Use of heat pipe/heat sink for thermal management of high performance CPUs

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ABSTRACT

This paper will describe various cooling solutions in notebook PC and desktop/server applications. In the notebook PC application, miniature heat pipes of diameter 3-6 mm, flatten to desire thickness, are commonly used to improve heat spreading and more efficient transfer heat generated from the CPU to a remote heat dissipation area. Examples of three typical thermal solutions in notebook PC are given in this paper.

Whereas in the desktop server application, a flat type rectangular heat pipes or a so-called vapor chambers are used to attach under the base of the heat sink to help temperature uniformity across the heat sink base. This will reduce the spreading resistance in the heat sink base and therefore improve the heat sink performance. Experimental results showed that with a vapor chamber installed, can achieved a 45% improvement in the heat sink performance for heat sink of length 110 mm, width 72.5 mm, height 50 mm and base thickness 7 mm.

INTRODUCTION

In the demand for closing the performance gap between desktop and notebook computer, more and more power performance processors had been developed for use in notebook. The drawback in the higher performance processor is that they have larger heat generation. This creates a challenge in providing thermal solution in notebook since high performance processor and additional features such as more Cache, more DRAM, larger HDD, PCMCIA and CD-ROM leads to higher total power dissipation in notebook. It is even more challenge to provide the thermal solution without compromising the notebook's size and weight.

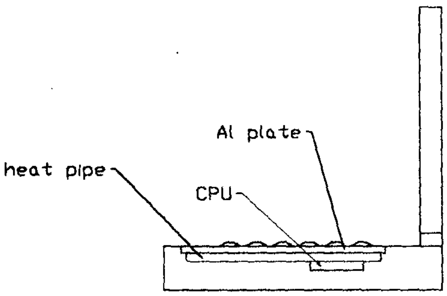
Fortunately, heat pipe emerges as the most appropriate technology and cost effective thermal solution due to its excellent heat transfer capability, high efficiency and its structure simplicity. In this paper, we will review three thermal solutions for notebook application. The first thermal solution showed heat pipe used to spreading the heat generated from the CPU to an aluminum plate on the backside of the keyboard or on the chassis of the notebook. Second is a hinged heat pipe system that has heat pipe to transfer heat via the hinge of the notebook to the backside of the display panel. Third is a remote heat exchanger (RHE) system where heat pipe is used to transfer heat to a miniature fin heat sink that incorporated a fan for air cooling.. In the first two cases, the thermal solutions are passive where cooling is by means of air natural convection, whereas, in the last case it is an active thermal solution where air forced through the heat sink for cooling.

In the desktop/server applications, common thermal solution is having a heat sink on top of the CPU with fan directly placed on top of the heat sink or used the system fan to provide cooling air through the heat sink. In cases where the footprint of the heat sink need not be much larger than the size of the CPU package, the contribution of the spreading resistance in the base of the heat sink to the overall temperature rise of the device may not be significant and can be tolerated. However, today of high performance CPU of high heat dissipation, a much larger heat sink is needed and the impact of the spreading resistance in the base of the heat sink becoming significant and important factor in the design process. The spreading resistance in the base of the heat sink can be reduced significantly by use of vapor chamber that attached to the base of the heat sink. The vapor chamber has low thermal resistance and it provided a uniform temperature of the heat sink base and thus improves the overall thermal performance of the heat sink.

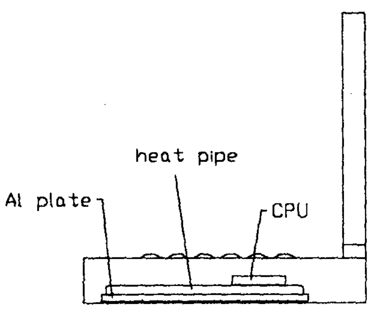
1. PC Notebook Thermal Solutions

(A) Heat pipe with spreader plate

Commonly heat pipe is used to transfer heat from the processor to a heat spreader plate, usually made of aluminum, under the keyboard or on the chassis of the notebook as shown in figure 1(a) and (b) respectively. This method has been put into practical use in many notebooks.



1(a) Heat Spreader Plate Under Keyboard



1(b) Heat Spreader Plate On Chassis

Figure 1 – Heat pipe /spreader plate

An example of this system consisted of a rectangular heat spreader plate made of aluminum, placed on the chassis of the notebook. The dimensions of the plate are approximately 0.6 mm thick, length 190 mm and width 100 mm. The heat pipe was a 3 mm round that was pressed into elliptic cross section of dimensions approximately 2 mm x 3.6 mm x 200 mm (height x width x length) to accommodate for the height constraint in the notebook. Heat pipe was mechanically attached to the heat spreader plate by used of rivets. The heating and cooling sections of the heat pipe is approximately 30 mm and 170 mm respectively. Test results of this system is shown in figure 4. The total thermal resistance R_t is calculated as follows:

$R_t = dT/Q$ where,
Q = Heat input (W)
R_t = Total thermal resistance (°C/W)
dT = Temperature difference between the processor surface temperature and ambient (°C)

If the maximum allowable surface temperature of the processor is set at 90 °C (maximum 95 °C) and the ambient temperature of 40 °C, then from figure 4, one can estimate that this system can dissipated about 6W. Xie et al. [3] conducted tests of similar configuration and obtained similar results.

(B) Hinged heat pipe system

For the hinged heat pipe system, the heat from the processor is routed onto the aluminum heat spreader plate located on the back screen of the display as shown in figure 2. Basically this system consisted of two heat pipes and a hinge connector. The primary heat pipe is fixed and is in contacted with the heat source, transferring heat to the secondary heat pipe via a hinge connector that joined the two heat pipes together. The second heat pipe is used to transfer heat onto the aluminum heat spreader plate. The purpose of the connector is to enabling heat transfer from first to second heat pipe and to allow the second heat pipe to rotate when opening and closing notebook's lid.

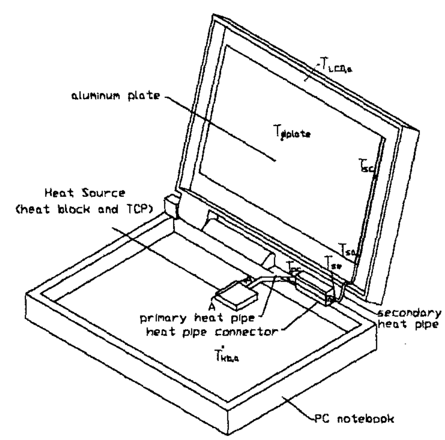


Figure 2 – Hinged heat pipe system

Approximate dimensions (in mm) of the system are as follows :

- First heat pipe: 4 x 130 (dia. x length)

- Second heat pipe: 4 x 250 (dia. x length)
- Hinge connector: 7 x 25 x 16.8 (width x length x height); material copper C1020.
- Heat spreader plate: 174 x 250 x 0.4 (width x length x thickness); material A1050.
- Heat block : 30 x 30 x 3 (width x length x thickness); material A1050.
- Heat source : 133 MHz processor (TCP)

As shown in figure 4, the total thermal resistance R_t of the hinged heat pipe system was about 4.1 °C/W at heat input of approximately 10 watts. Based on the temperature constraint of the CPU temperature of 90 °C and ambient of 40 °C, this system can be used to dissipate about 12 watts, the same as for the hybrid system. At 10W heat input and ambient of 22 °C, the temperature measured at the back of the LCD and the plastic skin (T_{LCD}) was about 45 °C.

(C) Remote heat exchanger system

This system is a combination of heat pipe, aluminum plate heat sink and fan as shown in figure 3. One end of the heat pipe was soldered to a copper block, and the other end was soldered to the base of the aluminum heat sink. The heat sink is fully ducted for 100% airflow through the heat sink.

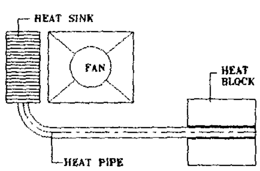


Figure 3 – Remote heat exchanger system

Approximate dimensions (mm) of the system are as follow :

- 6mm round heat pipe flatten to 2.4 x 8.1 x 150 (height x width x length)
- Plate heat sink: 3 x 8 x 50 x 15 x 0.4 x 1.2 x 41 (base x fin height x width x length x fin thickness x pitch x no. of fins). Approximate 100 cm^2 total fins surface area.
- Heat block : 30 x 30 x 3 (width x length x thickness)
- Fan: 50 x 50 x 9 (width x height x thickness); 2.7 CFM free airflow and 10 mmH_2O static pressure.

Test results are shown in figure 4. The total thermal resistance R_t measured about 2.5 °C/W at heat input of 20 watts, and at airflow through the heat sink estimated about 2 CFM. If the CPU surface temperature set to limited at 90 °C (maximum 95 °C) and ambient of 40 °C, this remote heat exchanger can be used to dissipate 20 watts.

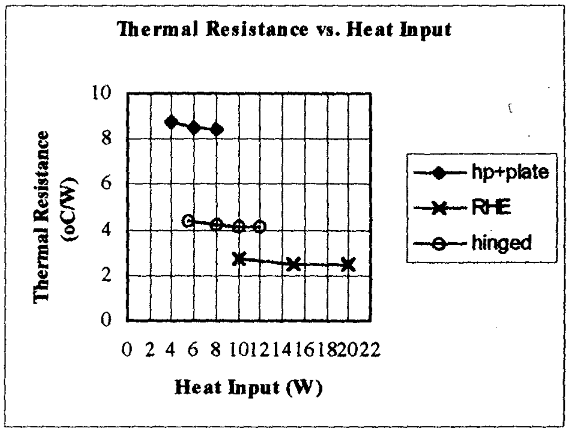


Figure 4 – Test results for notebook PC cooling systems

2. Desktop/Server Thermal solutions

A schematic presentation of the heat sink – heat pipe solution is shown in figure 5. In this solution a fan can be placed on top of the heat sink to provide cooling air or use of system fan to pull or push air through the heat sink.

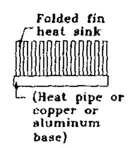


Figure 5 – Heat sink / Heat Pipe solution

In order for thermal performance comparison three heat sinks were tested. One heat sink has vapor chamber base, second has copper base and third has aluminum base. In all three cases the heat sinks were soldered to the base. A summary of the heat sink configurations and test results are shown in table 1 and figure 6. Tests of the heat sink performance were carried out in the airflow chamber that has airflow capacity of 500 CFM, 0.4 m in diameter and 1.2 m in length. The heat sink was fully ducted and air was pulling through the heat sink. A heater of square shape 20 mm by 20 mm applied to the center of heat sink as a heat load. Thermal grease was used as interface material between heater and heat sink.

Table 1 – Heat sink configuration

Heat sink	1	2	3
Length, Width, Height, fin thickness, pitch (mm)	110x72.5 x43 0.4 x 2.2	Same	Same
Base	HP 7mm	Cu 7mm	Al 7mm
Airflow (CFM)	15	15	15
Heat sink performance, Rsink (oC/W)	0.25	0.31	0.36

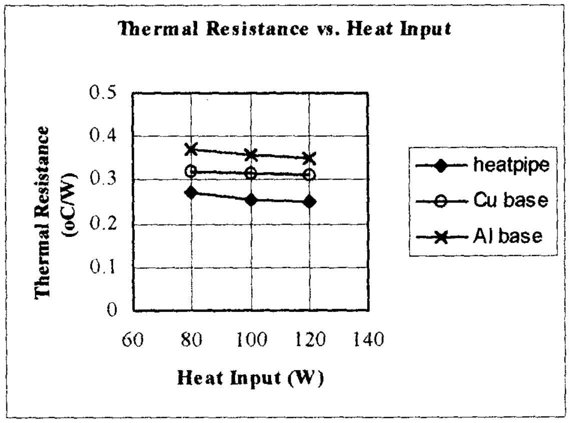


Figure 6 – Heat sink test results

The heat sink performance (Rsink) is defines as Rsink = (dT)/Q, where dT is the temperature difference between the center of the heat sink and inlet air, and Q is the applied heat load. The volume airflow through the heat sink was calculated by measuring the pressure drop across the orifice of the airflow chamber and correlated that to the pressure drop vs. airflow curve designed for the airflow chamber.

The results are shown in figure 6. At volume airflow of 15 CFM, the velocity measured at the inlet of the heat sink was about 3 m/s. The results showed that for this particular heat sink configuration, heat sink 1 which has vapor chamber base performed approximately 25% and 45% better than copper base and aluminum base respectively.

One can expect that the advantage of the vapor chamber base is more profound if the area ratio of the heat sink base to heat source increases, and less profound if this ratio decreases. This is due to the increase in spreading resistance for larger heat sink base in the case of solid metal. Whereas for vapor chamber the increase in spreading resistance is insignificant for the sizes applicable to desktop or server computers.

CONCLUSION

(1) Due to the limitation of the operating temperatures between the notebook and environment and the sizes of the notebook the maximum heat dissipation for any passive system is about 10-12W. This is shown in system 1(a) and 1(b). For higher heat dissipation needed forced air cooling as in an example 1(c) that can dissipates 20W.

(2) For the heat sinks studied in this paper, the heat sink having the vapor chamber performed 25% and 45% better than the copper base and aluminum base respectively.

(3) The advantage of the heat sink with the vapor chamber base is more profound if the area ratio of the heat sink base to heat source increases, and less profound if this ratio decreases.

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