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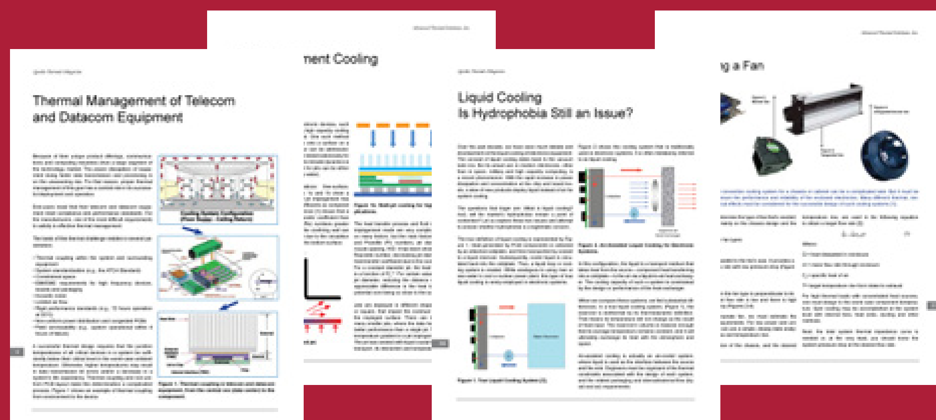

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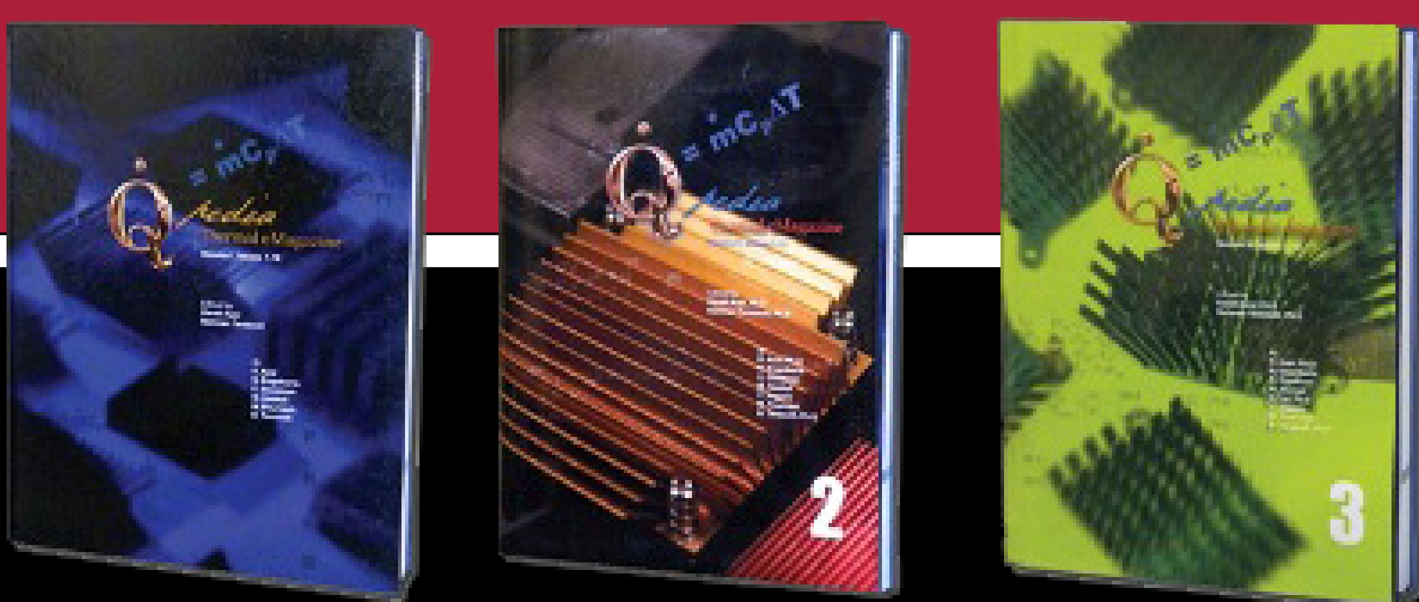

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Utilizing Stacked Microchannels

Moore's Law, which states that the numbers of transistors that can be placed inexpensively on an integrated circuit will double every 18 months, has been valid for more than 50 years. But, as the transistor's size keeps shrinking, it is more difficult to put more transistors together and maintain their physical properties and electric functions. Also, it is more difficult to transfer the heat out of transistors and keep their junction temperature low. To extend Moore's Law to the foreseeable future, it will require a change from mere transistor scaling to novel packaging architectures such as so-called 3D integration, the vertical integration of chips and innovative cooling solutions.

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 a 3D chip architecture. Unlike current processors, the CMOSAIC project considers a 3D stack-architecture of multiple cores with an 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.

"In the United States, data centers already consume two percent of the electricity available, with consumption doubling every five years. In theory, at this rate, a supercomputer in the year 2050 will require the entire production of the United States' energy grid," said Prof. John R. Thome, professor of heat and mass transfer at EPFL and CMOSAIC project coordinator. 3D chip stacks with interlayer cooling not only yield higher-performance, but more importantly, allow systems with a much higher efficiency, thereby avoiding the situation where supercomputers consume too much energy to be affordable, [1]. "As we will demonstrate with ETH in the Aquasar project, employing microchannels carrying liquid coolants offers a significant advantage in addressing heat-removal challenges, and this should lead to practical 3D systems," said Bruno Michel, manager advanced thermal packaging, IBM Research - Zurich. "Water as a coolant has the ability to capture heat about 4,000 times more efficiently than air, and its heat-transporting properties are also far superior."

As the chip design goes to 3D, there comes the requirement for a cooling solution that goes three dimensions, too. Integrating a multilayer of liquid cooling microchannels inside a 3D chip structure, or using stacked microchannel heat sinks to cool high power chips, not only requires advanced micro-manufacture technology, but also relies on a fundamental understanding of the flow inside microchannels and heat transfer coupling between different layers of microchannels. This paper summarizes some recent experimental research works on stacked microchannel heat sinks by Wei [2] and Lei et al. [3].

The two-layer microchannel heat sink Wei [2] tested is illustrated in Figure 1. It consists of five layers of silicon plates. Two microchannel layers provide the cooling located at the bottom. Two manifold layers above the microchannel layers distribute the fluid. The fifth layer with inlet and outlet ports is for fluid connection. The microchannels, manifolds and inlet-outlet ports were all fabricated using the deep reactive ion etching (DRIE) technique. The dimensions of the two layers of microchannels are shown in Figure 2 and Table 1. Figure 3 shows the magnified photo of the DRIE etched microchannel heat sink.

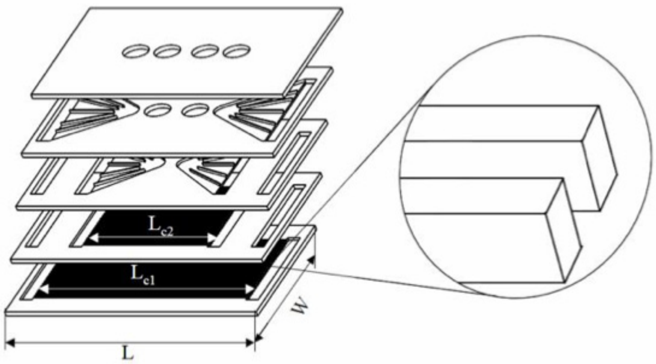

Figure 1. Two-Layer Microchannel Heat Sink Schematics [2]

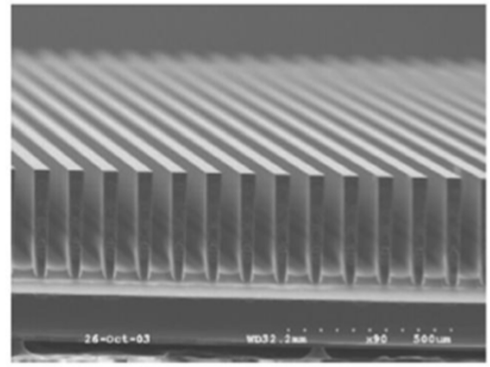

Figure 3. Photo of Magnified Microchannel Heat Sink [2]

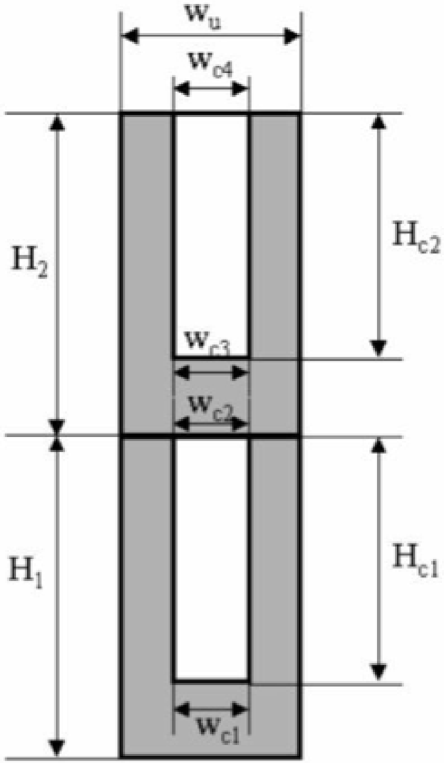

Figure 2. Two-Layer Microchannel Heat Sink Dimension [2]

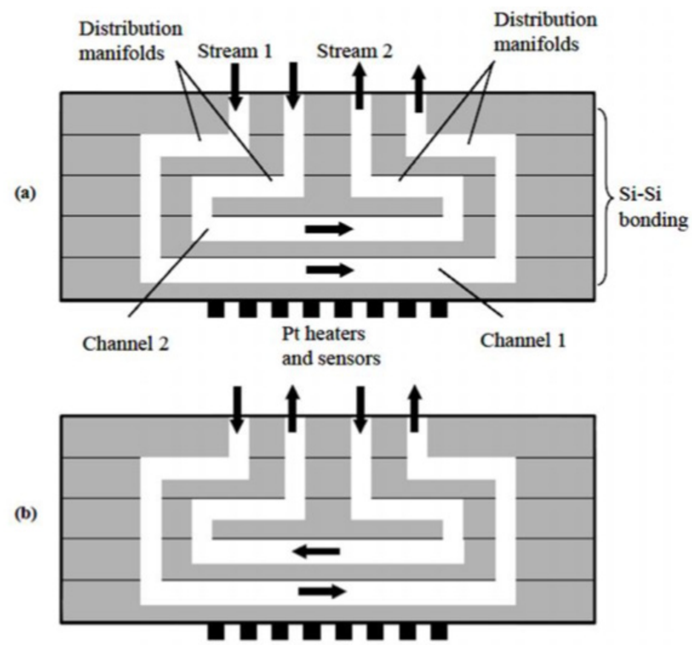

Figure 4. Schematic of Two-Layer Microchannel Heat Sink (a) Parallel Flow Arrangement (b) Counter Flow Arrangement [2]

L_{c1}	L_{c2}	W_u	W_{c1}	W_{c2}	W_{c3}
18	10	0.1	0.056	0.054	0.061
W_{c4}	H_{c1}	H_{c2}	H_1	H_2	
0.053	0.284	0.243	0.48	0.48	

Figure 1. Two-Layer Microchannel Heat Sink Schematics [2]

In Wei's [2] experiments, platinum heaters and resistive temperature sensors were deposited on the backside of the structure shown in Figure 4 to provide heating and temperature sensing respectively. The de-ionized (DI) water was used as working fluid in Wei's experiments and two different flow arrangements: parallel flow and counter flow (see Figure 4) were studied. As for the results of the experiments, Wei concludes:

1. A thermal resistance of less than 0.1 K/W was achieved for both counter flow and parallel flow configurations.
2. For the low flow rate range, the parallel flow arrangement results in a better overall thermal performance than a counter flow arrangement
3. For the large flow rate range, the thermal resistances for both the counter flow and parallel flow configurations are indistinguishable.
4. The counter flow arrangement provides better temperature uniformity for the entire flow rate range tested.
5. For both counter flow and parallel flows, total thermal resistance decreases as more fluid is pumped through the bottom microchannel layer. However, the pressure drop significantly increases.

Lei et al. [3] investigated the thermal and hydraulic performance of multilayer microchannel heat sinks experimentally. The structure of the test module is illustrated in Figure 5. The test module consists of a copper microchannel heat sink, a housing, a cover plate and a power intensifier. The housing and cover plate were made of a thermoplastic material with a thermal conductivity of 0.24 W/(m.°C). The geometry of the copper heat sinks is illustrated in Figure 6. The heat sinks were made of copper and the channels were precisely machined. Each heat sink was composed of several parts and the individual layers were soldered together. The dimensions of the copper heat sinks tested are presented in Table 2. All heat sink samples have same length and width - 1.2 × 0.5 inches (30.5 ×12.7 mm), channel dimensions of 0.02 × 0.02 inches (0.508 × 0.508 mm), base thickness of 0.02 inches (0.508 mm) and wall thickness of 0.04 inches (1.016 mm).

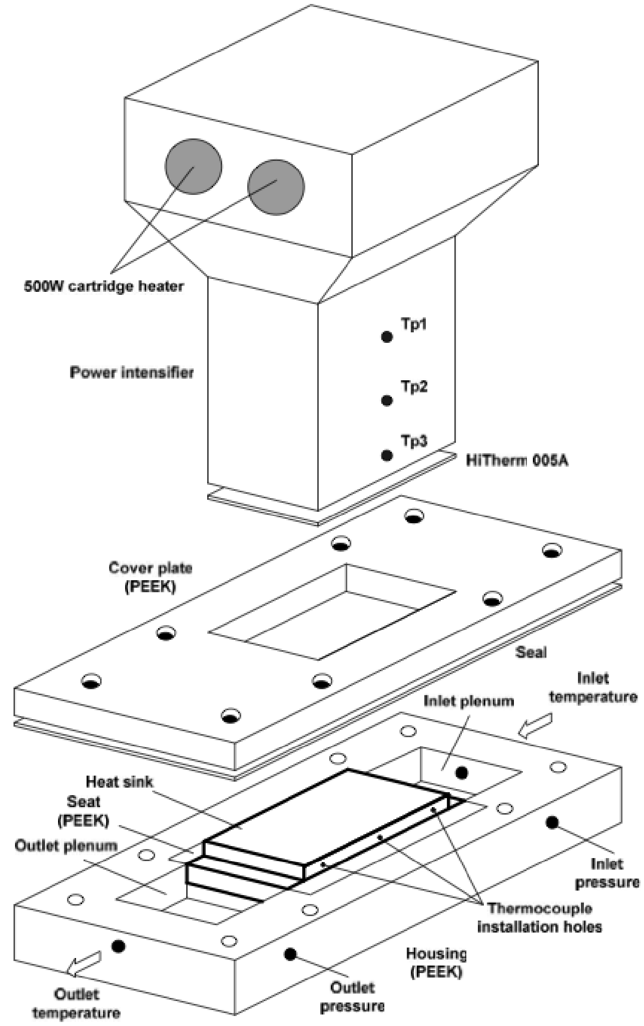

Figure 5. Test Module Configuration [3]

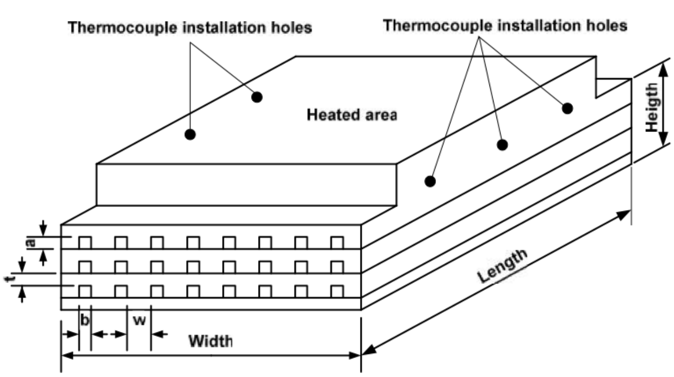

Figure 6. Copper Microchannel Heat Sink Geometry [3]

Sample ID	H (mm)	a×b (mm)	Channels/layer	No. of layers
Cu-1	1.52	0.508×0.508	8	1
Cu-2	2.54	0.508×0.508	8	2
Cu-3	3.56	0.508×0.508	8	3
Cu-4	4.57	0.508×0.508	8	4
Cu-5	5.59	0.508×0.508	8	5

Table 2. Copper Microchannel Heat Sink Dimensions [3]

Distilled water was used as the working fluid in the Lei's experiments. By comparing multilayer microchannel heat sinks with single-layer microchannel heat sinks, Lei et al. found that:

1. Multilayer microchannel heat sinks have smaller thermal resistance than single- layer heat sink at low water flow rate. For high flow rates, the flow inside single- layer heat sink becomes turbulent so it outperforms two-layer microchannel heat sinks, but 3, 4, and 5-layer heat sinks still outperform single-layer one due to much larger surface area.

2. At the same volumetric flow rates, multilayer microchannel heat sinks have a smaller pressure drop than single-layer ones due to their larger cross section areas, which lead to decreasing of flow velocity. For example, the 5-layer copper heat sink achieved a thermal resistance of 0.33 $K/W/cm^2$ with 0.03 Watts of pumping power in the experiments.

3. There is a limit on the maximum number of layers for practical purposes, since multilayer microchannel heat sinks have much larger volumes than single-layer microchannel heat sinks.

The studies of Wei [2] and Lei et al. [3] demonstrate the effectiveness of using stacked microchannel heat sinks to dissipate high heat fluxes. Compared to traditional single-layer microchannel heat sinks, stacked microchannel heat sinks have lower thermal resistance and require less pumping power. This means that the stacked microchannel heat sinks can keep the device temperature lower with less energy. As Wei [2] showed that the microchannel can be etched directly on a silicon die, it is feasible to integrate multilayer microchannel in 3D chips. However, making the multilayer microchannel is more difficult than a single-layer microchannel. There still are some application problems, such as sealing, flow distribution and fluid control that needed to be addressed before large scale usage can be attempted.

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Performance of Fans and Blowers in Thermal Management

With the increase in power dissipation of components, there is a need for more air flow before resorting to liquid cooling. The increase in air flow demand and the price of energy have placed greater attention on the efficiency of air delivery systems. For example, the IT industry has already surpassed the aviation industry in annual energy consumption and it is estimated to double over the next three years. Approximately 50% of this energy is used for cooling purposes [1].

The most common types of air delivery systems in thermal management are axial fans and blowers. Now the question is how efficient these are and how much they differ for different sizes. The efficiency of a fan can be defined as follows:

$$\varepsilon = \frac{P_{fan} G_{fan}}{\varepsilon_{motor} V_{motor} I_{motor}}$$

Where,

P_{fan} = fan pressure drop (pa)

G = Volumetric flow rate (m^3/s)

ε = Fan efficiency

ε_{motor} = Electrical efficiency of the motor

V_{motro} = Voltage to the motor

I_{motor} = Current to the motor

The electrical efficiency can be estimated approximately as 70%.

The commercial fans provide their performance as a function of flow rate and pressure drop. One such curve is shown in Figure 1.

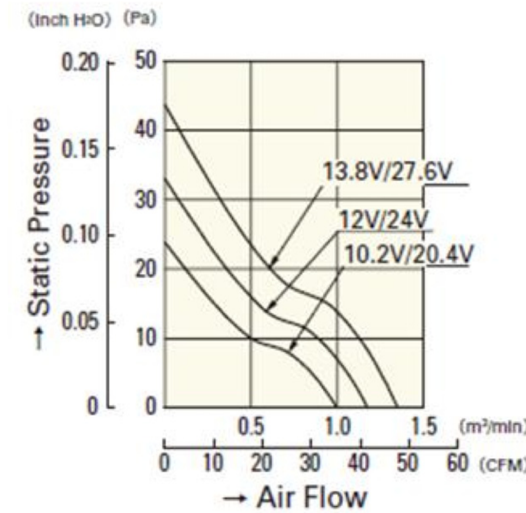

Figure 1- Performance Curve of a Commercial Fan [2]

These performance curves can be approximated as a line.

$$P = \frac{-P_{max}}{G_{max}} G + P_{max}$$

Where P_{max} and G_{max} are maximum pressure and volumetric flow rates, respectively. The maximum efficiency of the fan is where the product P_{fan} G_{fan} is maximum. Considering the product as below:

$$P \times G = \frac{-P_{max}}{G_{max}} G^2 + G P_{max}$$

$$\frac{d(P \times G)}{dG} = 0 \quad \text{This yields} \quad (P \times G)_{max} = \frac{G_{max} P_{max}}{4}$$

This point corresponds to the midpoint on the line with the corresponding maximum efficiency of

$$\varepsilon_{max} = \frac{P_{max} G_{max}}{4 \varepsilon_{motor} V_{motor} I_{motor}}$$

Let's look at some commercial fans and blowers and see what their efficiencies are. It is assumed that the product of voltage and current stays nearly the same for all loads. Table 1 shows some of these commercial fans with their respective size, thickness, voltage, current, volumetric flow rate, pressure and efficiency.

Type	Size(mm)	Thickness (mm)	P_{max}(pa)	V_{max}(m^3/min)	V(volts)	I(Amps)	Efficiency (%)
Blower	76	30	98	0.31	12	0.27	5.6
Blower	76	30	151.9	0.36	12	0.37	7.3
Blower	76	30	58.8	0.25	12	0.14	5.2
Blower	76	30	98	0.31	24	0.14	5.4
Blower	76	30	151.9	0.36	24	0.17	8.0
Blower	76	30	58.8	0.25	24	0.1	3.6
Blower	97	33	410	1.04	12	0.9	23.5
blower	97	33	760	1.34	12	1.8	28.1
Blower	97	33	490	1.11	12	1.1	24.5
blower	97	33	610	1.22	12	1.4	26.4
Blower	97	33	410	1.04	24	0.45	23.5
blower	97	33	760	1.34	24	0.83	30.4
Blower	97	33	490	1.11	24	0.55	24.5
blower	97	33	610	1.22	24	0.7	26.4
Blower	120	32	175.4	0.78	12	0.6	11.3
Blower	120	32	109.8	0.61	12	0.32	10.4
Blower	120	32	175.4	0.78	24	0.3	11.3
Blower	120	32	109.8	0.61	24	0.16	10.4
Blower	160	40	313.6	1.62	12	1.3	19.4
Axial fan	40	15	192	0.36	12	0.17	20.2
Axial fan	40	28	143	0.38	12	0.28	9.6
Axial fan	80	25	80.4	1.5	12	0.38	15.7
Axial fan	100	25	708	2.03	48	0.36	49.5
Axial fan	133	91	395	6.39	48	0.55	56.9
Axial fan	140	38	98	4.5	12	0.73	30.0
Axial fan	140	51	130	5.9	12	1.25	30.4
Axial fan	172	51	1000	15.46	48	2.91	65.9
Axial fan	175	69	360	9	48	0.65	61.8

Table 1- Typical Commercial Fan and Blower Efficiencies

The table shows that the efficiencies range from 3.6% to 65%. For small fans, the efficiency is very low, gradually increasing for bigger fans. For example, for 40x40x28 mm, the efficiency is about 9.6%. For typical servers in data centers, the fan size is about 172x172x51 mm, with efficiency of about 66%. For smaller fans, one can see that the energy lost is huge. For example, a 1-U system, using a 40x40x28 mm fan, has an efficiency of only 9.6%. This means that 90% of the energy input is lost, contributing to the cost of energy for cooling the electronics. Even for larger fans, an efficiency of 66% is low. The above efficiencies are based on the assumption of maximum efficiency, which is almost at the midpoint of the P-Q curve. In practice, the operating point may shift far away from the optimum point at the middle. For example, if you look at figure 1:

P_{max} = 45 pa
G_{max} = 1.35 m^3/min
P = -45/1.35G+ 45

Now assume the operating point is at the left hand side of the optimum point, at G = 0.3 m^3/min, P_{fan} = 35 pa

$$\varepsilon = \frac{P_{fan} G_{fan}}{\varepsilon_{motor} V_{motor} I_{motor}} = \frac{35 \times 0.3}{\varepsilon_{motor} V_{motor} I_{motor}} = \frac{10.5}{\varepsilon_{motor} V_{motor} I_{motor}}$$

$$\varepsilon_{max} = \frac{P_{max} G_{max}}{4\varepsilon_{motor} V_{motor} I_{motor}} = \frac{45 \times 1.35}{4\varepsilon_{motor} V_{motor} I_{motor}} = \frac{15.2}{\varepsilon_{motor} V_{motor} I_{motor}}$$

Comparing the maximum efficiency with the real efficiency, we can see that there is almost a 50% drop. In most applications for servers with increasing number of components, the pressure drop is most likely to be higher than that of the optimum point, so a 50% drop of the maximum efficiency would yield about 30-40% efficiency. The smaller fans have a much worse efficiency than the larger fans.

The situation gets worse for blowers, as can be seen from Table 1. In general, blowers are less efficient than fans. Figure 2 shows the theoretical characteristic and efficiency curve for an axial fan[3]. Point C is the design point, which corresponds to maximum efficiency. By moving to the right hand side of point C, the flow increases and the pressure decreases, but the efficiency drops very fast. To the left of point c, the situation is reversed and the efficiency drops very rapidly, too. If there is too much resistance on the fan to move the operating point close to around point D, the fan blades stall, resulting in discontinuity of the characteristic curve which causes instability of the fan.

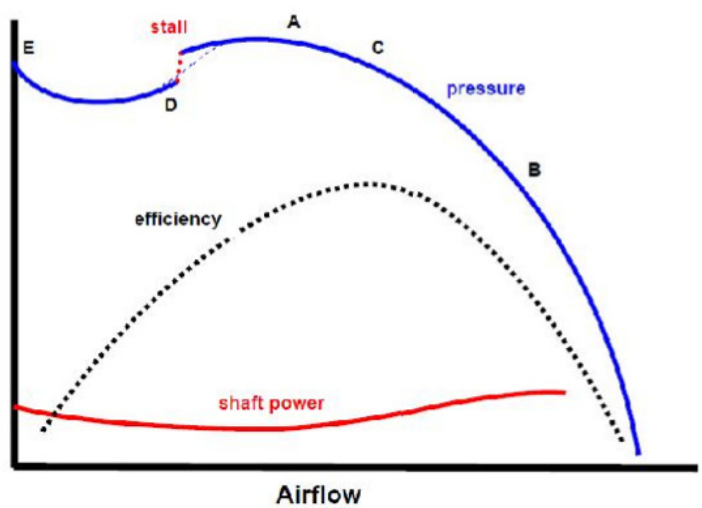

Figure 8. Loss Coefficient as a Function of Percent Blockage Area for a Fan [3]

To the left of point D, due to severe flow restriction, the boundary layers break away from the blades and centrifugal action occurs, producing recirculation around the blades. In practice, there are two losses in axial fans [3]. The recoverable losses that are associated with the vortices and rotational components leaving the fan. These losses can be minimized by operating at the design point and by utilizing guide vanes. As we depart from the design point, however, the swirling will build up.

The non recoverable losses are associated with friction at the bearing, drag on the casing, supporting rods, the casing and the blades. These losses are converted to heat, which is input to the system. Fans have been traditionally been used in cooling devices and will be used for the foreseeable future, since their implementation is the easiest. As the world becomes more concerned about energy uses and efficiencies of the systems, it is imperative that the designer takes into account all the factors that influence the performance of the fan. For example, in a data center with thousands of fans running, it is not difficult to see the benefit of improving the fan efficiencies which lead to huge financial gains and reduction of energy usage.

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Recent Developments in Liquid Cooling Approaches for Data Centers

It has been said that data centers are the cell phone towers of this decade. More and more are being installed quietly and unobtrusively. The proliferation of users, growth of social media, increase of online marketing and boost in availability of cloud-based storage are among the reasons why more data centers are being installed.

An important difference from cell towers is the energy needed to power the world's data center grid. One estimate is that 2% of all electricity is used to keep data centers running. All of these high power data centers face thermal management issues from increasing heat loads densities.

While air cooling systems have been the norm, the combination of environmental concerns, energy conservation and increasing heat have led to a new generation of liquid cooling solutions to manage data center heat. Liquid cooling can provide high performance while achieving high energy efficiency in power densities, beyond air cooled equipment. And, as overclockers and gamers have shown, at the PC level, liquid-cooled processors run more efficiently.

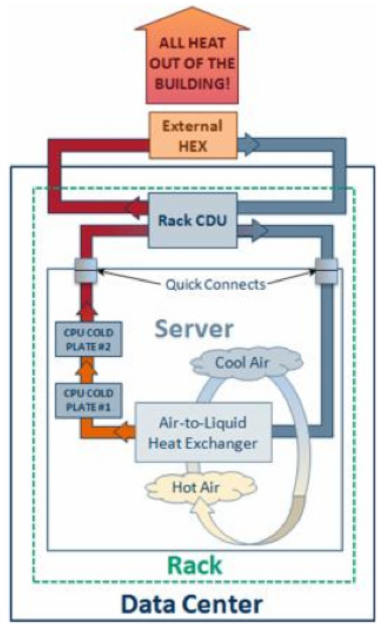

Figure 1: Sealed Servers are Self-Contained Cooling Units That Do Not Exchange Air with Their Surroundings. All Heat Generated Within the Server is Removed via Cooling Liquid to the Exterior Environment. [1]

In fact, Asetek, an industry leader, recently introduced a range of data center cooling solutions designed to remove heat directly from processors, and to move this heat to an optimal location for dispersal to the environment. The Asetek data center liquid cooling solutions provide three tiers of server cooling. These include internal liquid loops for high wattage processors in high density servers, liquid coolers for rack servers and blades, and a sealed server cooling system that avoids the use of air for cooling purposes. [1]

Figure 2: Four-Rack CarnotJetTM System is One of the Company's Fluid Submersion Cooling Solutions. Servers are Submerged in Mineral Water- based GreenDEF™ Coolant. [2]

Other liquid cooling methods call for submersion of the server in a dielectric, environmentally benign fluid. The CarnotJet™ system from Green Revolution Cooling is a fluid submersion cooling system for rack-based servers in the company's GreenDEF™ coolant. This is described as a white mineral oil with 1200x more heat capacity by volume than air. These systems can accommodate a series of 42U racks. Fans and thermal grease must be removed prior, and hard drives must be encapsulated. But the result can be 40- 50% less overall data center power consumption. [2]

Efforts to create greener data centers certainly include new approaches to liquid cooling. The recent Green Grid Forum put a spotlight on the benefits of locating a data center by a river, lake or sea. [3] The nearby water is harnessed for cooling and safely returned to the environment. The Green Mountain Data Center in Norway is carved into a mountain near a fjord and claims to have no carbon footprint. Google's Finland data center is cooled by the icy water of the Baltic Sea.

If those waters sound too cold, eBay's Phoenix-based data center uses water from outdoor tower tanks for thermal management. Water in the tower can reach 87°F. But that's cooler than the data center itself, where temperatures inside can be 115°F.

Figure 3: The eBay Data Center in Phoenix uses Hot Water from Outdoor Yanks for Cooling Its Servers. [4]

Aptly named Project Mercury, the installation has actually pitted Dell and HP against each other to see who can provide better hot water cooling system. Dell has implemented a tower cooling system, while HP is using an adiabatic system, which uses sharp pressure alterations to change water temperature. Nelson declines to say who's winning, but the point is that both are determined to do so. [4]

Competition and cooperation can both affect new advances in liquid cooling schemes for data centers. As a resource, ASHRAE last year published its Thermal Guidelines for Liquid Cooled Data Processing Environments.[5] Building on earlier documents, the document places increased emphasis on energy efficiency. It also focuses on performance and the use of waste energy. The guidelines recommend several ranges of facility supply water temperatures to meet the business and technical needs of different data centers.

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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.

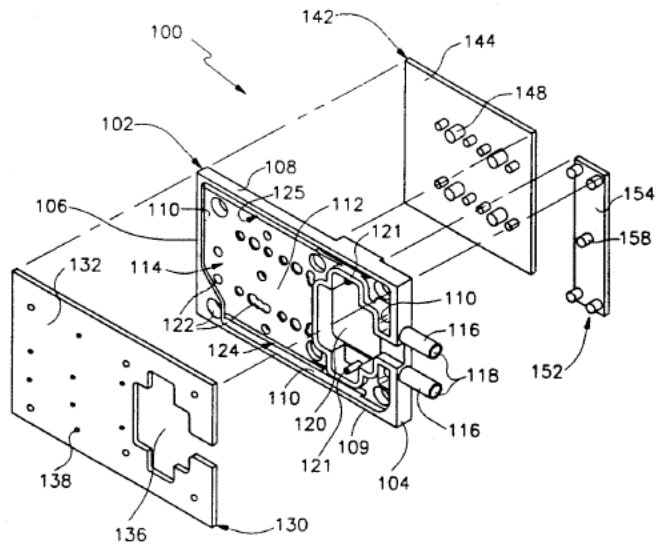
This invention features a coolant management system for cooling electrical components. The coolant management system consists of a heat transfer plate with a high thermal conductivity that is mounted to hot electronic components, and a coolant management system that directs coolant against the first 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.



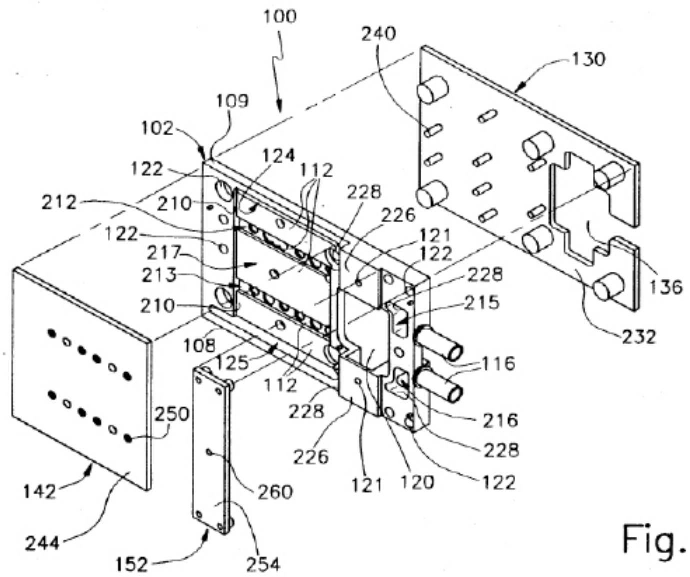
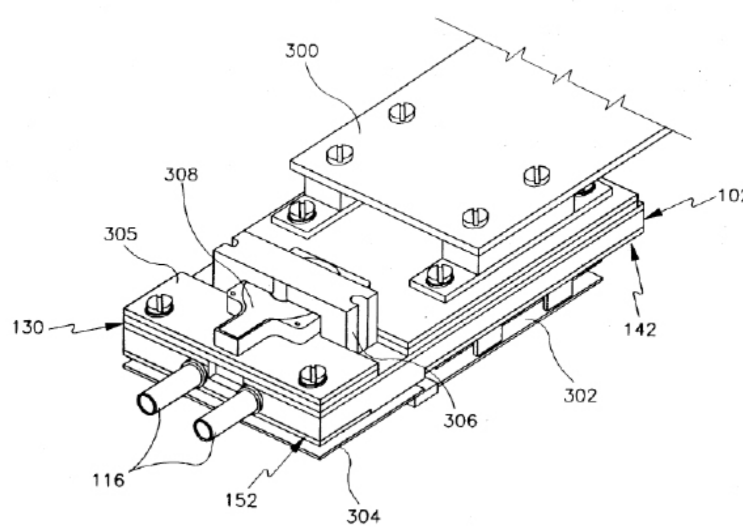


Fig.



LIQUID COOLING APPARATUS FOR USE WITH ELECTRONIC EQUIPMENT

5,871,042, Gutfeldt, et al.

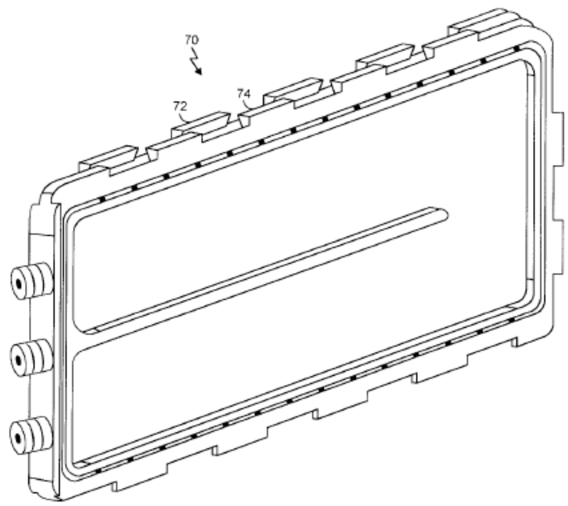
Electronic devices can generate heat and often require cooling in order to be maintained at an optimum operating temperature. Some liquid cooling designs are known and references are made to devices described in U.S. Pat. Nos. 4,109,707,4,938,279; 4,879,632; 4,997,032; 5,000,256; and 5,040,051. These 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.

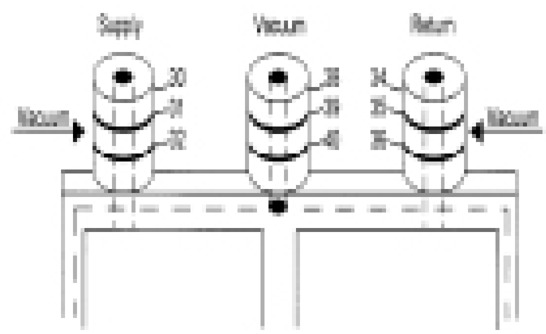
Electronic equipment such as printed circuit boards tends to have sharp protrusions including edges and soldered connections. Moreover, it is known that electronic equipment is very sensitive to liquids because liquids can corrode or short out the electronic components. However, many conventional containers 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.

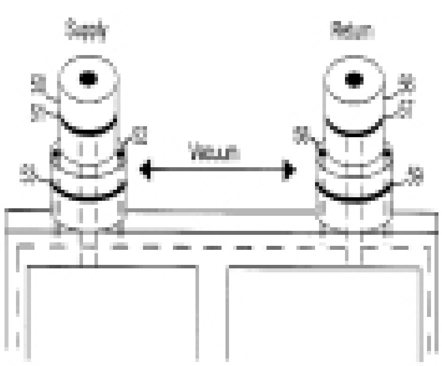
The goals for this invention are to overcome these limitations and to provide an apparatus that offers the benefits of liquid cooling along with an access method to for detecting leaks in the cooling device before damage takes place, and a way to protect the electronic components from any leakage.

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.







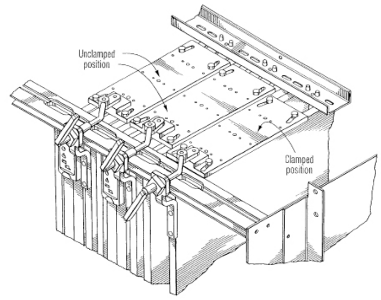
LIQUID COOLING OF REMOVABLE ELECTRONIC MODULES BASED ON LOW PRESSURE APPLYING BIASING MECHANISMS

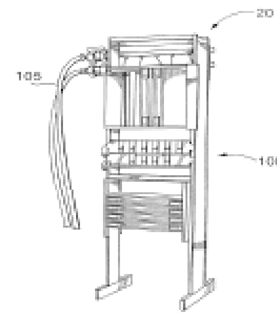
6,393,853 Bl, Vukovic, et al.

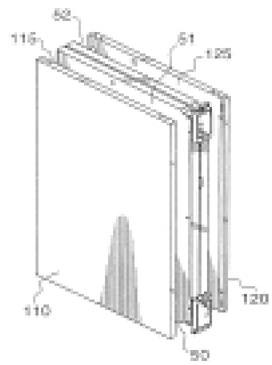
This invention addresses the liquid cooling of removable electronic modules. It describes an apparatus for cooling an electronic module in a shelf unit comprising a cold plate and a mechanism for moving cold plates toward and away from the module into operating and released positions, respectively, relative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







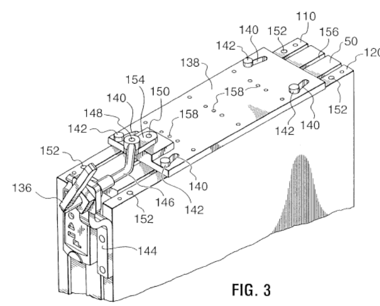
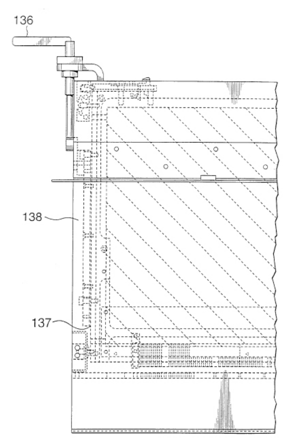


FIG. 3



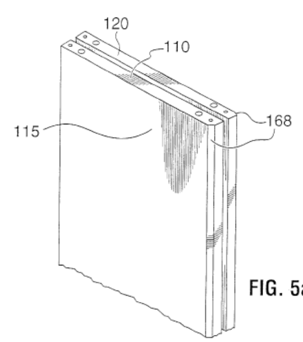


FIG. 5a

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/cm2, 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°Cat 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.

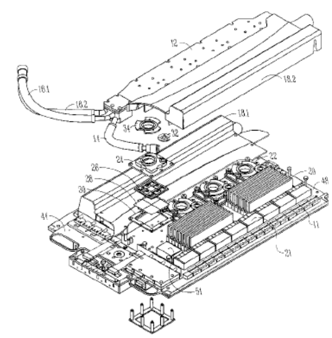
Several options for the enclosure are as follows. For instance, in one option, the cooling means includes a cooling coil and means for directing water through the cooling coil. In another option, the enclosure further includes means for spray evaporative cooling over a second set of electronic components. 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.

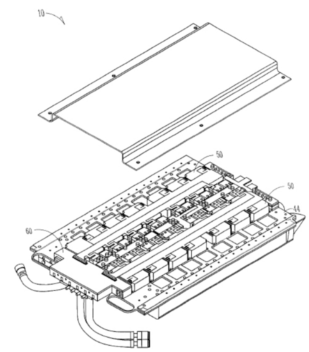
In another set up, a system includes a chassis with one or more modules containing one or more electronic modules and at least one fluid conditioning unit, and at least one of the electronic modules includes at least one spray evaporative cooling assembly. The system further includes a gas distribution 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.

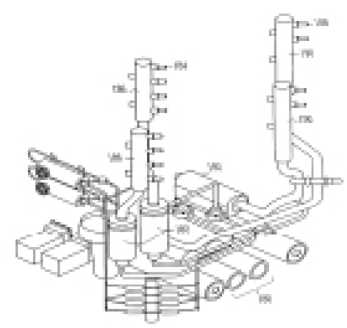
A method of cooling an electronics enclosure is provided in which air is forced over a first set of electronic components, cooling these components, heating a liquid to a temperature near its boiling point, directing the heated liquid against a second set of electronic components where at least portion 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.







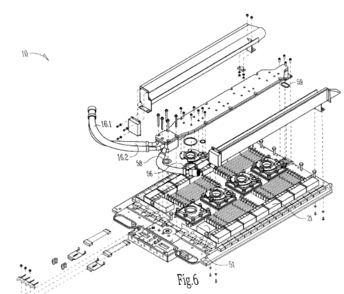
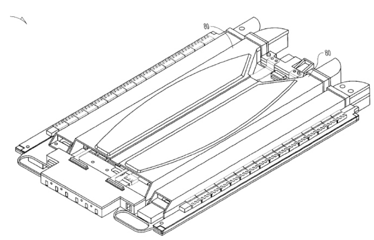


Fig.6



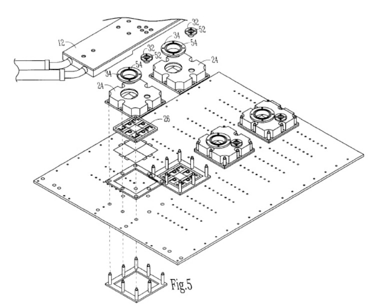


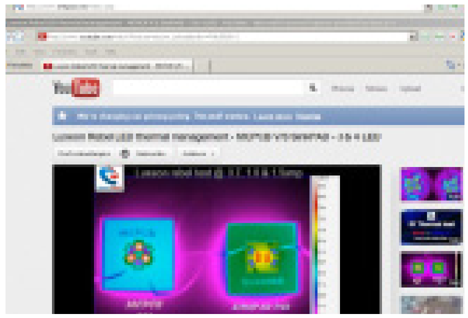
Fig.5

Cooling News

New Products, Services and Events from around the Industry

Air-to-Air Heat Exchangers

Delta Electronics has launched the world's first Air-to-Air Heat Exchanger series, providing capacity from 50W/K to 260W/K that offers a simple and integrated thermal solution to the outdoor cabinet in telecom applications. The heat exchangers provide up to a 30% increase of energy efficiency to reduce operation cost, in a size that is 50% smaller than traditional heat exchangers. Customer benefits include lower operation cost and small space requirements. Delta's Air-to-Air Heat Exchanger provides complete isolation protection from air contamination, dust and humidity. The heat exchangers are designed in compliance with IP55, TUV, CE, and UL, and have passed severe salt fog cycle tests.



Video Compares LED Cooling Methods

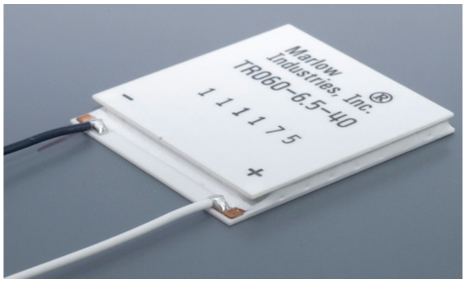
SinkPAD Corporation has posted a new video which compares the performance of their cooling technology with that of an MCPCB (metal core PCB), when applied to a high power Luxeon Rebel. The video features IR images that help demonstrate SinkPAD's claim that in the case of an aluminum PCB or MCPCB printed circuit board, a SinkPAD can transfer heat at the rate of 135 W/m·K compared to the industry standard of 1-4 W/m·K, and the rate of transfer for heat can be up to 385 W/ m·K in the case of copper SinkPAD. The video is available on the company's website.

Fan Cord Thermostatically Controls AC Fans

The Green Fan Cord, from fan accessory specialist Gardtec, is the only fan supply cable available that can thermostatically control AC fans. Now available from Aerco, this patent-pending design is described as revolutionary to the AC fan industry, as it replaces an existing fan cable and requires no additional wiring, circuit boards, controls boxes or design changes. It is particularly suitable for multiple fan configurations, such as fan trays. With the Green Fan Cord, the AC fan is automatically turned on and off to keep a system operating at a pre-set optimum temperature, thus saving energy, reducing costs, minimizing noise and increasing product life, says the company.

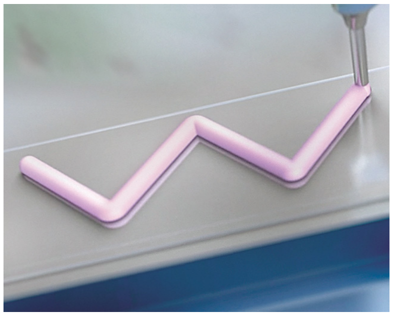
PCB-Mount Temperature Controllers Deliver Stable Performance

The PTC Series PCB-Mount Temperature Controllers deliver stable performance and long-term reliability. PTC Series controllers are found in such diverse applications as particle and droplet measurement, communications, manufacturing test and medical systems. The PTC controllers operate from a single power supply between 5 V and 30 V, and two models drive ±5 amps or ±10 amps to a Peltier thermoelectric cooler or a resistive heater. These controllers mount directly to a circuit board. PTC controllers interface with a variety of temperature sensors, and the bias current is adjustable in order to maximize controller sensitivity and stability for any application.



Thermoelectric Modules Keep Electronics Cool

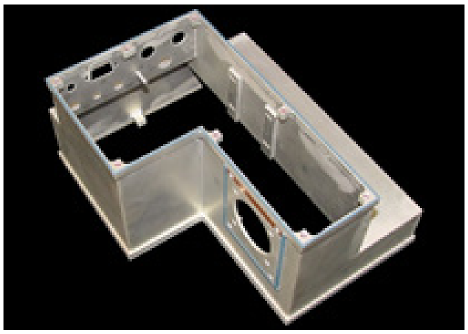
Marlow Industries has announced the availability of a new Triton ICE thermoelectric module series that will chill electronics as much as 2°C below current market offerings. Inspired by sub-zero temperatures on Neptune's moon Triton, the coolers can dramatically improve customer electronic systems in thermal performance, cost, noise, weight, size or efficiency. The Triton ICE modules exceed the industry standard in cooling capacity, rate and efficiency, while using the same input power. They can chill electronics as much as 2° C below current market offerings. Inspired by sub-zero temperatures on Neptune's moon Triton, the coolers can improve electronic systems in thermal performance, cost, noise, weight, size or efficiency.

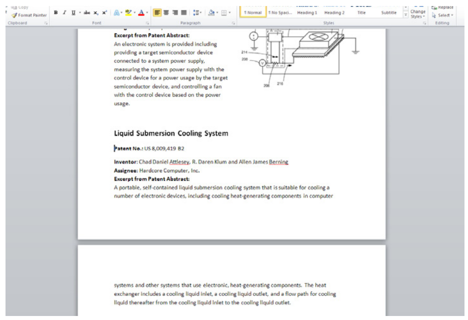


Thermal Gap Filler Provides Slump Resistance

Gap Filler 1000SR, from Bergquist, is a two-part, thermally conductive, liquid gap filling material that features superior slump resistance. The mixed system will cure at room temperature and can be accelerated with the addition of heat. Unlike cured thermal pad materials, a liquid approach offers infinite thickness variations with little or no stress to sensitive components during assembly. As cured, Gap Filler 1000SR provides a soft, thermally conductive, form-in-place elastomer that is ideal for fragile assemblies or for filling unique and intricate air voids and gaps. Thermal conductivity is 1.0 W/m-K. Gap Filler 1000SR exhibits low level natural tack characteristics and is intended for use in applications where a strong structural bond is not required.

Industry News





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.

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.

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.
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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.

ATS ADVANCED THERMAL SOLUTIONS, INC.
Innovations in Thermal Management®

Upcoming Thermal Management Events

coolingZONE LED 2012 - www.coolingzone.com

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

coolingZONE and InnovationFAB will be hosting a dedicated conference on LED thermal management and smartCooling. The conference is a combination of the technical and manufacturers presentation on thermal management of LEDs. The conference will be preceded by a series of short courses dedicated to thermal management and characterization of LEDs.

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