THE IMPORTANCE OF THERMAL DESIGN

Martin Brabham, Managing Director

"Heat has a number of effects on a system, including reliability and performance"

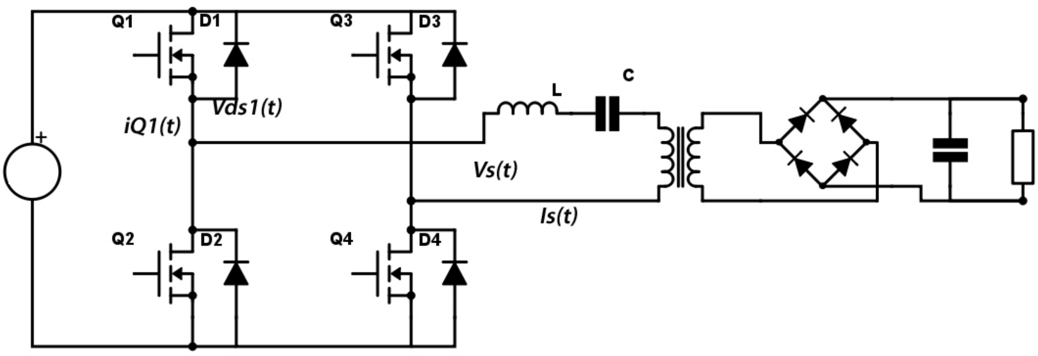
Thermal behaviour is important to determining the lifetime performance of electronic system design and the power supply is a critical element in determining that behaviour. Heat has a number of effects on a system. The most problematic at a system level is one of long-term reliability. High operating temperatures tend to reduce the operating lifetime of electronic components and therefore reliability. According to the Arrhenius equation that is often used to model reliability, each 10°C rise in temperature reduces the average lifetime of an electronic device by approximately 50 per cent.

The power-supply designer has a number of tools at their disposal. One is to focus on the raw efficiency of the conversion circuitry. Innovations in components and power-conversion topologies have reduced energy losses. The savings can be dramatic even though the gains appear to be just a few percentage points. A 250W power supply that operates at full load with an efficiency of 85 per cent will dissipate more than 44W in heat. A power supply just 5 per cent more efficient will waste 16W less.

Exploring Topologies

To achieve these efficiencies and improve on them, engineers have turned to resonant and quasi-resonant topologies. Older techniques impose high stresses on semiconductor devices and suffer from switching losses because they force the switching events to occur when significant amounts of energy are flowing through them. Resonant topologies take advantage of the resonant filtering effect of inductors and capacitors in the output that are used to smooth the output voltage and current.

There are a number of resonant switching techniques now being employed by designers of high-efficiency power supplies. One is zero-current switching (ZCS). As its name implies the switching events take place when current is at a minimum. During each cycle, charge first flows into a capacitor in the resonant filter and its voltage rises towards a maximum. A switch then allows the energy stored in the capacitor to transfer to an inductor in the output stage until the current drops to zero and the switch can be turned off again ready for the next cycle.



Resonant techniques reduce component stress and reduce losses incurred by older architecture

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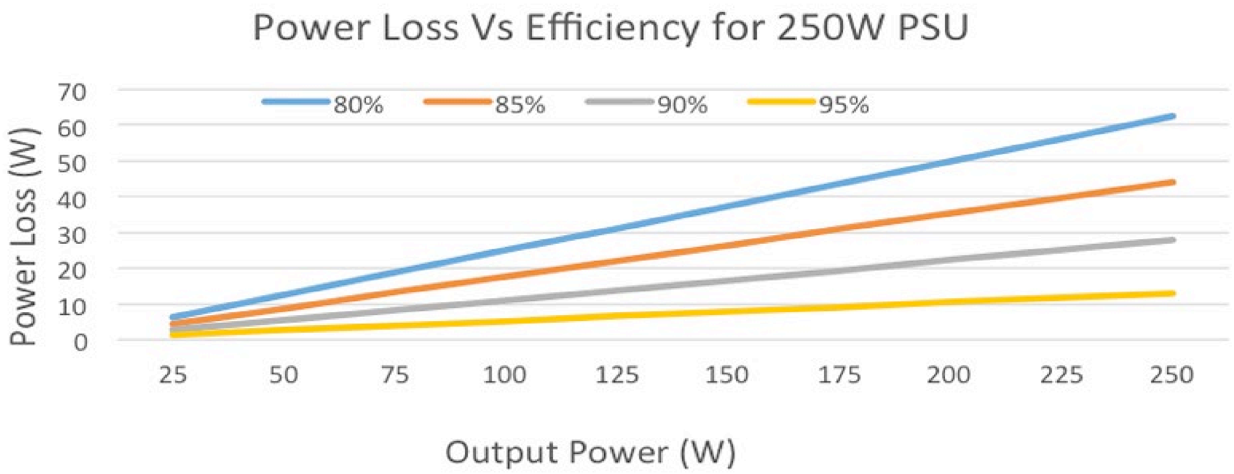
A zero-voltage switching (ZVS) supply rearranges the passive components. The topology allows current to flow first into an inductor then, when the switch feeding the inductor is turned off, the energy flows into the resonant capacitor. The resulting voltage is sinusoidal, with switching events occurring as the waveform approaches zero.

Not only do resonant techniques reduce component stress, they reduce losses incurred by older architectures caused by switching, so boosting efficiency. To optimise the switch timing, power supply designers are turning to more sophisticated digital-control techniques. These make it possible to deliver high efficiency and guarantee stability over a wide range of loads.

At the component level, heat can be beneficial within the power supply if the effects are localised and the design uses system-level techniques to ensure the combination of electrical and thermal stress do not impact reliability. One example of harnessing heat for improved performance is in diodes. In a number of process technologies used for power-handling diodes the forward resistance drops with an increase in temperature. There is a limit to how far the operating temperature can be pushed before there is an impact on reliability, but the technique can provide benefits in the front-end converters of AC/DC power converters.



Power lost based on different efficiencies

Self-heating may need to be addressed in other parts of the system. For example, the effective series resistance of large capacitors used to reduce voltage ripple can, if too high, lead to the production of excess waste heat. Component selection that favours low-ESR capacitors or using multiple capacitors to reduce the overall ESR within the filter circuit can address the issue. Again, as with the thermal behaviour of diodes, it is a careful tradeoff. As electrolytic capacitors are often sensitive to higher temperatures when it comes to reliability, it may be important to ensure that waste heat from the switching circuits is not directed over them.

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Thermal Stress

Designers of special-purpose power supplies that deliver bursts of power to a load, such as those used for high-voltage tests, need to consider the role of thermal stress in overall performance. Although constant elevated temperature will tend to reduce the reliability of any electronic design, temperature cycling can lead to a number of failure modes. The bond wires that join the semiconductor dice of power transistors to their packages become more likely to break, and differences in coefficients of expansion may lead to joint failures between IC packages and the PCB.

As well as the sources and local effects of heating, the power-supply designer needs to consider how waste heat can best be directed out of the system. There are a number of mechanisms that can be used to direct waste heat out of the supply to ensure that it does not affect sensitive parts of the overall system.

The key pathway for heat to be transferred away is convection: transferring energy from the solid components of the electronic components to air molecules as they move past. Forced-air cooling – usually driven by fans – will provide a greater degree of cooling than the natural movement of air driven by thermal energy. But fans add noise and take up more space within the design. Both are undesirable in a wide range of products.

The key factor in designing for convection is to ensure that the warmest air is steered away from sensitive components on the power-supply board or from the critical parts of the host system. The use of heatsinks and overall component placement are critical to ensuring good convection performance.

A secondary avenue for heat removal, though important in space-constrained designs, is conduction through a PCB substrate or system chassis. The high copper content of a PCB, as well as the metal within an enclosure, can be harnessed to provide good paths for heat flow away from heat-sensitive parts of the system. Suitable choices over materials as well as structural design can maximise heat transfer.

For all of these reasons, thermal engineering has become a vital part of the design flow for efficient and reliable power supplies. For decades, many engineering teams have relied on rules of thumb and experience to deliver the designs they need. Today, more advanced techniques are needed to be able to make the informed decisions that will lead to high efficiency and excellent thermal performance under the full range of systems conditions.

Thermal simulation builds on techniques developed for computational fluid dynamics to model the flow of heat around a design. The power supply and its components are represented as a 3D mesh of elements that generate and absorb heat from the PCB or from the air. Although it can provide excellent insight into the thermal behaviour of an electronic subsystem with a high level of detail, the job of mesh generation and simulation requires expertise and experience.

A fine-grained mesh increases simulation time dramatically although it provides high accuracy. As a result, experienced users of thermal simulation tune the detail of the mesh to focus on critical parts of the design and on components that are most likely to affect thermal performance, such as heatsinks and components that handle high current levels. Calibration to real-world conditions is also important to ensure the simulation does not produce misleading results. But if these issues are taken into account computational thermal simulation is an increasingly important tool in power-supply design.

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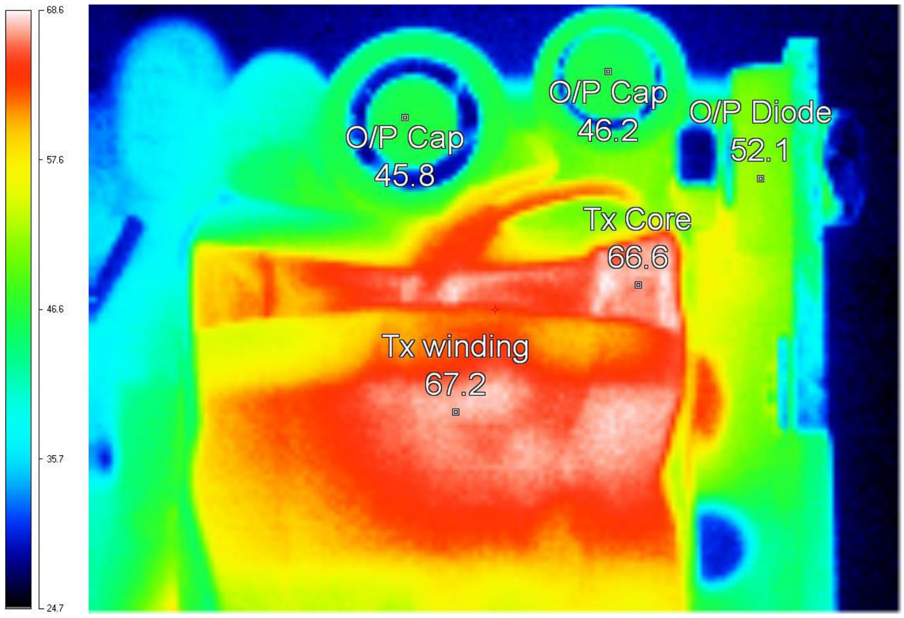

Thermal simulation is an increasingly important tool

There will be situations where, despite the best efforts of the design team, the thermal behaviour goes outside normal parameters. Digital monitoring and control provide a way to ensure that the supply continues to operate safely. The open-standard PMbus provides a way to add intelligence to power supplies, giving them the ability to report to a system manager their current status. The system manager can, in return, dynamically alter their voltage and current outputs to deal with problems.

If a thermal hotspot is developing, possibly due to a short-circuit or excessive consumption by the load, the system manager can use PMbus commands to put the power supply into a safe state or turn parts of the circuitry off to prevent damage. By providing active control over the power supply, the PMbus is a suitable complement to the digital control techniques now used in high-efficiency power supplies.

Thanks to the use of technologies such as digital control, advanced topologies and thermal simulation, designers can deliver cost-effective, compact and efficient power-supply subsystems. To be able to make use of all these tools and techniques, the engineering teams requires depth of experience – but that level of expertise is available from specialist, outsourced power-supply design and manufacturing providers.

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