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Most data centers have relied on ambient air cooling solutions (alternating cool and hot rows) to meet their cooling needs. However, ambient air cooling solutions are often unable to handle high heat loads, are not targeted and can be cost and energy inefficient. As high power applications and server densities increase, new ways are needed to dissipate heat.

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Effect of Flow Oscillation

on Enhancing Heat Transfer or a 3D Object

With the increase in heat dissipation of components and management of heat extraction, innovative cooling solutions are proposed on a continuous basis. The active researchers in this area are trying to come up with new technologies to increase the heat transfer and remove the heat from the component at a reasonable cost. One of the techniques that might be useful is flow induced oscillation that enhances the heat transfer. The oscillating flow promises a higher heat transfer rate than a continuous flow and is a good candidate to be deployed in thermal management systems. Even though there have been a lot of articles on the fluid dynamics of the oscillation behind an object, very little work has been done on the heat transfer part of it.

One of the few to have conducted an experiment for simulating the oscillating flow heat transfer is Tae et al [1]. Figure 1 shows the concept behind this experiment. A square-shaped object 15x15 mm is placed in a uniform flow. There is an oscillation imposed on this uniform flow. The unsteady flow can be represented as:

$$U_t = U_0(1 + A\sin 2\pi ft)$$

Where:

U_t = instantaneous velocity, (m/s)

U_0 = time averaged velocity, (m/s)

f =frequency of pulsation, (Hz)

t = time, (s)

The goal is to compare the heat transfer before and after the oscillation.

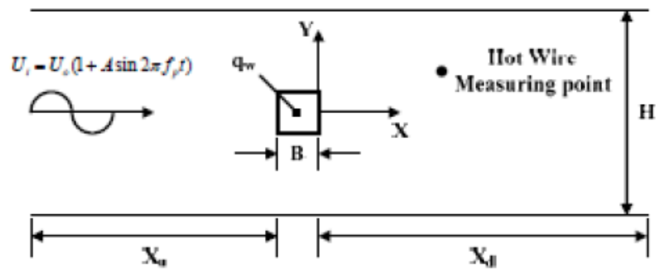


Figure 1- Concept of Oscillating Flow Experiment [1]

Figure 2 shows the schematic of the experiment in more detail

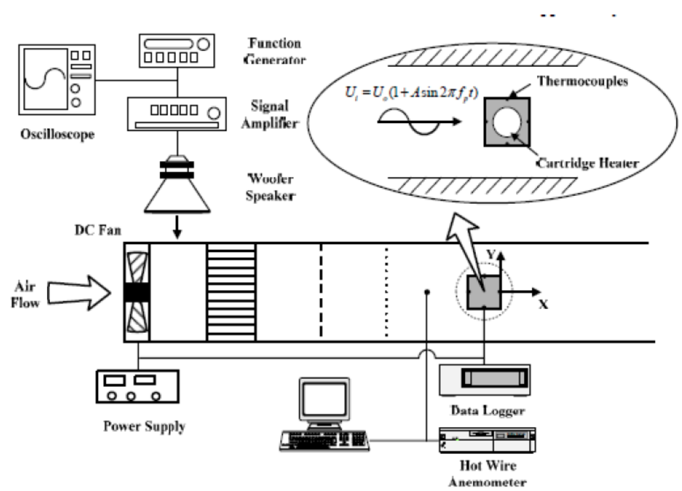
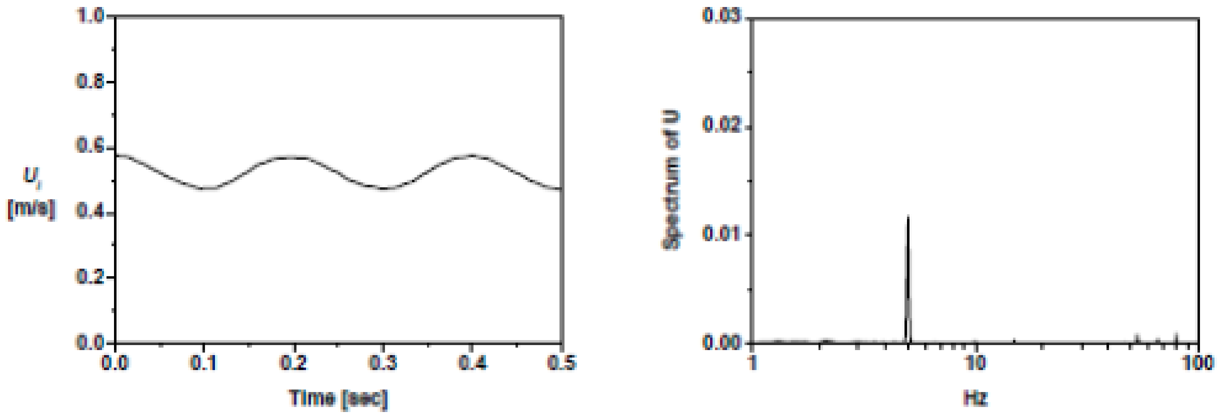
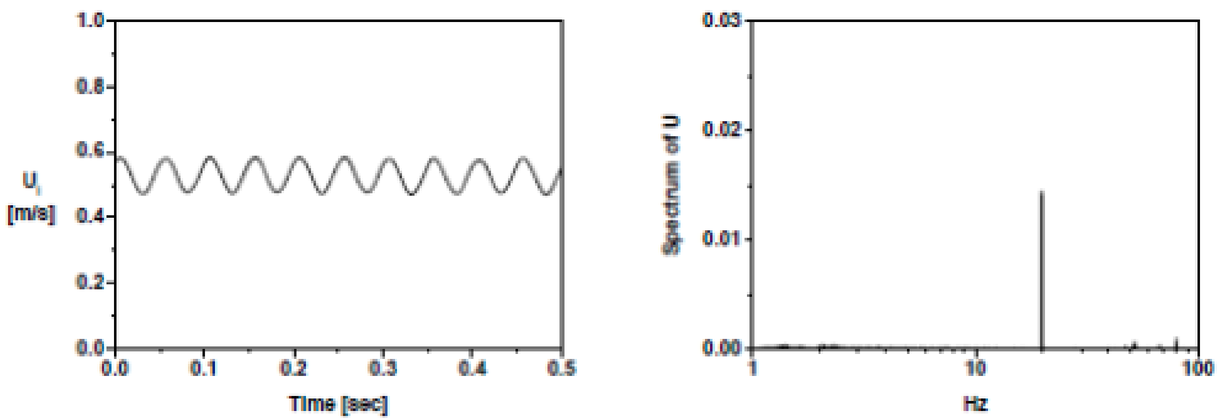


Figure 2- Schematic of the Oscillating Flow Experiment [1]

The flow was generated by a commercial fan and varied from 0.37 m/s to 0.57 m/s. To induce the oscillations, a 300 mm-woofer speaker was installed at the downstream of the fan. A function generator signal was sent to a signal amplifier and the output was fed to the speaker. A honeycomb and two screen meshes were installed at the downstream section of the speaker to make the flow uniform and to reduce the turbulence intensity. The channel width, length and height are 150 mm, 960 mm and 150 mm respectively. A cartridge heater was inserted at the center of the block to generate the heat. To ensure the periodic motion of the flow, a hot wire anemometer was inserted at the upstream of the component and the velocity was measured. Figure 3 shows the sinusoidal motion of the flow and its spectrum. The amplitude of the oscillation was kept fixed at 0.05 m/s. Figure 3a shows the velocity as a function of time at 5 Hz frequency. Its spectrum shows all the oscillation is at one harmonic of 5 Hz. Similarly figure 3b shows the flow and its spectrum at 20 Hz. This proved the flow to be clean at the upstream of the component.



(a) $f_p = 5$ Hz



(b) $f_p = 20$ Hz

Figure 3- Periodic Motion of Flow and Its Spectrum [1]

After the surface temperature of the component reached a steady state, the speaker was turned on and the surface temperature of the component was measured after the temperature got to a steady state. A hot wire anemometer was installed at the downstream of the component to measure the time dependent velocity. Then an FFT (Fast Fourier Transform) was performed on the time dependent data to obtain their spectrum. Figure 4a shows the vortex shedding frequency which happens at the natural frequency fs_0 for the block when the speaker is off. When the speaker is on, the spectrum clearly shows that, in addition to the natural frequency of the vortex shedding, there is another component of frequency which is the frequency of the pulsations of the speaker, which occurs in the wake. This can be seen at Figures 4b, 4c, 4d and 4e for speaker frequency of 9, 10, 20 and 40 Hz. This experiment was done for a Reynolds number of 540.

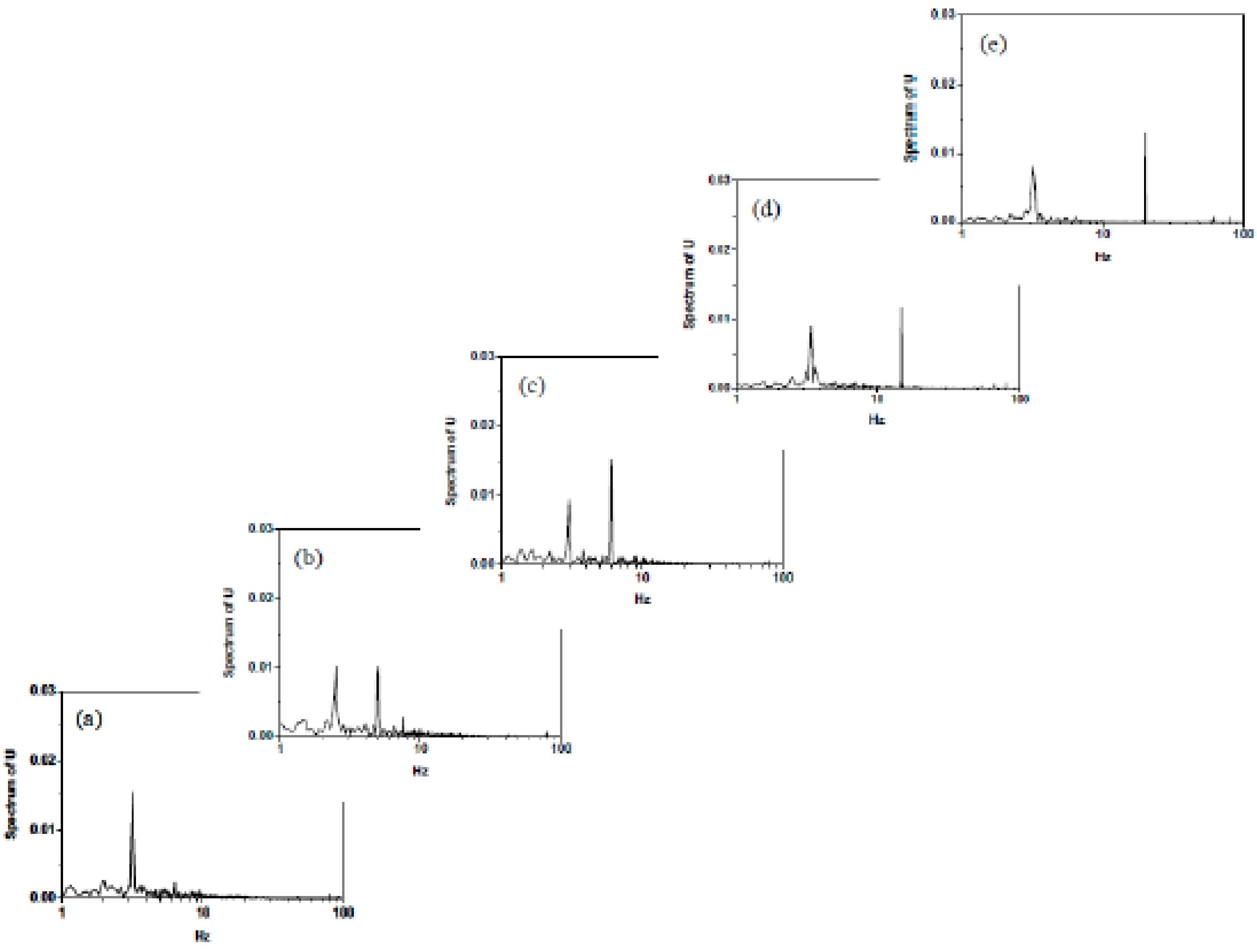


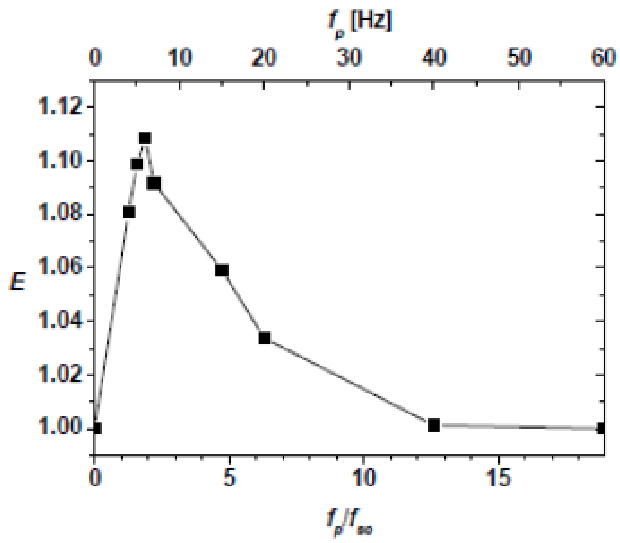
Figure 4- Spectrum of The Flow Induced Oscillations [1]

The measured Nusselt number was calculated based on the heat input and the temperature data as follows:

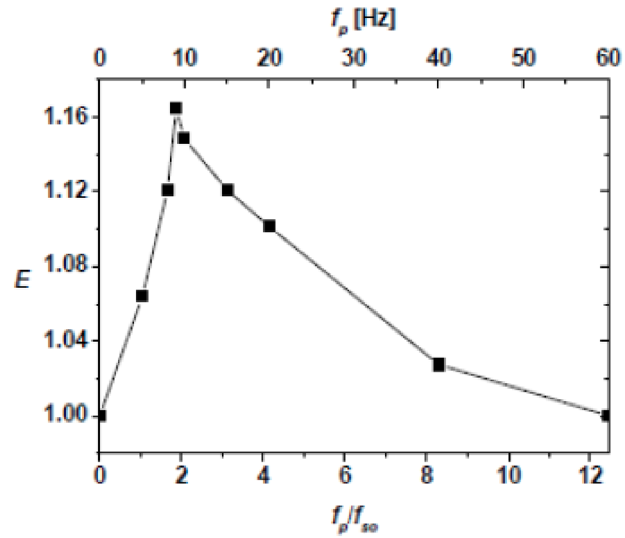
$$Nu = \frac{hB}{K} = \frac{\dot{q}B}{K(T_s - T_f)}$$

Where:
q = heat flux (W/m²k)
K = air thermal conductivity (W/m.k)
B = side length of component (m)
T_s = component surface temperature (ºC)
T_f = air inlet temperature (ºC)

Figure 5 shows the ratio of the Nusselt numbers before and after the imposed oscillation of the speaker, as a function of speaker frequency at two Reynolds number. The data was taken for two Reynolds numbers of 350 and 540. It is interesting to see that the improvement peaks at twice the natural frequency of the vortex shedding. It also can be observed that, as the Reynolds number increases, the improvement also increases. At a Reynolds number of 350 a 10% improvement in heat transfer was realized, while at a Reynolds number of 540 a significant 16% improvement in heat transfer was obtained.



(a) $Re = 350$



(b) $Re = 540$

Figure 5- Heat Transfer Improvement Due To Flow Induced Oscillations [1]

In a recent paper, Sung et al [2] conducted an experiment on a natural convection micro fin structure enhanced by acoustic vibration. Figure 6 shows the schematic of the experiment. They placed two micro fin heat sinks back to back and rested it in a rectangular chamber covered on top by a mesh screen. A 50 mm woofer loud speaker was placed at 10.25 mm from the fin structure. Thin film resistive heaters were attached to the backside of the heat sinks using a metal deposition and etching process.

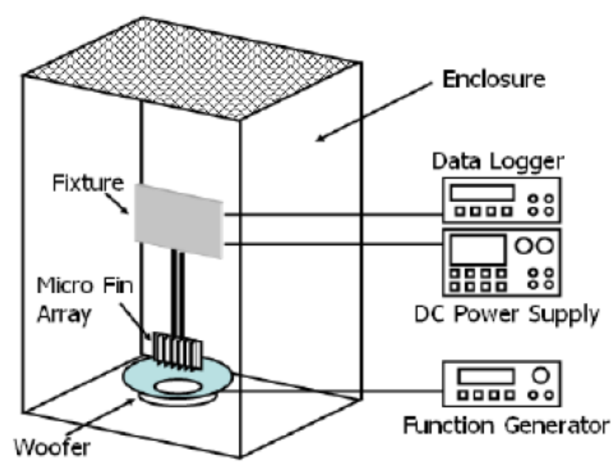


Figure 6- Natural Convection Experiment with Loud Speaker Excitation [2]

The size of the box was 300 mm height, 200 mm width and 200 mm depth. The dimensions of the microstructure are shown in table 1.

	H [μm]	S [μm]	L [mm]	W [mm]	Total area [m^2]
Array 1	100	160	10	16	0.0006712
Array 2	200	260	10	16	0.0007752
Array 3	200	160	10	16	0.0009912

Table 1- Dimensions of the Microstructure Heat Sink [2]

Where H is the height of the fins perpendicular to the flow, L is the length of the fins and S is the spacing between fins. Figure 7 shows the enhancement of the heat transfer coefficient as a function of excitation frequency. The figure shows that at a non-dimensional frequency of 0.011, the enhancement has peaked. The authors argue this might be due to the damping effect of the woofer rather than resonance effect.

Where

$h_c = h_t - h_r$ where h_c is convective heat transfer coefficient
h_t = total heat transfer coefficient
h_r = radiation heat transfer coefficient

And the non-dimensional frequency is defined as:

$$\omega = \frac{fH^2}{\alpha}$$

Where

f = frequency of vibration
α = Thermal diffusivity of air (m^2/s)

Figure 8 shows the enhancement of the heat transfer coefficient as a function of amplitude. The figure shows that the enhancement increases monotonically with amplitude.

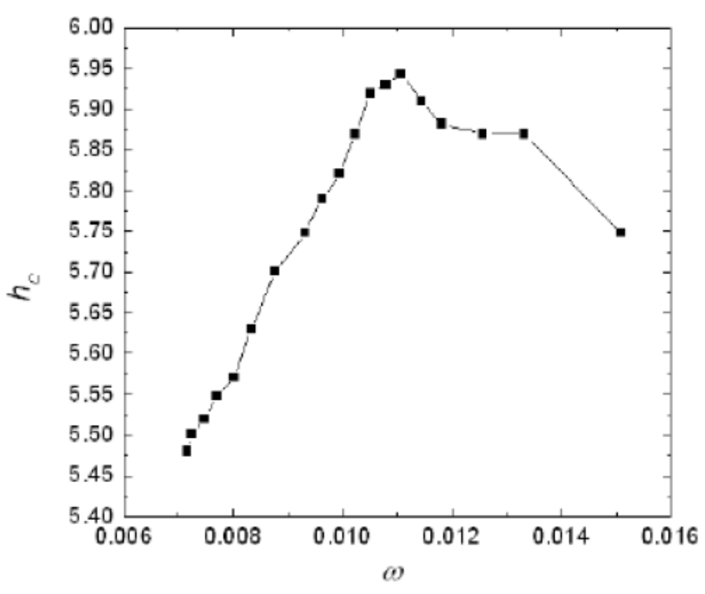


Figure 7- Heat Transfer Enhancement as a Function of Frequency[2]

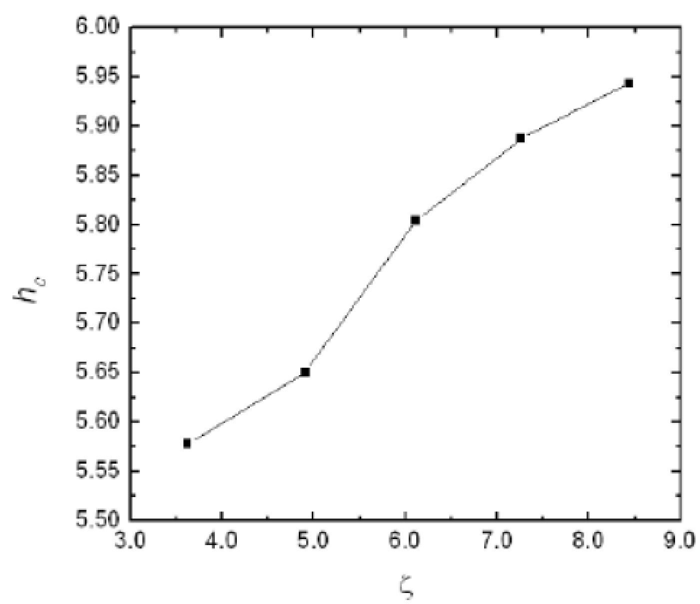


Figure 8. Heat Transfer Enhancement as a Function of Amplitude [2]

Where,

$$\zeta = \frac{AL}{\alpha}$$

A = Amplitude of velocity fluctuations (m/s).
L = length of the heat sink (m)

Figure 9 shows the ratio between heat transfer coefficients before and after the oscillation for different heat inputs (Rayleigh numbers). It also shows that the enhancement increases with the rise of heat dissipation. The acoustic interaction with the boundary layer enhances the mixing thus increasing the heat transfer.

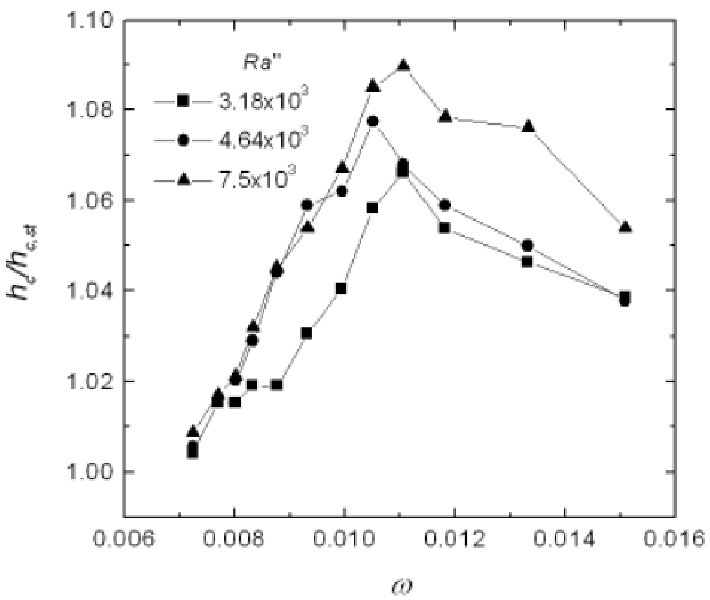


Figure 9- Heat Transfer Enhancement for Different Heat Inputs [2]

Azar [3] also conducted an experimental investigation to study the effect of forced oscillation of the fluid entering an electronic circuit pack channel on component cooling. A realistic air-cooled channel, made of two vertically mounted circuit packs containing nine components each, was employed. The experimental setup consisted of a channel with heated protrusions on one wall and a blade attached to a mechanical shaker at the inlet. Both natural and forced convection cooling were considered. The incoming fluid at the channel inlet was forced to oscillate at low frequencies. The results showed that forced oscillation improved component flow exposure and resulted in enhanced cooling of up to 15 percent in forced convection cases. Several parameters such as angle of shaker blade, channel height, and inlet velocity were examined and their contributions were highlighted.

More experimental results are needed for acoustic excitation to decide if this is a viable technique for electronics cooling. For example, what happens when the Reynolds number increases beyond 540 for a forced convention flow? The typical flow on a PCB is about 1 m/s which is double the value of the flow in the experiment done in [1]. This corresponds to a Reynolds number of 1080.

Data is also needed to evaluate the effect of the amplitude for the forced convection flows. The amplitude in the experiment [1] was fixed at 0.05 m/s. What would be the result if the amplitude increased to 0.1 or 0.15 m/s? What are the limits before getting to a point of no return? After a more comprehensive testing, it can be determined if deploying a speaker in an electronic enclosure would contribute substantially to the cooling of components. In this process, the cost and noise implications should also be considered.

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Using a Refrigeration System

for Electronic Cooling

The advance in semiconductor technology and leap in transistor density has coerced engineers into looking for more innovative and effective methods to cool semiconductor devices loaded with increasing power density. Traditionally, the air- cooled heat sinks dominate the electronic cooling market, due to their simple design, low cost, high reliability and versatility. But the continuing effort of shrinking MOSFET gate size has made it impossible for pure air-cooled technology to handle the heat load dissipated by some high-power devices such as high end CPUs, power transistors, DSP chips, etc. To keep the junction temperature below the maximum operating temperature and to handle high heat dissipation, engineers are looking for innovative ways to cool the electronic devices. One of the promising cooling techniques is refrigeration.

Refrigeration is a process in which work is done to move heat from one location to another. The work of heat transport is traditionally driven by mechanical work, but can also be driven by magnetism, electricity, laser or other means. By using refrigeration, the junction temperature of electronics can be maintained and reduced to sub-ambient temperature, if required. The lower operating temperature enables the electronics to operate at higher frequency and also increases the device reliability and life.

The common methods of refrigeration can be classified as non-cyclic, cyclic, thermoelectric and magnetic. In non-cyclic refrigeration, cooling is accomplished by melting ice or by subliming dry ice (frozen carbon dioxide). These methods are used for small-scale refrigeration, such as in laboratories and workshops, or in portable coolers.

Cyclic refrigeration cooling consists of a refrigeration cycle, where heat is removed from a low-temperature space or source and rejected to a high-temperature sink with the help of external work. The most commonly used refrigeration cycle for electronic cooling is the vapor-compression cycle.

Thermoelectric cooling (solid state cooling) uses the Peltier effect to create a heat flux between the junctions of two different types of materials. This effect is usually employed in portable coolers and for cooling electronic components that use electro- optic devices and small instruments.

Magnetic refrigeration, or adiabatic demagnetization, is a cooling technology based on the Magneto Caloric Effect, an intrinsic property of magnetic solids. A strong magnetic field is applied to the refrigerant, forcing its various magnetic dipoles to align and placing the refrigerant into a state of lowered entropy. A heat sink then absorbs the heat released by the refrigerant, due to its loss of entropy. Thermal contact with the heat sink is then broken so that the system is insulated, and the magnetic field is switched off. This increases the heat capacity of the refrigerant, thus decreasing its temperature below the temperature of the heat sink. Because few materials exhibit the needed properties at room temperature, applications have so far been limited to cryogenics and research [1].

A vapor-compression cycle is the most commonly used refrigeration method. Figure 1 shows a personal computer equipped with a refrigeration system to cool its CPU; the refrigeration system is manufactured by Thermaltake [2] and uses a vapor- compression cycle. Figure 2 illustrates the system’s components and refrigeration cycle.

Figure 1. Thermaltake Xpressar Refrigeration System for PC [2]

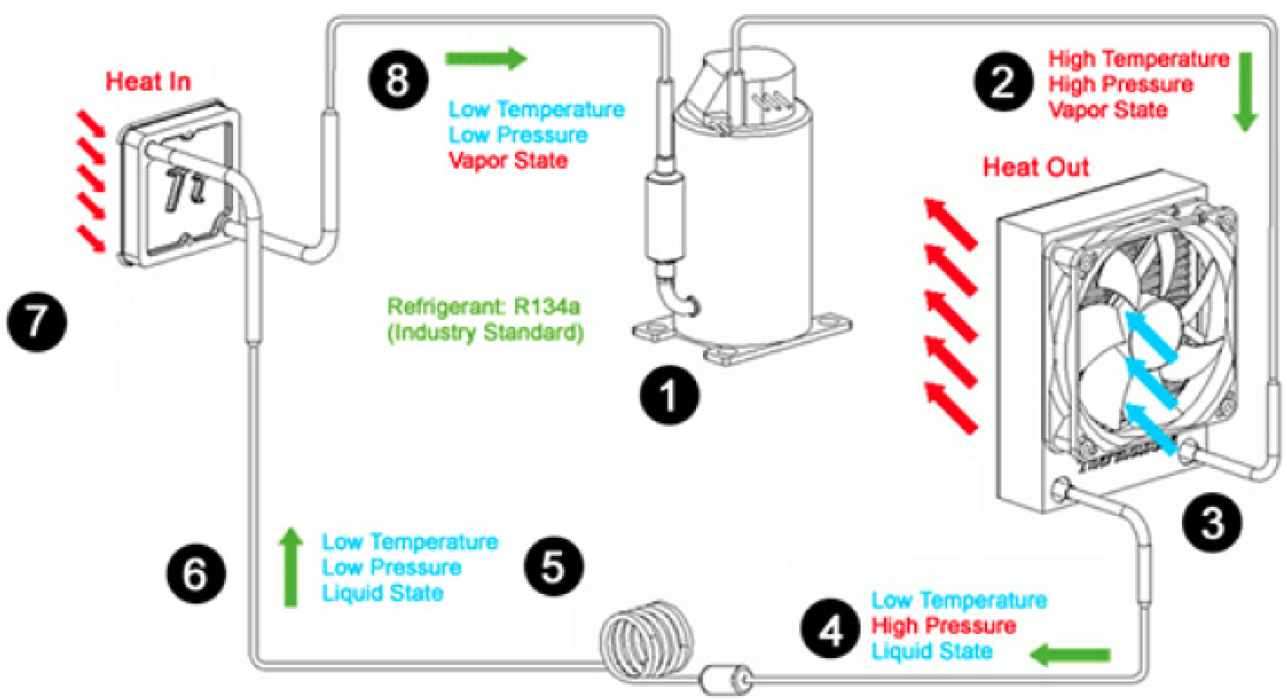

Figure 2. Thermaltake Xpressar Refrigeration System Schematic [2]

Component 1 is a compressor, which compresses the vapor and increases its pressure and temperature simultaneously. The compressor also serves as a pump to move the refrigerant around the loop. Component 3 is a condenser with a fan. When high pressure/high temperature vapor moves through the condenser, it condenses to a high pressure/low temperature liquid. The condenser also works as a heat exchanger and removes the heat from the system to the ambient. Component 5 is the expansion valve/coils, which reduces liquid pressure. Component 7 is a cold plate, which absorbs heat from the CPU and transfers the refrigerant from liquid to vapor. The vapor is then delivered to a compressor and the cycle is repeated again.

To get even better cooling performance, the component can be a micro-evaporator heat sink directly integrated to the back of the electronic chip; this method is generally called “two-phase on-chip cooling”. Figure 3 shows the magnified photo of the deep reactive ion etching (DRIE) microchannel heat sink made by Wei [3]. The DRIE method directly etches the high aspect ratio microchannel on silicon die. This kind of microchannel heat sink can be bonded to a chip die or even integrated in the chip. By doing so, the interfacial resistance between the chip and the heat sink can be minimized.

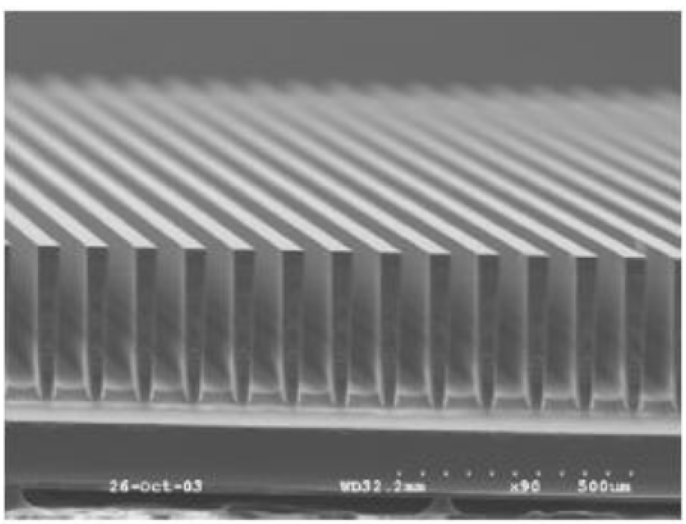

Figure 3. Photo of Magnified Microchannel Heat Sink [3]

In 2010, IBM, École Polytechnique Fédérale de Lausanne (EPFL) and the Swiss Federal Institute of Technology Zurich (ETH) signed a four-year collaborative project called CMOSAIC to understand how the latest chip cooling techniques can support 3D chip architecture. Unlike current processors, the CMOSAIC project considers a 3D stack-architecture of multiple cores with a interconnect density from 100 to 10,000 connections per millimeter square. Researchers believe that these tiny connections, and the use of hair-thin, liquid cooling microchannels measuring only 50 microns in diameter between the active chips, are the missing links to achieving high- performance computing with future 3D chip stacks. The integrated three dimension, two-phase cooling is ideal for this kind of applications.

The next most commonly used refrigeration process is thermoelectric Peltier cooling. Thermoelectric cooling transfers heat from one location to another location without moving parts; hence, the name of solid state refrigeration and heat pump. The typical thermoelectric module is manufactured using two thin ceramic wafers with a series of P and N doped bismuth-telluride semiconductor material sandwiched between them. The ceramic material on both sides of the module adds rigidity and the necessary electrical insulation. The N type material has an excess of electrons, while the P type material has a deficit of electrons. One P and one N make up a couple, as shown in Figure 4.

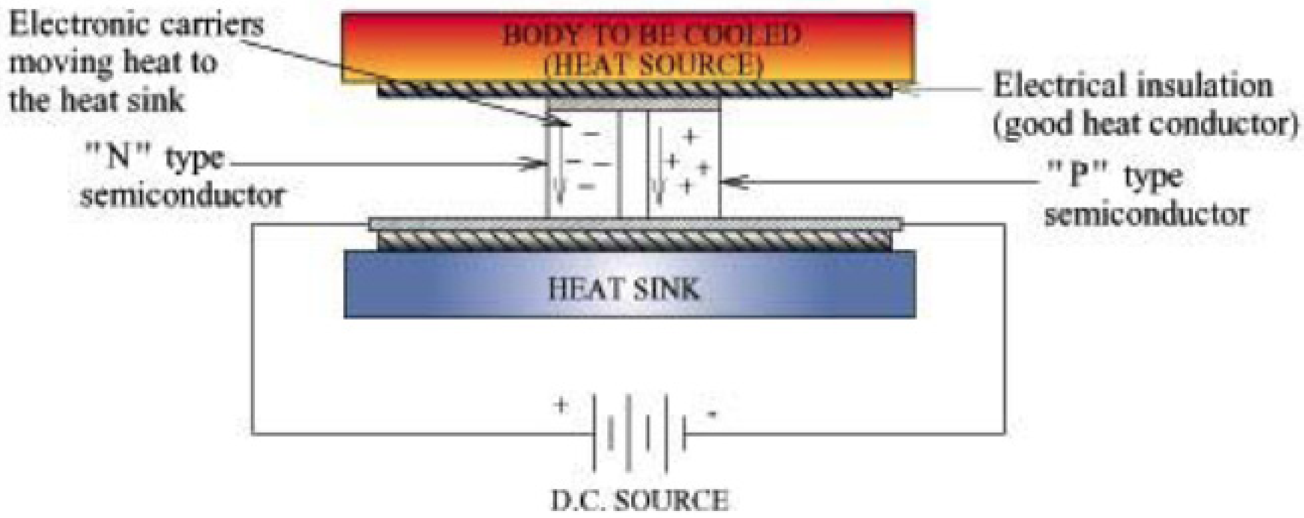

Figure 4. Illustration of Thermoelectric Module [4]

When a DC current is applied to the circuit, a thermoelectric module can work as a cooler or heater, depending on the direction of current. A thermoelectric cooler (TEC), or solid state heat pump, transfers heat from one side of the device to the other side against the temperature gradient. There are many products using thermoelectric coolers, including small refrigeration systems, CCD cameras, laser diodes and portable picnic coolers. They are also used in thermal management of electronic devices, such as microprocessors, memory modules, etc. Figure 5 shows the Cooler Master V10 TEC CPU heat sink.

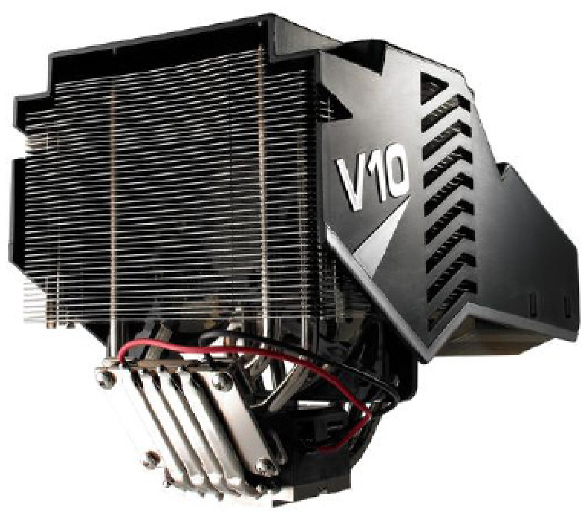

Figure 5. Cooler Master V10 TEC CPU Heat Sink [5]

Although the TEC provides a very simple and reliable solution for cooling electronic devices, its poor thermal performance prevents it from gaining broader acceptance. Compared with traditional refrigeration systems, the coefficient of performance (COP) of the TEC is only around 1/5 of that of a refrigeration system using a vapor compression cycle. Currently, the use of the TEC in electronics cooling is limited to certain applications, such as systems that require temperature stability, sub-ambient operating conditions, or devices with special design to accommodate TECs. At the chip level, there is active research focusing on using the TEC to cool the hot-spot on microprocessors. Localized areas of high heat flux on microprocessors produce hot spots that limit their reliability and performance. Chip scale thermal solutions utilizing TECs keeps hot spots below a critical temperature, thus avoiding unnecessarily overcooling of the rest of the CPU and adding to heat-sink load. Figure 6 shows such a concept of integrating a TEC in a heat spreader proposed by Snyder et al [6]. Figure 7 shows the eTEC they made, which is an embedded thermoelectric cooler with a total height of 100 microns and with a 2.5 mm x 2.5 mm footprint.

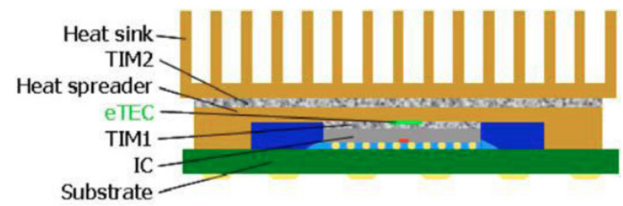

Figure 6. Flip-chip Package with A TEC Mounted on Heat Spreader [6]

Figure 7. Photo of eTEC [6]

Many researchers have demonstrated that the use of the vapor-compression cycle and two-phase cooling is a very effective way to remove high heat flux from electronics and lower their junction temperature. However, using the vapor-compression refrigeration system still faces many obstacles for commercial applications. The main technical issues that need to be addressed are:

1. The miniaturization of the vapor-compression refrigeration package, especially the compressor.
2. For “two-phase on-chip cooling”, the refrigerant should be compatible with electronics.
3. Refrigerants need to be more environmentally friendly and have good thermal properties.
4. The system needs to be field deployable and very reliable.
5. The cost of the refrigeration cooling system needs to be low enough to justify its applications.

For the thermoelectric cooler (TEC), there is continuing research on searching out and identifying better material and manufacturing technology to boost its efficiency. Unless there is a breakthrough in material used in the TEC, its application in electronics cooling is restricted to limited areas.

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Liquid Cooling of Data Center Servers

Energy costs for data centers are considerable, and include the expense of cooling the increasingly hot- running hardware. Most data centers have relied on ambient air cooling solutions (alternating cool and hot rows) to meet their cooling needs. However, ambient air cooling solutions are often unable to handle high heat loads, are not targeted and can be cost and energy inefficient. As high power applications and server densities increase, new ways are needed to dissipate heat. The use of liquid cooling solutions is an increasingly popular part of many datacenter cooling strategies.

A typical data center has an air-centric infrastructure designed to provide thermal management. A collection of chillers, compressors and air handlers replace hot air with cold, and rows of servers can be laid out to alternate warmer zones with cooler ones.

But while these methods can provide cooler computing environments, they may not be the most efficient approaches when it comes to managing costs. In some cases, localized cooling solutions at the rack and board level can deliver needed cooling at a lower expense.

Ambient Air Cooling

Data center ambient air cooling solutions use alternating aisles of cool air between their racks. Cool air is supplied to the cold row through ducts under the raised data center floor supplied by CRAC units. The air is exhausted from the back of the rack in the hot row. Another way to cool inside a data center is to use fans mounted to the roof or rear door of a server rack and use rack-mounted and wall air conditioners. Ambient air cooling solutions are limited in their ability to handle high heat loads, as they typically are only able to effectively cool 5 to 10 kW per rack.[1]

One provider, Asetek offers a range of liquid cooling solutions for HPC clusters in data centers. Their cooling technology removes heat directly from processors and moves it to an optimal place for transfer to the environment. The Asetek approaches include internal loop liquid cooling for cooling fast processors; rack CDU liquid cooling takes component heat from rack servers and blades out of the data center without the need for air conditioners or water chillers; and the company's sealed server liquid cooling process removes all server heat from the data center meaning that no air in the data center needed for server cooling. [2]

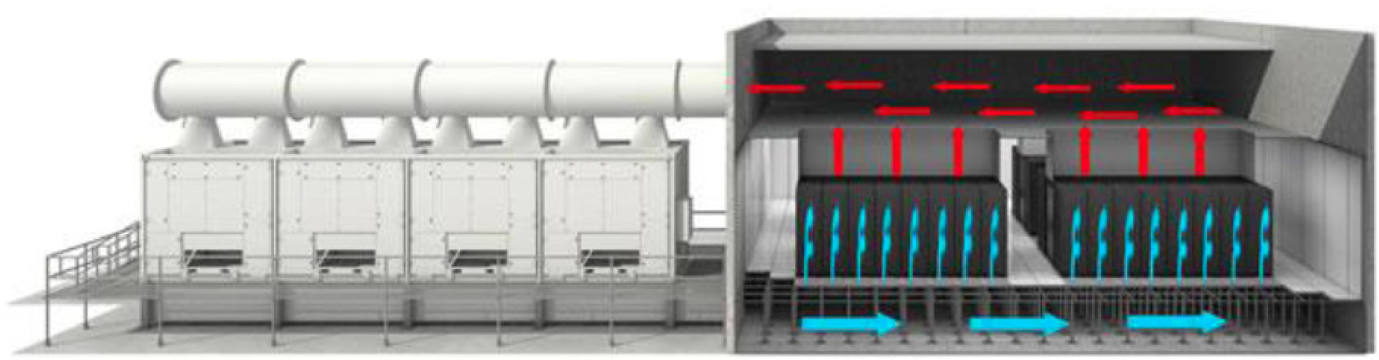

Figure 1. Air from hot data center servers rises into a plenum and feeds into a conditioning unit where it is cooled and returned to the base of the data center and used to cool the server racks to safe operating temperature . (APC)

Internal loop liquid cooling captures heat from CPUs and GPUs in high density servers and transfers it into an air stream. This enables the use of higher wattage CPUs and processor overclocking in a server that otherwise could not be relied on for safe performance. In these systems, multiple CPUs are liquid cooled when cold plates remove the processor heat into the flowing cooling liquid. Low power pumps, installed at each cold plate provide the flow, drawing cool liquid from a liquid-to-air heat exchanger, pump it at very low pressures through the cold plates and return it to the heat exchanger. The standard chassis fans move air through the heat exchanger. Heat in the liquid is transferred to the air flowing through the chassis.

Asetek's rack coolant distribution unit, CDU, uses liquid to directly cool the high heat flux component within servers, including CPUs and GPUs. By directly liquid cooling hot spots in a server, this method removes more than half of the thermal load on CRAC, computer room air conditioning.

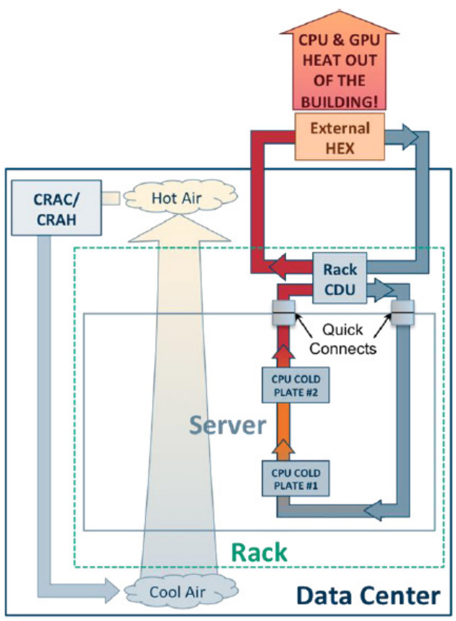

Figure 2. Data centers with a rack cooling CDU use two cooling paths to remove heat from the data center. A traditional air path with CRAC units removes heat generated by disk drives, power supplies and other low heat flux components. The rack CDU system uses a direct liquid cooling path to remove all processor heat from the data center. (Asetek)

Sealed server liquid cooling is a method for removing all server heat from a data center and eliminating the need for a CRAC system. These are self-contained cooling units that do not exchange any air with the surrounding. Two liquid loops are involved: a low pressure server loop and a facilities loop. They do not share liquids. Heat moves between the loops in a liquid-to-liquid heat exchanger. All heat within the sealed server is removed via liquid to the exterior environment. Re-circulated cooler internal air cools the other components within the server.

Google's Data Center Cooling Solution

Google has customized much of the operation of its data centers, which serve as the engines powering its massive Internet business. This includes their cooling solutions. The liquid cooling design patented by Google features custom motherboards with components attached to both sides. Heat-generating processors are placed on the side of the motherboard that comes in contact with the heat sink, which is an aluminum block containing tubes that carry cooling fluid. Components that produce less heat, such as memory chips, are placed on the opposite side of the motherboard, adjacent to fans that provide air cooling for these components. Motherboards are attached to either side of the heat sink, creating a "server sandwich" assembly that can be housed in a rack. [3]

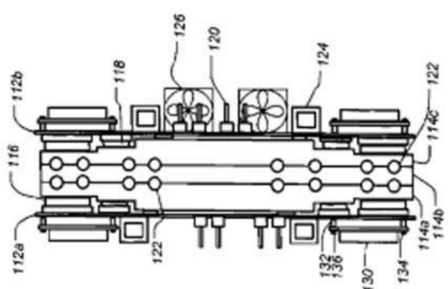

Figure 3. Google patent drawing shows a cross-section of a design for a liquid-cooled server assembly featuring a heat sink with motherboards on either side.

Server cabinets with integrated chilled-water cooling units provide highly-efficient thermal management of blade servers, 1U servers and other high density heat loads. Data Center Resources offers self-contained cabinets for use in non-conditioned spaces including warehouses, server closets and more. Alternatively, water-cooled heat exchanges can absorb IT heat load in data centers with traditional cooling to significantly reduce cooling requirements and energy costs.

References:

1. Datacenterresources.com

2. Asetek.com

3. Datacenterknowledge.com

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Technology Review

Liquid Cooling, 1992 to 2003

In a new series, Qpedia reviews the different technologies that have been developed for electronics cooling applications. This series looks at the patents awarded to developers in industry and academia around the world who are actively involved in addressing 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 breath 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 that offer some representation of the entire field. We do not mean to ignore the exceptional accomplishments of other inventors, and you are encouraged to do your own patent investigation. Further, if you have been awarded a patent and you would like to have it included in these reviews, please send us your patent number or patent application.

In this issue, the focus is on the liquid cooling. There is much discussion about its deployment in the electronics industry, and these patents show some of the salient features that different inventors have focused on. The following four patents are reviewed:

PATENT NUMBER	TITLE	INVENTORS	DATE OF AWARD
5,159,529	COMPOSITE LIQUID COOLED PLATE FOR ELECTRONIC EQUIPMENT	Lovgren, et al.	Oct. 27, 1992
5,871,042	LIQUID COOLING APPARATUS FOR USE WITH ELECTRONIC EQUIPMENT	Gutfeldt, et al.	Feb. 16, 1999
6,393,853 BI	LIQUID COOLING OF REMOVABLE ELECTRON-IC MODULES BASED ON LOW PRESSURE APPLYING BIASING MECHANISMS	Vukovic, et al.	May 28, 2002
6,580,609 B2	METHOD AND APPARATUS FOR COOLING ELECTRONIC COMPONENTS	Pautsch, G.W.,	Jun.17, 2003

COMPOSITE LIQUID COOLED PLATE FOR ELECTRONIC EQUIPMENT

5,159,529, Lovgren, et al.

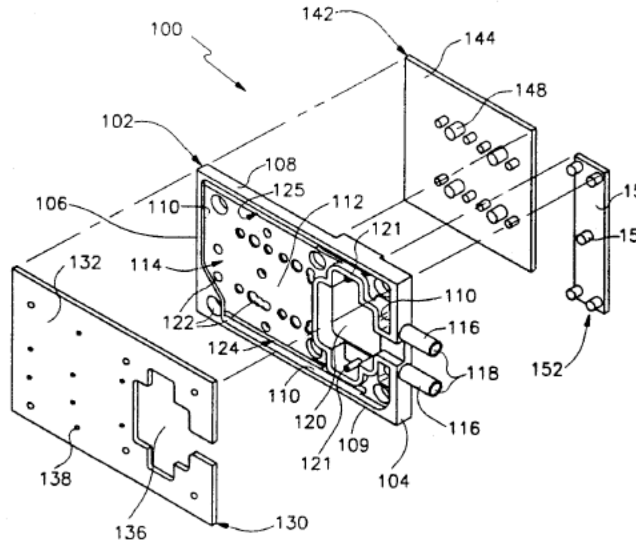
This invention features a coolant management system for cooling electrical components. The coolant management system consists of a heat transfer plate with a high thermal conductivity that is mounted to hot electronic components, and a coolant management system that directs coolant against the first heat transfer plate. The heat transfer plate is ideally made of copper. The coolant management system has a lower thermal conductivity than the heat transfer plate, and is preferably made from molded plastic material. When the heat transfer plate is attached to the coolant management system, a coolant cavity of desired flow characteristics is formed between them. The composite liquid cooled plate can accommodate a second heat transfer plate that can be attached to the coolant management system to form a second coolant cavity. With this option, the two coolant cavities may permit coolant flow between them via a fluid conduit.

The composite liquid cooled plate is easily manufactured and particularly lightweight. By restricting the use of copper or other material with a high thermal conductivity to only those areas of the plate requiring thermal conduction, the plate remains relatively lightweight and compact in size.

The invention also provides an optimized cooling path to direct coolant to areas requiring the greatest heat transfer. Therefore, if several electronic components are to be cooled, the plate may be configured to account for the individual cooling requirements of each electronic component. The coolant management system has coolant flow channels to direct coolant against the plate underneath "hot" components, thereby providing a short conduction path between "hot" components and the coolant.

A further advantage can be achieved in enhancing the final package design by first determining the layout of the device to be cooled and then routing the channels of the liquid cooled plate to areas that require the greatest heat transfer.

The following figures show the schematic of patent awarded to Lovgren, et al.



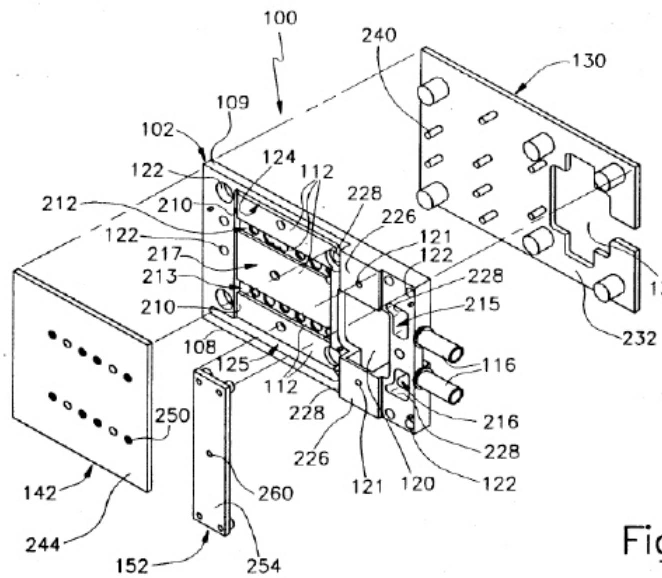
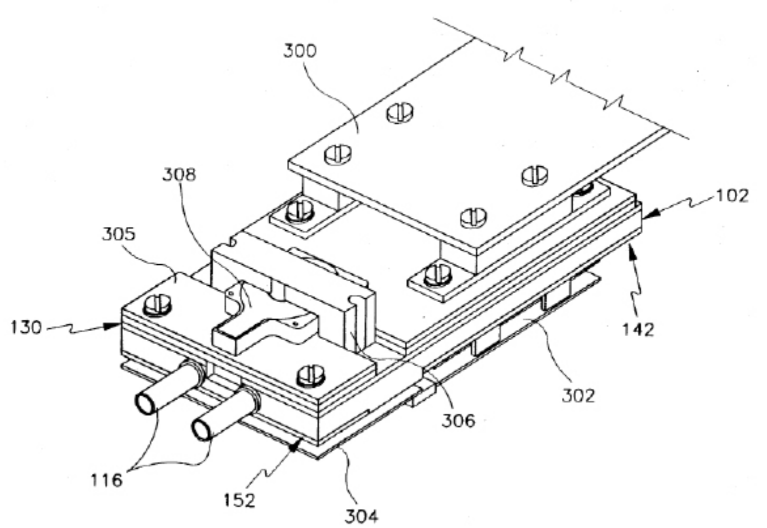
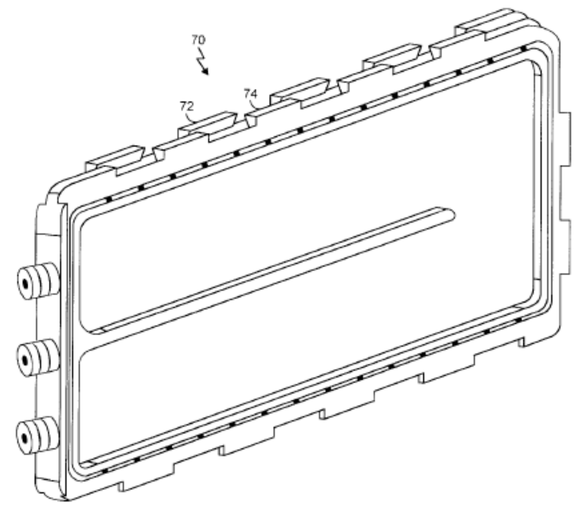


Fig.



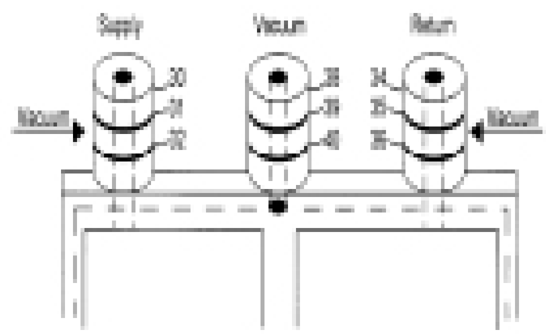
LIQUID COOLING APPARATUS FOR USE WITH ELECTRONIC EQUIPMENT

5,871,042, Gutfeldt, et al.



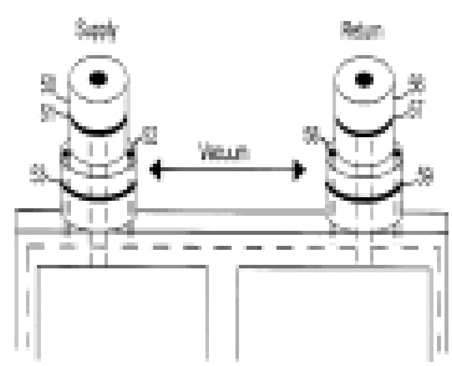
Electronic devices can generate heat and often require cooling in order to be maintained at an optimum operating temperature. Some liquid cooling designs are known and references are made to devices described in U.S. Pat. Nos. 4,109,707,4,938,279; 4,879,632; 4,997,032; 5,000,256; and 5,040,051. These devices typically use a plastic bag or some other container in which a cooled liquid is circulated. When the container is close to the electronic equipment, the equipment is cooled and can be maintained at an optimum operating temperature.

Electronic equipment such as printed circuit boards tends to have sharp protrusions including edges and soldered connections. Moreover, it is known that electronic equipment is very sensitive to liquids because liquids can corrode or short out the electronic components. However, many conventional containers employ membranes such as thin plastic that can easily tear. In conventional devices, a physical inspection is required to determine whether a leak has occurred. A limiting factor of current liquid cooling devices is that they do not offer adequate protection against leaks to prevent damage from occurring to the electronic components.



The goals for this invention are to overcome these limitations and to provide an apparatus that offers the benefits of liquid cooling along with an access method to for detecting leaks in the cooling device before damage takes place, and a way to protect the electronic components from any leakage.

The invention overcomes the identified problems. An exemplary embodiment of such a liquid cooling device includes a frame adapted to fit in a chassis with electronic equipment. An inner container and outer container are attached to the frame. A liquid inlet is disposed in the frame and has an opening in liquid flow communication with the inner container. A liquid outlet is disposed in the frame and has an opening in liquid flow communication with the inner container. A vacuum outlet is disposed in the frame and coupled to a space between the inner container and the outer container.



In one set up, a detector is coupled to the vacuum outlet and configured to detect air and/or liquid escaping from the vacuum outlet. In another set up, dual films may be sealed to one another with inlet, outlet and vacuum fittings, dispensing the need of a frame.

LIQUID COOLING OF REMOVABLE ELECTRONIC MODULES BASED ON LOW PRESSURE APPLYING BIASING MECHANISMS

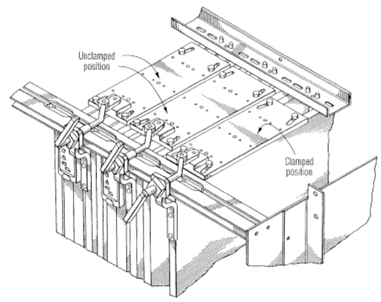
6,393,853 Bl, Vukovic, et al.

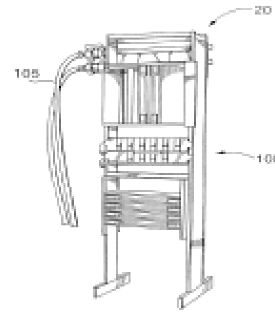
This invention addresses the liquid cooling of removable electronic modules. It describes an apparatus for cooling an electronic module in a shelf unit comprising a cold plate and a mechanism for moving cold plates toward and away from the module into operating and released positions, respectively, relative to the module when in place there, such that:

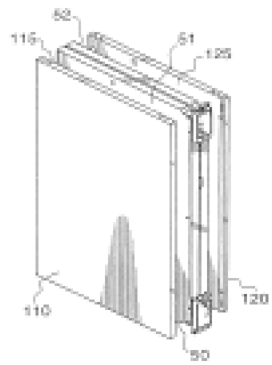
- when the cold plates have moved toward the module into the operating position, a surface of each said cold plate comes into heat transferring relationship with an associated surface of the module so that, in use, as a coolant flows through each cold plate, heat is transferred from the module to the coolant in each cold plate, and

- when the first and second cold plates have been moved away from the module into the released position; the module is spaced from the cold plates to enable the module to be readily removed from between the cold plates.

The invention is designed for electronic shelf unit used in the communications industry, but here it is populated with electronic modules. These modules are removable and supported by the shelf unit, the shelf unit comprises an apparatus for liquid cooling of an electronic module in a shelf unit. The system contains a biasing mechanism to provide pressure capable of forcing the first and second cold plates toward the module to provide close heat transferring relation between the plates and the module as the cooling liquid flows. A travel stop mounts the first and second cold plates together, and a spring is positioned between the first and second cold plates so that the spring force applies pressure forcing the first and second cold plates toward the module. In addition, the invention offers a fast, easy, drip free removal and replacement of liquid cooled high power electronics equipment.







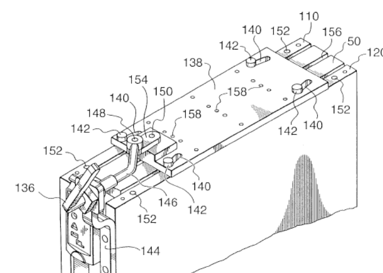
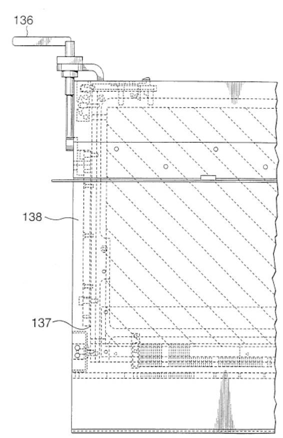


FIG. 3



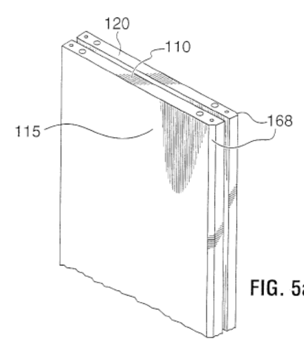


FIG. 5a

METHOD AND APPARATUS FOR COOLING ELECTRONIC COMPONENTS

6,580,609 B2, Pautsch, G.W.

Demand for higher performance supercomputers continues to create challenging thermal and packaging design environments for today's computer packaging engineers. As the performance of CRAY supercomputers continues to grow exponentially, in general agreement with Moore's law (Bar-Cohen, et al, 1988), the thermal and packaging solutions continue to become more complex. The increase of supercomputer performance over the last 30 years was initially achieved with an increase in the complexity of the computer's CPU by increasing the number of ICs within the CPU. The next step in performance was achieved by adding more gates per IC and increasing the clock rate. Performance was further increased by the paralleling of CPUs and then the scaling of groups of CPUs.

In order to continue on the path of Moore's law, we are again pushing the IC technology and ultimately the performance of each individual CPU. One technology that hasn't been able to keep pace with the ICs is printed circuit board (PCB) technology. The demands for component placement and IC net routings have exceeded the current state of the art in PCB technology.

One solution to this problem implements a multi-chip module with thin film routing layers (MCM-D) for the packaging of these high performance chip sets. This high density packaging design is, however, capable of producing heat fluxes on the ICs and MCM that approach values of 50 and 15 W/cm^2, respectively. The control of the IC's junction temperature is important for its reliability and for the performance of two communicating devices. The amount of induced leakage "noise" that exists on an integrated circuit is also a function of its temperature.

A number of cooling methodologies have been described by

- Bar-Cohen, A., "Thermal Management of Electronic Components with Dielectric Liquids", JSME International Journal, Series B, vol. 36, No., 1993.
- Simons, R. E., "Bibliography of Heat Transfer in Electronic Equipment", 1989, IBM Corporation)
- Incropera, F. P., "Convection Heat Transfer in Electronic Equipment Cooling", Journal of Heat Transfer, Nov. 1988, Vol. 110/1097.
- Bergles, A. E., "Liquid Cooling for Electronic Equipment", International Symposium on Cooling Technology for Electronic Equipment, March 1987.

Studies by

- Chu, R. C., and Chrysler, G. M., "Electronic Module Coolability Analysis", EEP-Vol. 19-2, Advances in Electronic Packaging-1997 Volume 2, ASME 1997.
- Nakayama, W., "Liquid-Cooling of Electronic Equipment: Where Does It Offer Viable Solutions?", EEP-Vol. 19-2, Advances in Electronic Packaging-1997 Volume 2, ASME 1997.

However, there are indications that these approaches are no longer capable of satisfying today's high density packaging requirements (Chu and Chrysler, 1997), (Nakayama, 1997). As heat flux continues to increase, the most promising methods are those that utilize direct liquid cooling with dielectric fluids.

Direct liquid cooling circumvents the problems of high thermal interface resistance associated with conventional technologies and is capable of providing very high heat transfer rates (Bar-Cohen, 1993). A number of such direct liquid cooling techniques are described in "Thermal Management of Multichip Modules with Evaporative Spray Cooling," by G. W. Pautsch and A. Bar-Cohen, published in ASME Advances in Electronic Packaging 1999, EEP-Vol.26-2, 1453-1463, the discussion of which is incorporated herein by reference. That paper concluded that the method of choice for cooling high heat flux electronic components is described as "High Density, Pressure Atomized Evaporative Spray Cooling". This condition occurs when a fluid is sprayed on a surface at a rate that maintains a continuously wetted surface, whose temperature is less than 25°C above the saturation temperature of the thermal coolant. This method, with the selection of an appropriate fluid, such as Fluorinert™ FC-72 which has a boiling point of 56°C at standard atmospheric conditions, allows one to maintain high heat flux components at operating temperatures below 85°C. Each of the above cooling approaches has its deficiencies. What is needed is a system and method for cooling electronics components that addresses these deficiencies.

To address the problems stated above, and to solve other problems, a system and method for cooling electronic components is described herein. An enclosure is provided which includes a plurality of a first set of electronic components, cooling means for cooling a gas, and distribution means for directing the gas across the electronics components and the cooling means, where the distribution means forms a closed system limiting the transfer of the gas both into and out of the distribution means.

Several options for the enclosure are as follows. For instance, in one option, the cooling means includes a cooling coil and means for directing water through the cooling coil. In another option, the enclosure further includes means for spray evaporative cooling over a second set of electronic components. In yet another option, the first set of electronic components is low power components and the second set is high power components. In yet another embodiment, a system includes a chassis with one or more modules with a plurality of electronic components, where the chassis forms a closed internal system. The system further includes a gas distribution member positioned within the chassis and configured to direct a chilled gas toward the electronic components. A gas cooling device is positioned within the chassis and configured to cool the gas after the gas has been heated by the electronic components. Several options for the system are as follows. For instance, at least one of the modules includes a mechanical subsystem having multiple electronic modules and at least one fluid conditioning unit, and optionally at least one of the modules includes a spray evaporative cooling assembly. In yet another option, the gas cooling device includes a heat exchanger

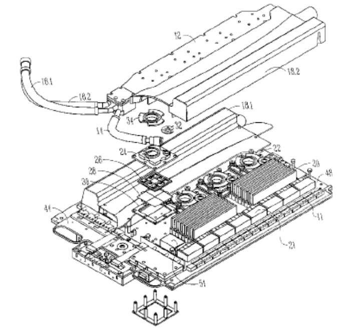
In another set up, a system includes a chassis with one or more modules containing one or more electronic modules and at least one fluid conditioning unit, and at least one of the electronic modules includes at least one spray evaporative cooling assembly. The system further includes a gas distribution member positioned within the chassis and configured to direct a chilled gas toward the electronic components. The system further includes a gas cooling device positioned within the chassis that is configured to cool the gas after it has been heated by the electronic components.

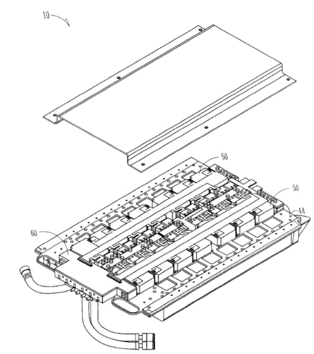
Several options for the system are as follows. In one option, at least one spray evaporative cooling assembly and the at least one fluid conditioning unit form a closed system. In another option, the chassis forms a closed internal system. In another option, at least one fluid conditioning unit includes at least one pump and a heat exchanger. The spray evaporative cooling assembly, in another option, includes a fluid charged with a non-corrosive, inert gas, for example Nitrogen.

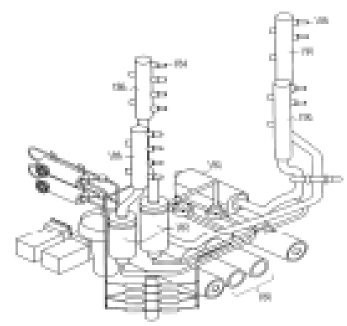
A method of cooling an electronics enclosure is provided in which air is forced over a first set of electronic components, cooling these components, heating a liquid to a temperature near its boiling point, directing the heated liquid against a second set of electronic components where at least portion of the heated liquid vaporizes, drawing the vapor and the heated liquid away from the electronics components, condensing the vapor back into liquid, and cooling the air and recirculating the air through the enclosure, where the air is maintained within the enclosure in a closed system.

Several options for the method are as follows. In one option, the method further includes recirculating the liquid, where the liquid and vapor are maintained within the enclosure in a closed system. In another option, the method further includes filtering the liquid, or charging the liquid with a non-corrosive gas. In another option, the heated liquid is directed against a second set of electronic components having a higher power than the first set of electronic components.
In yet another embodiment, a method of cooling an electronics enclosure having a plurality of electronics components includes directing a gas over electronic components to cool them, cooling the gas within the electronics enclosure, and recirculating the gas within the enclosure, where the air is maintained within the enclosure in a closed system.

Several options for the method are as follows. For instance, in one embodiment, cooling the gas includes passing the gas through a water cooled heat exchanger. Optionally, recirculating the gas includes directing the gas up sides of the enclosure to air plenums at the top of the enclosure. The method further optionally includes funneling the gas across heat sinks thermally coupled with the electronic components.







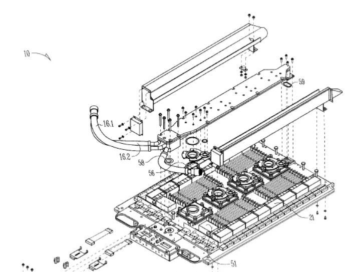
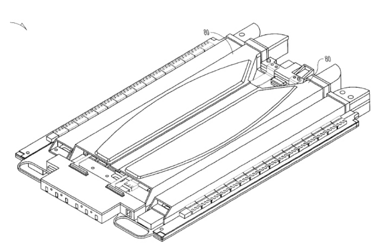


Fig.6



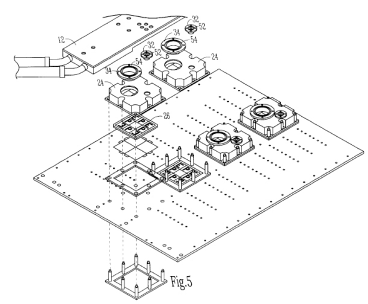
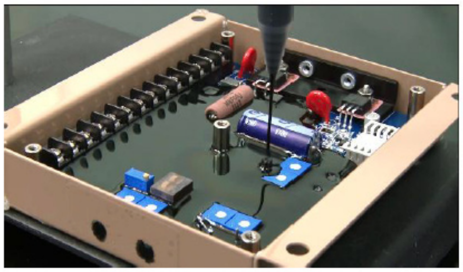


Fig.5

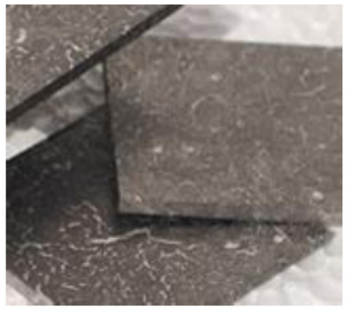
Cooling News

New Products, Services and Events from around the Industry



Flame Retardant Thermally Conductive Polyurethane

The 50-2185FR potting and encapsulating compound from Epoxies, Etc. has been formulated to provide a low glass transition temperature, low durometer, high thermal conductivity and flame retardancy. This system offers excellent heat transfer, low exotherm and excellent electrical properties. The 50-2185FR meets the non-burning requirements of UL 94 V-0. Additionally, the 50-2185 compound has outstanding thermal cycling properties and low embedment stress to sensitive components. This system will maintain its integrity over an operating temperature range of -50 to 120°C.



New Carbon-Based Thermal Management Material

Applied Nanotech has unveiled the next generation of CarbAl, a passive thermal management material that could effectively replace the aluminum and copper in electronic circuits. CarbAl is a carbon-based material with a unique combination of low density, high thermal diffusivity and low coefficient of thermal expansion. CarbAl's attributes allow it to exceed the capabilities of conventional thermal management materials, such as copper and aluminum. New electroplating and surface coatings have improved its durability and functionality, making it a solution for electronics manufacturers to keep temperature under control. CarbAl is lighter in weight and has increased thermal performance, compared to competing materials. CarbAl has a density of 1.75 g/cm^3 , compared to 2.7 g/cm^3 for aluminum and 8.9 g/cm^3 for copper.

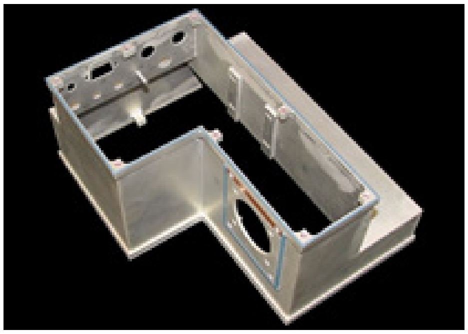
Combiner Box Offers Rugged Protection and Versatility

The Hoffman Solar Combiner Box, from Pentair Technical Products, provides a simple solution for combining electrical inputs for photovoltaic applications into a single output, while offering robust protection against harsh environmental conditions and sufficient flexibility to keep pace with emerging demands. The Combiner Box is available in POLYPROTM and 14-gauge mild steel models. Non-metallic POLYPRO material is composed of non-glass-filled polyester that offers a superior and cost-effective combination of corrosion, impact, chemical and UV resistance, and protects against wind and moisture. POLYPRO boxes provide an overlapping tongue-and-groove raised cover and gasket for a secure seal and are Type 4X rated. Mild steel models offer a cost-effective option with continuous hinges, oil-resistant gaskets and a Type 4 rating.

MoCu Materials: Low Thermal Expansion, Excellent Thermal Conductivity
MoCu, WCu, Cu-Mo-Cu and Cu-Mo-Cu-Cu laminates from Plansee reliably dissipate heat in electrical components and help cool IGBT modules, RF packages, LED chips and other products. The materials combine the low thermal expansion of molybdenum and tungsten with the excellent thermal conductivity of copper. Plansee has optimally engineered these composite materials to meet the requirements of silicon, GaAs and GaN-based semiconductor materials. MoCu has a low density and consequently a low specific weight. It is particularly suitable in applications where every gram counts.

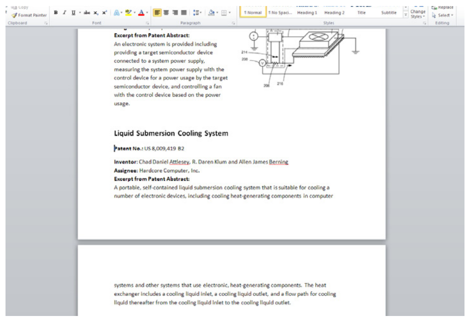
Liquid Cooling System Uses Safe, Non-Flammable Solvent
Iceotope has released new cooling products that use 3M's Novec, an engineered non-flammable solvent that makes the cooling process safer. The environmentally friendly, inert chemical coolant is used in fire sprinklers for environments containing expensive equipment, such as museums, hospitals and banks, as it becomes a gas immediately after discharge. In the data center, Novec can rapidly convect heat away from electronics, transferring it to a sealed low-pressure gravity fed tube system to provide 24/7 free cooling for ICT at any place and any time. Overall, it claims the solution can reduce cooling costs by 97% and compute power load by 20% by removing the need for air handling and refrigeration, with no chillers or CRAC units required.

Ultra-Compact 200W Improve End-User Thermal Management
Open frame AC-DC power supplies from Power-One provide 200W of power in an ultra-compact 2“ x 4” footprint with a single 12V, 24V or 48V output. The ABC200 power supplies use a universal 90 to 264VAC input range with active power factor correction, delivering over 90% efficiency at 230VAC. The series ensures minimal power losses in end-use equipment, thereby facilitating lower operating costs and easier thermal management. The ABC200 is ideal for industrial equipment, high-end AV, telecom, datacom and other applications.



J. Kittredge and Sons Acquired by Niagara Thermal Products LLC

Under an acquisition, J. Kittredge and Sons Inc. of Hudson, Mass., becomes part of Niagara Thermal Products LLC, A New York concern, producing compact heat exchangers, cold plates and heat transfer surfaces and thermal management systems. “The addition of Kittredge’s industry recognized dip brazing, welding, machining and fabricating capabilities for complex thermal and mechanical electronics components and assemblies enables Niagara Thermal to offer its aerospace, defense and electronics customers an unprecedented array of cost effective, platform-wide solutions,” said Barry Heckman, president and chief executive officer of Niagara.



Excerpt from Patent Abstract:
An electronic system is provided including providing a target semiconductor device connected to a system power supply, measuring the system power supply with the control device for a power usage by the target semiconductor device, and controlling a fan with the control device based on the power usage.

Liquid Submersion Cooling System

Patent No.: US 8,009,419 B2

Inventor: Chad Daniel Attlesey, R. Daren Klum and Allen James Berning
Assignee: Hardcore Computer, Inc.
Excerpt from Patent Abstract:
A portable, self-contained liquid submersion cooling system that is suitable for cooling a number of electronic devices, including cooling heat-generating components in computer systems and other systems that use electronic, heat-generating components. The heat exchanger includes a cooling liquid inlet, a cooling liquid outlet, and a flow path for cooling liquid thereafter from the cooling liquid inlet to the cooling liquid outlet.

Liquid Submersion Cooling System

Patent No.: US 8,009,419 B2
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Assignee: Hardcore Computer, Inc.
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A portable, self-contained liquid submersion cooling system that is suitable for cooling a number of electronic devices, including cooling heat-generating components in computer systems and other systems that use electronic, heat-generating components. The heat exchanger includes a cooling liquid inlet, a cooling liquid outlet, and a flow path for cooling liquid thereafter from the cooling liquid inlet to the cooling liquid outlet.

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Date: May 29-31, 2012
Place: Berlin, Germany

coolingZONE LED 2012, the only LED show dedicated to the thermal management of LED Lighting, will be held in Berlin, Germany May 29-31, 2012. This event will feature world renowned experts in the field of thermal management of LED to share their latest developments, research and practical approaches to LED cooling. Engineers across the globe attend coolingZONE LED to learn what new cooling challenges will confront them, where the solutions will be found, and who can help them with effective products and services to manage today's thermal challenges.

The coolingZONE LED 2012 agenda includes a full day of technical presentations from leading experts in industry and academia. Short technical sessions will be provided by corporations who are advancing the thermal management community with innovative and practical thermal solutions. Four short courses are also a part of the program, to allow for in depth training.

Papers and speakers to be presented at coolingZONE LED 2012 include:

smartCOOLINGTM of LEDs – solutions, techniques, systems
Thermal transport in LED-based lighting
Thermal characterization of LEDs
Thermal and flow simulations in LED lighting applications
Thermal coupling in LED based lighting systems
Cooling solutions for LED based lighting – from residential to industrial applications
Advances in LED packaging
Thermal characterization of LED cooling solutions
Role of LED packaging in its thermal management
Role of temperature in reliability estimations and life expectancy predictions of LED based lighting
LED energy consumption and their comparison with other lighting methods
LED cooling – from natural convection to liquid cooling

ITherm 2012 / ECTC2012 - www.ithermconference.org / www.ectc.net

Date: May 30 – June 1, 2012
Place: San Diego, California, USA

ITherm 2012 is an international conference for scientific and engineering exploration of thermal, thermomechanical and emerging technology issues associated with electronic devices, packages and systems. ITherm 2012 will be held along with the 62nd Electronic Components and Technology Conference (ECTC 2012 - http://www.ectc.net), a premier electronic packaging conference.

CoolingZONE-12 International Conference and Exhibition LED - www.coolingzone.com

Date: August 28-30, 2012
Place: Cambridge, MA, USA

The Summit gathers together world re-known experts in thermal management to share their latest developments and research, and discuss emerging technologies in advanced thermal management, power generation and control.

Register