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Miniaturization of Cooling Solutions

The market's demand for increasingly powerful products, in smaller and smaller packaging, creates a cooling problem. Integrated circuit (IC) lifetime is dependent upon its operating temperature, creating a trade-off situation: either you enlarge the package to accept additional cooling, or you sacrifice IC lifetime.

Cooling Consumer Products

In the case of consumer products, such as kitchen appliances and telephones, the market will accept little increase in product size as a result of the addition of processing capability. In these cases, cooling is limited to the thermal conductivity of the packaging materials and whatever airflow is provided inside the system. As consumers demand more and more functionality from these products, and IC manufacturers increase the functionality available, the number of ICs tends to increase. Designers can reduce the heat generated by the electronics by integrating functions wherever possible. One IC providing two functions generates less heat than two separate ICs providing the same functions. In this case, miniaturization of the cooling solution is also miniaturization of the electronics themselves. The designer can maximize cooling of these ICs by placing them optimally in the air stream or adding a thermal spreader that moves the heat to the exterior packaging.

In consumer products there is often no airflow and no space for any type of cooling. In these instances, it may be necessary to use lower voltage components, often with reduced functionality. Otherwise, lifetime may be sacrificed to maintain product size.

Cooling Notebook Computers

In notebook computers, a special sector of commercial products, cooling is given more attention. For high-end systems with powerful microprocessors, graphics, and communications capability, cooling is a necessity. The most space-effective cooling strategy is wise product placement. Simply keeping hot components in the air stream and keeping the heat-sensitive hard drive away from the processor offer significant cooling without increasing package size. In addition, techniques such as those described below for industrial applications, cool the sensitive components in high-end notebooks. To maintain the small size and weight required by notebook designs, notebooks often contain lower-powered components running at lower frequency and performance. This is why notebook capability lags a little behind desktop computers. For thin notebooks using high-powered components, the trade-off may favor shortened lifetime over package enlargement for adequate cooling.

Industrial and Embedded Computers

Industrial computers require longevity, so reliable cooling becomes a priority. Package size is still an issue, requiring miniaturization of the cooling solution. A new standard, CompactPCI, specifically addresses industrial and embedded processing systems. This specification is an adaptation of the Peripheral Component Interconnect (PCI) that addresses the need for more robust components in industrial applications. The specification provides a system that is electrically compatible with PCI, allowing low-cost PCI components to be incorporated into industrial systems as needed.

CompactPCI form factors mandate board spacing at 20.32 mm, or 0.8 inches, severely limiting the amount of space available for cooling. The best cooling designs take advantage of every cubic millimeter of this space. Some techniques used to best use this space include heat pipes, copper spreaders, thermal vias, and low-profile fan heat sinks.

Heat Pipes

Thin, flattened heat pipes allow the thermal engineer to pipe heat from one area of the system to another. An application using a 133 MHz or 166 MHz Pentium Processor, limited to an ambient temperature of 60-70° C with natural convection airflow (less than 200 LFM), may have to use a custom heat pipe with a cooling device. The heat pipe spreads the heat from the processor to a heat sink for dissipation in an air stream or conduction of the heat to the product enclosure.

Unfortunately, the performance of a heat pipe decreases as the diameter decreases, and also when it is flattened. As with most thermal solutions, efficiency is lost with miniaturization.

Copper Spreaders

Copper spreader layers inside the printed circuit board spread the heat over a larger surface area where system airflow can then remove it. These copper planes are very effective at reducing the semiconductor case temperature in a system without a heat sink, and are more cost effective than a heat pipe. Spreaders are not as effective as heat pipes, however, so they may not be the ideal solution for the most demanding application.

Thermal Vias

Thermal vias, made of copper runs through the printed circuit board, move heat rapidly from one side of the board to the other. Typically, one end of the via attaches to the IC, and the other attaches to a heat sink. This technique works especially well with BGA (Ball Grid Array) packaged devices. Conduction of heat through the printed circuit board takes up no additional real estate, qualifying vias as a miniature thermal solution.

Low-Profile Fan Heat Sinks

Often industrial applications expose the electronics to harsh environments. Dust, machining residue, or even corrosive fumes exist in many industrial environments. To protect the electronics in these applications, they must be enclosed in a sealed chassis with no airflow. In these applications, a thin fan mounted directly on top of the IC is often the best miniature cooling solution available.

Low-profile fan heat sinks can help solve these cooling problems created by space, cost, and environmental constraints. They are small, some as small as 7 mm (0.3 inch), making them compatible with the CompactPCI limit of 7 mm or less. The small size does not compromise their reliability. They are available with long-lived, ball-bearing fans, with a typical lifetime of three to five years. Less reliable fans are available so it is important to select a vendor that offers life-testing data. These unique solutions can be attached directly to an IC, allowing newer, more powerful boards, which require increased cooling, to fit into CompactPCI spacing.

The fan heat sink provides all the necessary airflow to cool the processor. This allows the chassis to be sealed, keeping out potentially damaging particles or chemicals.

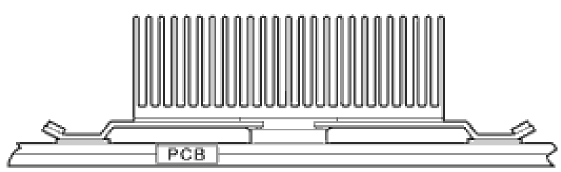

Figure 1

Figure 1: Traditional top-side heat sink solution requiring 1-inch tall heat sink for adequate thermal performance.

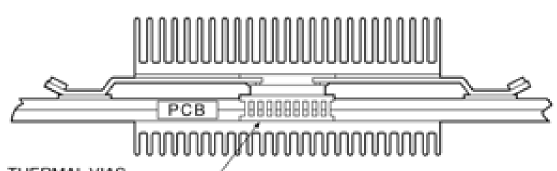

Figure 2

Figure 2: By adding thermal vias, a bottom-side heat sink can be used to reduce the overall profile by allowing heat to escape from the chip through the top and bottom. This more efficient thermal path allows a top-side heat sink to be .5-inch with a bottom-side heat sink that is .25-inch. This provides identical thermal performance to the 1-inch all heat sink in figure 1.

Component Packaging, Placement, and Airflow

In all applications, product placement and airflow are important for minimizing the size of the thermal solution. Keeping heat-sensitive components away from heat-generating components reduces the overall cooling need. Optimizing fan placement may allow the use of a single fan instead of two, reducing the footprint required for the fans. Placing two heat-generating components close together and using a single heat sink to cool both may reduce the footprint required for the heat sink. Computer modeling offers a cost-effective method for optimizing the size of the thermal solution.

Conclusion

Miniaturization of devices has called for miniaturization of the thermal solution. Heat pipes, embedded copper spreaders, thermal vias, and low-profile fan heat sinks are enabling more and more powerful devices to be used in smaller and smaller packages, ensuring long life in automated industrial systems. Thermal modeling allows optimization of the size of the overall thermal solution. As computing becomes more pervasive, these innovative cooling solutions may begin to find their way into more embedded products, such as other industrial electronics applications and home appliances.

CHRISTOPHER CHAPMAN, *GLOBAL COMPUTER INDUSTRY MANAGER* - is a veteran in the surface mount components industry, bringing to Aavid Thermal Technologies more than 7 years experience in product engineering and product management of thermal components. Mr. Chapman formerly served as a product engineer at Aavid and as a sales application engineer for Aavid in California's Silicon Valley. In his current position as computer industry manager, Mr. Chapman is responsible for the development and marketing of cooling solutions for computer applications. Drawing on Aavid's broad-base of cooling technologies, including surface mount components, extrusions, die castings, and liquid cooling, Mr. Chapman aids in the development of tailored, cost-effective solutions as well as off-the-shelf thermal solutions.

Mr. Chapman earned his Bachelor's of Science degree in Chemical-Environmental Engineering from the University of New Hampshire, where he has frequently returned to give graduate and undergraduate lectures on heat transfer and microelectronics cooling. He has published many technical papers in nationally recognized electronic trade journals and has spoken at national electronics trade shows such as Portable By Design, International Society for Hybrid Microelectronics [ISHM], Semi-Therm and the Electronics Industries Forum of New England.