Thermal Performance of Heat Sinks

with Heat Pipes or Vapor Chambers for Servers

Most blade servers for data and telecommunication systems use air to cool the high power chips inside. As the power level of these chips keep increasing, the pressure is on thermal engineers to design ever higher performance air-cooled heat sinks. In recent years, advancements in manufacturing of thinner heat pipes and vapor chambers have enabled engineers to integrate the heat pipes and vapor chambers into the blade server heat sinks.

A heat pipe is a device with high thermal conductance that can transport large amounts of heat with a small temperature difference between its hot and cold ends. The idea of a heat pipe was first proposed by Gaugler [1]. However, only after its invention by Grover [2, 3] in the early 1960s, were the remarkable properties of heat pipes realized by scientists and engineers. It is now widely used to transport heat from one location to another location or to smooth the temperature distribution on a solid surface.

A heat pipe is a self-driven two-phase heat transfer device. A schematic view of a heat pipe is shown in Figure 1. At the hot section (evaporator), the liquid evaporates and turns to vapor. The vapor flows to the cold section (condenser) and liquefies there. The liquid is driven back from the cold section to the hot section by a capillary force induced by the wick structure. By using boiling and condensation, the heat pipes can transfer and spread the heat from one side to another side with a minimum temperature gradient.

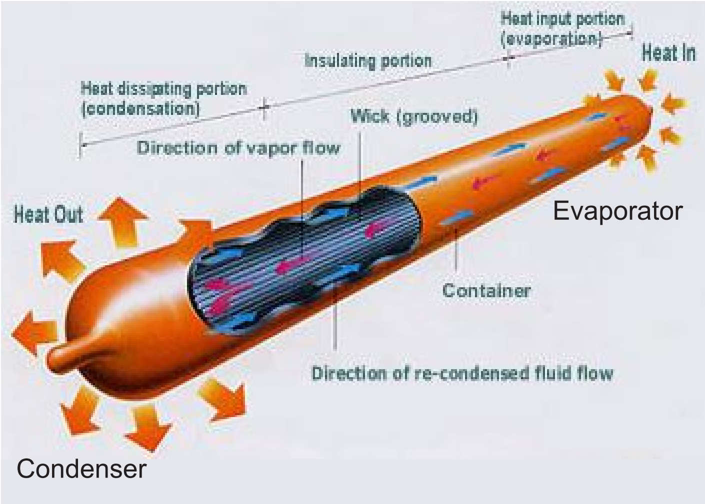


Figure 1. Typical Heat Pipe [4]

Vapor chambers are flat heat pipes with very high thermal conductance. They have flat surfaces on the top and bottom sides. See Figure 2, which can be easily attached to a heat source and a heat sink.

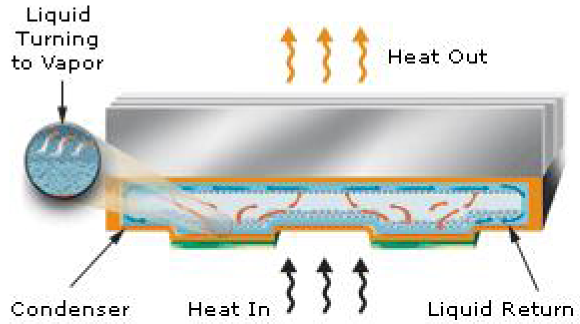
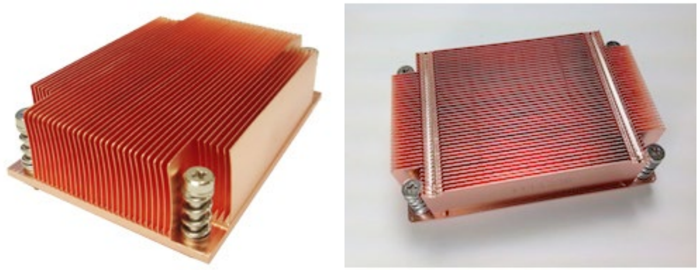


Figure 2. Vapor Chamber [5]

Just like heat pipes, vapor chambers use both boiling and condensation to maximize their heat transfer ability. A vapor chamber generally has a solid metal enclosure with a wick structure lining the inside walls. The inside of the enclosure is saturated with a working fluid at reduced pressure. As heat is applied at one side of the vapor chamber, the fluid at locations close to the heat source reaches its boiling temperature and vaporizes. The vapor then travels to the other side of the vapor chamber and condenses into liquid. The condensed fluid returns to the hot side via the gravity or capillary action, ready to vaporize again and repeat the cycle.

In electronics cooling, heat pipes are generally used to move the heat from electronics to heat dissipation devices. For example, in a desktop computer, multiple heat pipes are used to transfer heat from a CPU to an array of cooling fins, which dissipate the heat to ambient environment through convection. Vapor chambers are generally used to spread heat from a small size device to a larger size heat sink, as it is shown in Figure 2. If used in server heat sinks, the heat pipes and vapor chambers are both used to spreading the heat due to the low profile and large footprint of the heat sinks. Compared to copper heat spreaders, heat pipes and vapor chambers have the following merits. First, they have a much higher effective thermal conductivity. The pure copper has a thermal conductivity of 401 W/m.ºC and the best conductive material of diamond has a thermal conductivity of 1000-2000 W/m.ºC. The effective thermal conductivity of a well-designed heat pipe and vapor chamber can exceed 5000 W/m.ºC, which is an order of magnitude higher than that of pure copper. Second, the density of the heat pipe and vapor chamber is much lower than that of copper. Due to its hollow structure, the heat spreaders made by vapor chambers are much lighter than those made of copper. These properties make them the ideal candidate for high heat flux and weight sensitive heat spreading applications.



(a) (b)

Figure 3. Dynatron Passive Heat Sinks (a) R12 (b) R19 [6]

Dynatron Corporation is an electronic cooling provider specializing in heat sink for servers. This article compares the thermal performance of its server heat sinks, some of which have integrated vapor chambers. Figure 3 shows the photos of two Dynatron 1U passive server heat sinks for Intel's Sandy Bridge EP/EX Processors. The R12 is made of pure copper with skived fins. The R19 has a vapor chamber base and stacked copper fins. The heat sink specification is listed in Table 1. The R19 is 150g lighter than the R12.

	R12	**R19**
Material	Copper 1100 Skiving Fins	Vapor Chamber Base with Copper Stacked Fin
Overall Dimension	106.0 x 70.0 x 25.5mm	106.0 x 70.0 x 27.0mm
Overall Weight	550g	400g

Table 1. Dynatron Passive Heat Sink Specification

Figures 4 and 5 show the thermal performance of R12 and R19 at different flow rates. At 10CFM, both heat sinks have a thermal resistance of 0.298 ºC/W. When the flow rate increases to 20CFM, the R19's thermal resistance is 0.218 ºC/W, which is 0.020 ºC/W lower than that of R12.

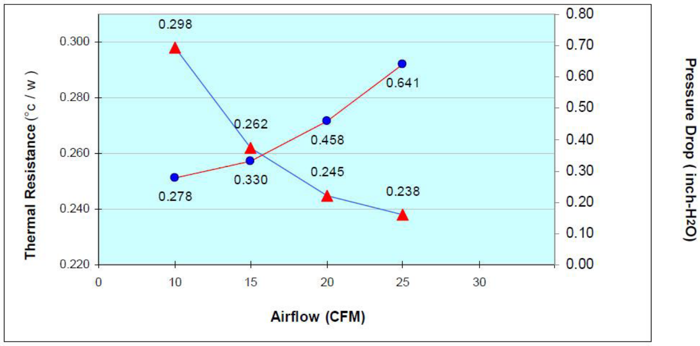


Figure 4. Dynatron R12 Heat Sink Performance [6]

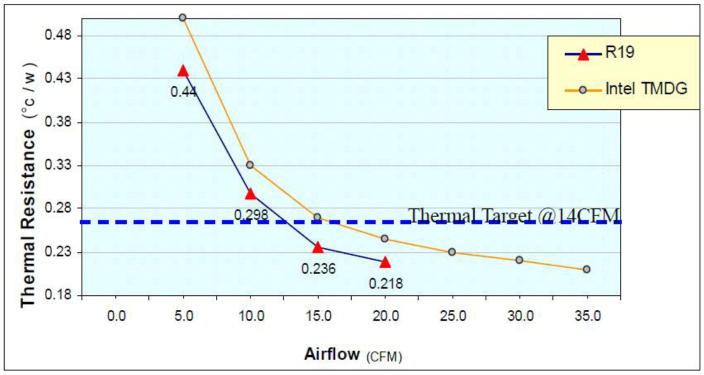


Figure 5. Dynatron R19 Heat Sink Performance [6]

Figure 6 shows the photos of two Dynatron 1U active server heat sinks for Intel's Sandy Bridge EP/EX Processors. The R18 is made of copper with skived fins. The R16 has vapor chamber base and stacked copper fins. Both heat sinks use same blower. The heat sink specification is listed in Table 2. The R16 is 90g lighter than the R18.

(a) (b)

Figure 6. Dynatron Passive Heat Sinks (a) R18 (b) R16 [6]

	R18	R16
Material	Copper 1100 Skiving Fins	Vapor Chamber Base with Copper Stacked Fin
Overall Dimension	90.0 x 90.0 x 27.7mm	90.0 x 90.0 x 28.0mm
Overall Weight	480g	390g
Blower Model	DB128015BU-PWMG	DB128015BU-PWMG
Blower Dimension	80 x 80 x 15mm	80 x 80 x 15mm

Table 2. Dynatron Active Heat Sink Specification [6]

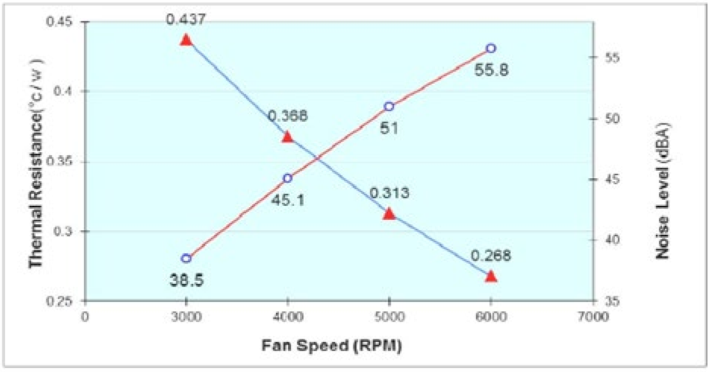


Figure 7. Dynatron R18 Heat Sink Performance [6]

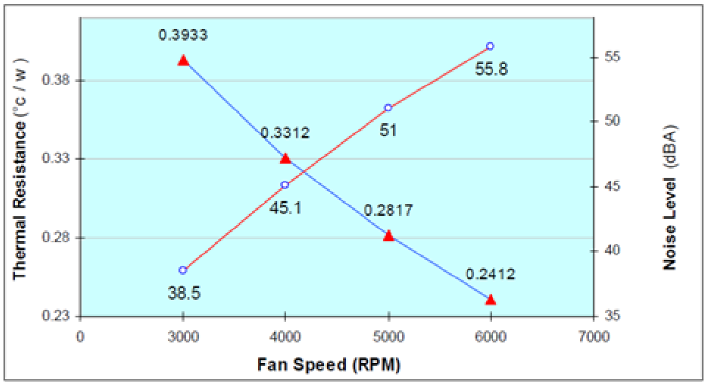


Figure 8. Dynatron R16 Heat Sink Performance [6]

Figures 7 and 8 show the thermal performance of R18 and R16 at different blower speeds. At 3000RPM, the R18 and R16 heat sinks have thermal resistance of 0.437 ºC/W and 0.393 ºC/W, respectively. When the blower speed increases to 6000RPM, the R18's thermal resistance is 0.268 ºC/W and the R16's thermal resistance is 0.241 ºC/W. The R16 is constantly able to outperform the R18 at different blower speeds and its thermal resistance is 10% lower than R18.

The comparison of the Dynatron heat sinks shows that heat sinks with vapor chambers have a slight thermal edge vis-a-vis its copper counterparts even though they are light. This is true for both passive and active heat sinks.

Heat Sink #	Base Thickness (mm)	Weight (g)	Description
A-1	3	270	Extruded heat sink with 2 mm thick embedded sintered powder VC strip in base, thicker fins.
B-1	3	373	Wire-mesh VC base with Al zipper fins.
C-1	3	318	VC base wick structure: Heating side sintered powder, cooling side-wire-mesh; Al zipper fins.
C-2	3	246	Al base with 3 embedded heat pipes in parallel, inserted 1"x1" Cu block in center of base; Al zipper fins.
D-1	4	320	3 heat pipes cantilevered off the Cu center block base with Al stacked fins.

Table 3. Cisco Tested Heat Sink Specification [7]

Glover et al., from Cisco, have tested different heat sinks either with embedded heat pipes or vapor chambers for their servers and published their findings [7]. They tested five different heat sinks from different vendors, who utilized different manufacturing technologies to fabricate the heat sinks. The five heat sinks are similar in size: 152.4 x 101.6 x 12.7mm. Table 3 summarizes the physical attributes of these five heat sinks.

Figure 9-11 shows the three vapor chamber heat sinks with different vapor chamber structures and fin designs. Heat sink A-1 is an extruded aluminum heat sink with a vapor chamber strip. The 40 mm wide vapor chamber strip is embedded in the center

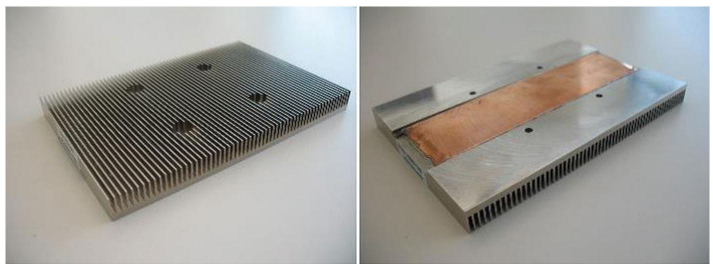


Figure 9. Heat sink with Vapor Chamber A-1 [7]

Figure 10. Heat sink with Vapor Chamber B-1 [7]

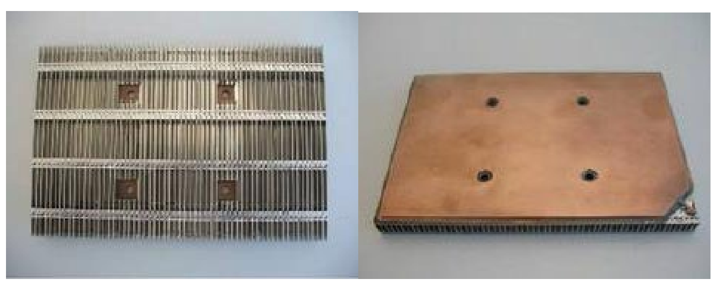


Figure 11. Heat sink with Vapor Chamber C-1 [7]

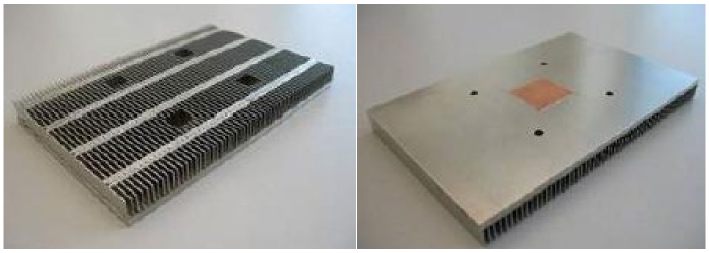


Figure 12. Heat sink with Heat Pipes C-2 [7]

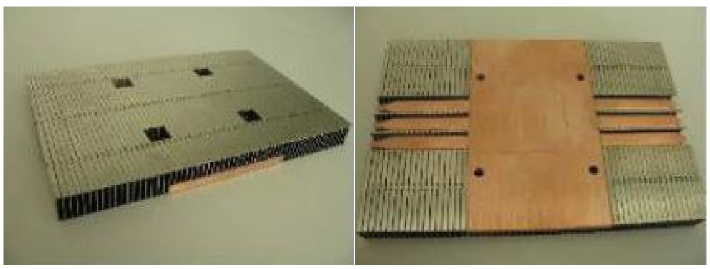


Figure 13. Heat sink with Heat Pipes D-1 [7]

of the base. It is the lightest one among five tested heat sink. Heat sink B-1 and C-1 have full base size vapor chamber and aluminum zipper fins.

Figures 12-13 show the two heat sinks with embedded heat pipes. Heat sink C-2 has heat pipes embedded inside its aluminum base. It uses zipper fins and has a copper slug in the middle of the base. Heat sink D-1 has three flat heat pipes embedded in its base. It has a copper plate as base.

Heat Sink	P=30W				P=60W			
	θ_{sa}		T_s	ΔT_{base}	θ_{sa}		T_s	ΔT_{base}
	(°C/W)	Diff	(°C)	(°C)	(°C/W)	Diff	(°C)	(°C)
A-1	0.23	21%	42	4.4	0.22	21%	48	7.9
B-1	0.23	20%	42	5.0	0.21	13%	47	7.6
C-1	0.19	0%	41	3.8	0.18	0%	46	6.1
C-2	0.23	21%	42	4.7	0.22	23%	48	9.1
D-1	0.26	37%	43	NA	0.25	39%	50	NA

Table 4. Heat Sink Performance at 3m/s with Horizontal Mounting Position and Bottom Heating [7]

Glover et al. tested the five heat sinks at different mounting orientation and air velocity. Table 4 presents the summary results of the heat sinks at 3m/s approach air velocity. The tested heat sinks were mounted horizontally with heat sources underneath the heat sink bases.

The C-1 heat sink has the lowest thermal resistance; thus, its values are used as the benchmark for other heat sinks. The performance of heat sinks are purely design dependent. For vapor chamber heat sinks, the thermal resistance value varies from 0.19 to 0.23°C/W for 30W of power. For heat sinks with heat pipes, the C-2 heat sink has a thermal resistance of 0.23°C/W, which matched with that of A-1 and B-1. The D-1 heat sink has the highest thermal resistance, which is the result of inferior design and manufacture. However, the D-1 heat sink still has relatively low thermal resistance when it is compared to a regular heat sink without a heat pipe and vapor chamber.

Figure 14 shows the thermal resistance of the five heat sinks for 60W of input power at different air velocities. The C-1 heat sink performs best for all velocities and the D-1 heat sink's performance is the worst.

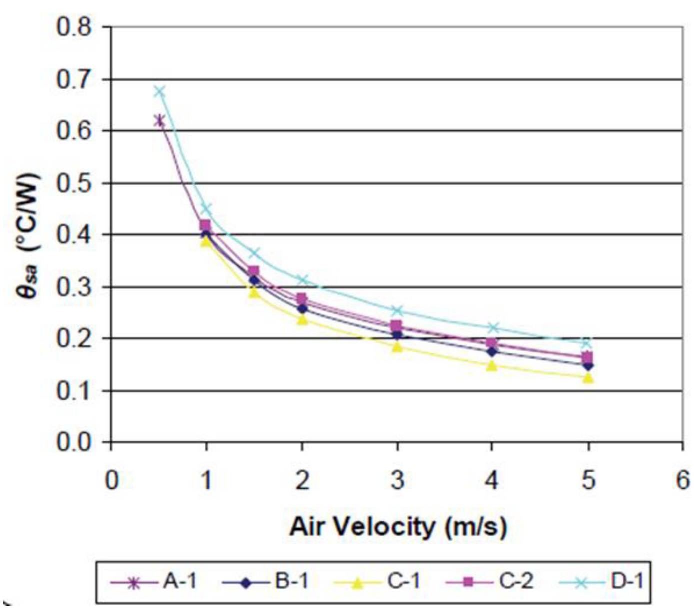


Figure 14. Heat sink Thermal Resistance at 60W [7]

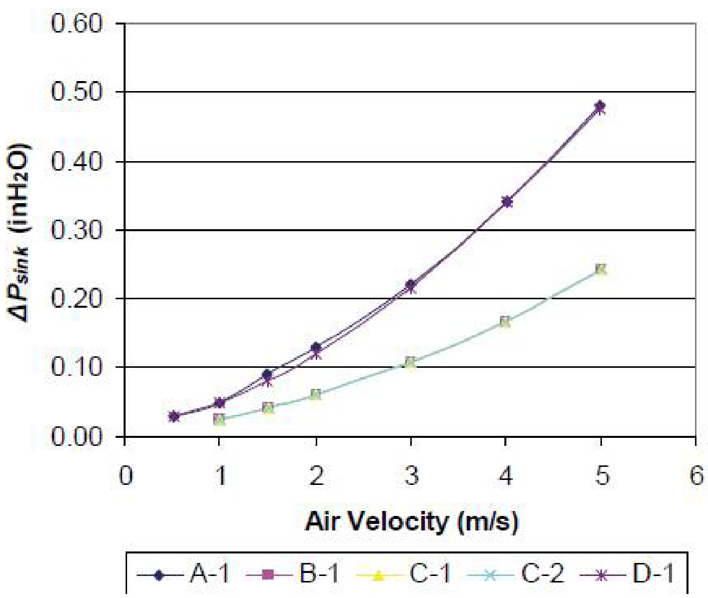


Figure 15. Heat sink Pressure Drop [6]

The pressure drop across the heat sink at different air velocities was also measured and the results were plotted in Figure 15. The B-1, C-1 and C-2 heat sinks have similar fin structures. Therefore, their pressure drop is similar, too. The pressure drop of the A-1 and D-1 heat sinks are similar and higher than the other heat sinks. This is because the A-1 heat sink has thicker fins and the D-1 heat sink has a thicker base.

Because the heat pipes and vapor chambers use capillary force to drive liquid back from the condensation section to the evaporation section, their thermal performance is prone to orientation variation. Glover et al. also investigated the effects of the mounting orientation on the performance of the five heat sinks. They found the effect of the orientation is design dependent and is the result of both the wick structure and the entire heat sink assembly construct.

The heat sink specification from Dynatron Corporation and the test results from Cisco, show that the server heat sinks with embedded heat pipes or vapor chamber have a better thermal performance than their copper counterparts. The heat sinks with embedded heat pipes or vapor chamber are also lighter than the pure copper heat sinks, which make them more suitable for applications which are weight sensitive. If the cost of such heat sinks is justified, they are definitely good candidates for server cooling applications.

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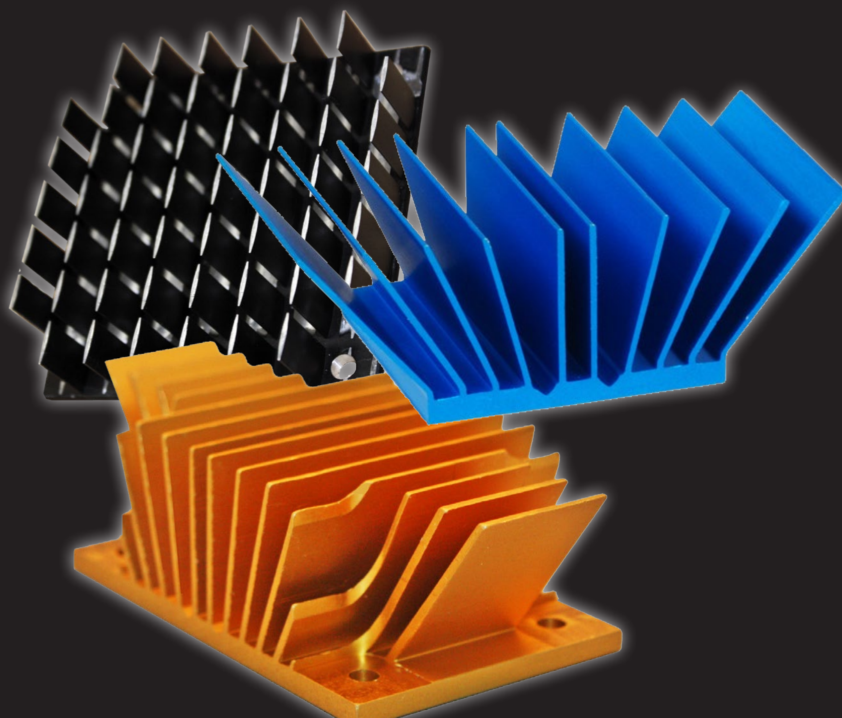

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