As Cool as a Cucumber

Many of us tend to think of semiconductors as low power, cool devices. But as the number of transistors in an integrated circuit increases, so does power consumption increases and the need to dissipate the resulting heat load. Microprocessors, in particular, consume more and more power with increase in speed and complexity.

The simplest way of removing heat is the movement of ambient air over the hot chip. In any enclosure, adding strategically placed vents will enhance air movement, providing cooling at the lowest cost, without sacrificing footprint, reliability or longevity.

The cooling of critical devices can be improved by simply placing the device in the best location in the enclosure. When component placement is not ideal, simple thermal solutions cannot remove enough heat to maintain microprocessor reliability, and the system designer must turn to other options, such as heat sinks, fans, heat pipes, or even liquid cooled heat plates.

Thermal modeling can help demonstrate the effectiveness of any solution and can predict its longevity. By applying the power curve from Figure 1, the designer can test the design for successive generations of microprocessor, and give an estimate for the number of years during which the design will remain a satisfactory thermal solution.

The need to dissipate heat has been recognized by ic manufacturers, package designers, board manufacturers and system houses alike as a critical design constraint. The proactive approach of companies like Linear Technology and Aavid Thermal Products has made the transition from one clock speed to another as simple as buying a new power chip and an off the shelf heat sink, both of which fit in the existing board layout. Miracles can only go so far, however, and only wise choices in packaging, board and system layout, in combination with advances in heat sink design, will allow future generations to remain cool and reliable in the same footprint as existing products.

Increases unavoidable?

As more transistors are squeezed in the same area, power consumption also increases. This increase in areal density is the key to ongoing improvements in ic capability. When smaller transistors are pushed closer together, signals travel faster between them, allowing an increase in clock speed. When chip size remains constant, the increase in the number of transistors enables the microprocessor to move to the next generation of performance. Thus, in the last five years, we have moved from 32bit, 66MHz processors drawing as little as 3W, to 64bit, 300MHz processors drawing more than ten times as much power. Figure 1 shows the advancement of processor technology with the corresponding power consumption.

Packaging effects

Trends in packaging technology also have an effect on how well a system deals with this increasing heat generation. Leaded packaging, such as quad flat packs (qfp), can no longer accommodate the high I/O levels required by current microprocessors. In the early 1990s, Motorola introduced the plastic ball grid array (pbga) package, which replaced the traditional gull wing style leads with eutectic solder balls that sit directly under the ic package. This package style easily accommodates more than 260 I/O points, while improving other aspects of ic attach, with few drawbacks.

The large array of solder balls under the ic in a bga package provides considerable heat transfer, dissipating as much as 4W without a separate heat sink. While this is a significant improvement over previous packaging types, most modern microprocessors need additional heat dissipation. The selection of bga packages can greatly affect the ability to dissipate this additional heat.

All plastic packages are insulated at the top of the device, making cooling through top mounted heat sinks more difficult and more expensive. Plastic packages are, therefore, a poor choice for high power microprocessors.

Metal heat spreaders incorporated into the top of the package, on the other hand, enhance the ability to dissipate power from the chip, and accommodate a number of thermal options. Top mounted heat sinks, fan heat sinks, and heat pipe assemblies can effectively cool microprocessors packaged this way.

Thermal options

Surface mount technology enables improvements in board design and cost of assembly, but offers challenges to heat sink attachment. Surface mount compatible components are generally smaller, allowing a smaller board to provide the same functions as a larger, through hole board.
The surface mount process is typically fully automated, reducing assembly costs. However, many traditional style heat sinks cannot be readily incorporated into surface mount processing, requiring a separate manual assembly process.

Surface mounted power devices, such as the TO252, TO263, and TO268, enable the system designer to power increasingly power hungry surface mounted microprocessors. These devices incorporate a metal heat transfer plate on the bottom of the package to enable efficient heat transfer from the semiconductor package.

Unlike their through hole counterparts, where typically the thermal transfer plate is clipped (or otherwise attached) to the heat sink that is then secured to the board, the heat transfer plate for these units is designed to be soldered directly to the board.

In order to enable this move in technology, Aavid has teamed up with several ic manufacturers to develop a surface mountable heat sink for these type of packages. The heat sink comes in tape and reel format, allowing automated placement by the surface mount equipment. In a departure from traditional attachment methods, these heat sinks attach directly to the board during the solder reflow process. Because these units connect directly to the board through the solder joint, both the mechanical connection to the board and the thermal connection to the semiconductor are excellent.

This type of solution to a manufacturing process change enables all areas of the electronic ‘food chain’ to continue the rapid pace of technology advancement.

Prudent system design can improve thermal transfer for a more robust, long lived product.

Improvements in heat sink design

Almost daily releases of new heat sink designs allow previously impossible designs to be cost effectively implemented.

By paying close attention to changes in manufacturing techniques, Aavid developed the surface mount compatible heat sink for power devices. Thermal modeling has lead to developments such as ‘pin fin’ devices, where additional surface area improves the cooling in the same footprint. Further modeling optimized placement of the pins in a device called the ‘Opti pin’, which incorporates reduced pressure drop with enhanced cooling capabilities.

The ultimate thermal challenge

The constraints of notebook computers demand consideration of thermal issues at every level. The demand for mobility restricts product size; limiting airflow and requiring compact components. At the same time, the chassis must not heat up so much it burns the user. So heat must be dissipated through media other than the chassis itself.

Like other computer designs, the longevity of the notebook design will drive long term development and marketing costs. Looking at the thermal issues in two to three generations will increase the likelihood that the design will last.

Weight is always of concern with notebook computers. Fans and other active cooling devices pull draw current from the battery, shortening processing time available under battery power, requiring the end user to carry additional, heavy batteries. The weight of any cooling devices may also be a concern.

Creative solutions to notebook heat dissipation abound. Heat pipes move heat passively from one area of the notebook (such as the hot microprocessor) to another. In low end systems, the heat pipe delivers the heat to a stamped aluminum plate on the back of the keyboard, which has been demonstrated to absorb 2 to 4W without significant temperature rise. System fans with incorporated temperature sensors conserve battery power by turning on only when needed.

Finned heat sinks dissipate the most power in the smallest amount of space. Using heat pipes to move heat from multiple devices to the finned heat sink manages the total system load by quickly moving the heat out of the system.

The future

As microprocessor technology continues to advance, the increased power requirements will demand an outlet for the concurrent heat load. Failure to consider this heat load may lead to a generation of error ridden, short lived computers.

Solutions lie in every area of electronic design, including the package type selected, board and system layout, and heat sink selection.

Working closely with a thermal management consultant can expedite the thermal design time. By using advantages offered in each area of electronic design, robust, long lived designs are possible.