Thermal Design Leading the Charge

By Ferdinand Sluijs, Technology Manager, NXP Semiconductors – Smart Power

Quite a lot has been written about the benefits of moving the thermal design activity higher up the product development workflow to cut down the amount of rework needed later on, eliminate physical prototyping for thermal reasons, etc. That said, thermal considerations are normally indicated as advice, or constraints on the main electrical and mechanical design flows.

In the case of the power adapters that NXP Semiconductors' Smart Power Division are developing thermal considerations have really come to the fore, driven by the trends we see in mobile power adaptors, which are getting smaller and have a higher output power. Thermal limits are now constraining all aspects of the design.

A recent project involved fitting a 25W charger into the smaller casing previously used for an 18W charger, some 26% smaller, while still meeting the thermal limits which constrain the casing temperature to a maximum of 50°C averaged over an area not exceeding 2cm x 2cm, against an ambient temperature of 25°C. Increasing the size of the charger, while thermally desirable, would make the charger inconvenient to use. Airflow through the charger, while again thermally desirable was ruled out for safety concerns due to the mains voltage inside.

The first question is "what is possible?" This can be answered by finding out how much power dissipated within the device gives this maximum case temperature condition. By building a simple block representation of the adapter consisting of just two blocks for the body and two for the pins, with a uniform internal power distribution, the power dissipation can be increased until the temperature limit is reached. The adapter casing, and the thermal model of this the ideal case with no hot spots is shown in Figure 1.

This simulation showed that in theory, the adapter could dissipate maximal 2.7W. Given that the output power needs to be 25W, the minimum efficiency, η needs to be:

$$\eta = \frac{25W}{25W + 2.7W} = 90.3\%$$

Providing a performance constraint on the electronic design.

The next step is to model the initial design of the new adapter to see the surface temperature distribution and where the temperature would exceed the limit. At 2.91W the initial design will certainly exceed the maximum temperature, but an insight into the temperature distribution in this design will help identify hot spots and so guide design improvements.

To build this model components that have a significant power dissipation were included in the model, along with electrolytic capacitors as these are both large, influencing the overall thermal behavior and also temperature sensitive. One key aspect of the electrical design is the need to isolate the high voltage mains supply from the low voltage output stage. This is achieved by leaving a large distance on the main PCB between the mains connected high voltage primary side, and the output connected low voltage secondary side. A small second PCB was added as not all secondary side components fit on the main PCB.

Each of these PCBs were expected to have four layers – two 35µm outer signal layers, and two 70µm internal power planes (mainly used for internal low voltage supply and ground). These boards were modeled with discrete layers, but with averaged material properties for each layer, assuming 30%

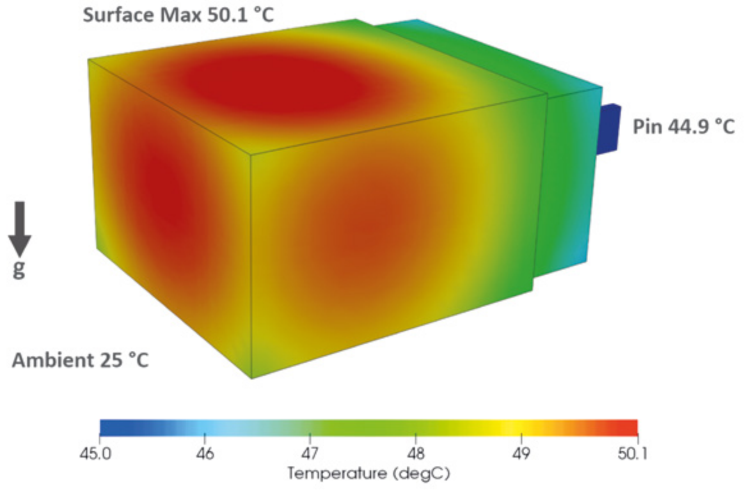

Figure 1. 18W Charger (inset) and simple block model of to determine maximum power dissipation for 25W charger

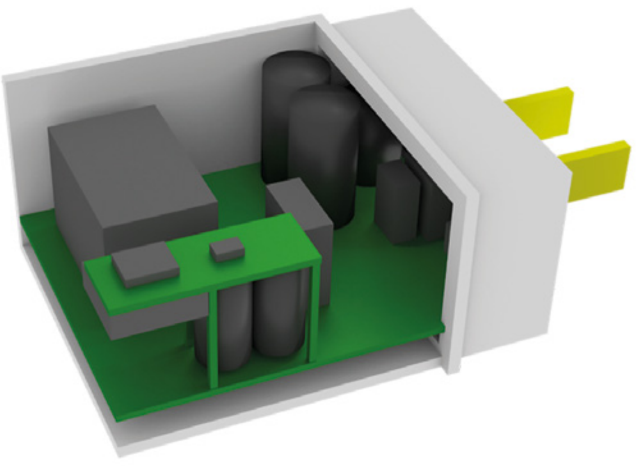

Figure 2. Initial Design

copper coverage for the signal layers and 70% for the power planes. A key decision in early design is how to model the components. Most components were modeled as discrete blocks having a uniform internal power dissipation and material properties, with values chosen based on the primary material for the part.

As expected, the case temperature exceeded 50°C in several places due to local hot spots inside the adapter, with a maximum surface temperature of 61°C.

Two key hot spots inside the adapter were the primary MOSFET on the main board, and the SyncRec MOSFET on the small second board, as shown in figure 4. Next to these two components, also the transformer has a high dissipation and gets warm, but has better cooling because of its larger size.

Rectifying these issues to achieve an acceptable thermal design within the deadline our customer required was very much a team effort, requiring close collaboration between the application engineers working on the sizing of the components, and providing power estimates; the layout engineer working on the PCB layout; and myself as the thermal engineer to also suggest thermal improvement suggestions and to investigate the thermal impact of these by performing FloTHERM simulations. The process involved sitting together and listing ideas, which I then tried out in FloTHERM, and based on the results we decided which ideas to accept and which to reject. We went through that cycle several times, described in more detail below, resulting in the final PCB layout that was simulated, and later assembled.

As the power dissipation was known to be too high, optimization of the circuitry and control was started, focusing mainly on reducing the

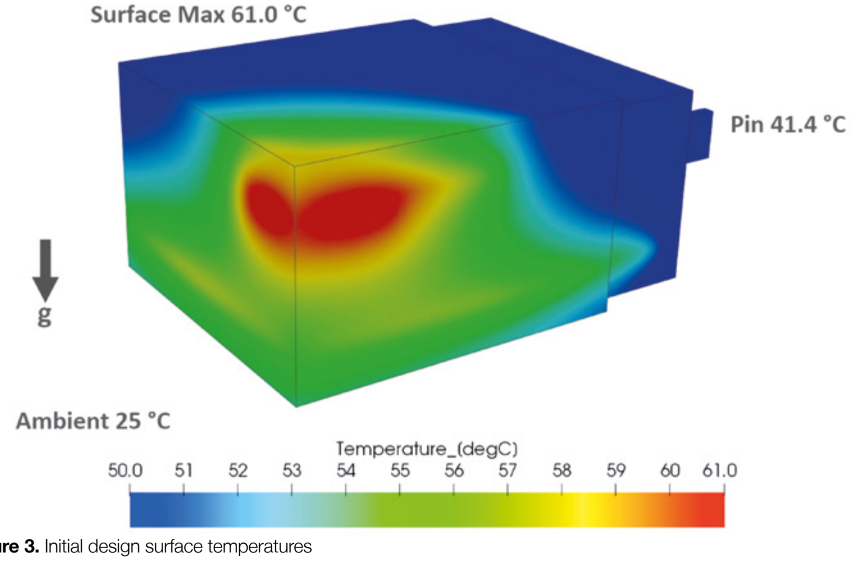

Figure 3. Initial design surface temperatures

power dissipation in the primary MOSFET, the transformer, and the Synchronous Rectifier MOSFET which was used in preference to a rectifier diode as it dissipates less power, but requires a drive signal provided by the Synchronous Rectifier IC. This work resulted in a total power dissipation of 2.2W, giving a 91.9% efficiency. As this is below the 2.7W theoretical maximum, cooling this should be possible provided hot spots on the casing can be reduced, so as well as forcing a redesign of the circuitry and control, thermal constraints also necessitated a significant redesign to alter the layout of the components to better spread the heat dissipation throughout the adapter.

Key changes were to move the primary MOSFET from the top of the main board to the bottom, and away from the transformer to separate these dissipating sources. The primary MOSFET was mounted flat onto the PCB to conduct away more of its heat. The four bridge diodes were then moved to the top of the main board. These changes meant

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that one the large cylindrical capacitors on the main board also had to be moved. This was mounted on its side and raised off the main board.

The size of the small second board was increased to improve heat spreading, and the location of the connecting wires changed. Between the transformer and the secondary board a vertical plastic wall is added to help conduct heat from the secondary PCB down into the main board and into the transformer to help remove heat from the Synchronous Rectifier MOSFET. The final change was to move the USB connector to the main board, as the cable, which will be present when the adapter is charging, and so dissipating heat, will help remove heat from the adapter, as will the pins supplying mains power to the unit as these will conduct heat into the mains socket.

These changes dropped the temperature of the casing adjacent to the Synchronous Rectifier MOSFET by 10°C and with the maximum casing temperature averaged over a 2cm x 2cm area of 48.8°C, as measured by a FLIR infrared camera with a USB cable attached, thereby meeting the design requirements. This work illustrates the importance of thermal design for electronic products and the insights possible using FloTHERM. The simulation results of the final adapter design are in close agreement with the surface temperature maximum and distribution measured on the casing after the adapter had been fabricated, so no further design rework was necessary.

Had this design not met the requirements we still had the opportunity to increase the size of the charger slightly to improve the external cooling, and use more expensive electronic components internally, or increase the copper content of the PCB. All of these would have added cost to the final product and FloTHERM helped us to find what we believe is the lowest cost cooling solution for the product.

Acknowledgements:
The author would like to thank Frank van Rens for the optimization of the adapter's circuitry and control, and Thady Bruton for the thermal measurements performed on the adapter.

Reference:

[1] Ferdinand Sluijs (2017), "Thermal Modelling to Optimize Design in Mobile Charging Applications", Proc. of 23rd THERMINIC Workshop, Amsterdam NL, September 2017, pp. 1-5. ISBN 978-1-5386-1928-8

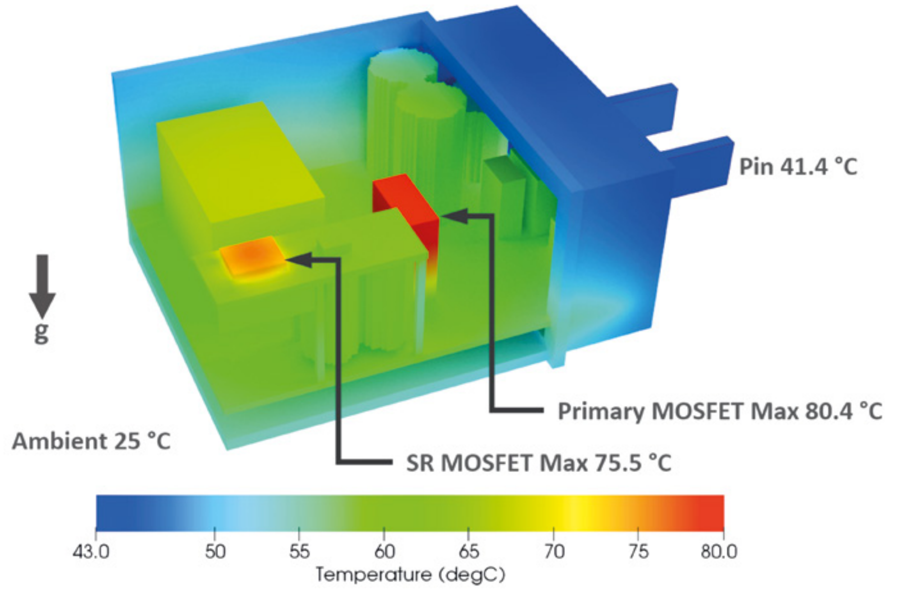

Figure 4. Initial design showing internal hot spots

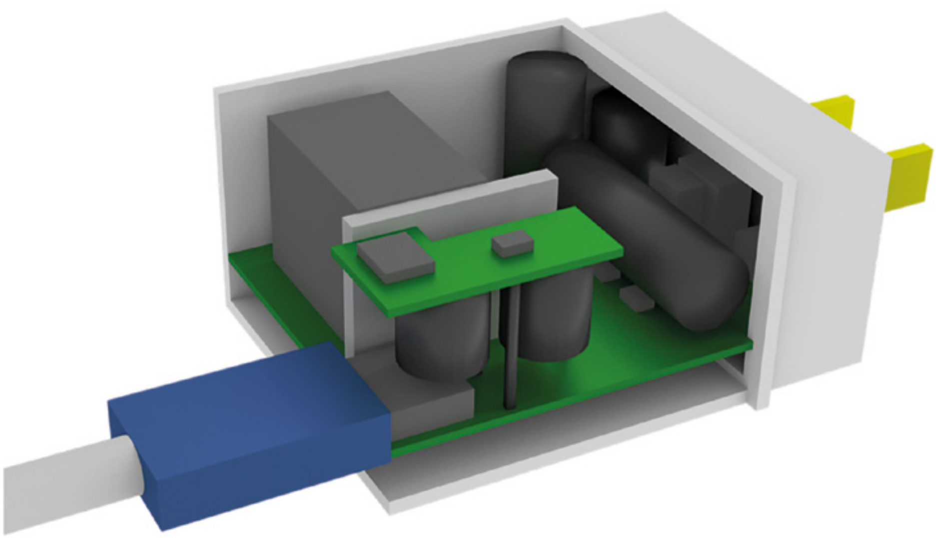

Figure 5. Final design

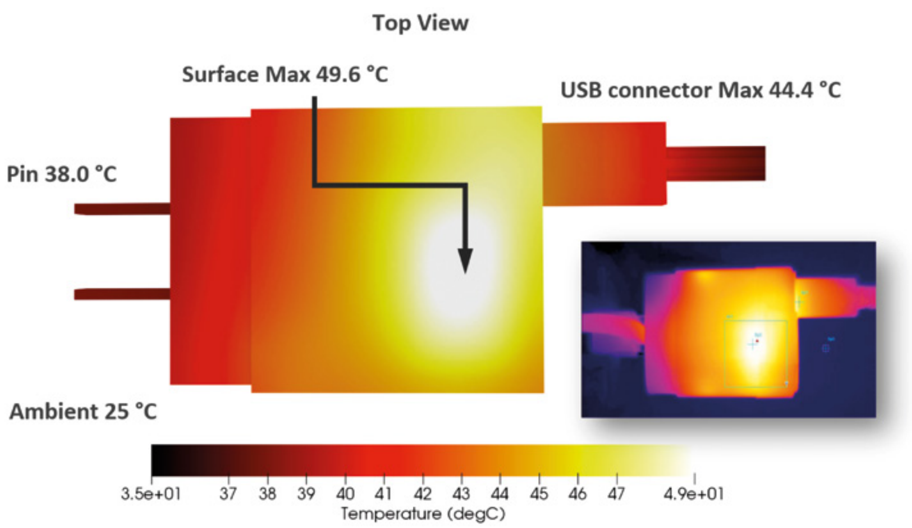

Figure 6. Final design showing surface temperature comparison with measurement

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