A friend was having a problem with her computer. Every few hours, the system would reboot itself for no apparent reason. She tried the obvious solutions: adding an uninterruptible power supply and running the modem line through a surge suppressor. When the problem still did not go away, she took the system back to the store where she bought it. When she picked it up a few days later, the store owners handed her the active heat sink—a single-fan extruded cooler for a socketed Pentium µP—that they had removed from her computer. This heat sink has a Teflon-like interface material on the bottom. The interface material was shiny in spots, which the shop owners explained was due to overheating of the µP. The store owners had replaced this heat sink with a more reliable model and used a dielectric thermal compound between the new heat sink and the µP. Her computer has run reliably ever since.

As devices become more complex, they need more power to operate, and the need to dissipate heat from the devices increases. Off-the-shelf and custom heat sinks can help dissipate the extra heat, but they are only part of the overall thermal-transfer path. For sufficient heat dissipation through the heat sink, heat must be able to travel from the device through a thermally conductive path to the heat sink. Design considerations that omit this thermally conductive path can cause a device to become overheated, leading to premature failure or long-term reliability problems, such as the above-described experience.

For heat to transfer efficiently from the device to the heat sink, the two solid mating surfaces must be in intimate contact. Most electronic components, however, have sufficient surface unevenness to allow less than 1% contact between the device and the heat sink. The air separating the remaining 99% of the surface is a poor heat conductor. In fact, this dead air space is about the worst conductor of heat available in nature.

The thermal path between a device and a heat sink improves with the use of a metal screw or a clip, an interface material that may or may not bond the two parts together, or even a solder path on the pc board. Tapes and adhesives are good traditional alternatives to screws and clips. Often, tapes and adhesives have good thermal-transfer properties, and you can preapply these products to the heat sink. Heat sinks that you mount using tape or adhesive usually sit atop the semiconductor package.

Ultimately, applications demand different interface paths and heat-removal methods, depending upon process requirements, ease of assembly, and the overall thermal requirements of the project. The selection tree in Figure 1 serves as a guide for choosing the most appropriate interface material.
Select a thermal-interface material

Thermal-interface materials reduce the air gaps between a device and a heat sink. A number of materials with varying mechanical and electrical properties, including thermal greases, thermal adhesives, thermally applied compounds, double-sided thermal tapes, and thermal-interface pads, eliminate these air gaps.

Thermal greases provide a good, cost-effective thermal interface for applications that don't require physical adhesion of the heat sink. This traditional method of interfacing can be messy to apply, and some compounds include silicone, which has a tendency to migrate and contaminate electronic assemblies and reflow solder baths. Greases can dry out over time, reducing the reliability of the overall package. Grease also can be a problem in volume-production applications. The application thickness of grease is difficult to control and can lead to problems in the field.

Thermal adhesives bond the heat sink to the heat-generating device or other material. Adhesives can be epoxy or acrylic and electrically conducting or nonconducting, and they have different drying and curing properties. Because adhesives are difficult and messy to apply, heat-sink manufacturers often pre-apply the adhesives to another interface material.

Thermally applied compounds, which comply with any surface voids or irregularities through a phase-change process on heating, also eliminate air voids. Unlike grease, however, these compounds cure to a rubber film. This film eliminates many of the problems associated with thermal greases. Commercial hot-stamping equipment can apply some compounds, and there is little mess associated with any of these compounds. The lack of silicone eliminates contamination problems. The thermal resistance of these compounds is similar to that of grease. Application of these compounds often requires a preheated heat sink, complicating the assembly procedure.

Double-sided thermal tapes offer good thermal characteristics and adhere the heat sink to the device. Easy-to-apply, double-sided tapes also can serve an electrical-isolation function. A fully insulating film in some tapes ensures electrical isolation of the heat sink from the semiconductor. Electrically conductive coatings provide the opposite function. Thermal tapes require no curing time and need no mechanical support to provide thermal or physical contact between the device and heat sink.

Although tapes appear to be the most convenient thermal-interface method, they provide little better thermal conductivity than a dry joint. In addition, the adhesive qualities of double-sided thermal tapes are only as good as the precleaning process you use on the two mating surfaces. You typically use isopropyl alcohol or some other solvent to prepare the surface.

Thermal-interface pads are similar to double-sided thermal tapes but are thicker and often include other characteristics to improve the performance of the device-and-heat-sink assembly. Like tapes, interface pads can be conductive or insulating. A typical application of thermal-interface pads is in discrete power devices for which electrical isolation is necessary. Some pads also compensate for thermal distortion of the semiconductor. Other, more elastic pads fill large gaps between the device and the heat sink, conforming to uneven surfaces. In some cases, the interface pads come without adhesive for applications that use other attachment methods, such as screws or clips, and when later removal of the pad is a concern.

Maintain the proper contact pressure

All of these interface materials operate by reducing the contact resistance between the surface of the heat source and the heat sink. These materials fill the voids and gaps created by an imperfect
surface finish of the device and the heat sink, forcing air out and improving surface contact and the conduction of heat across the interface. Although most thermal-interface materials offer little thermal resistance, you must include this resistance when thinking about the thermal resistance of the heat sink. Table 1 shows the resistance of some commercially available materials.

The performance of the material, measured in thermal resistance, varies with the contact pressure. The thermal resistance of interface pads strongly depends on the mounting pressure, and fasteners or springs must maintain this mounting pressure. Interface materials also vary in reliability under various conditions, such as one-time high-temperature exposure, thermal cycling, aqueous cleaning, changes in humidity, and exposure to fungus.

Numerous authors have investigated the thermal properties of interface materials (Reference 1). The best performing material was zinc-oxide grease because grease not only conforms to the roughness of the mating surfaces, but also flows to form an extremely thin coating—often less than 0.001 in. Boron-nitride-filled film and alumina-filled film offer excellent intrinsic thermal properties. However, these materials produce unusually high resistance because the contact pressure is too small to force out all the trapped air at the interface.

The performance difference between the manufacturer's listed thermal resistance and the observed thermal resistance in an application was due to mounting pressure gradients, severe warping of one of the surfaces, heat-density gradients, and variations in junction temperatures. Additional experimentation shows that an interface material requires only contact pressure to initially conform to the mating surfaces, and pressure losses over time do not affect the performance of the material. In typical microelectronics packaging applications, the contact pressure ranges from 10 to 50 psi. However, many interface manufacturers rate their products at pressures as high as 350 psi. Care is necessary to ensure that the attachment method is compatible with the interfacing parts.

**Measuring performance**

Figure 2 shows the thermal resistance as a function of contact pressure for several materials. As expected, the thermal resistance decreases as the pressure increases. Generally, the resistance at a low application pressure is three times the published manufacturer's data. (The manufacturer in this case is the producer of the raw material.) All of the materials perform better than the bare surface contact except for Material B. This result is due to the thickness variations between the manufacturer's and the measured data. The material tested was 50% thicker than specified by the manufacturer. Materials A and C help to significantly reduce the interface resistance at low contact pressure. Thermal grease shows the lowest resistance, and its performance is virtually independent of the contact pressure.

The results show that data collected using high contact pressures provide an inaccurate representation of interface-material resistance in the typical pressure range in microelectronics-packaging applications. The measured results at low pressures are approximately three times the published values. Thermal properties of the materials change with changes in surface finish, contact pressure, and application techniques. Any air trapped in the application of the interface material increases thermal resistance. Application of the thermal material, therefore, becomes a critical part of the thermal design.

Attaching the heat sink to the device using a screw or slip results in a package with good thermal-transfer capabilities. The force that a screw or a clip generates forces the surfaces into contact, which improves the thermal-transfer characteristics. The magnitude of this force is directly proportional to the overall conductivity of the interface. Screws and clips also provide a secure physical connection between the device and the heat sink. Screws require a corresponding screw
hole in the device, which is not always available. The use of screws and their related nuts or threaded inserts can add substantially to the cost of assembly as well as to the potential for assembly problems. You must set the proper torque at installation and maintain this torque on the screws to achieve the desired mounting pressure and thermal resistance.

**Screws and clips aid thermal transfer**

Spring clips require no screw holes, so they are more broadly applicable, and clips can be inside the heat sink (Figure 3). To assemble a board using this type of heat sink, you must first insert the device into the clip and then solder the device to the board. Because of the physical constraints in this type of heat sink, each heat sink works with only one type of device.

External clips are easy to use and remove. Preparing the clip attachment to the heat sink is the most important part of designing this type of assembly. Careful design allows for manufacturing tolerances yet still maintains sufficient contact pressure at the interface. Assembly personnel typically hand-install this type of clip. If the contact pressure is high, the amount of force required to install the clip may demand a special tool or a complete assembly fixture for a successful and repeatable installation.

A new style of surface-mounted heat sink that can help to cool new, higher power surface-mount components comes in tape-and-reel format. This tape-and-reel packaging is similar to other surface-mount devices allowing automated placement by surface-mount equipment. In a departure from traditional attachment methods, these heat sinks use the solder mask to attach the heat sink to the board and to provide thermal transfer from the device to the heat sink (Figure 4). A widened copper pad underlies both the device and the heat sink. Additional solder masks provide connection points for the feet of the heat sink. Heat passes from the back of the device through the attachment via the solder contact into the heat sink, providing significant thermal transfer.

The overall design of some surface-mount heat sinks allows compact system design. The design in Figure 4 allows tight packing of board components under the "wings" of the heat sink. This design also allows a short board-to-board distance for multiple board systems.

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**REFERENCE**

1. *Early, Malcolm; Seri Lee, PhD; and Mark Pellillo, Thermal performance of interface materials in microelectronics packaging applications*, Aavid Thermal Technologies Inc, Laconia, NH.