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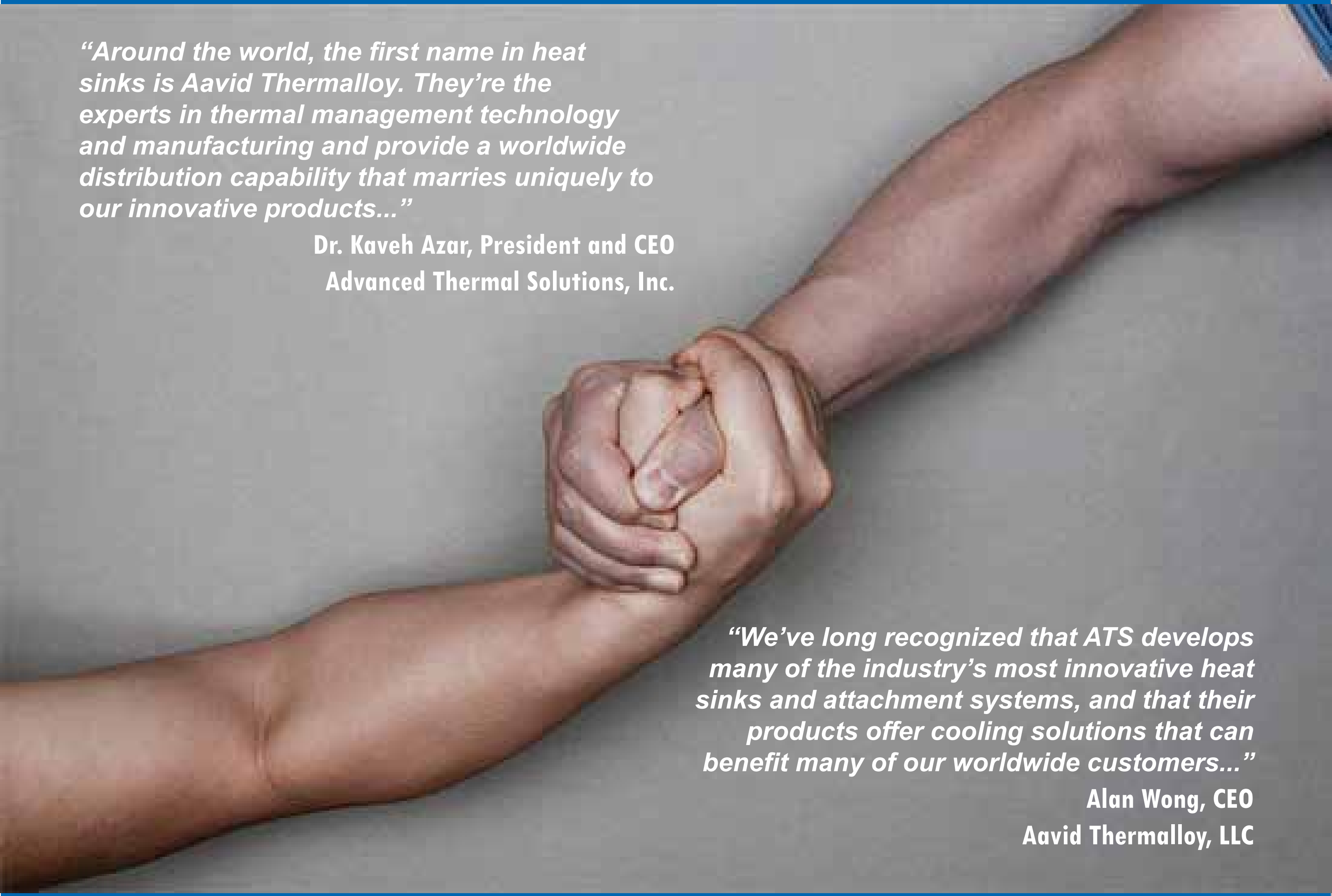

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Piezoelectric Fans

and Comparisons to Traditional Axial Fans

In a recent Qpedia article, the theory behind the operation of piezoelectric fans was introduced [1]. An electric current applied to a piezoelectric transducer (PZT) will cause it to bend. An alternating current will cause it to oscillate back and forth, which, with the addition of a cantilevered blade, can be used to make a simple fan. Piezoelectric fans tend to be small, on the order of several centimeters long, and their size may allow them to fit in applications where a traditional axial fan or blower may not.

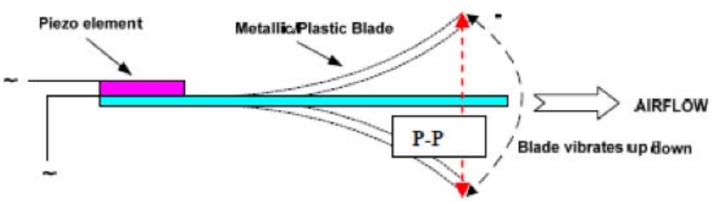

Figure 1 - Schematic of a Typical Piezoelectric Fan [2]

Acikalin et al. [3] studied the transient flow patterns generated by a piezoelectric fan at startup, and were able to estimate what the fully developed flow would look like. In Figure 2 above, the blade of the piezoelectric fan is indicated by the dark line in the middle. The movement of its tip is up and down, and the vortices generated by the tip of the blade are clearly visible. These vortices help break up the boundary layer, which raises the convection coefficient from the surface.

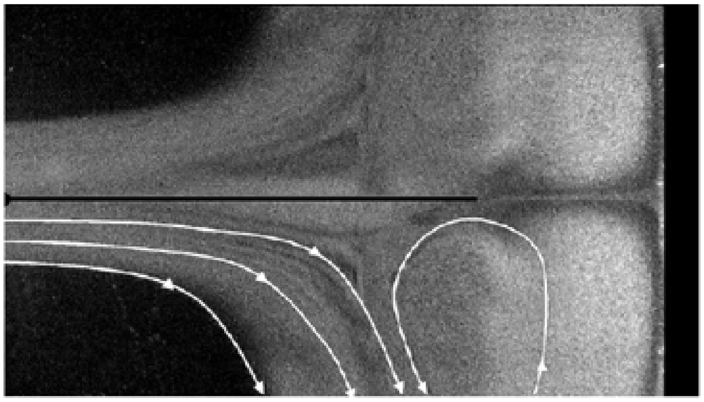

Figure 2 - Flow Visualization From A Piezoelectric Fan [3]

In this visualization, it was found that the primary air intake was near the blade pivot point on the left, and also on the right near the blade tip. The maximum air speed was estimated to be about 30 cm/s [3].

These findings are reinforced by Kimber et al. [4] who placed walls around a piezoelectric fan and measured the effect of the wall position and maximum pressure and flow rate. In their tests, the distance S was defined as shown in Figure 3 below. S was varied from 32mm to 9mm, and the resulting flow was plotted against pressure and flow rate, shown in Figure 4.

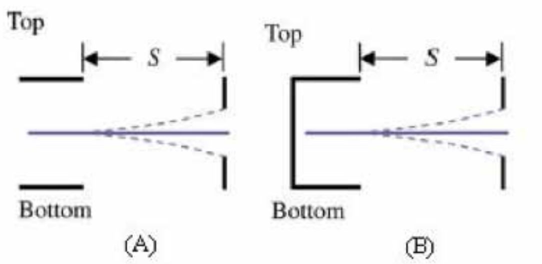

Figure 3 - Variable Inlet Test Arrangements [4]

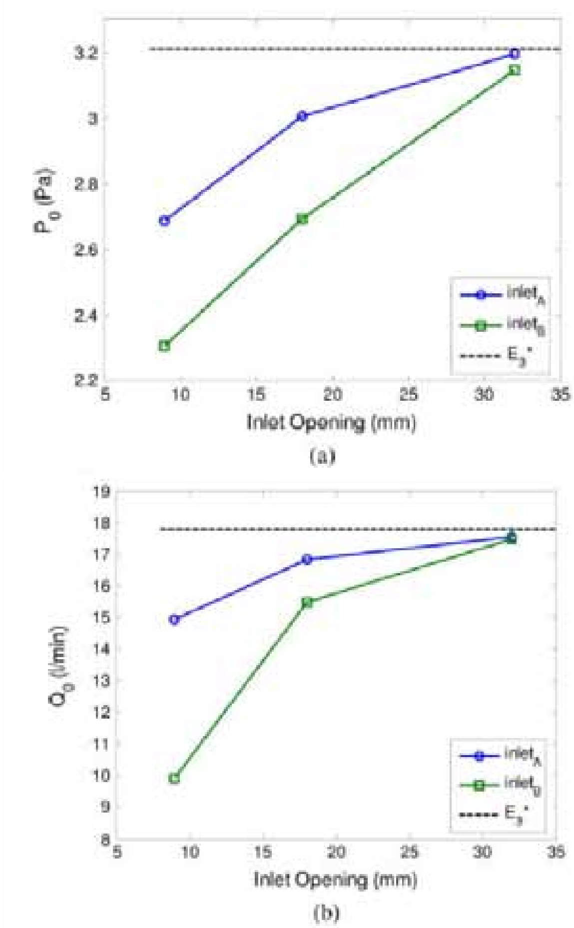

Figure 4 - Effect of Inlet Opening On Pressure Drop and Flow [4]

In Figure 4, the setup referred to as E_3 is one with the top and bottom walls completely removed. It can be seen that the large top and bottom inlet allow for the most air flow, and that air flow from the blade pivot area is less important when the top and bottom airways are open. When the areas above and below the fan are blocked, however, then a significant amount of air is drawn from the pivot area of the fan. Kimber et al. conclude that walls above and below the blade tip should be at least 4-5 times the vibration magnitude away from the fan in order to maximize the flow rate [4].

This flow pattern is much different from the swirling flow of an axial fan, but it turns out that in terms of flow rate and static pressure, piezoelectric fans can compare favorably to axial fans. Kimber et al. set up piezoelectric fans as shown in Figure 5, and performed tests using Mylar or Steel as the blade material. These piezoelectric fans were compared to small axial fans that were chosen to have comparable performance, although the dimensions of the fans were not discussed.

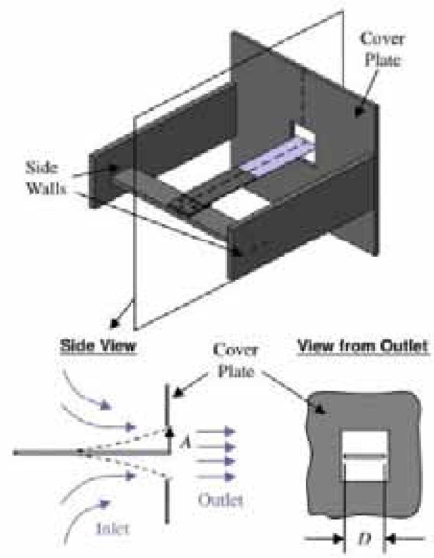

Figure 5 – Piezoelectric Fan Flow Test Setup [4]

From the results in Figure 6, it can be seen that the flow rates achieved by the piezoelectric fans are very similar to an axial fan which uses an order of magnitude more power. The piezoelectric fans do, however, produce a lower static pressure than the axial fan under the same conditions. In general, by looking at the data in Figure 6, it would appear that piezoelectric fans are capable of good flow rates using much less power than an axial fan, but they are not as good at overcoming backpressure. Keep in mind that all of the fans in this test are quite small, and that these results probably would not scale up to larger applications. A large piezoelectric fan blade would simply have too much mass to oscillate at the frequencies that make small ones effective.

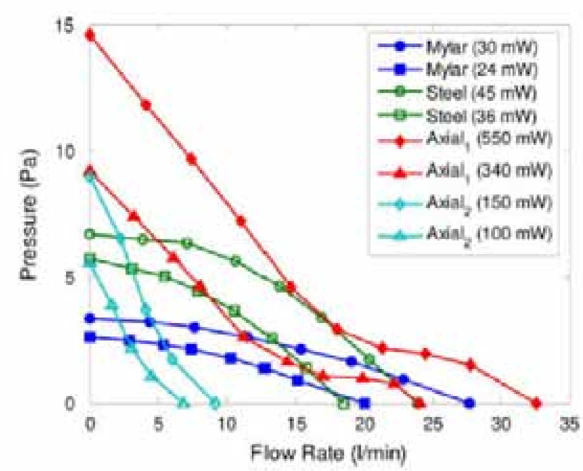

Figure 6 - Experimental Fan Curve Data [4]

It is also interesting to note that both the mylar and steel bladed piezoelectric fans have similar flow rates when there is no backpressure, but the steel bladed piezoelectric fan is capable of much higher static pressure. In this setup, the steel blade exhibits lower amplitude of vibration than the mylar blade, but its frequency is higher, and the steel blade consumes more power. Kimber et al. found that flow rate is related to a combination of frequency and amplitude, while the pressure generated is more heavily dependent on frequency.

Sauciuc et al. also compared small form factor piezoelectric fans to conventional fans, looking at several factors [2]. The test rig consisted of a 4mm tall fully ducted heat sink attached to a heat pipe with a heat source at the other end. In order to make comparisons between the piezoelectric fan, axial fan, blower fan and no fan (natural convection), three dimensionless ratios were defined with the format:

$$\text{Cost Ratio} = \frac{\text{Cost(Technology Considered)}}{\text{Cost(Natural Convection)}}$$

Similarly, Volume Ratio and Power Ratio were defined as the volume and power consumed by the cooling technology compared to the heat sink with natural convection. In Figure 7 below, the scale for the ratios is listed on the left side, and the actual thermal resistance (Performance) of each setup is indicated on the right.

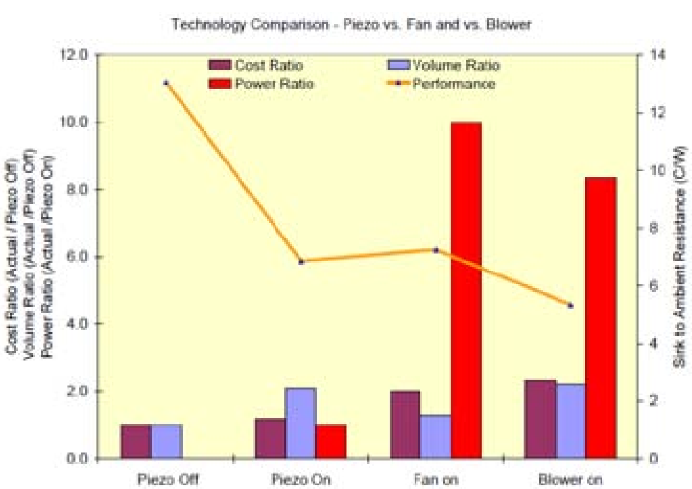

Figure 7 - Comparison of Various Cooling Technologies [2]

The tests were performed with fans that would perform similarly to the piezoelectric fan, but it can be clearly seen that the piezoelectric fan uses much less power compared to the traditional fans. The volume occupied by the piezoelectric fan is also comparable to the other technologies, although it should be kept in mind that the different methods will suit certain form factors better than others. For example, a piezoelectric fan would need a wide and low space to operate, whereas an axial fan would need a narrower but taller duct. As for cost, piezoelectric fans are very simple devices and have the potential to be inexpensive, but at the moment their use is not mainstream and traditional fans are generally cheaper.

Piezoelectric fans have been a tantalizing subject for research because of the potential of a simple, quiet, efficient option for thermal management in compact applications. Obstacles still remain to their widespread use, such as the requirement for relatively high input voltage [5] and the need for alternating current. Research in piezoelectric materials with multiple layers has reduced this voltage requirement, but the technology still requires more work before it becomes commonplace.

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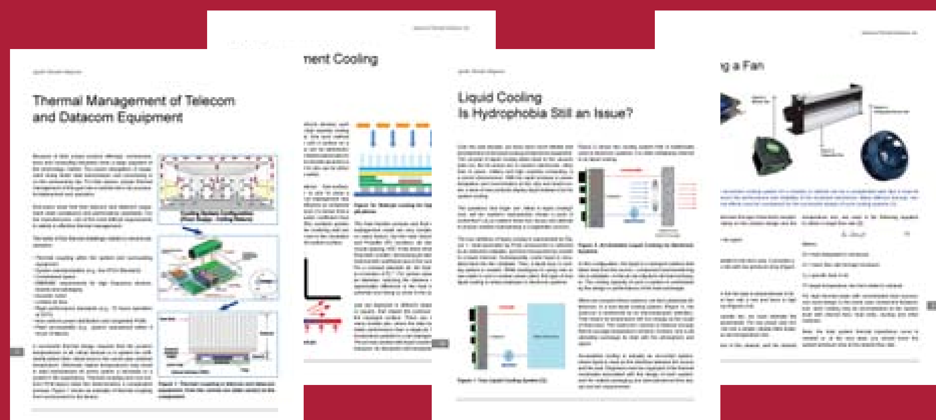

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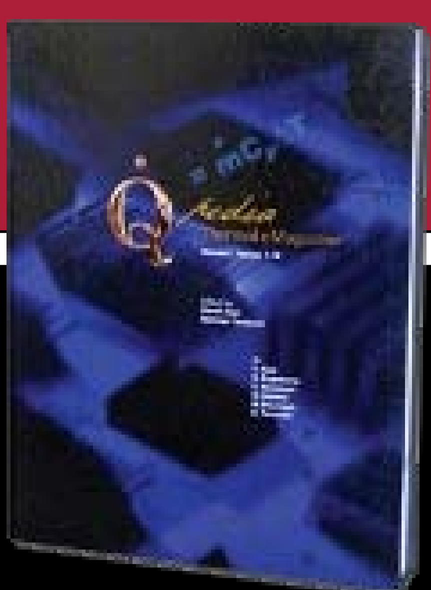

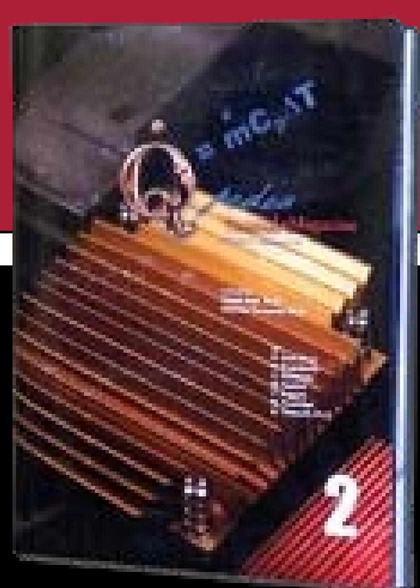

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High-Performance Server Cooling

High-performance servers are devices specially designed to handle large computational loads, a huge amount of communication signals, fast data processing, etc. Due to their task oriented nature, high-performance servers must have high reliability, interchangeability, compact size and good serviceability. To achieve high computational speed, high- performance servers generally have dozens of CPUs and memory models. They also have dedicated date process modules and control units to ensure seamless communication between CPUs and parallel data processing ability. To reach higher speeds, the power dissipation of high–performance CPUs has been increasing continuously in the past decade for its use in high-performance servers.
Cooling dozens of kW servers brings a unique challenge for thermal engineers. To deal with the ever-growing high heat flux issue in high-performance servers, it will need the cooperation of electrical, mechanical and system engineers to solve the problem. The job to remove the high heat flux from CPUs to ambient requires chip level, board level and cabinet level solutions.

Wei [1] described Fujitsu's thermal management advancements in their high-end UNIX server PRIMEPOWER 2500. The server cabinet is shown in Figure 1. Its dimension is 180cm × 107cm × 179cm (H×W×D) and has a maximum power dissipation of 40 kW. The system configuration of PRIMEPOWER 2500 is shown in Figures 2 and 3. It has 16 system boards and 2 Input/Output boards installed vertically on two back-panel boards. The two back- panel boards are interconnected by six (6) crossbars installed horizontally.

Figure 1. PRIMEPOWER 2500 Cabinet [1]

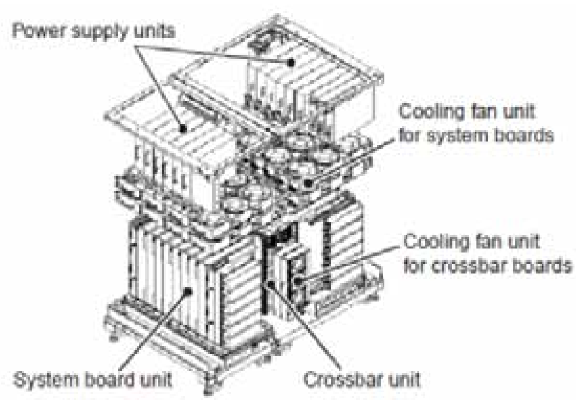

Figure 2. PRIMEPOWER 2500 System Configuration [1]

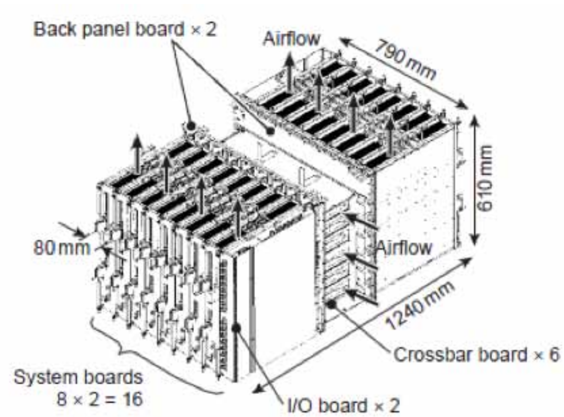

Figure 3. PRIMEPOWER 2500 System Board Unit [1]

To cool the electrical components inside PRIMEPOWER 2500, forty eight (48) 200mm- diameter fans are installed between the system board unit and the power supply unit. They provide forced air cooling for system boards and power supplies. In addition, six (6) 140mm-diameter fans are installed on one side of crossbar to cool the crossbar boards with a horizontal flow. The flow direction is shown in Figure 3. Each system board is 58cm wide and 47cm long. There are eight (8) CPU processors, thirty two (32) Dual In-Line Memory Modules, fifteen (15) system controller processors, and associated DC-DC converters on each system board. The combined power dissipation per system board is 1.6 kW at most.

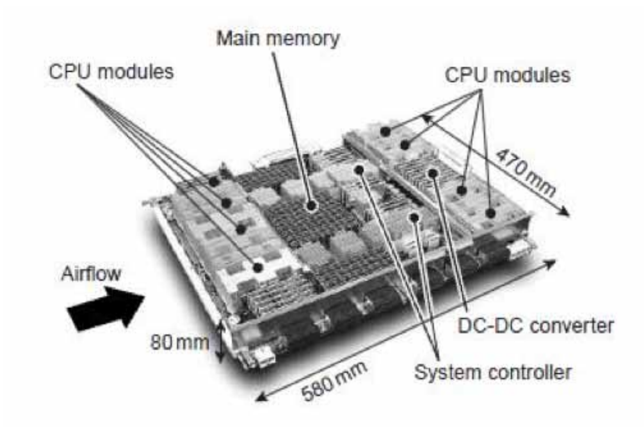

Figure 4. PRIMEPOWER 2500 System Board [1]

Forced air cooling technology is commonly used in computers, communication cabinets, and embedded systems, due to its simplicity, low cost and easy implementation. For high-performance servers, the increasing power density and constraints of air cooling capability and air delivery capacity have pushed forced air cooling to its performance limit. For high power systems like PRIMEPOWER 2500, it needs a combination of good CPU design, optimized board layout, advanced thermal interface material (TIM), high-performance heat sinks, and strong fans to achieve desired cooling.

The general approach to cool the multi-board system is first to identify the hottest power component with the lowest temperature margin. For the high-performance server, it is the CPUs. For multiple CPUs on a system board, generally, the CPU located on downstream of a board or other CPUs has the highest temperature. So, the thermal resistance requirement for this CPU is,

$$R_{ja} = \frac{T_{j,\max} - T_a - \Delta T_a}{q_{max}} \qquad (1)$$

Where $T_{j,max}$ is the allowed maximum junction temperature, T_a is the ambient temperature, ΔT_a is the air temperature rise due to preheating before the CPU, and q_{max} is the maximum CPU power.

The junction-to-air thermal resistance of the CPU is

$$R_{ja} = R_{jc} + R_{TIM} + R_{hs} \qquad (2)$$

Where R_{jc} is the CPU junction-to-case thermal resistance, R_{TIM} is the thermal resistance of thermal interface materials, and R_{hs} is the heat sink thermal resistance.

To reduce the CPU junction temperature, it is critical to find intuitive ways to minimize R_{jc}, R_{TIM}, and R_{hs}, because any reduction in thermal resistance is important in junction temperature reduction.

The CPU package and heat sink module of PRIMEPOWER 2500 are shown in Figure 5. The CPU package has an integrated heat spreader (IHS) attached to the CPU chip. A high- performance TIM is used to bond the CPU chip and IHS together, see Figure 6. The heat sink module is mounted on the IHS with another TIM in between.

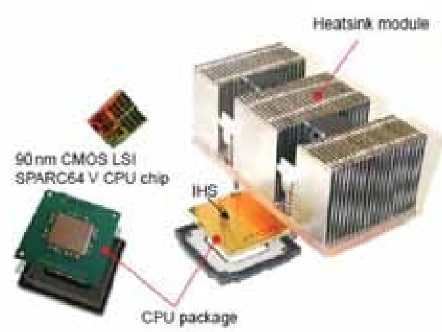

Figure 5. PRIMEPOWER 2500 CPU Package and Heat Sink Module [1]

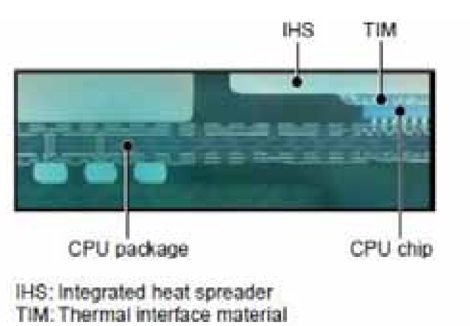

Figure 6. CPU Package [1]

The TIM used in between the CPU chip and the IHS is crucial to the CPU's operation. It has two key functions: to conduct heat from the chip to the IHS and to reduce the CPU chip stress caused by the mismatch of the coefficient of thermal expansion (CTE) between the CPU chip and IHS. Fujitsu developed a TIM made of In-Ag composite solder for the above application. The In-Ag composite has a low melting point and a high thermal conductivity. It is relatively soft, which is good for absorbing thermal stress between the chip and the IHS. Wei [2] also investigated the impact of thermal conductivity on heat spread performance. He found a diamond composite IHS (k=600 W/(m.K)) would result in a lower temperature gradient across the chip and low temperature hot spots, compared with aluminum nitride (k=200 W/(m.K)) and copper (k=400 W/(m.K)). The simulation results are shown in Figure 7.

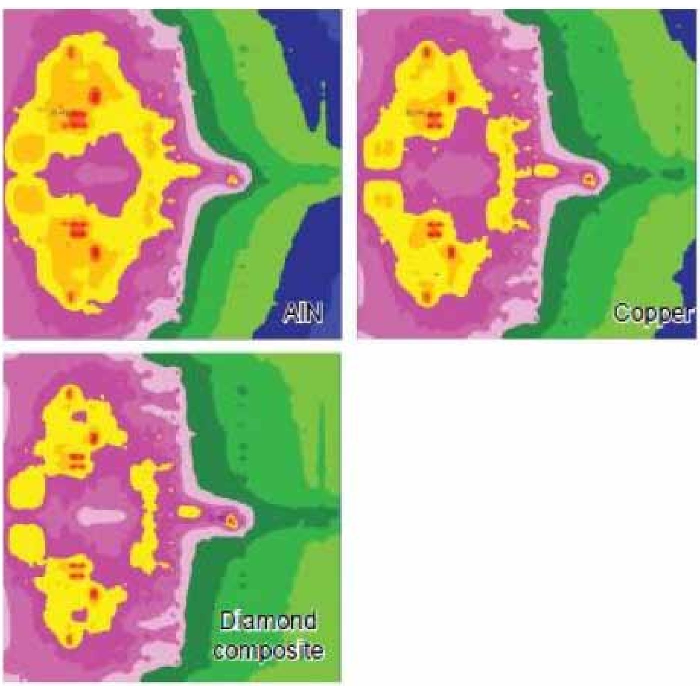

Figure 7. Heat Spreader Material Comparison [2]

In high-performance servers like the PRIMEPOWER 2500, the thermal performance gains by optimizing the TIM and the IHS are small, because they compose only a small portion of the total thermal resistance. Heat sinks dissipate heat from the CPU to air and have an important role in the thermal management of the server. In a server application, the heat sink needs to meet not only the mechanical and thermal requirements, but also the weight and volume restraints. Hence, heat pipes, vapor chambers, and composite materials are widely used in place of high-performance heat sinks.

Koide et al [1] compared the thermal performance and weight of different heat sinks for server application. The results are shown Figure 8. They used the Cu-base/AL-fin heat sink as benchmark. Compared with the Cu-base/AL-fin heat sink, the Cu-base/Cu-fin heat sink is 50% heavier and gains only 8% performance. If the heat pipe is used in base, the heat sink weight can be reduced by 15% and the thermal performance increases by 10%. If the vapor chamber is embedded in the heat sink base, it reduces the heat sink weight by 20% and increases the heat sink performance by 20%.

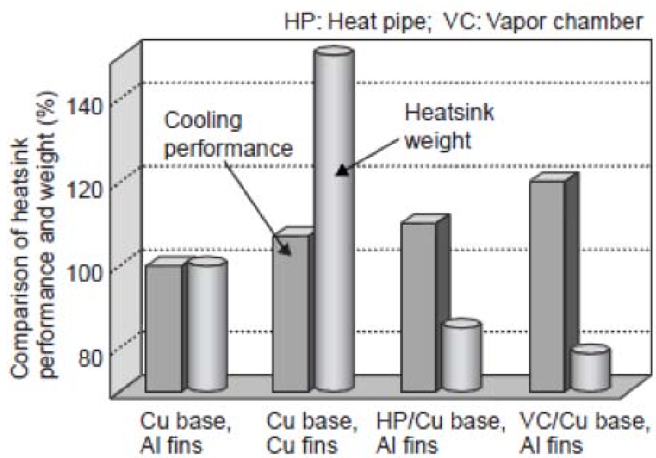

Figure 8. Thermal Performance and Weight Comparison of Different Heat Sinks [1]

(a)

(b)

Figure 9. (a) USIII Heat Sink for Sun Fire 15K Server, (b) USIV Heat Sink for Sun Fire 25K [3]

Sun Microsystems' high-performance Sun Fire 15K Server uses USIII heat sink to cool its 72 UltraSparc III (USIII) processors. In Sun Fire 25K Server, the CPUs are upgraded to UltraSparc IV (USIV), which has a maximum power of 108W. To cool the USIV processor, Xu and Follmer [3] designed a new USIV heat sink with copper base/copper fin, see Figure 9. The old USIII heat sink has seventeen (17) forged aluminum fins, the USIV heat sink has thirty three (33) copper fins. Both heat sinks have the same base dimensions and height.

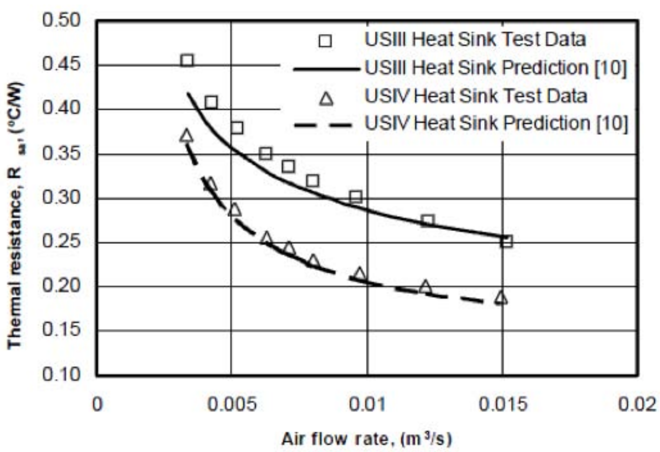

Figure 10. Thermal Resistance Comparison between USIII Heat Sink and USIV Heat Sink [3]

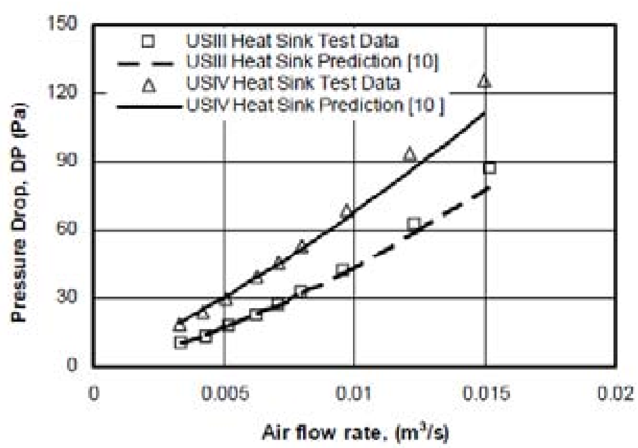

Figure 11. Pressure Drop Comparison between USIII Heat Sink and USIV Heat Sink [3]

Figure 10 shows the thermal resistance comparison between the USIII heat sink and the USIV heat sink. The thermal resistance of the USIV heat sink is almost 0.1°C/W lower than that of the USIII heat sink at medium and high flow rates, which is a huge gain in thermal performance. The thermal performance improvement of the USIV heat sink is not without penalty. Figure 11 shows the pressure drop comparison between the USIII heat sink and the USIV heat sink. For the same air flow rate, the pressure drop of the USIV heat sink is higher than that of the USIII heat sink. That means the Sun Fire 25K Server needs stronger fans and better flow arrangements to ensure the USIV heat sinks have adequate cooling flow.

The design of the cooling method in high-performance servers follows the same methodology used in the design cooling solution of other electronic devices, but at an elevated scale. The main focus is to identify the hottest components, which in most cases is CPUs. Due to extreme high power of CPU and memory modules, heat spreader, TIM and heat sinks have to be designed properly to achieve the desired cooling in the server. The goal of thermal management is to find cost-effective ways to maintain the junction temperature of the CPU lower than specifications and ensure the continuous operation of the server. Wei [1] has proved a 40kW server can be cooled by forced air cooling. However it requires highly integrated design and a huge amount of air flow that the fifty four (54) fans inside PRIMEPOWER 2500 can generate. In the near future, it would be very difficult for a forced air cooling method to cool cabinets with more than 60 kW power. It would require bigger fan trays to deliver huge amounts of air flow and large size heat sinks to transfer heat from the CPUs to air, which makes it impossible to design a reliable, compact and cost effective cooling system for the server. We have to find alternative ways to deal with this problem, Other cooling methods, such as air impinging jets, liquid cooling and refrigeration cooling systems, have the potential to dissipate more heat. But, it will require intuitive packaging to integrate them into the server system.

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NEBS Standards

and Testing Criteria

The NEBS standard was developed by Bell Labs in the 1970s to standardize equipment that would be installed in a central office. The objective was to make it easier for a vendor to design equipment compatible with a typical regional Bell operating company central office, resulting in lower development costs and easing the equipment's introduction into the network. Telcordia now manages the NEBS specifications. The four largest US Telecommunications companies (AT&T, Verizon, BellSouth, and Qwest) created the Telecommunications Carrier Group (TCG), a group formed to synchronize NEBS standards across the industry in the US. The TCG checklist specifies the individual NEBS requirements of each of its members in a matrix, making it simple to compare them.

Figure 1 - Environmentally Controlled Chamber for NEBS Testing [1]

NEBS Thermal Criteria

The purposes of the NEBS criteria are personnel safety, protection of property and operational continuity. Although NEBS standards are unique in focusing on the US telecommunications facility environment, they are largely based on national/international standards of FCC requirements. The NEBS standard's thermal criteria require equipment to operate normally after being subjected to various thermal conditions. For example, after exposure to extreme ambient temperatures and humidity, the equipment needs to operate as intended when returned to normal ambient conditions. Testing for NEBS thermal criteria is done in specialized, thermally controlled environments, as shown in Figure 1 and 2. In addition to thermal requirements, the NEBS standard also cover various physical and electrical criteria.

Figure 2 - Thermally Controlled Chamber [1]

Extreme Temperature Exposure and Thermal Shock

One of the thermal criteria of the NEBS standard is extreme temperature exposure and thermal shock. The packaged equipment cannot sustain any damage or functional deterioration after it has been stored in an extreme temperature environment. For this testing, the equipment functionalities are initially tested under normal operating conditions.

Then it will be subject to the temperature profiles shown in figure 3 for low extreme temperature and figure 4 for high extreme temperature. After the thermal soaks, a post- test equipment functionality test is performed once the equipment has recovered to normal operating conditions.

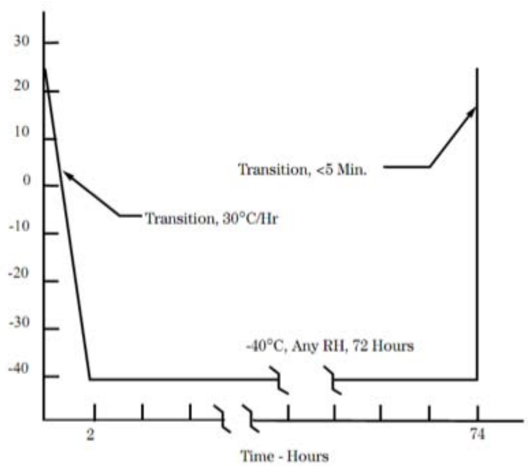

Figure 3 - Extreme Low Temperature Testing Profile [2]

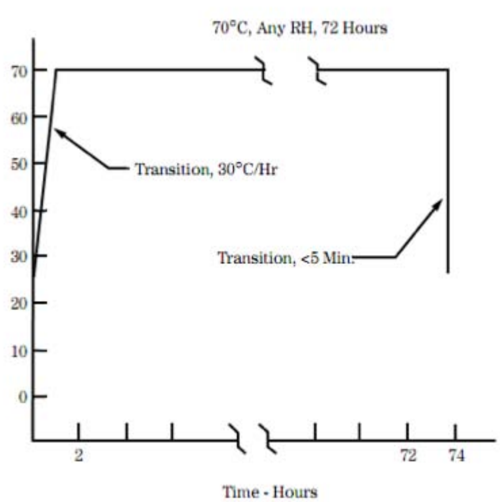

Figure 4 - Extreme High Temperature Testing Profile [2]

High Relative Humidity Exposure

The packaged equipment cannot sustain any damage or functional deterioration after it has been exposed to the high relative humidity environment. As in extreme temperature exposure testing, functionality testing is initially conducted under normal operating conditions. Then the equipment is packaged and placed into a test chamber at 23ºC and 50% RH. At 40ºC, increase the chamber's RH to 93% within two (2) hours and maintain for more than ninety six (96) hours. Transition the chamber's RH back to 50% at 40ºC within two (2) hours. Figure 5 shows the criterion's temperature/relative humidity profile. A post- test equipment functionality test is performed, once the equipment has recovered to normal operating conditions.

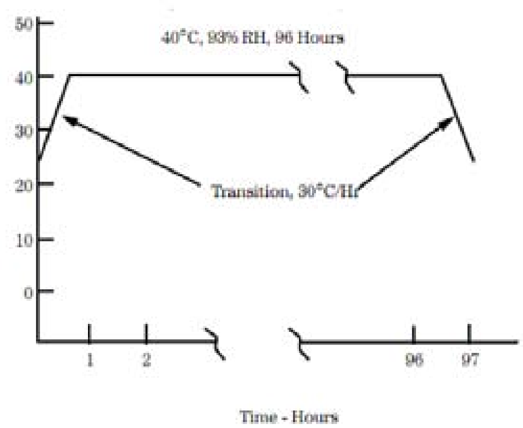

Figure 5 - High Relative Humidity Testing Profile [2]

Operating Temperature and Humidity

In order to ensure continuous equipment operation, the equipment cannot sustain any damage or functional deterioration when operating at the ambient environment stated in the operating temperature and humidity criterion. The control temperature and humidity sensor must be placed 1.5m (59in) from ground and 380 mm from the front of the equipment, as shown in Figure 6. The equipment must operate at 23ºC and at an RH level of 50% for at least four (4) hours to achieve steady state operation. Once steady state operation is achieved, the equipment needs to be subject to the temperature and RH profile shown in Figures 7 and 8. For shelf-level equipment, the maximum temperature

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must be 55ºC instead of 50ºC. If the product encounters a functional anomaly which requires a hardware replacement, a Root Cause Analysis shall be performed and the test will be repeated in full.

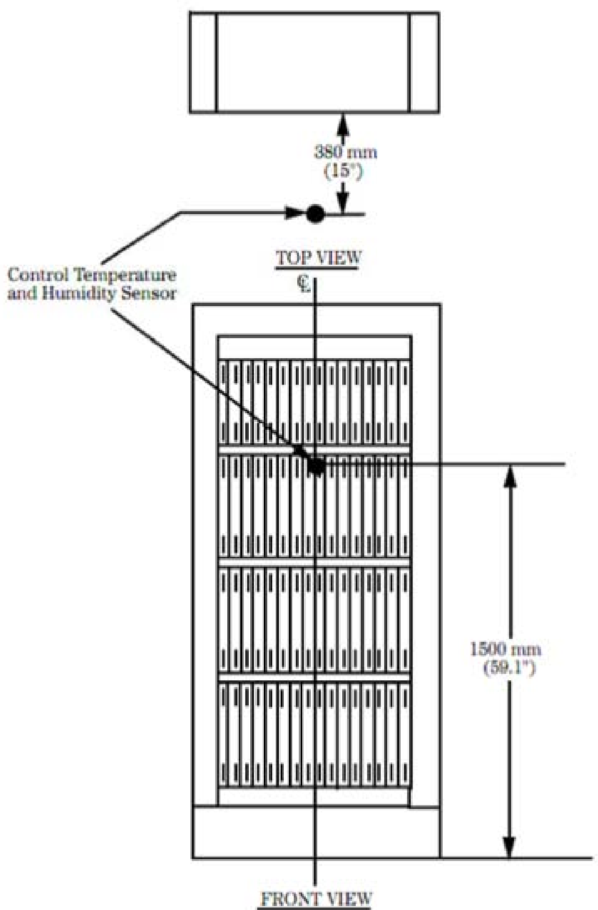

Figure 6 - Temperature and Humidity Measurement Location [2]

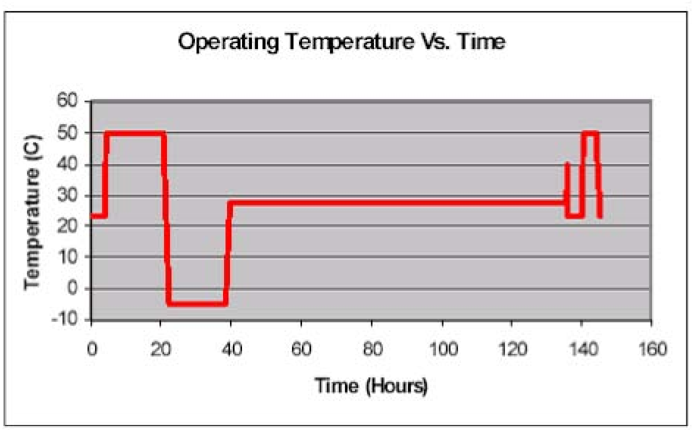

Figure 7 - Temperature Profile for Operating Temperature and Humidity Criterion Testing [2]

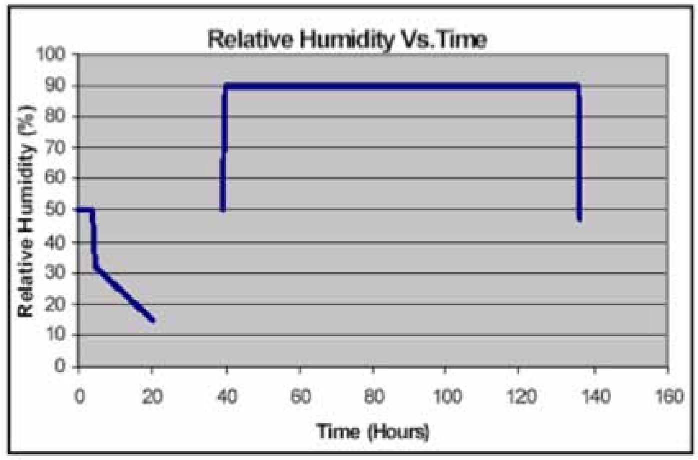

Figure 8 - Relative Humidity Profile for Operating Temperature and Humidity Criterion Testing [2]

Temperature Margin Evaluation

In addition to high and low operating temperature requirements and humidity criterion, the NEBS standard requires one to determine the equipment response to temperatures up to 10ºC above the short-term extreme temperature. The threshold temperature of the functional deterioration shall be reported. The equipment does not have to function normally under these conditions. This is only for informational purposes. In order to determine the threshold temperature, the equipment needs to achieve steady state operation at 23ºC and RH levels of 50% for at least four (4) hours. Then, the ambient temperature is to be increased to 50ºC for frame-level equipment (55ºC for shelf equipment), at a rate of 30ºC/hr, and maintained for 1 hour. The chamber temperature is then increased by 5ºC at a rate of 30ºC/hr and maintained. If there are performance changes, the temperature and the performance changes should be noted. If there are no performance changes, the chamber temperature increase of 5ºC must be repeated.

Altitude

The packaged equipment needs to be functional at different altitude ranges. For equipment installed above 1800m, the product documentation shall provide special requirements, if any. After the equipment reaches steady state operation at an ambient temperature of 25ºC and ambient pressure, the testing chamber's temperature is increased to 40ºC at a rate of 30ºC/hr. Then, it is further increased to 50ºC at a rate of 5ºC/hr. The chamber's pressure is then decreased to 80kPa at a rate of 15kPa/hr. NEBS standards require the condition of 50ºC and 80kPa to be maintained for eight (8) hours. Then, the chamber's temperature is decreased to 30ºC at a rate of 5ºC/hr, while decreasing the chamber's pressure to 60kPa at a rate of 15kPa/hr. The condition of 30ºC and 60kPa is maintained for eight (8) hours. The chamber's temperature is increased to 40ºC at a rate of 30ºC/hr and maintained at 40ºC and 60kPa for right (8) hours. Finally, the chamber's pressure is increased back to ambient at a rate of 15kPa/hr and the chamber's temperature is decreased to 25ºC at a rate of 5ºC/hr.

Fan Cooled Equipment

Equipment cooled by forced convection cannot sustain any damages or deterioration in functional performance when operated with a single fan failure at a 40ºC ambient temperature for a short period up to ninety six (96) hours. The equipment is required to have a remote alarm notification of a fan failure. The product documentation shall have replacement procedures for fans and cooling units. An estimated time of replacement is required if service interruption is needed for cooling unit replacement. In order to test fan failure, one of the fans that would most likely cause the greatest temperature increase in the system is de-energized, after equipment steady state is achieved. This condition is maintained for eight (8) hours and the equipment functionality is recorded. The test is complete if no other fans are to be tested. Otherwise, test must be repeated with each additional fan.

Surface Temperature

In order to protect maintenance personnel, equipment surfaces that face the aisle or upon which normal maintenance is anticipated shall not exceed 48ºC, when the equipment is operating in a room with an ambient air temperature of 23ºC. Passive equipment, where no heat is generated, is exempted from testing. Locations of the maximum temperature, and any temperature over 48ºC on the front surface of the equipment, need to be recorded after twenty four (24) hours of normal operation. The same procedure needs to be conducted for any surfaces to which a person may be exposed. The measured surfaces need to be described by part description/location and whether the part is a short term or long term exposure surface.

Heat Dissipation

NEBS standards require maximum heat release and the method of cooling to be documented. The heat release is to be specified as Watts and as W/m² or W/ft². The equipment heat release should not be greater than the values in Figure 9. If so, the heat release shall be clearly identified in the product documentation, along with a note indicating that special equipment room cooling may be required.

Individual Frame	
Natural Convection	1450 W/m² *(134.7 W/ft²)*
Forced-Air Fans	1950 W/m² *(181.2 W/ft²)*
Multi-Frame	
Entire System	860 W/m² *(79.9 W/ft²)* *
Any 6.1-m × 6.1-m (20-ft × 20-ft) square area within a larger system	1075 W/m² *(99.9 W/ft²)* *
Shelf	
Natural Convection	740 W/m² per meter *(20.9 W/ft²/ft)* of vertical frame space the equipment uses.
Forced-Air Fans	995 W/m² per meter *(27.9 W/ft²/ft)* of vertical frame space the equipment uses.

* Systems totally comprised of forced-air cooled equipment may increase these levels to 1075 W/m² *(99.9 W/ft²)* and 1290 W/m² *(119.8 W/ft²)*.

Figure 9 - Equipment Area Heat Release Limits [2]

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Power Issues in Data Centers

Within the electronics industry, we know that there has been a constant evolution towards higher density equipment. But, as with Moore's law and Rock's law; with the escalation in capabilities also comes an escalation in cost. This has lead to design concerns at the board and chassis level, as well as growing concerns with the network systems and data centers. For the purpose of this article, we will be discussing the phenomenon in which companies across the industry are now working within a self-fulfilling prophecy: the constant focus from marketing and engineering to stay within the realm of the accepted Moore's law -- continuing to produce improved performance -- has, in turn, increased the capital cost of manufacturing. This article will look into system design tradeoffs, cooling capabilities, and power consumption; keeping in focus the corporate thrust to minimize the total cost of ownership (TCO).

There is increasing pressure to improve Data Center efficiency, but Data Centers strive to host mission critical activities for their customers and up-time is their most important performance indicator. Thus, this limits the scope for cutting back on cooling and cooling costs. There are basic ways in which components can be effectively cooled, those being air cooling, and alternative (liquid) cooling. Gone are the days that the simple application of heat spreaders, or the optimization of heat sinks, or the switching to bigger fans, are sufficient. Design innovations have been presented to increase the cooling capacity at the shelf and cabinet level, both via air cooling and liquid cooling. On the air cooling side, there have been some innovative developments for both the 1-U and ATCAs. Figure 1 shows the concept of jet impingement and Figure 2 shows the application of Therm-Jett (jet impingement) in a μTCA chassis. Figure 3 shows the application of jet impingement in a 1-U chassis. In both of these two applications, the experimental data shows a 30-40% reduction in component temperatures. The application of jet impingement increases the heat transfer coefficient, which in turn reduces the energy need to cool devices with traditional cooling methods.

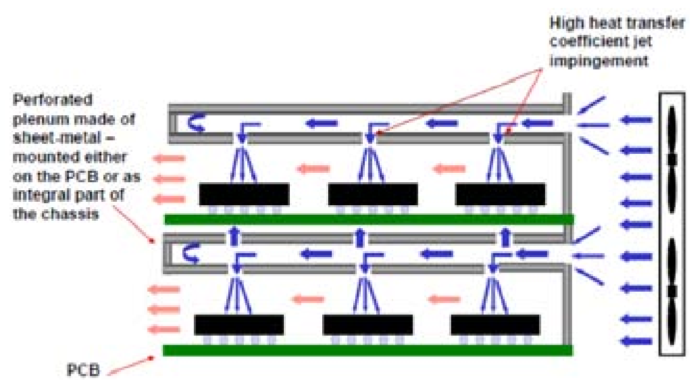

Figure 1 - Jet Impingement Concept [1]

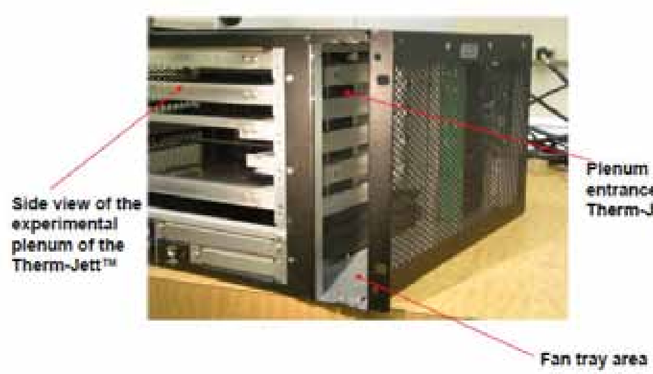

Figure 2 -Therm-Jett™-μTCA Application [1]

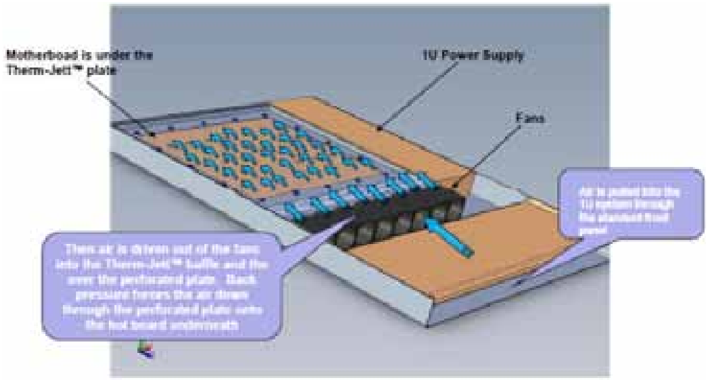

Figure 3 -Therm-Jett™-1-U Application [1]

Regular air-cooled cabinets have almost reached terminal cooling within the same envelope and a recurring challenge lies with alternative cooling methods and the additional real estate necessary for the heat exchangers, pumps, leak detection systems and redundant components. One may think retrospectively and have similar thoughts of George Fuller designing a next generation "Tacoma" cabinet, but considerations will still need to be made within the facilities where these systems are already deployed. Not only do these systems increase the overall size required, but these unavoidable innovations in cooling increase reliability, availability, and serviceability (RAS) concerns and the system's TCO.

When networking author and consultant Tom Lancaster was asked:

> *"What does a VAR need to know from a client in offer to improve a network's cost efficiency?"*

His reply was that:

> *"You need to explore [the clients] tolerance for outages. It all boils down to how much revenue the business will lose when the network goes down."* [2]

As a benchmark for consideration when having a system designed, the Ponemon Institute (sponsored by Emerson Network Power) presented a research report based on forty one (41) independent data centers across the US within sixteen (16) different industries that experienced a partial or complete data outage during the 2010 calendar year. The split was 41% and 59% respectively. The average time for a partial outage was just under one hour, and a complete outage will last (on average) seventy five (75) minutes longer. According to the study, the cost of a data center outage ranges from a minimum cost of $38,969 to a maximum of $1,017,746 per organization, with an overall average cost of $505,502 per incident. [3]

The Power Usage Effectiveness rating (PUE) of Data Centers is becoming an important performance indicator, also. This is calculated as a facility's total power delivered divided by its IT equipment power usage level (The EU has chosen to use the reciprocal measure, facilities efficiency, the IT power use divided by the facilities power use also known as the DCIE). Table 1 shows the basic PUE values. Facilities are now specially designed buildings with improved air flow, solar powered cooling and other innovative features. Facebook, in Oregon is adding a 160,000 square feet shell to the 147,000 square feet complex currently being built to LEED gold standards with an expected PUE rating to be 1.15. Google's E Data Center has achieved a PUE rating of 1.12 and HP's Wynyard facility is close behind with a 1.16 rating. The Yahoo Computing Coop center, which opened in September 2010, leads the way with a 1.08 PUE rating. [4]

PUE	DCiE	Efficiency Level
3.0	33%	Very Inefficient
2.5	40%	Inefficient
2.0	50%	Average
1.5	67%	Efficient
1.2	83%	Very Efficient

Table 1 – PUE Rating [3]

The pie chart in Figure 4 breaks down the energy consumption pattern of data centers, and from the PUE and DCiE ratings we can determine:

• Opportunities to improve a datacenter's operational efficiency.
• How datacenters compare among one another.
• How operators are improving designs and processes over time.
• Ways in which energy may be repurposed for additional IT equipment.

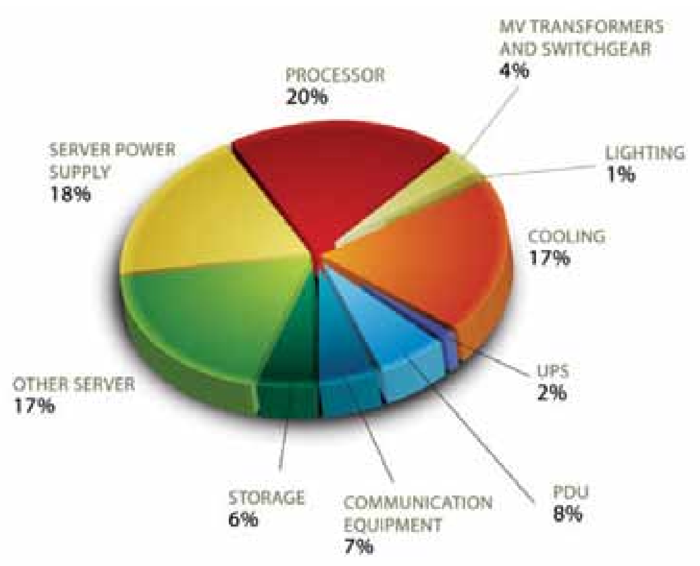

Figure 4 - Data Center Power Consumption [5]

Data Centers currently consume approximately 1.5% of total electricity use in the U.S. and cost $4.5 Billion/year to operate. This number is the result of the doubling effect over the last five years, and energy use via the data center is poised to repeat, doubling again in 5 years. [5] As reported by Intel, 60 to 70 percent of data center power may be used for facilities' power and data center cooling. In the case of Intel: Cooled air is provided at 68º F, which passes over their data center blades raising the temperature to 126º F. During recirculation, the air conditioning required to cool the air by 58º F draws upon a lot of energy. With businesses worldwide increasing focus on productivity and cost control, lowering their carbon footprints left by these mega systems, is enabling companies to boost their PR and receive tax breaks, by going green by default. What if we could save energy by stripping our data centers down, cooling using raw, coarsely filtered outside air, with minimal regard to the ambient temperature and operating temperature within humidity fluctuations from 4-90%? Does this even make sense? Enter Air Economization. Air Economizers also represent one potential way to reduce data center power consumption and cooling cost. Instead of cooling and recirculating the hot air from the servers, air economizers simply expel the hot air outdoors and draw in outside air to cool the IT equipment. Their proof of concept (PoC): approximately 900 production design servers were split into two rooms, each room contained eight racks. Each rack contained four blade servers with fourteen (14) blades each, for a total of 448 blades per compartment. This represented a power density of more than 2178 W/m^2. All this was dropped into a desert climate with generally low relative humidity. The PoC began in October 2007, and the test continued for ten (10) months -- until August, 2008. The results show that total power consumption of the trailer was approximately 500 kilowatts (KW) when using air conditioning in both compartments. When using the economizer, the DX cooling load in the economizer compartment was reduced from 111.78 KW to 28.6 KW, representing a 74 percent reduction in energy consumption. [5]

In conclusion, as Sir Winston Churchill once said:

> *"Now this is not the end. It is not even the beginning of the end. But it is, perhaps, the end of the beginning."*

We have made great strides in cooling and managing the power as it is distributed through the network and Data Center; however, there has been a constant paradigm shift, and in moving forward, significant changes will be needed to be made to allow for the continued demands of our future society.

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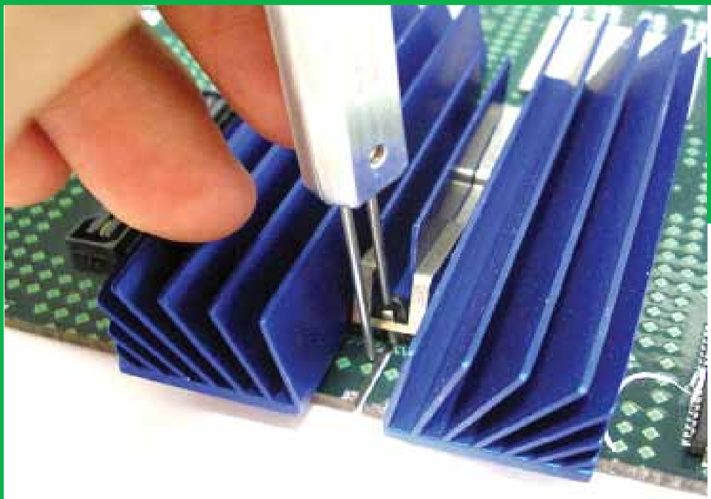
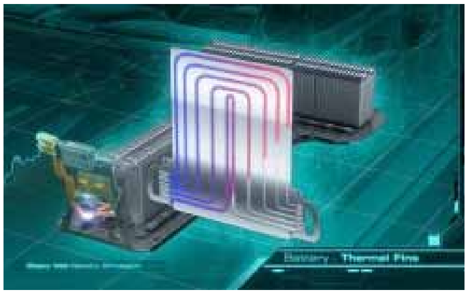


Cooling News

New Products, Services and Events from around the Industry



Cooling Fins Aid Volt Battery Thermal Management

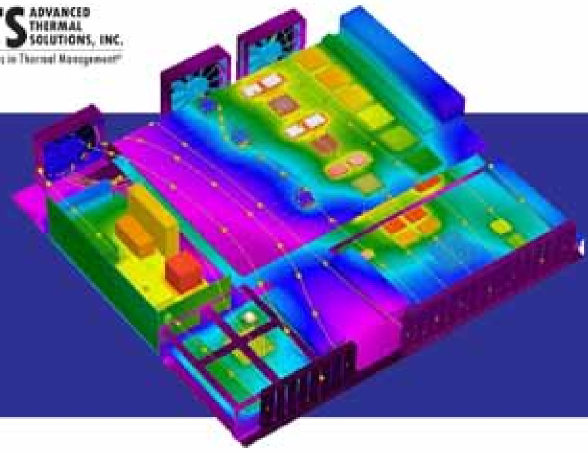
Cooling fins by Dana Corp. help keep Chevrolet Volt batteries at just the right temperature. The Volt's T-shaped battery pack consists of 288 individual cells arranged into nine modules. Plastic frames hold pairs of lithium-ion cells that sandwich an aluminum cooling fin. The design and construction of that aluminum plate is critical to ensuring an even temperature distribution with no hot or cool spots across the flat, rectangular cell. The cooling fin consists of two lightweight aluminum plates joined by a proprietary clean nickel-brazing process. The carefully designed grooves stamped into the plates form channels that allow battery coolant that is pumped through the pack to flow over the entire cell surface.

Wireless Power Generator Uses Heat for Electricity

Thermobility™ power generation technology from Nextreme uses heat as a source of electricity for low-power wireless applications. Solid-state thin-film thermoelectric technology converts heat into electricity for a variety of self-contained, autonomous systems. When paired with wireless transmitters, the Thermobility solution can provide electric power for decades of maintenance-free operation, thus expanding the possibilities for new wireless sensor applications in industrial control, transportation, automotive and building management.

New Thermal Management LED Spotlight Cooler

The new ZFlow 90, Spotlight Cooler 60W by Nuventix enables 60W/3500 lumen output in the solutions track light and recessed downlight form factors. The new 60W spotlight cooler provides more than 100,000 hours of run time at 70°C and near-silent acoustics. Using an optimized nozzle size, the Spotlight Cooler 60W allows for a more efficient airflow between Synjet and the heat sink. It is designed to enable small designs and is ideal for retail and commercial environments. This product cools up to 60W with a 118 mm diameter.



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August 25, 2011 at 2:00PM (EST)

How to Develop the Right Thermal Management Solution for Commercial and Consumer LED Lighting Applications

Why does thermal management matter in LED lighting? Excess heat directly affects both short-term and long-term LED performance. The short-term effects are color shift and reduced light output, while the long-term effect is accelerated lumen depreciation and thus shortened useful life. Participants will learn how to diagnose and solve thermal issues in consumer and commercial LED applications.

September 22, 2011 at 2:00 p.m. (EST)

Tools and Techniques for the Thermal Management of Small, Medium and Large Scale Data Centers

Datacenters are effectively large scale systems whose components are racks of computers. Novel approaches to cooling datacenters of various sizes are being undertaken today to obtain the best and most green cooling possible. This webinar will consider approaches for small, medium and large scale datacenters to achieve a given datacenters cooling goals.

October 27, 2011 2:00 p.m. (EST)

Understanding and Choosing the Best Thermal Interface Materials to Improve Heat Sink Thermal Performance

To cool hotter components, engineers are turning to larger fans and heat sinks and increased surface areas. The downside is that these hardware changes add significant cost to the design. Alternatively, a cooling system's performance can be improved just by using a better interface material to lower thermal resistance at the interface of the case and the heat sink. Participants will learn to overcome related thermal challenges by making simple and cost-effective changes in thermal interface materials.

November 17, 2011 at 2:00PM (EST)

Design Out Your Heat Sinks with Smart PCB Thermal Design

A thermal management strategy is often manifested as a "power" approach, using strong fans and multiple heat sinks. Such tactics appear to quickly solve thermal problems, but they often create costly overruns for a system's thermal design budget. This webinar discusses how to design for the least number of heat sinks and potentially none at all. A case study will be presented as a model of what can be accomplished by considering the thermal management solution up front in system design.

December 15, 2011 at 2:00 p.m. (EST)

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