Modelling a small system

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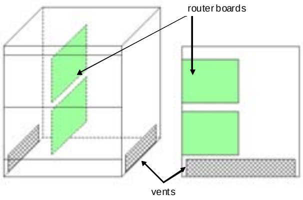
- The target product is a telecommunications rack
- Rack is 15U high, 465mm wide and 450mm deep
- Two rows of seven router boards, each row 6U high, are situated within the cabinet
- Two vents are incorporated at the bottom of the rack
- System also has a fan mounted on the top of the enclosure

We've seen how an individual router board might be modelled, and this follow-on case study concerns the complete rack, containing two rows of boards. Because it is a standard cabinet, there is significant room available at the back and at the bottom of the cabinet, so there is some scope for variation. Compared with the earlier case study, this is very much an equipment-biased simulation, though we cannot ignore the detail of the individual modules.

The ventilation scheme uses a puller fan mounted on the top of the enclosure, with two vents at the bottom of the rack. These vents are fitted with grilles in order to prevent the ingress of anything unwanted.

Grateful thanks to Chris Hill of NXP for allowing us to quote significant elements from his work on this case study and the previous one, *Comparing modelling methods*. Chris has also contributed to other parts of this project: there is an interview with him in *The need for thermal management* and he presents the tool demonstration in *How the tools work*.

Views of the enclosure



isometric view side view

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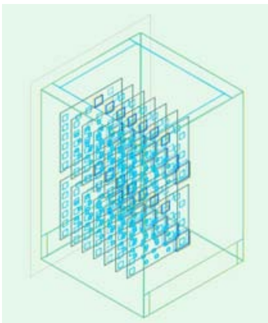
The position of typical router boards within the enclosure is shown in this slide, in both isometric view and side view. Considerable space has been left at the back of the enclosure for interwiring, but the boards shown are in typical positions within two standard sub-racks.

Enclosure model in FLOTHERM



enclosure with router boards ? initial set-up

You get a better impression of the whole structure in this diagram, which has been extracted from the model built within Flotherm. Whereas in FloPCB the boards are shown as 2D representations, the model in Flotherm is three-dimensional and more complex.

At this stage we haven't considered any metalwork associated with the sub-racks, and modelled the case as impermeable, except at the vents. This degree of simplification was necessary in order to be able to build the enclosure using Flotherm's drawing tools.

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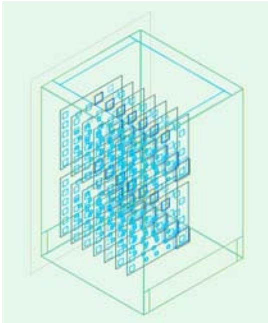
Enclosure model in FLOTHERM

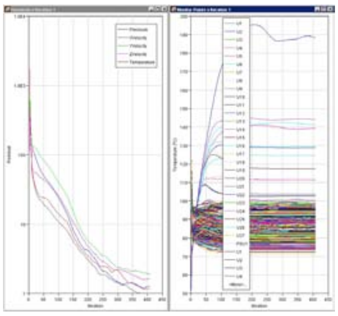


enclosure with router boards ? initial set-up

For a practical application, where the physical representation is available in a CAD package such as Pro/Engineer, this can be imported into the thermal modelling package. However, there is a very real danger when the model contains too much fine detail, because this has a disastrous effect on the gridding.

As well as building a model of the enclosure, and defining the dissipation and other characteristics of each of the cards which can be imported from earlier work, we need to place temperature probes within the simulation, and run it. Scope for a cup of coffee or three while the simulation converges!

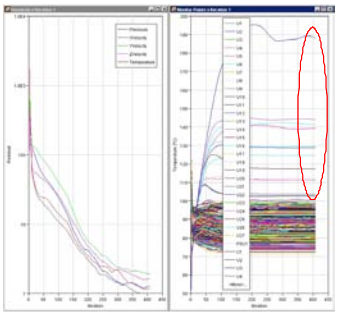
Residuals and monitor points



residuals and monitor point plots for the initial set-up

This display is typical of the output from the modelling tool. It plots the temperature of the monitor points, but more critically shows the residual error against the iterations. Whilst the residual error starts high, it rapidly reduces, and a residual error in single figures generally indicates acceptable convergence and a valid solution. If residuals fail to move towards zero, this means that the simulation has not converged, and 99% of the time that's because of the gridding that has been used.

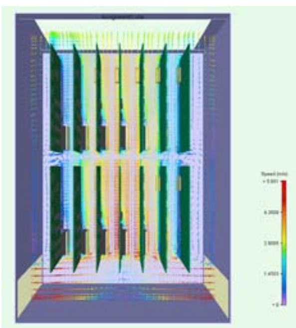
Residuals and monitor points



residuals and monitor point plots for the initial set-up

On the right hand part of this illustration we see the temperature of key probe points. In this case, there are many unnecessary points in much the same "safe area" in terms of temperature rise, but a number of key excursions which are circled with a red line. Not only does this show over-temperature, but the flat response indicates that the simulation is yielding consistent results

System airflow



airflow speed plot for the initial set-up

When we have checked for convergence, we can "freeze" our model, and examine it in various ways. In this case, we can see an air-flow plot, based on the original vent positions.

Note that, whilst the pattern of air-flow is as generally would be expected, with air moving upwards from vents to fan, around the outer boards in the lower row the air is shown as flowing downwards. Such counter-intuitive phenomena are not unusual, and serve to demonstrate the difficulty of calculating complex airflow patterns manually.

But at a macro level, it's clear that the boards near the edges of the enclosure are significantly bypassed by cooling air, so we can expect over-temperature in this area.

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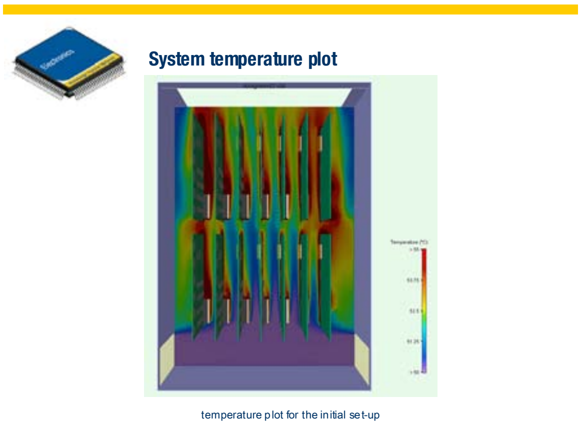
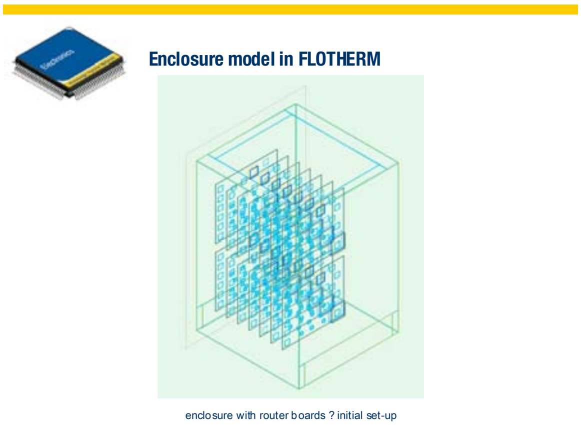
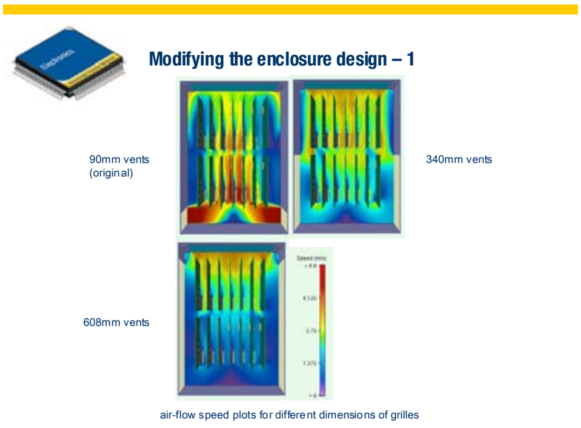


The existence of high temperatures is confirmed by this temperature plot for the initial set-up. The temperature scale was deliberately chosen to provide high contrast between high and low temperature areas, and the plot is actually a section of the enclosure through the power supply units, so the heat plumes emanating from these elements could clearly be seen.

In general, the temperatures are lower where the air velocity is highest, and in the lower row of cards which is not subject to heating effects from elements below them. It is clear that the least effective cooling is in the outer positions of the upper row.

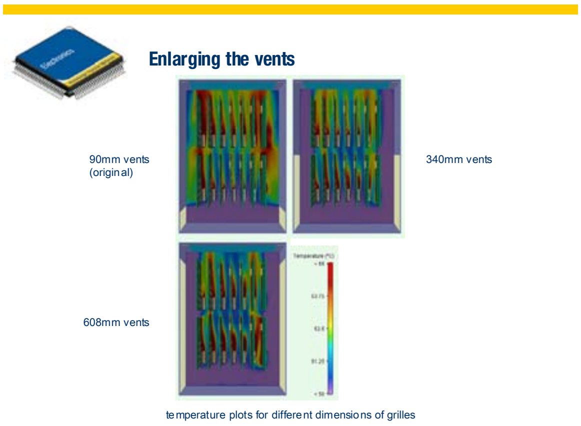


The whole purpose of building an enclosure model and simulating its performance is to be able to make changes. As well as applying heat sinks at the board level, one could try different positioning of fans and vents, or make partitioning changes to the system, such as moving from individual power supplies to a central power supply. All these changes can readily be modelled in order to arrive at an optimal result.



Given the poor distribution of air-flow with the small vents, an obvious change was to look at increasing their size. The original air-flow distribution is shown at the top left, and the effect of significant increases is shown in the other two plots

Note that this illustration looks subtly different from the air-flow plot a few slides back. That is because the earlier diagram used extra computational effort to indicate the direction of air flow, and not just the flow speed.



The effect of the changed airspeed can be seen in these plots, which are of the resulting temperature. Changing the size of the vents has generally cooled the outer boards, and shifted the position of the hot spots.

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Improved cooling … up to a point!

vent height (mm)	maximum T_J (°C)	maximum air temperature (°C)
90	~100	~188
340	~95	~150
608	~98	~166

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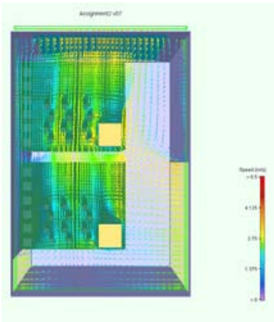
These are the same results expressed in terms of temperature, rather than visually, and confirm that increasing the vent size reduces the temperature, but only up to a point – if the vents are too large the temperature might start to increase in some parts of the enclosure. This is because air tends to flow mainly along the path of least resistance, so will tend to flow preferentially through the top of the grill, which is nearest the fan, at the expense of air-flow lower down.

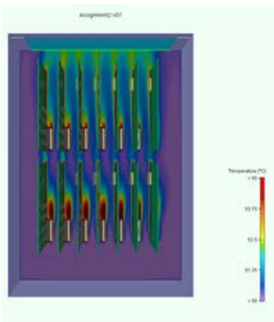
Modifying the enclosure design – 2



airflow plot for the enclosure with front and rear vents

Although the potential for other vent locations is limited, one alternative is to have vents on the front or rear of the enclosure rather than the sides. Intuitively this should give more uniform air-flow, because, with side vents, the air-flow is partially obstructed by the boards at the end of the rows. The plot above shows the simulation for air-flow in the enclosure with this rearrangement, as viewed from the side. The pattern of air-flow is parallel over the surface of the boards …

Changing vent position



temperature plot for the enclosure with front and rear vents

…and this gives both a shorter convergence time for the simulation and a much more uniform temperature throughout the enclosure, this time as viewed from the front.

Modifying the enclosure design – 3

- Beneficial modifications
  - increasing vent size
    - without depriving some regions of the enclosure of airflow
  - repositioning the vents at front and rear of the enclosure
- Ineffective or harmful modifications
  - increasing the vent size above a certain dimension
  - removing the protective grilles over the vents
  - adding another fan in a "push-pull" arrangement

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There are of course many possible modifications that can be simulated with relatively little effort, though at the expense of some considerable amount of computing time and the necessary waiting – thermal engineers need to be patient!

In summary, it was found beneficial to increase the vent size, at least to some degree, and to reposition the vents at the front and rear of the enclosure.

Changes that were found to be ineffective or counter-productive included increasing the vent size above a certain dimension, removing the protective grilles over the vents, and adding another fan in a push-pull arrangement.

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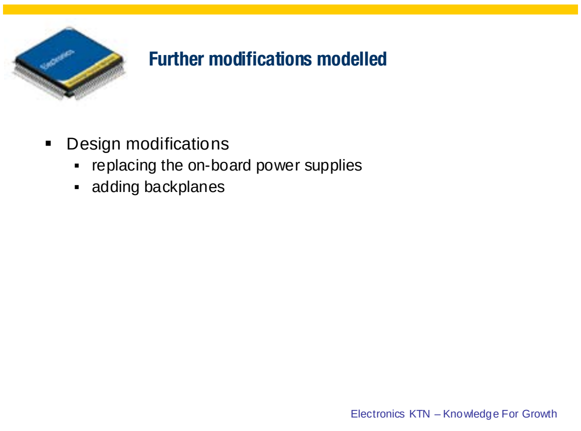
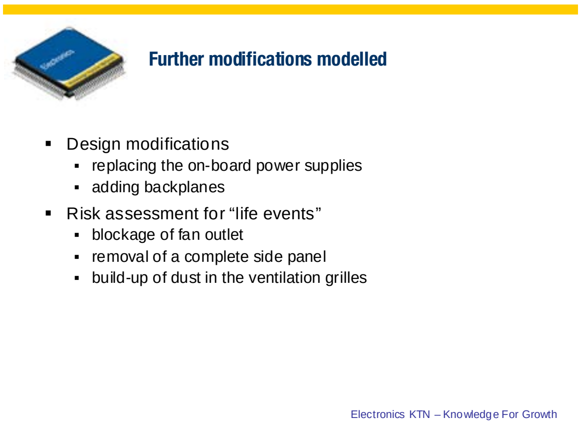
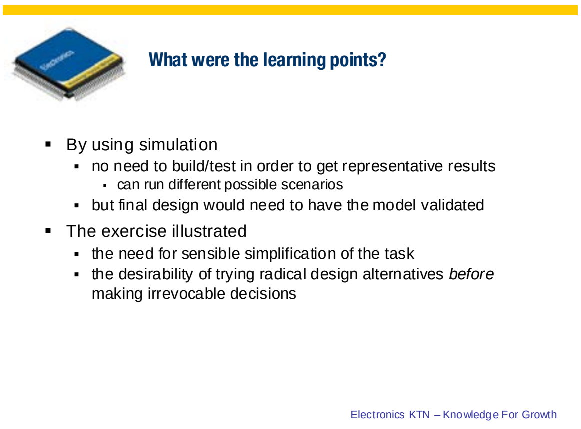


Other types of modification were also tried, such as replacing the individual on-board power supplies with one or two common heavy duty supplies, thus reducing the dissipation of individual boards. This was found to be generally beneficial.

Another design area considered involved investigating the effect of the backplane and sub-frame, which will generally impede air-flow, but appropriate extra baffling might actually be beneficial in evening out the air distribution. Of course, any impedance in the air-flow will have an effect on the fan, and major changes might require re-specification of that unit in order to achieve the required static pressure.



A second group of modelling tasks was less about the design itself, and more about potential "life events", to ensure safe operation under fault conditions. The modelling including blocking the fan outlet, for instance by the user manual being placed on top of the enclosure, which is not unknown, the removal of a complete side panel for servicing, and the anticipated build-up of dust in any vent filters.



The key benefit of this simulation approach is that a number of different possible scenarios could be run and representative results achieved without any need for building and testing, though the final design would need to have the model validated.

The exercise illustrated the need for sensible simplification of the task, and the desirability of trying radical alternatives at a stage in the design cycle before irrevocable decisions had been made.