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Cooling takes on smaller forms

By Martin Mayer

Passive cooling techniques fall short of doing the job for today's high-performance processors in small form factor systems. By deploying more advanced techniques, fast processors can be kept cool with cool-bearing fan sinks, improved sealing technology, and flexible heat pipes. Martin discusses the technology behind these approaches and their benefits.

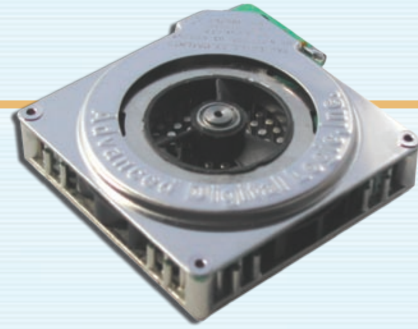

Figure 1

Designing successful embedded systems demands efficient PCB design, power requirement fulfillment, and an effective cooling solution. While heat reduces the life of systems, practical cooling solutions directly result in long-term reliability. OEMs who partner with their solution provider early in the design and integration process will find a variety of cooling techniques available. Often, innovative solutions to heat-dissipation issues will create an improved operational envelope and lower total cost of ownership for those systems.

Simply put, a successful cooling solution meets or exceeds the performance goals of the OEM's design. Military and other high-reliability designs must thrive in high-temperature environments while maintaining sufficient processor throughput to meet the embedded application's computational demands. Market forces drive designs to optimize price for performance, continuing the trend toward full CPU utilization for a given deployment. Thus, it is important for thermal management solutions to handle worst-case loads.

Power consumption requirements also drive thermal management solutions. Incorporating Intel's Pentium M CPU into small form factors such as PC/104 has pushed power envelopes to new levels. And the Intel Core Duo more than doubles the current 15 W range of the previous Pentium III generation.

Traditional convective- and conductive-cooling solutions may not be adequate to meet the new demands and could end up costing OEMs more over the life of the system. Ineffective mounting and planar alignment problems degrade the performance of most thermal management solutions. Using space technologies to specifically address this issue can extend the life of systems and reduce both time to market and overall cost of ownership.

Going beyond tradition

One popular method for traditional heat-conductive applications is the deployment of a flat-surface heat spreader designed to make thermal contact with the CPU and other support chips. This spreader attempts to provide a high heat-conductive path from the contacted chips directly to the chassis wall. These solid solutions can transfer impact shock from the chassis directly to the CPU die. To accommodate interior flat chassis wall mounting, it is necessary to provide OEM customers with heat-conductive solutions that adapt the board topography to a flat planar mounting surface.

For heat-convective applications that allow active cooling, adding an appropriately sized fan can improve the traditional extruded heat sink. Cooling solution attachment points are usually required on a per-chip basis to accomplish this. A Pentium M system requires individual heat sinks for the CPU and the highly integrated 82855GME. The ownership costs related to maintenance, such as renewing worn fans and cleaning contaminated heat sinks, may only be acceptable to some market segments or during early design, proof-of-concept creation, and prototype phases of a design project.

In cases where traditional extrusion offers insufficient performance, pin-fin heat sinks should be considered. Integrated pin-fin heat sink and fan combinations can obviate the problem of bolting fans to pin-fin heat sinks. The Advanced Digital Logic fan sink (Figure 1) combines patented flat motor design with a customized pin-fin heat-sink base. In a volume of space 37 percent smaller than comparable traditional extruded heat-sink solutions, the fan-sink solution is capable of heat dissipating more than 30 W when in full base contact.

This fan sink also protects the bearings, which incidentally are the most common cause for failure in mechanical devices. By directing airflow through the central opening in the impeller, and therefore, through the motor, the precision double ball bearings of the fan sink are placed directly in the inlet airflow path. This keeps the bearings cooler than conventional brushless DC motor designs where air is drawn around the motor, leaving the bearings shielded in a zone where heat can concentrate.

Enclosed: A way to remove heat

Once heat-conductive thermal solutions transport heat from the PCB to the chassis wall, heat-convective solutions are often required to continue drawing heat away from the chassis wall. Outer packing can be ribbed to induce natural heat convection over very large surface areas or outfitted with a secondary thermal interface to carry heat into the structure to which it is mounted. OEM designers choose the large area of a chassis and moderate complexity of chassis exteriors to complete the thermal solution.

A flat-interface surface on the interior is desirable to keep chassis design simple and cost effective. With traditional thermal solutions, the chassis surface must be planar with the PCB or die face for optimum heat transfer. In reality, this planarity is practically impossible to achieve. Extra work, design cost, and installation cost is often required just to meet minimum requirements. For example, accommodating both the PC/104 mechanical stacking and interior thermal attachment can require simultaneous use of numerous loose-fit through holes drilled through the flat interior area of the chassis itself. Sealed cases also need precision drilling, gasket washers, and counter sinking of exterior holes to maintain the original gas-tight system.

The flat mounting surface is also typically found at the bottom of the chassis system. In this case, a PC/104 stack is constructed off the pin side of the PC/104 interconnect system. Oftentimes, this type of mounting has the added benefit of locking connector headers in place when the CPU is mounted.

In all cases, a heat-conductive solution that adapts the board topography to a flat chassis planar mounting surface is required for optimal performance and reliable system longevity.

Flat not just for flat's sake

Because the inside wall of the OEM chassis is a flat plane, all attachment points provided by the CPU are required to match this plane. To meet this need, it is necessary to resolve the uncontrolled nature of the CPU and chipset planes that source the heat supply of the thermal-conductive interconnect.

In the case of the Flip-Chip Ball Grid Array package (FCBGA), the thermal interface plane height varies with respect to the plane of the ball contact to the PCB (as shown in Figure 2). FCBGA chips delivered by Intel and other suppliers have published solder-ball plane-to-top surface height ranges. In addition to these published ranges, design considerations include a friendly disclaimer that reflow processing can affect both installed height and plane alignment.

The fact that both the Pentium M CPU and the popular 82855GME support chip are housed in FCBGA packages implies an uncontrolled planar relationship between the thermal interface points on each of the dies.

Staying in contact

For one-piece heat-spreader solutions, the spreader must be mounted to maximize the CPU die. This can be accomplished because the 82855GME support chip's significantly lower power dissipation requirement allows a wider range of thermal interface options. Using a high-quality thermal compound is essential because this mounting often results in a small gap on the order of 0.005" (.127 mm) between the chipset's die and bottom of the heat spreader. Several reworkable two-part gap-filler compounds can provide the heat-conductive path to the support chip in a manner that does not increase mechanical stress on the board.

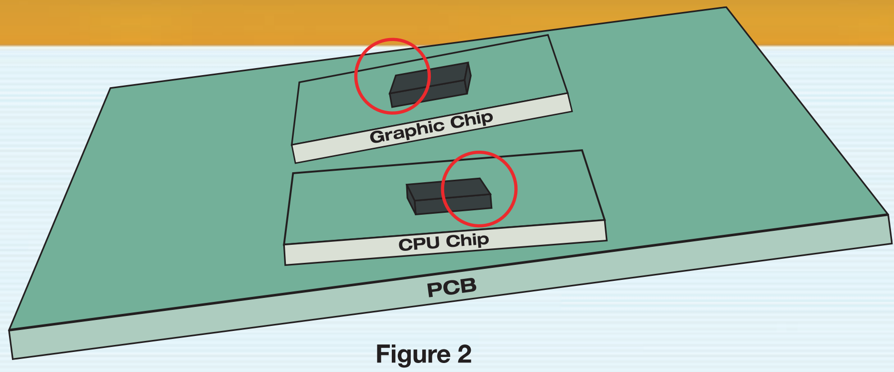

Figure 2

Once mounted, a single-piece heat spreader defines the mounting plane that will attach to the inside wall of the OEM's enclosure. It is necessary to ensure that the standoffs used for PC/104 structural mounting share the same plane as that of the enclosure. This may involve machining overly long standoffs to fit a particular unit or adding small precision shims to raise short standoffs to the plane of the heat spreader.

Achieving maximal performance with a one-piece heat spreader requires attention to detail and patience. Performing these operations prior to shipment and providing fitted standoffs presents the OEM customer with an out-of-the-box solution that can be bolted into their application with minimal effort. By designing this into the solution, OEMs do not need to perform the alignment process in the field.

When designing one-piece heat spreaders, it is critical to choose the nominal spreader height in relationship to commonly available standoffs recognized by the PC/104 standard. Research shows that 0.591" (15 mm) is the predominant interboard spacing in European integrations, while 0.600" (15.24 mm) has become the SAE equivalent. The nominal difference between the two is roughly 0.010" (0.25 mm). This is significant because original board planarity should be maintained to one-tenth of this difference 0.001" (0.025 mm). Adapters may be required to satisfy SAE and European customers.

Piping the heat away

The detailed manufacturing required to achieve reliable performance with one-piece heat-spreader solutions obviously affects the total cost of ownership. As each spreader is custom fit to each CPU, there is little opportunity to benefit from the economics of scale. This results in a significant per-unit cost for OEMs.

A new approach to multichip conductive thermal management is needed to:

- Improve standardized European and SAE dimensional differences
- Reduce installation cost
- Lower total cost of ownership
- Stabilize the Gaussian performance characteristics across all installations
- Improve reliability

To achieve these goals, OEMs should partner with the PCB layout team to implement a superior thermal solution attachment method.

After much review and parallel testing, teams at Advanced Digital Logic developed a highly reliable, RoHS-compliant, soldered-interconnect heat-pipe solution (Figure 3). Capable of handling the dynamic heat loads of Intel's latest Core Duo processor and advanced chipset offerings, this flexible solution meets all of the design goals and is backwards compatible for OEMs with existing designs based on one-piece conductive interfaces.

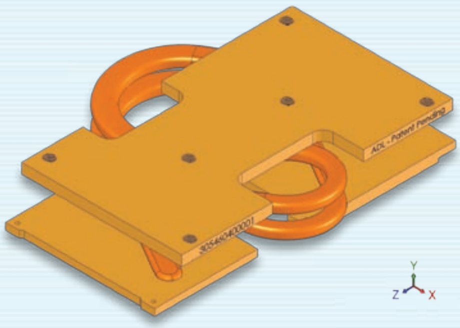

Figure 3

Each chip to be cooled is attached to one of the adapter plates. The adapter plate makes contact with the die of the CPU or chipset and each is allowed to independently match the final plane of the assembled chip. As with Intel's desktop options, the fiberglass of the motherboard itself serves as the tension mechanism. Using tripoint mounting enables full planar adjustment for each device.

The adiabatic section of the individual heat pipe, which loops above the chip to connect with the main thermal interface plate, compensates differences in planarity. Sufficient heat-pipe flex allows differences in board-to-chassis planarity to be accommodated easily, such that any standoffs from 0.5905" (15 mm) to 0.625" (15.88 mm) may be utilized.

The Naval Research Laboratory for the WindSat program has diligently studied heat-pipe assembly reliability for deployment aboard spacecraft and, in particular, to regulate the thermal environment of low-noise amplifier subassemblies. The Naval Research Laboratory's results conclude not only that heat pipes accomplish the design goal, but that their reliability is directly correlated to the sealing process utilized. For more information on this study, visit www.nrl.navy.mil/content.php?P=04REVIEW153.

Zero-gravity heat pipes made from smooth walled copper are employed because the orientation of embedded systems cannot be restricted. Powdered copper is fused (or sintered) to the wall of the copper pipe and to itself. This forms a wick along the interior wall that resembles the star pattern of a standard extruded wick, but presents orders of magnitude more surface area. In such a heat pipe, the capillary action of the water working fluid provides the migratory force, even against the pull of gravity. Because the liquid phase is spread thinly, deformation or expansion damage does not occur when a liquid-solid transition of the working fluid is encountered.

This choice enables the customer to mount the CPU unit in any orientation or environment, from a static factory floor to the dynamic orientation of an acrobatic aircraft.

For the supplier, flexible heat-pipe solutions provide a self-adjusting, simple-fit procedure that reduces assembly time. OEMs now can choose structural standoffs that simplify the supply chain. The ability to field-swap a CPU unit onto an existing heat-pipe unit also lowers cost of ownership when compared to one-piece conductive interfaces.

Figure 4 compares Advanced Digital Logic's heat pipe with several alternative spreader/fan and conventional heat-sink solutions. The heat pipe (shown in light blue) delivers nearly the performance of a conventional heat sink with a large fan (shown in blue), but without requiring the airflow or the physical size for the fan. In fact, the heat pipe outperforms many thermal solutions and does not require extensive installation and alignment to perform well.

The greater the differential in temperature, the better the heat pipe performs. Figure 4 shows the heat pipe beat the one-piece spreader/fan solutions in the first minutes quite clearly.

A heat pipe will have better final temperature than most one-piece solutions due to the fact that sufficient temperature rise is needed to overcome the vaporization energy of water, which is quite high.

Pick the right solution

OEMs who partner early in the integration process with their suppliers will find they can save considerable money over the life of their systems when using effective thermal solutions. Traditional thermal solutions may be inadequate at handling the power requirements and heavy loading of new embedded system designs. Mounting and planar alignment are real issues that need real solutions. The good news is solutions are available in the form of cool-bearing fan sinks, reliable sealing technology, and flexible heat pipes. For small form factor designs, look to fan sinks and soldered-interconnect heat-pipe solutions to keep systems running longer and cooler.

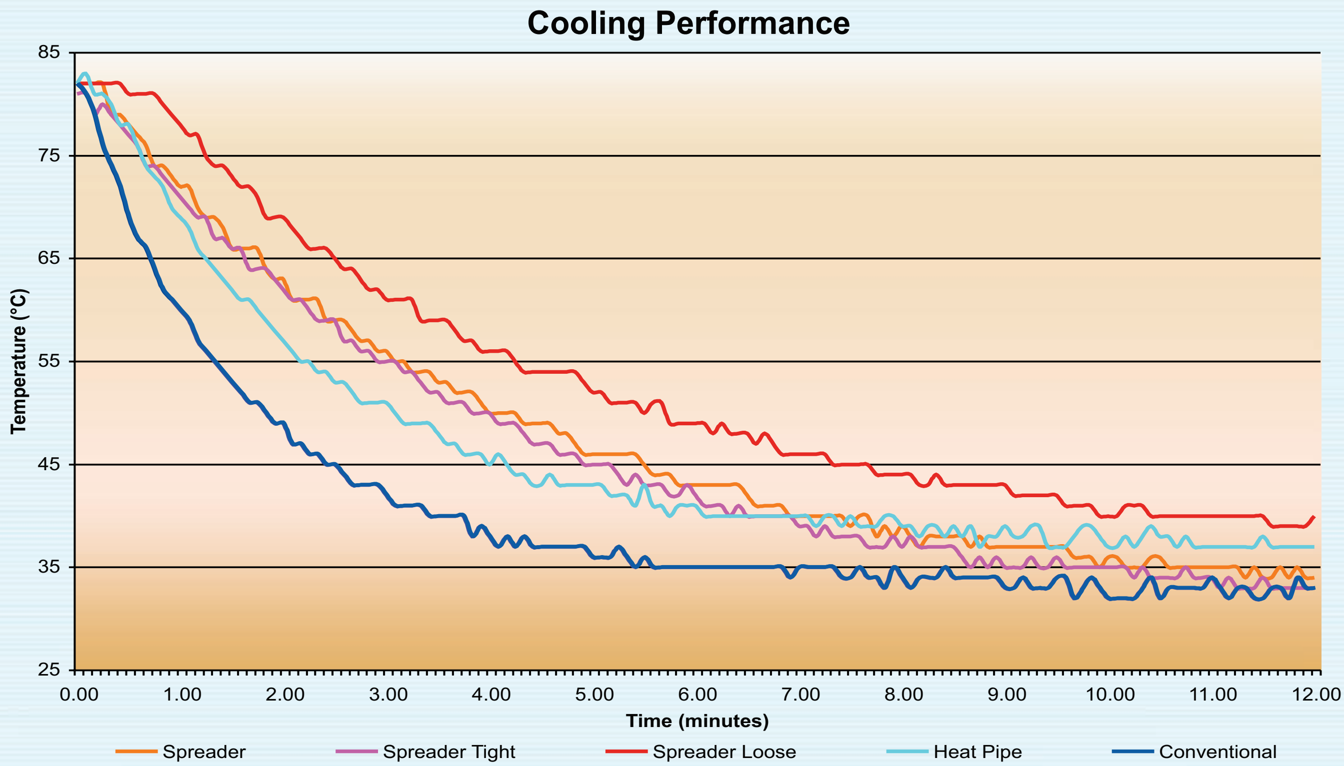

Figure 4

Martin Mayer *is currently the head of Research and Development for Advanced Digital Logic. With more than a decade of experience in the embedded sector, starting with writing platform-independent management code for echo cancellers to control code for oil-field applications, he joined Advanced Digital Logic in 1999. Martin earned a BS/CS with Math and Physics minors from Sonoma State University in 1995.*

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