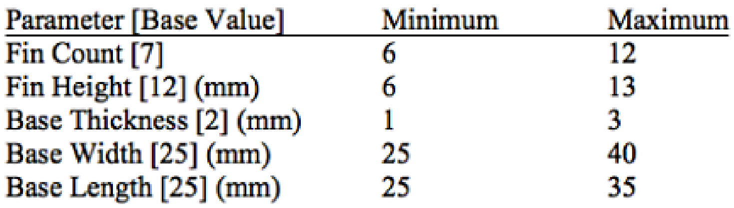
- RJC: 0.5 °C/W
- RJB: 20 °C/W
- TIM: 0.5 °Cin2/W
- Heatsink material: 201 W/mK

For this cPCI card, we'll run through various scenarios to analyze the following cases:

- Case 1: Minimize the mass of U7 and U8 heatsinks, which are identical, to maintain U8 junction temperature at 100 °C.
- Case 2: Minimize U8 junction temperature. U7 and U8 heatsinks are identical.
- Case 3: Minimize the mass of U7 and U8 heatsinks, which are the same extrusion but with different fin lengths, which maintains U8 junction temperature at 100 °C. Additionally limit the difference in U7 and U8 junction temperatures to 1 °C.

DESIGN OF EXPERIMENTS

Before optimization, we'll use the Command Center design of experiments (DOE) option to create 50 simulation models to be analyzed with CFD. For this study, the following input parameters are used:



Parameter [Base Value]	Minimum	Maximum
Fin Count [7]	6	12
Fin Height [12] (mm)	6	13
Base Thickness [2] (mm)	1	3
Base Width [25] (mm)	25	40
Base Length [25] (mm)	25	35

Additional constraints used during the DOE include:

1. Input constraint limiting the maximum height of the heatsink to 15.5 mm (Cases 1-3).
2. Linear constraints to ensure U7 and U8 heatsinks remain centered on respective components as heatsink base dimensions change (Cases 1-3).
3. Linear constraints to ensure all dimensional parameters of the U7 heatsink are identical to the U8 heatsink, that is, the same heat sink (Cases 1-2).
4. Linear constraints to ensure all dimensional parameters of the U7 heatsink except fin height are identical to the U8 heatsink, that is, the same extrusion (Case 3).

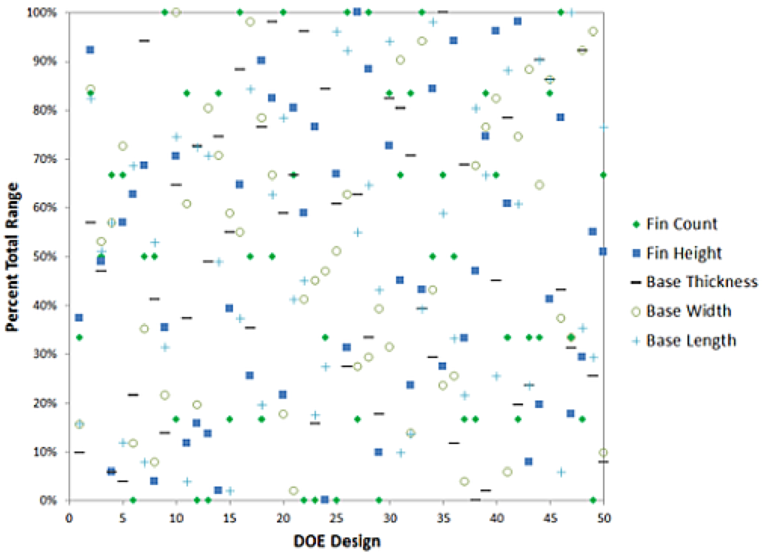


Figure 3

Figure 3 represents the distribution of input parameters over the design space for Cases 1 and 2. A separate DOE is performed for Case 3 where U8 and U7 fin heights are allowed to vary independently (Figure 4).

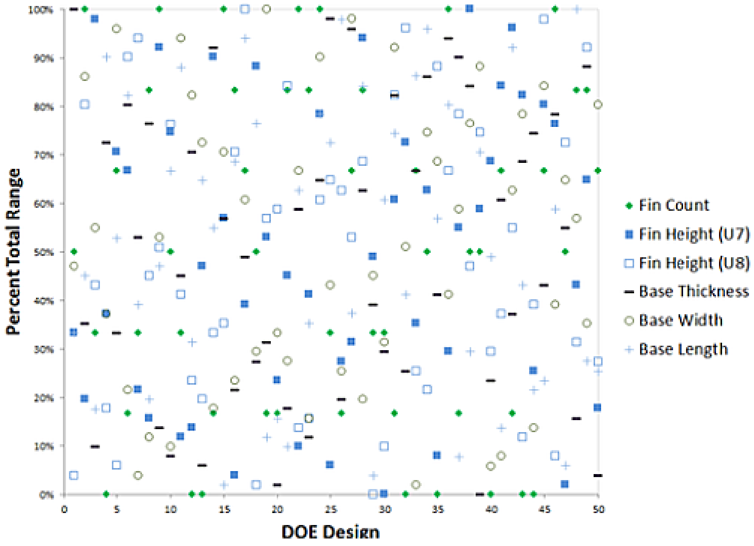


Figure 4

Downstream components will naturally run hotter than upstream components, which requires the fins to be taller to operate at the same temperature, and the program can be given a range to run simulations with independently varying fin heights. An input constraint example is where the base has to be a certain width and fin certain height. Output constraints also can be used, such as the output temperature has to be less than certain value.

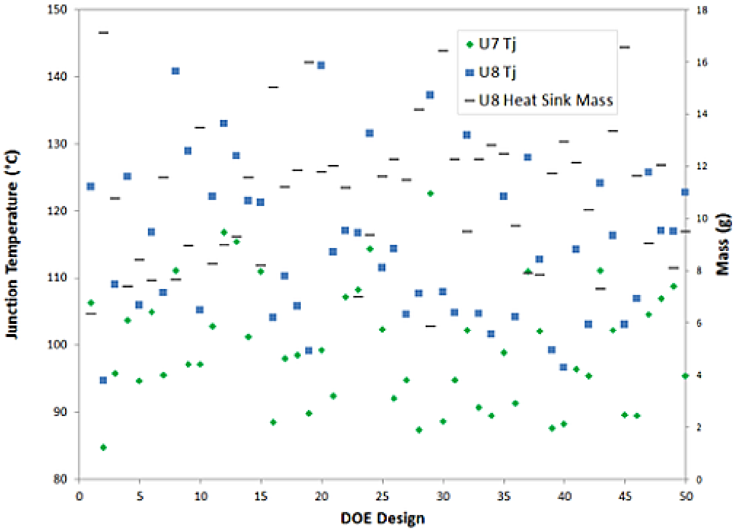


Figure 5

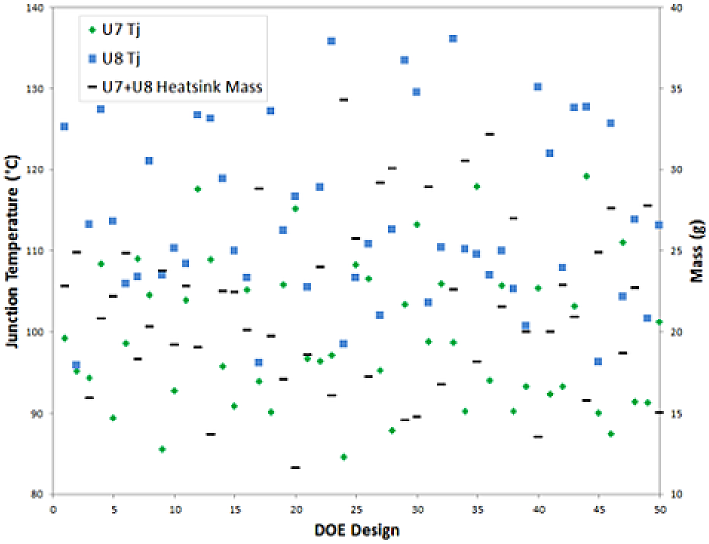


Figure 6

The results from the simulations are shown in Figures 5 and 6. From the results, it is impossible to determine what would be the optimal design but it does indicate the range of output ranges that are achievable. It takes approximately 30 minutes for the software to analyze the 50 designs using CFD.

The next step to fine-tuning our design is response surface optimization.

RESPONSE SURFACE OPTIMIZATION

For each of our 50 design cases analyzed in the DOE, a response surface optimization (RSO) is performed. The RSO fits a response surface to the data and mathematically predicts the optimum design. An additional 1-2 minutes is needed to perform the RSO. For this cPCI card, the following output constraints are used for each of the RSO optimizations:

- Case 1: Maximum allowed U8 junction temperature = 100 °C.
- Case 2: No output constraints applied.
- Case 3: Maximum allowed U8 junction temperature = 100 °C. Maximum junction temperature difference between U7 and U8 = 1 °C.

The following are results for each optimization case considered. Both the mathematically predicted optimum and the actual results from the CFD simulation are shown for comparison. Also included is the error in the RSO predicted optimum, which is part of the software's standard output. (Table 1)

	Design Parameter	Case 1	Case 2	Case 3
	U7 Fin Height (mm)	13	13	8.29
	U8 Fin Height (mm)	13	13	12.49
	Fin Count	8	11	10
	Base Thickness (mm)	1	2.5	1
	Base Width (mm)	40	40	35.12
	Base Length (mm)	25	31.55	25
	Results			
U7 T_J (°C)	RSO	96.5	85.2	101
	CFD	96.35	84.41	100.3
U8 T_J (°C)	RSO	100	92.77	100
	CFD	102.6	92.75	99.82
	RSO Error Estimate	(+/- 0.1%)	(+/- 1.7%)	(+/- 0.3%)

Table 1

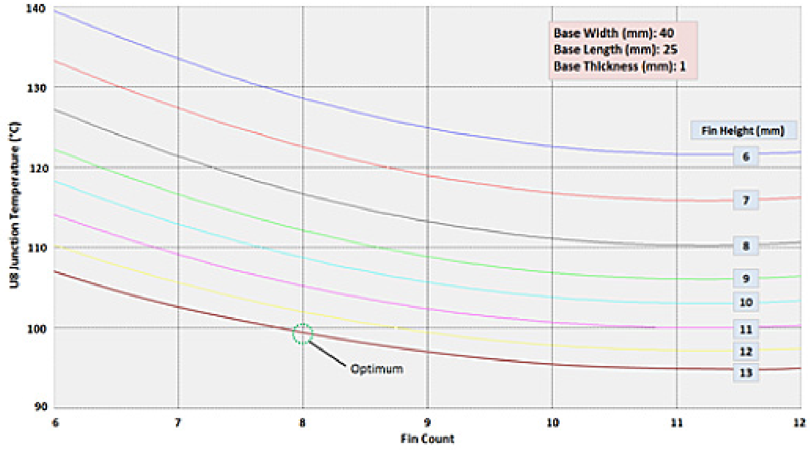


Figure 7

In addition to the predicted optimum design point, the RSO calculation produces 2D/2.5D and 3D plots. Plots from Case 1 are shown here as an example. Figure 7 shows U8 junction temperature vs. fin count for each fin height in a 2.5D plot, with all other parameters set to the RSO predicted optimal value.

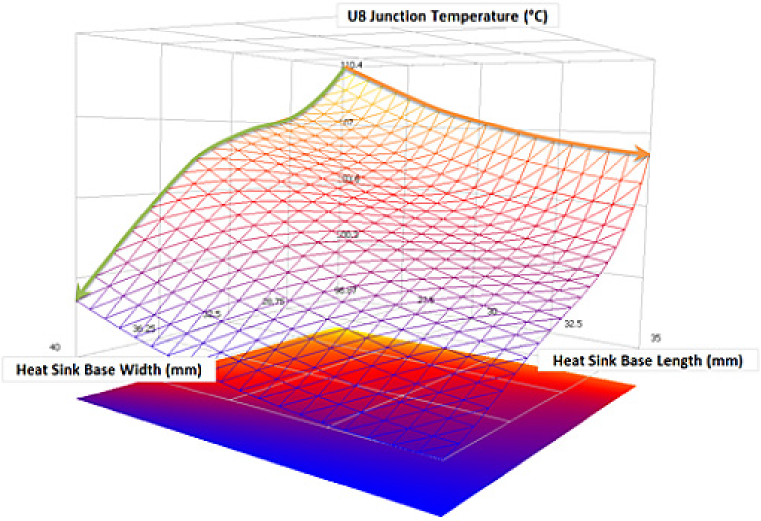


Figure 8

Figure 8 shows a 3D plot of U8 junction temperature vs. base length and base width. These plots are useful in understanding the sensitivity of the design to various inputs. In this example, we see that increasing the base length beyond 35 mm is much less effective as increasing the base width.

WHAT TO AVOID

In the results for this case study, the RSO predicted junction temperature for U8 was 100 °C, which was the value used in the output constraint; however, the CFD result showed the junction temperature to operate at 102.6°C. Further refinement through additional DOE simulations is recommended to satisfy this constraint. The RSO optimal base width Case 1 and Case 2 is 40 mm, which is the maximum value in the allowed range. Additional margin or an improved design might be possible if this base-width maximum size is increased. The RSO 2D/2.5D and 3D plots are essential in understanding the sensitivity of the thermal design to an individual input when allowing multiple changes to occur in any given simulation.

Essentially, this CFD optimization process lets us know which variables are important to design around and which ones are not. Using this latest technology, we only have to run CFD once, and then we can run many simulations with different variables. It also illustrates the reasons for making a particular design choice.

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