Comparison of thermal models

Comparison of thermal models

- 208-lead PQFP (Plastic Quad Flat Pack)
  - die size 10×10mm
  - heat dissipation 2W
- In a number of typical cooling environments
  - single bare package in natural convection
  - single package with heat-sink in natural convection
  - single bare package in forced convection at 2m/s
  - single bare package under impingement flow (jet exit velocity 1m/s)
  - package with adjacent components in forced convection at 2m/s

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In this brief case study we are looking at different thermal models developed for a 208-lead plastic quad flat pack with a significantly large silicon die 10mm x 10mm, and a power dissipation of 2W, at which level it will survive in natural convection, but it's on the borderline for use with a heat sink.

We are considering how different models work under a range of different but typical environments, including natural convection with and without a heat sink, and with forced convection. We will be looking at how the model behaves under what is referred to as "impingement" flow, where the airflow is directed onto the package, and also at the potential influence of adjacent components.

Comparison of thermal models

- 208-lead PQFP (Plastic Quad Flat Pack)
- In a number of typical cooling environments
- Simulated as:
  - Two-resistor model
  - Detailed model
  - DELPHI model
- Platform
  - 4-layer PCB with a size of 100×100 mm
- Ambient temperature
  - natural convection environments: 30°C
  - forced convection environments: 25°C

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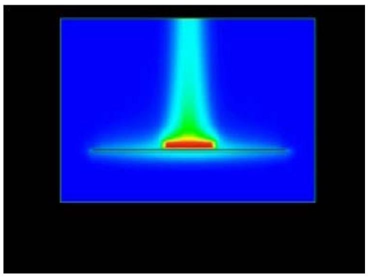
We have simulated these in three different ways, a two-resistor model, a detailed model and a DELPHI model, in order to examine the variation between them. The test platform was similar to a JEDEC standard test board, a four-layer PCB 100mm square and the tests were standardised in two ambient temperatures, 25°C for forced convection, and 30°C for the natural convection cases.

Two-resistor model in natural convection



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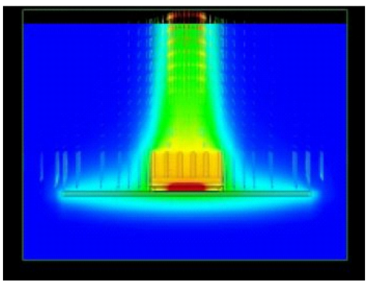
This is the first of five images from the simulation, showing a two-resistor model in natural convection. You can see that the model is just shown as a block, which reflects the fact that it really is a very simple model! However, it still shows the hot areas, and the plume of heat rising from the component.

Detailed model with heat sink in natural convection



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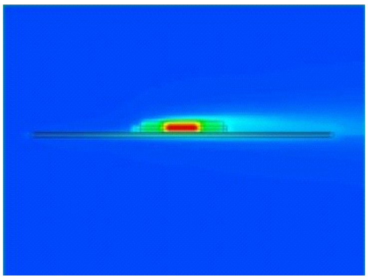
This is a detailed model in natural convection, but this time with a heat sink. The detailed model represents the device more accurately.

Comparison of thermal models

DELPHI compact model in forced air at 2m/s



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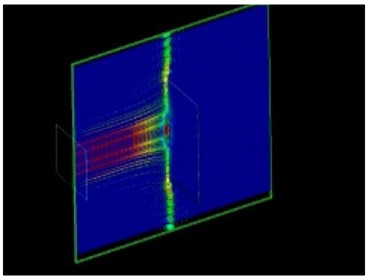
This shows a DELPHI compact model in forced air. Note how the plume of relatively warm air has been displaced, and blown downwind.

Detailed model in impinging jet at 1m/s



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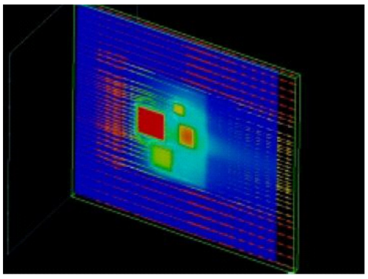
In this model we are looking at airflow focused on the component, and this time taking a view from a slightly different perspective …

Detailed model with adjacent components in forced air at 2m/s



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… which is similar to that shown here, with forced air and adjacent hot components. We don't have the pictures, but it is interesting to speculate how the situation for the main device might have changed had it been downwind of the additional sources of heat.

Comparing different models

ENVIRONMENT	Detailed	2-res	Delphi	Error,2-res	Error, Delph
Natural	92.1	86.6	88.7	-8.9	-5.5
Natural, heatsink	71.3	71	72.1	-0.7	1.9
2 m/s	72	57.8	67.8	-30.2	-8.9
1 m/s, impinging	75.2	64.6	73.2	-23.5	-4.4
2 m/s, components	77.1	62.3	72.6	-31.4	-9.6

Simulated junction temperature (T_J, °C) and errors (%)

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This slide shows the measurements given by different models. Results are for junction temperature, and the comparison is made against the results from the detailed model which is taken as the point of reference.

In natural convection the two-resistor model exhibits a fairly low error, within 9%, but the DELPHI model is a bit better. However, once you get to forced convection situations, the two-resistor model starts to "fall apart".

Comparison of thermal models

Comparing different models

ENVIRONMENT	Detailed	2-res	Delphi	Error,2-res	Error, Delphi
Natural	1.77	1.59	1.71	-10.2	-3.4
Natural, heatsink	1.47	1.1	1.42	-25.2	-3.4
2 m/s	1.26	1.05	1.2	-16.7	-4.8
1 m/s, impinging	1.4	1.17	1.32	-16.4	-5.7
2 m/s, components	1	0.93	1.04	-7.0	4.0

Simulated heat flux from PQFP to board (W) and errors (%)

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In this case, what we are looking at are the simulation results for the heat flux from the device to the board, again making comparisons with a detailed model. As with the junction temperature, the two-resistor model has significant errors, ranging from 10% to above 25%, whereas the DELPHI model shows a reasonable degree of accuracy.

An observation on heat flow

ENVIRONMENT	Detailed	2-res	Delphi	Error,2-res	Error, Delphi
Natural	1.77	1.59	1.71	-10.2	-3.4
Natural, heatsink	1.47	1.1	1.42	-25.2	-3.4
2 m/s	1.26	1.05	1.2	-16.7	-4.8
1 m/s, impinging	1.4	1.17	1.32	-16.4	-5.7
2 m/s, components	1	0.93	1.04	-7.0	4.0

when reviewing these figures, keep in mind that the total device dissipation is 2W

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It is easy to focus on the comparisons, without looking at the physical significance, and it is worth keeping in mind that the total device dissipation is 2W, so that in every case more than half the heat is leaving the device through the board, and the percentage is much higher for natural convection, even when a heat sink is mounted on the upper surface. So improving the heat transfer through the board might be a very effective way of cooling this particular device.

Using DELPHI models

- Two-resistor model predicted the junction temperature rise and heat flux to the board to within approximately 30%
  - useful for some limited design objectives
- Errors of such a magnitude are not acceptable when accurate temperature predictions are required under challenging design constraints

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Modelling a single component is not a challenging task, and a detailed model is relatively easy to produce, but for more general applications we need a simplified model of some form. A two-resistor model proved not to be very accurate, although it might be useful for some limited purposes. But errors of 30% aren't acceptable when parts are being operated near their limits – for a challenging design, accurate temperature predictions are required.

Using DELPHI models

- Two-resistor model predicted the junction temperature rise and heat flux to the board to within approximately 30%
- Errors of such a magnitude are not acceptable when accurate temperature predictions are required under challenging design constraints
- DELPHI model yielded better than 10% error for both the junction temperature and the heat flux simulations
- Time savings realised by using the DELPHI model over the detailed model were a factor of five or more

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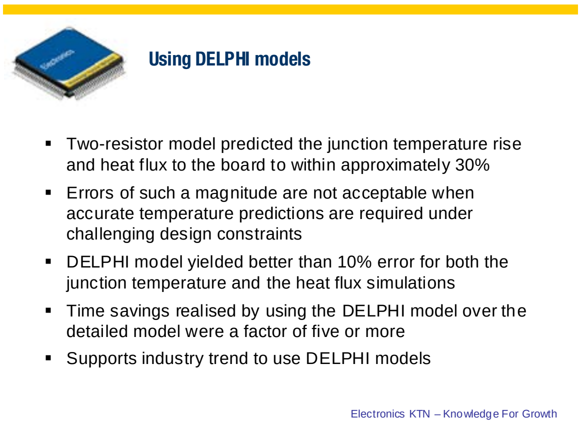
So we need a better compact model, and in this case the DELPHI model was within 10% of the detailed model for simulating both junction temperature and heat flux. And the time taken was less than 20% of that needed by the detailed model. This is not an issue for a single heat-generating component, but is clearly significant for most practical purposes.

Comparison of thermal models



Whilst the results relate to this particular study, and it was somewhat limited, it supports the trend in industry to use DELPHI models where possible, based on them being computationally far more efficient that using a detailed model for each heat source.

And of course we don't have to "roll our own model", but we can get good information both from component vendors, who need to provide boundary condition independent thermal models of the parts they sell, and there are libraries of information and other online resources where models can be downloaded or built easily.