# Technology Review:

## Reducing Spreading Resistance in Heat Sinks

Qpedia continues its review of technologies developed for electronics cooling applications. We are presenting selected patents that were awarded to developers around the world to address cooling challenges. After reading the series, you will be more aware of both the historic developments and the latest breakthroughs in both product design and applications.

We are specifically focusing on patented technologies to show the breadth of development in thermal management product sectors. Please note that there are many patents within these areas. Limited by article space, we are presenting a small number to offer a representation of the entire field. You are encouraged to do your own patent investigation. Further, if you have been awarded a patent and would like to have it included in these reviews, please send us your patent number or patent application.

In this issue, our spotlight is on reducing thermal spreading resistance in heat sinks. There is much discussion about its deployment in the electronics industry, and these patents show some of the salient features that are the focus of different inventors.

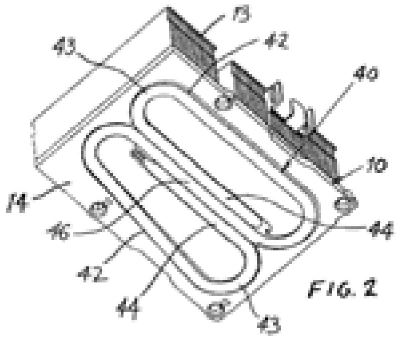
**Heat Sink Base Plate With Heat Pipe,**
US 8,286,693 B2, Whitney, B., et al.

According to the invention, a base plate for a heat sink is provided with an open channel in one surface, cooling fins on the opposite surface, and a heat pipe arrangement nested in the channel. The channel has at least one first or remote region with a first width, and a second or central region having a second width which is greater than the first width. The heat pipe arrangement has at least two evaporator sections juxtaposed side by side in the central region of the channel, and two condenser sections in respective remote regions of the channel. The evaporator sections are brought into direct contact with an object to be cooled, typically a CPU, so that the higher thermal resistance offered by an intervening metal plate is eliminated.

The heat pipe arrangement may be formed as discrete heat pipes, or as a single heat pipe, which may be in the form of an S having a center section and hooked ends which form the evaporator sections.

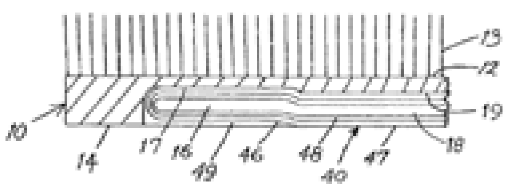
By having multiple evaporator sections juxtaposed in the central region of the channel, and multiple

| PATENT NUMBER | TITLE | INVENTORS | DATE OF AWARD |
|---|---|---|---|
| US 8,286,693 B2 | HEAT SINK BASE PLATE WITH HEAT PIPE | Whitney, B., et al | Oct. 16, 2012 |
| US 8,299,590 B2 | SEMICONDUCTOR ASSEMBLY HAVING REDUCED THERMAL SPREADING RESISTANCE AND METHODS OF MAKING SAME | Rahman, Arifur | Oct. 30, 2012 |
| EP 1 647 171 B1 | THERMAL DIFFUSION APPARATUS | Barry, A., et al | Nov. 12, 2012 |

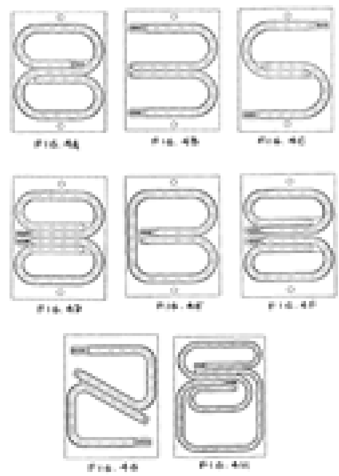



condenser sections in respective remote regions of the channel, thermal characteristics allowing heat spreading comparable to that of a vapor chamber are obtained, while allowing multiple cost, weight, and performance trade-offs, e.g. the use of lighter and less costly aluminum in place of copper for the base plate.

Heat transfer in the evaporator sections is maximized by providing the central region of the channel with a rectangular cross-section, and flattening the heat pipe sections in this region so that they have a rectangular profile with a collective width which is the same as the width of the central region of the channel.



According to another aspect of the invention, the portions of the heat pipe in the central region are coplanar with the bottom surface of the base plate, whereas the portions of the heat pipe in the remote regions are recessed from the bottom surface. This assures that the machining operation which is performed to achieve coplanarity of the evaporator sections cannot render the tubing wall too thin in other areas, which could cause leakage at an imperfection in the grain structure. The thinner wall section of the heat pipes produced by machining the exposed surfaces of the evaporator sections also improves the efficiency of the device, because the effective thermal conductivity of the evaporating



fluid is vastly higher than that of metal. For example, while copper has a thermal conductivity of 380 W/m-° K., evaporating water has an effective thermal conductivity in excess of 10,000 W/m-° K. Thus, reducing the wall thickness of the heat pipe, which is typically about 0.5 mm, by up to 50%, further improves the rate of heat transfer from the CPU to the fluid.

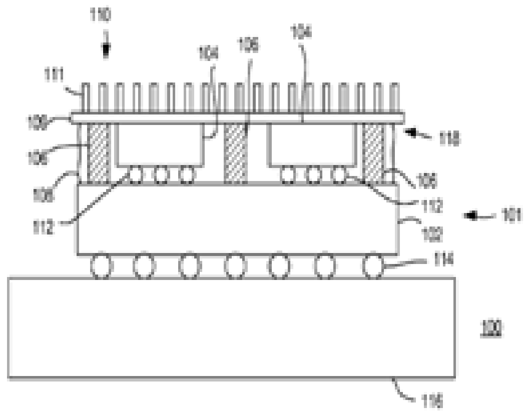
According to a further aspect of the invention, the base plate serves as a forming die for the heat pipe. That is, the heat pipe is first bent to a shape corresponding to the channel machined in the base plate, and the heat pipe or heat pipes are placed in the channel. At this point the heat pipe still has a substantially round profile throughout. A platen with raised sections corresponding to remote regions of the channel is then brought to bear against the bottom surface of the base plate, thereby deforming the heat pipe to form desired cross-sectional profiles. The heat pipe is then soldered or bonded in place, and the bottom surface is milled to provide the coplanarity which assures good thermal contact with the device to be cooled.

**Semiconductor Assembly Having Reduced Thermal Spreading Resistance and Methods of Making Same,**
US 8,299,590 B2, Rahman, Arifurl

As semiconductor technology has advanced, the amount and speed of logic available on an integrated circuit (IC) has increased. As a result, ICs are consuming more power. The more power that is consumed, however, the greater the heat that is generated. Conventionally, ICs include devices such as heat sinks to absorb and dissipate heat. A heat sink is an article that absorbs and dissipates heat from an IC using thermal contact. For conventional ICs, heat sinks are thermally coupled to the face side of the die. For flip-chip mounted ICs, heat sinks are thermally coupled to the backside of the die. Heat sinks are typically attached to ICs using a thermal paste. The term "face side" denotes the side of an IC die that receives the bulk of semiconductor processing such that circuitry and interconnect are fabricated on that face side. The backside is opposite the face side of the die.

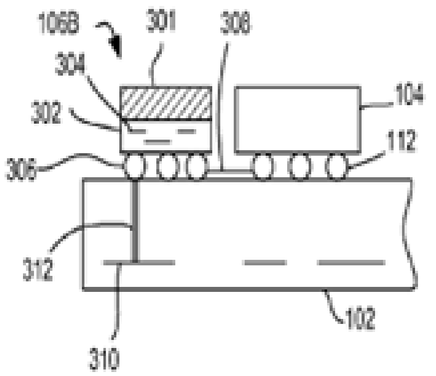
For a flip-chip IC, for example, the primary heat removal path is through the backside of the die, where a heat sink is attached. Heat is dissipated through several mechanisms, including: (1) vertical heat conduction to the backside of the die and to the heat sink; (2) vertical heat conduction through the die, as well as lateral heat conduction within the base of the heat sink and thermal paste (i.e., heat spreading); and (3) heat convection to the ambient environment. Lateral heat conduction in item (2) depends strongly on the ratio between die area and heat sink base area. When estimating the thermal resistance of a flip-chip package with a heat sink, engineers must account for the spreading resistance (a thermal resistance). The higher the ratio between heat sink base area and die area, the higher the spreading resistance.

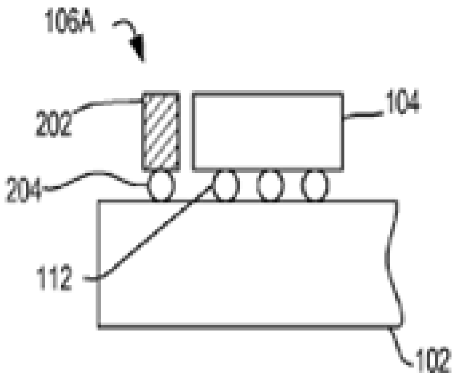
The increase in the speed and amount of logic on an IC has outpaced the number and performance of input/output (I/O) connections. As a result, IC die stacking techniques have received renewed interest to address the interconnection bottleneck of high-performance systems. In stacked IC applications, two or more ICs are stacked vertically and interconnections are made between them. One approach to IC stacking involves mounting a second die on the backside of a first die. The stacked IC




arrangement is then flip-chip mounted/packaged. A heat sink is then attached to the stacked die or dice.

When a die or dice are stacked on the backside of an IC, the thermal design of the IC may be compromised. For example, if stacked IC dice occupy a total area smaller than the area of the primary IC, there are additional components to spreading resistance. One such component is due to the interface between the primary IC die and the stacked die or dice. Another such component is due to the interface between the stacked die or dice and the heat sink. These additional spreading resistance components lead to poor thermal design and higher junction-to-package thermal resistance. Accordingly, there exists a need in the art for a semiconductor assembly having reduced thermal spreading resistance and methods of making
The semiconductor assembly 100 includes a semiconductor device 101, a heat extraction element 110, and a package substrate 116. The semiconductor device 101 includes a primary integrated circuit (IC) die 102 (also generally referred to as a first IC die) and at least one secondary IC die 104 (also generally referred to as at least one additional IC die). The primary IC die 102 includes circuitry formed on a semiconductor substrate and conductive interconnect formed over the circuitry. Likewise, each secondary IC die 104 includes circuitry formed on a semiconductor substrate and conductive interconnect formed over the circuitry. The primary IC die 102 and each




secondary IC die 104 may be fabricated using well known IC fabrication techniques. The primary and secondary IC dice 102 and 104 may comprise any type of digital, analog, or mixed-signal ICs.

The semiconductor device 101 is mounted on the package substrate 116 via an array of bump contacts 114. Notably, the array of bump contacts 114 is formed on a face side of the primary IC die 102. As discussed above, the term “face side” denotes the side of a die that receives the bulk of semiconductor processing such that circuitry is fabricated on that face side of the die. The side of a die opposite the face side is referred to as the backside of the die. The bump contacts 114 form an electrical and mechanical connection between the primary IC die 102 and the package substrate 116. The package substrate 116 may comprise any type of carrier capable of supporting the semiconductor device 101, such as a printed circuit board (PCB) or the like. The primary IC die 102 is mounted face-down on the package substrate 116 in flip-chip fashion.

Each secondary IC die 104 is mounted on the primary IC die 102 such that the secondary IC die 104 is vertically stacked with the primary IC die 102. In the present embodiment, each secondary IC die 104 is mounted to the backside of the primary IC die 102. In general, the surface of the primary IC die 102 upon which the secondary IC die 104 is mounted is referred to as the first surface of the primary IC die 102. Each secondary IC die 104 is mounted on the primary IC die 102 via bump contacts 112. The bump contacts 112 form an electrical and mechanical connection between each secondary IC die 104 and the primary IC die 102. In the present embodiment, each secondary IC die 104 is mounted face-down in flip-chip fashion.

**Thermal Diffusion Apparatus,**
EP 1 647 171 B1, Barry, A., et al.

Thermal diffusion apparatus 10 includes substrate 12 and insert portion 14 disposed therein. Substrate 12 includes a first side surface 18 and a second generally opposing side surface 20 defining a thickness "t" there between. The thickness "t" of substrate 12 defines a planar boundary thereof.

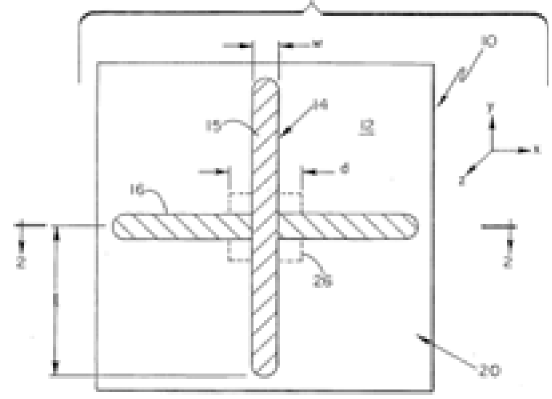
Insert portion 14 is preferably disposed in substrate 12 so as not to extend beyond the planar boundary of substrate 12 defined by thickness "t". As will be described in greater detail below, it is an important aspect of the present invention that insert portion 14 be configured so as not to extend beyond the planar boundary of substrate 12. In particular, apparatus 10 of the present invention is specifically configured so as to be adaptable to a wide variety of thermal dissipation applications. In other words, a substantially planar configuration for apparatus 10 is preferred for its ease of applicability to a wide variety of heat generating devices, as well as a wide variety of heat sink bodies.

In preferred embodiments of the present invention, apparatus 10 is operably and thermally coupled to a heat generating component such as at 24 for thermal diffusion therefrom. Heat-generating component 24 may be, for example, a microprocessor, a semi-conductor element, or any other heat-producing electronic component that is typically mounted on a printed circuit board 30 or the like. Apparatus 10 may be directly coupled to component 24, but is more typically thermally coupled to component 24 via a thermally-conductive adhesive or wax material that are well known in the art. Such an adhesive or wax material forms a thermally conductive interface between apparatus 10 and component 24. In preferred embodiments of the present invention, however, apparatus 10 is operably positioned in as near proximity to component 24 as possible to minimize thermal impedance effects of the thermal interface material.

In operation, heat-generating component 24 generates excess thermal energy, such that the body of component 24, as well as the immediately surrounding environment thereof is driven toward elevated temperatures. In the embodiment illustrated in Figure 2, at least a portion of such excess thermal energy is conducted through the laws of thermal dynamics to a body having a relatively greater thermal potential than component 24. Accordingly, excess thermal energy is drawn through a thermally conductive interface between apparatus 10 and component 24, and correspondingly into apparatus 10. Such thermal transfer results in a thermal footprint 26 at first surface 18 of apparatus 10, which thermal footprint generally corresponds to the thermally transmissive surface area at the interface between apparatus 10 and component 24. Preferably, therefore, apparatus 10 distributes and diffuses the thermal energy imparted onto it at thermal footprint 26.

In preferred embodiment of the present invention, substrate 12 of apparatus 10 is preferably operably coupled to a heat sink 32, which preferably includes a relatively large surface area for effective heat

Fig.-1



dissipation therefrom. Heat sink 32 is preferably a distinct finned element that is operably and thermally coupled to second surface 20 of substrate 12 through a thermally conductive adhesive or wax material. In other embodiments, however, heat sink 32 may be integrally formed with, and a portion of, apparatus 10. Of course, a wide variety of heat sink configurations are contemplated for use in and with the present invention, with the only limitation of the configuration of heat sink 32 being its adaptability to second surface 20 of substrate 12.

As described above, a desired functionality for apparatus 10 is to quickly and efficiently draw excess thermal energy from component 24, and to transfer such thermal energy to heat sink 32 for ultimate dispersal therefrom. In conventional systems of the prior art, thermal energy drawn from thermal footprint 26 is not effectively distributed to portions of the heat spreader plate distal from thermal footprint 26. As a result, transfer of thermal energy in prior art systems has been undesirably confined to a relatively small portion of the thermally coupled heat sink which therefore diminishes overall efficiency and efficacy of a thermal draw system.

Apparatus 10 of the present invention overcomes such drawbacks by incorporating a relatively highly thermally conductive insert portion 14 in substrate 12, and particularly adjacent to thermal footprint 26 in substrate 12. Preferably, at least a portion of

insert portion 14 is in immediate thermal contact with the heat source of component 24, in that at least a portion of insert portion 14 is positioned in substrate 12 at thermal footprint 26. Accordingly, thermal energy imported upon substrate 12 at footprint 26 is quickly and efficiently dispersed throughout substrate 12 via highly thermally conductive insert portion 14. In addition, insert portion 14 acts to quickly draw excess thermal energy from thermal footprint 26 at first surface 18 of substrate 12 toward second surface 20 thereof for subsequent transfer to heat sink 32. Such expedient heat transfer draws sufficient excess thermal energy away from component 24 so as to prevent component 24 from overheating.
Insert portion 14 is fabricated from a relatively highly thermally conductive material having a thermal conductivity of at least 1.5 times that of substrate 12 in at least two axial directions of insert portion 14. A particular example of a material useful in insert portion 14 is highly oriented pyrolytic graphite (HOPG), which has an anisotropic thermal conductivity characteristic. Specifically, HOPG has a thermal conductivity value of 1500 watts/m-k in two axial directions, and about 50 watts/m-k in the third axial direction. By comparison, materials typically utilized for substrate 12 have thermal conductivity values between about 100 and 400 watts/m-k.

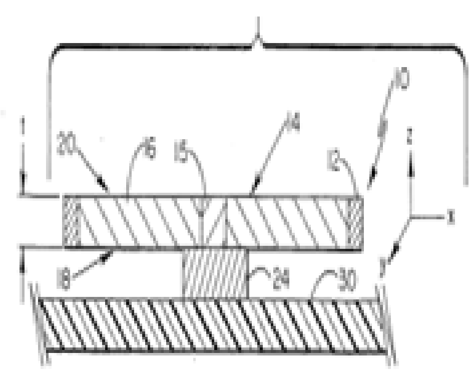
In embodiments of the present invention incorporating HOPG for insert portion 14, the HOPG material is preferably oriented so as to provide relatively high levels of thermal conductivity along the "z" axis, and one of the "x" or "y" axes. In such a manner, thermal energy passing from component 24 to apparatus 10 is quickly drawn from first side 18 toward second side 20 along the z axis, as well as along one of the x or y axes to further distribute thermal energy to distal portions of substrate 12.

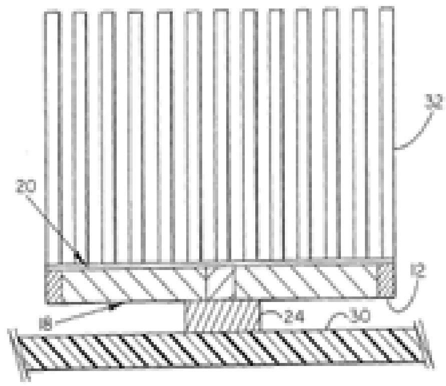
In a particularly preferred embodiment of the present invention, insert portion 14 incorporates at least two distinct pieces 15, 16 of the HOPG material, which distinct pieces 15, 16 are specifically oriented to provide a desired level



of thermal spreading to portions of substrate 12 distal from thermal footprint 26. In particular, HOPG insert piece 15 is oriented to provide about 1500 watts/m-k of thermal conductivity along the y and z axes, while HOPB insert piece 16 is oriented so as to provide 1500 watts/m-k along the x and z axes. Through such an embodiment, thermal energy at thermal footprint 26 is quickly spread in all three axial directions throughout substrate 12. Consequently, thermal transfer from heat-generating component 24 to heat sink 32 is made considerably more efficient than that of conventional systems.

Due to the relatively high cost of highly thermally conductive materials, it is a preferred aspect of the present invention to minimize the amount of such material incorporated into apparatus 10, while maintaining a desired degree of thermal diffusion properties. As such, it has been determined that specific configurations of insert portion 14 provide the most preferred balance between cost and performance. In particular, insert portion 14 includes one or more arms extending radially outwardly within the planar boundary of substrate 12 and from a location in substrate 12 immediately adjacent to, and in thermal contact with, thermal footprint 26. Most preferably, at least a portion of insert portion 14 is superimposed over thermal footprint 26 at first side 18 of substrate 12. Though insert portion 14 of the present invention is illustrated as extending substantially through thickness "t" of substrate 12, it is contemplated by the present invention to extend insert portion 14 between about 10% and 100% through thickness "t" from first side 18 of substrate 12.




According to the invention the respective radial arms of insert portion 14 have a lateral width "w" of between about 30% and about 70% of diameter "d" of thermal footprint 26 generated by component 24. In addition, the length "l" of the respective radial arms of insert portion 14 is greater than about 150% of diameter "d" of thermal footprint 26.

As described above, insert portion 14 is fabricated from a highly thermally conductive material having a thermal conductivity value of at least 1.5 times that of substrate 12, and more preferably at least 2.5 times that of substrate 12. A particularly preferred material for use in insert portion 14, as described above, is HOPG, which provides a high level of thermal conductivity while being relatively easy to manufacture and manipulate into desired configurations. However, a variety of highly thermally conductive materials may be utilized in insert portion 14 in the present invention. Such materials include, for example, diamond, pitch-based graphite, aluminum, copper, and copper-tungsten alloy.

Substrate 12 of the present invention is preferably fabricated from commonly-utilized thermally conductive materials such as copper, copper-tungsten alloy, aluminum, silver, gold, alumina, aluminum nitrite, boron nitrite, epoxy, and various engineering thermoplastics. It is a preferred aspect of the present invention that the material selected for insert portion 14 have a thermal conductivity value of at least 1.5 times that of the material selected for substrate 12.

Various manufacturing techniques may be utilized to permanently secure insert portion 14 within substrate 12 for continuous use as a thermal diffusion apparatus that is operably and thermally coupled to one or more selected heat generating devices. One method for securing insert portion 14 to substrate 12 is via high temperature, and preferably thermally conductive, adhesives. However, insert portion 14 may be welded, soldered, or otherwise affixed within pre-cut grooves or apertures in substrate 12.

In some embodiments of the present invention, substrate 12 includes a plurality of insert portions 14 disposed therein, such that a single substrate 12 may be applied to a plurality of heat generating devices 24. In such a manner, substrate 12 may include one or more distinct insert portions 14, as required for particular applications.

The following examples illustrate the enhanced effectiveness of thermal transfer achieved through the utilization of the apparatus of the present invention, as compared to conventional thermal transfer devices, by reducing the thermal impedance between a heat generating device and a heat sink/thermal dissipation structure. Such examples are by no means limiting in scope, in that a wide variety of materials and configurations are contemplated for use by the present invention.

**Example I**

To form the thermal diffusion apparatus, a 1.5" x 1.5" x 0.08" copper substrate and 1" x 0.08" x 0.08" (1 inch=2,54 cm) highly oriented pyrolytic graphite insert portions were obtained. Appropriately-sized slots were milled in the copper substrate, such that two pyrolytic graphite inserts were positioned and secured in the resultant opening within the copper substrate with Bergquist Sterling 7500™ thermally conductive grease acting as the interface between the inserts and the copper substrate. The inserts were positioned in a substantially perpendicular "cross" orientation, with the respective mid-points of the insert portions substantially intersecting with one another. The insert portions were oriented in the copper substrate such that a highly thermally conductive direction characteristic of the insert portions were oriented in a plane perpendicular to a plane of the substrate.

A Motorola IRF-840, TO-220 package, acting as the heat source, was operated at 60 watts and coupled to the thermal diffusion apparatus described above via Bergquist Sterling 7500™ grease. The heat-generating component was positioned on a first side of the thermal diffusion apparatus and superimposed over the intersection of the two pyrolytic graphite insert portions. To the opposing side of the thermal diffusion apparatus was attached a water-circulating chiller via Bergquist Sterling 7500™ grease.

Thermocouples were operably secured to the chiller and the heat-generating component for respective measurement of thermal output and input from the heat-generating component to the chiller. A similar arrangement was provided for comparison purposes, wherein the thermal diffusion apparatus had no insert portions disposed therein, and was simply a 1.5" x 1.5" x 0.08" (1 inch =2,54 cm) copper substrate.

The thermal impedance of the respective thermal diffusion structures were calculated by measuring the temperature differences between the heat-generating device and the chiller, and dividing the result by the power generated by the TO-220 package.

| DIFFUSER | THERMAL IMPEDANCE (°C/W) |
|---|---|
| Copper Only | 0.52 |
| Copper With Inserts | 0.48 |

**Example II**

Thermal diffusion structures with integrated finned heat sink configurations were provided. The heat sink devices were fabricated from aluminum and were 2.4" x 3.2" x 0.75" (1 inch=2,54 cm) in size, with one of the heat sink devices having highly oriented pyrolytic graphite insert portions in an upper side thereof. The heat sink device incorporating insert portions included two such portions, each of which were 1" x 0.12" x 0.08" in dimension, the two insert portions being positioned along the upper surface of the heat sink in a substantially perpendicular "cross" pattern, with the mid-points of each of the insert portions substantially intersecting with one another. To assist in removing heat from the heat sink devices, a 9.18 CFM maximum air flow fan was operated at 4500 rpm to direct such air flow across the fins of the heat sink elements.

TO-220 packages were secured to respective upper surfaces of the heat sink structures via Bergquist Sterling 7500™ grease. The TO-220 package was placed on the insert portion-containing heat sink apparatus at a location substantially superimposing the intersection of such insert portions.

| HEAT SINK | THERMAL IMPEDANCE (°C/W) |
|---|---|
| Aluminum Only | 0.83 |
| Aluminum With Insert Portions | 0.73 |

Temperature measurements were conducted at the TO-220 package (heat generating device) and the distal ends of the respective heat sink fins. Thermal impedance was measured and calculated as described above.