Development of Heatpipe-Based Remote Heatsinks for Desktop PCs

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ABSTRACT Recently the heat generation rate of electronic devices continues to increase, reaching as high as 100 W for CPUs in desktop PCs. Since conventional cooling methods are coming close to performance limits due to the restriction as to the outer dimensions allowed for heatsinks, there is a need for new cooling methods focusing on high-heat generating devices —in excess of 100 W. Accordingly, we have investigated the applicability of a new heatpipe-based remote heatsink (HP-RHS), where heatsinks with a sufficient heat-dissipating area are installed in an open space, and the heat is transferred there using heatpipes.

The experimental results show that, using an HP-RHS with a 120-mm square fan, a heat rate of up to some 150 W can be dissipated adequately while keeping the temperature difference between the CPU case and the ambient below 30°C. This paper describes the successful development of such a good heatsink, which is capable of cooling over-100W heat-generating devices offering practicality together with silent operation.

1. INTRODUCTION

As semiconductor devices such as CPU improve in performance, the heat they generate during operation continues to increase. Features of cooling technologies required for modern CPUs are such that multiple devices have to be cooled to cope with the graphic chips and the like that grow in heat generation, and that not only large heat generation but also high-density heat generation have to be dealt with because basically the size of the devices is decreasing. Thus there is a general requirement for CPU cooling technology to efficiently cool electronic devices that are high in heat generation rate as well as in heat density.

It is to be noted that, as can be seen from Figure 1, the heat generation rate of current desktop PCs is reaching as high as 100 W. In conventional cases where the heat generation rate was below 100 W, it was sufficient to adopt a cooling system in which, as shown in Figure 2, a heatsink was placed in an open space just above the CPU, and a fan is used to send air. But such a system has limitations in performance, because the open space just above the CPU is obviously limited so that —even if the fin array is densely packed— a sufficient heat-dissipating area of the heatsink cannot be assured when strict restrictions are posed on the outer dimensions of the heatsink. The performance of a heatsink may be represented by

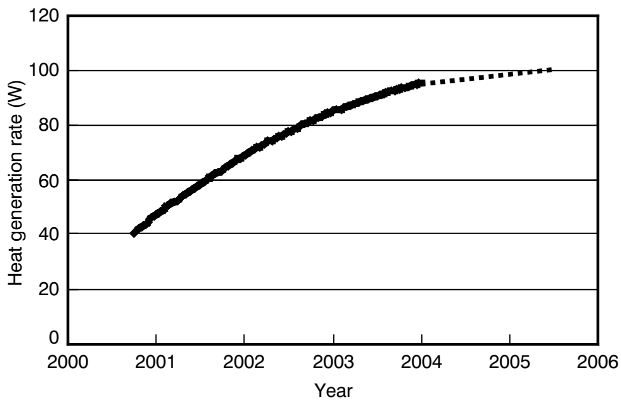

Figure 1 Trends in heat generation rate for CPU in desktop PCs.

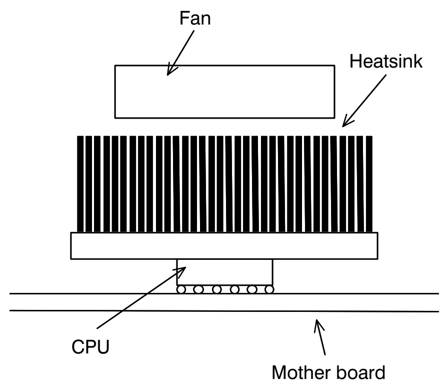

Figure 2 Conventional CPU cooling method.

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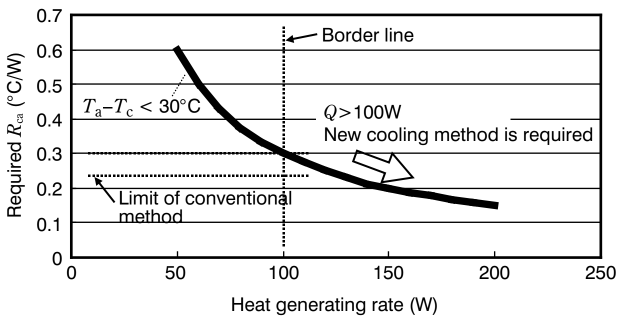


Figure 3 Thermal performance required for heatsinks.

thermal resistance R_{ca} which is defined as the difference between the CPU temperature T_c and the ambient temperature within the PC T_{amb} divided by the heat generation rate Q. Using this definition, the performance limit of the conventional cooling method can be estimated, through our prototype experiments for desktop PCs, as R_{ca} = 0.25~0.30°C/W.

In this context, Figure 3 shows the R_{ca} values required for sufficient heat dissipation. While the required R_{ca} values can slightly change depending on individual designs, Figure 3 shows representative values which was calculated based on an assumption that the allowable temperature difference between the CPU case and the ambient is 30°C. It can be seen from Figure 3 that the limit for conventional cooling systems is equivalent to a heat generation rate of 100 W, and that a new cooling method is required to replace conventional methods beyond the limit of heat generation rate of 100 W.

One of the prerequisites to be taken into consideration for designing a new cooling method is that in any designs the final destination of heat dissipation is the air, and that no solution can be reached unless heat dissipation from the heatsink to the air is suitably improved. Methods for improving heat dissipation into the air may include: increasing the speed of airflow; enhancing turbulent flow through modification of the fins; and increasing the surface area of the fin array. The first two ideas are rather unacceptable because these may eventually lead to an increase in airflow noise.

In an effort to devise some measures to increase the surface area of the fin array, we adopted a scheme of remote heatsink (RHS) in which a heatsink with a sufficient surface area is installed in an open space of the PC and the heat is transferred from the CPU to the heatsink using some means. The RHS method is advantageous in terms of the noise mentioned above, because a larger fan compatible with a larger fin surface area can be used to assure a sufficient airflow while suppressing the fan rotation that controls the noise level. Moreover, an additional fan may not be necessary if the ventilation fan can be shared with the RHS for cooling.

Transferring methods of heat to the RHS may comprise: circulating water using a pump —so-called water cooling; using heatpipes; and applying compressor refrigerators. Among these, use of heatpipe is most practical for the following reasons.

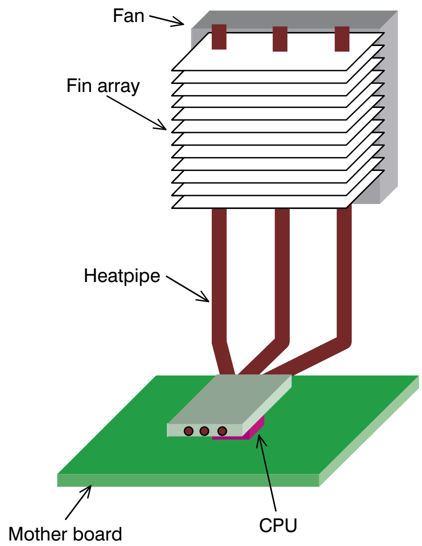


Figure 4 Schematic diagram of HP-RHS.

(1) It requires neither moving parts nor power source as is the case with pumps or compressors.
(2) It is low in cost because of its simple structure.
(3) High long-term reliability is assured.
(4) Because heat transfer is effected through phase change, heat with greater densities can be efficiently diffused.
(5) Because of its small amount of working fluid needed in addition to its excellent sealing performance, there is no danger of liquid leakage.

This paper reports on the results of experiments we have carried out with regard to the application of heatpipe-based remote heatsinks (HP-RHS) to desktop PCs, together with some application examples.

2. MAXIMUM HEAT TRANSFER RATE OF HEATPIPE

HP-RHS itself has already been in practical use in notebook PCs [1), 2)], but the heatpipes for desktop PCs obviously have to be longer due to the difference in the size of the equipment. While notebook PCs typically use heatpipes of 100~200 mm in length, the length may be extended to some 400 mm for desktop PCs. Since heatpipes have a tendency to decrease in the maximum heat transfer rate Q_{max} as the heat transfer distance increases, this presents a design problem to be solved.

On the other hand, while heatpipes are known to operate more efficiently in the bottom-heat mode where heat is transferred in the upward direction, it is advantageous that desktop PCs can be expected, when compared to notebook PCs, to be in an environment compatible with the bottom-heat mode. Figure 4 shows a typical layout of HP-RHS in bottom-heat mode, in which L-shaped heatpipes are used together with, e.g., a 120-mm square fan for cooling the RHS. Below will be described the results and some knowledge obtained of an experiment, in which Q_{max} of an L-shaped heatpipe alone was measured as an example of actively taking advantage of bottom-heat mode.

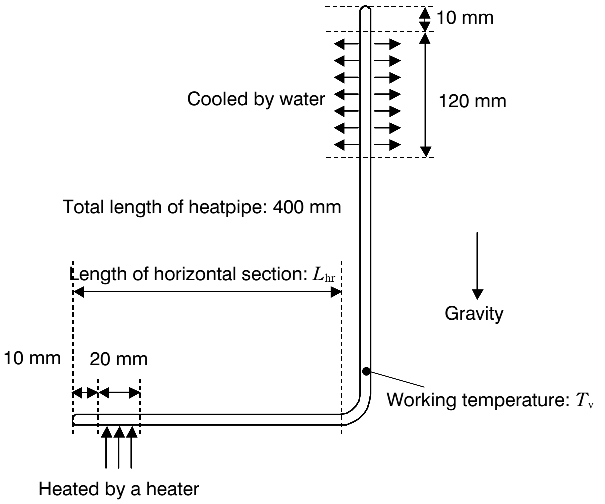


Figure 5 Setup for measuring L-shaped heatpipe.

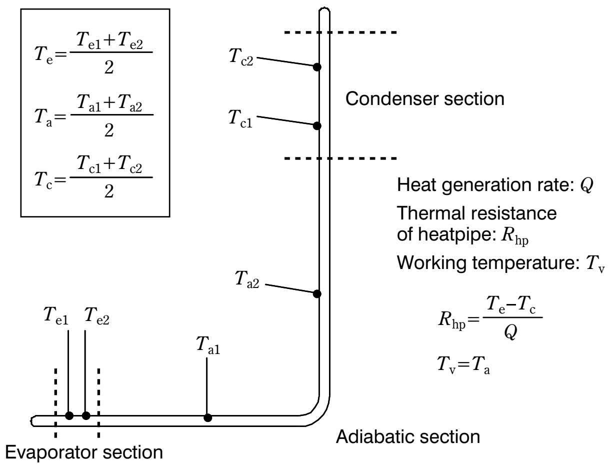


Figure 6 Layout of thermocouples.

In the experiment, for the sake of comparison, the diameter and length of the heatpipe were fixed to 6-mm ϕ and 400 mm, respectively. As Figure 5 shows, a heater 20 mm in length was attached on the horizontal portion of the L-shaped heatpipe to make an evaporator section, while a water-cooling jacket 120 mm in length was attached on the vertical portion to make a condenser section, and the other portions are covered with thermal insulators to make an adiabatic section. The working temperature T_v and the horizontal length L_{hr} were thought to be most influential factors, excluding the fixed conditions, in determining Q_{max}, so that we decided to carry out experiments using these two as parameters. As shown in Figure 6, temperatures were measured at two points of the evaporator, adiabatic and condenser sections respectively using thermocouples, thereby letting the averaged values represent the temperature of respective sections, namely: evaporator section T_e; adiabatic section T_a; and condenser section T_c. In addition the thermal resistance within the heatpipe R_{hp} and the working temperature T_v were defined as shown in Figure 6.

Figure 7 shows an example of thermal resistance measurements at various working temperatures for a heatpipe having a horizontal section length of 50 mm. In every case of working temperatures the R_{hp} is seen to

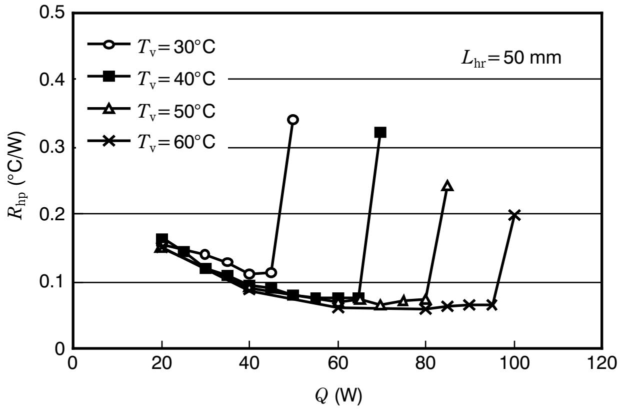


Figure 7 Example of thermal resistance measurements at various temperatures.

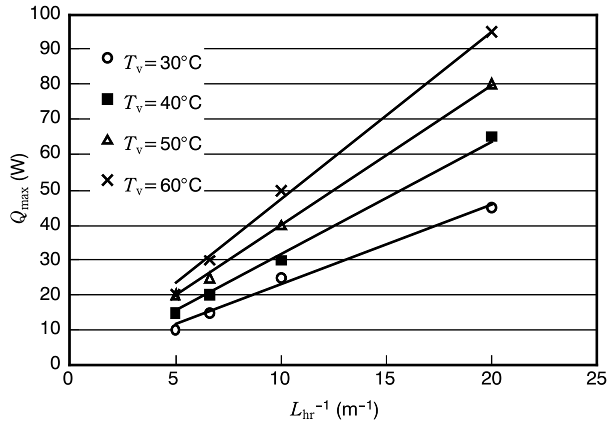


Figure 8 Q_{max} of L-shaped heatpipe under various conditions.

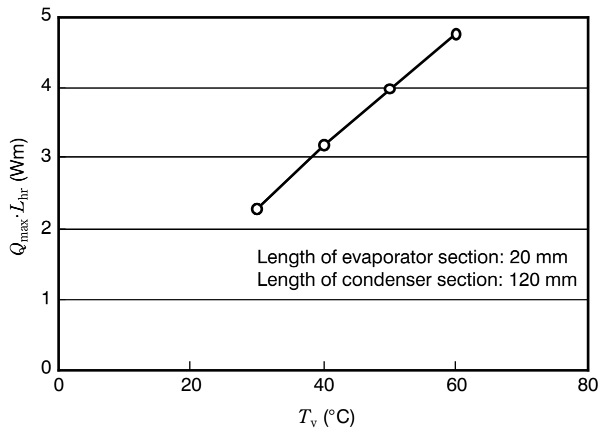


Figure 9 $Q_{max} \cdot L_{hr}$ of L-shaped heatpipe.

rapidly rise at a certain temperature, indicating that dry-out occurs within the heatpipe. Defining Q_{max} as the heat rate at the boundary where R_{hp} shows a rapid increase, Q_{max} at various conditions were obtained namely, for horizontal lengths of 50 mm, 100 mm, 150 mm and 200 mm; and for working temperatures of 30°C, 40°C, 50°C and 60 °C. Figure 8 shows these Q_{max} values under various conditions, where the data are divided into groups according to the working temperature and are plotted using X-axis that is scaled by the reciprocal of L_{hr} —the four conditions above mentioned correspond respectively to 20 m^{-1}, 10 m^{-1}, 6.7 m^{-1} and 5 m^{-1}. It can be seen that the data of the same working temperature can be fitted to a straight line, and that every straight line passes the origin of coordinates, meaning that the product $Q_{max} \cdot L_{hr}$ can neatly be expressed by a constant —the slope of the straight line. Accordingly, the Q_{max} of L-shaped heatpipes can be represented as shown in Figure 9.

Thus we have been able to clarify Q_{max} of L-shaped heatpipes experimentally, and succeeded in describing the performance using the index $Q_{max} \cdot L_{hr}$.

3. THERMAL RESISTANCE OF HEATPIPE

Let us now describe the thermal resistance of a heatsink in which heatpipes are actually integrated. While a cooling method using only RHS is shown in Figure 4, it was thought that simultaneous use of conventional heatsinks would be more effective for efficient cooling, so that we fabricated a prototype of combined heatsink shown in Figure 10, where a conventional heatsink is installed additionally just above the CPU, and carried out performance evaluation. Meanwhile, the heatsink installed just above the CPU is referred to as “direct cooling heatsink (DHS)” hereinafter in order to distinguish it from RHS.

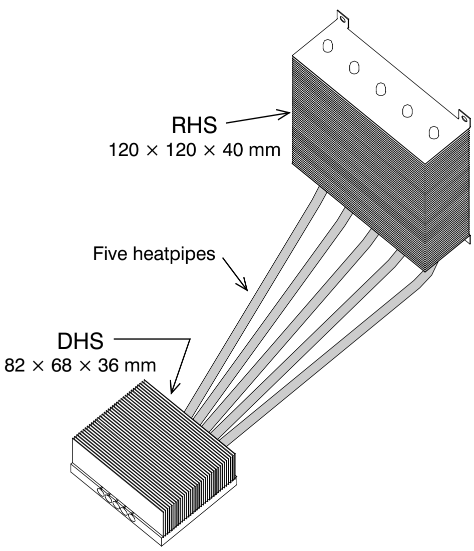


Figure 10 Schematic of combined heatsink.

In the prototype heatsink, five L-shaped heatpipes each with a horizontal length of 60 mm and a total length of 400 mm were used. With the aim of allowing arbitrary design of the distance between the DHS and the RHS while keeping the horizontal length short, the heatpipes were bent in a two-step configuration —to rise up aslant from the horizontal section then becoming vertical near the RHS. The Q_{max} of each heatpipe was estimated based on the elementary performance evaluation mentioned earlier to be about 50 W at a working temperature of 40°C. Since the fin efficiency of RHS becomes higher when multiple heatpipes are attached dispersedly on the fins, it is not necessary for a single heatpipe to accommodate all the heat rate. For a fin 120 mm in width, for example, it is considered preferable, from the point of fin efficiency, to attach three to five heatpipes dispersedly, and, therefore, a Q_{max} of some 50 W per heatpipe is sufficient for dealing with a heat generation rate in excess of 100 W.

On the DHS, 35 aluminum fins of 0.4 mm in thickness were mounted by mechanical crimping at a pitch of 1.9 mm. Also for the RHS, 98 aluminum fins of 0.2 mm thickness were mounted mechanically at a pitch of 1.2 mm to constitute a stacked fin array. The experiments were conducted under the condition of inputting a heat rate of 200 W from the bottom of the DHS using a 20-mm square heater, and cooling the DHS and the RHS individually using a 12V-DC fan —60 mm x 60 mm x 15 mm for the DHS and 120 mm x 120 mm x 40 mm for the RHS.

The heater and ambient temperatures were measured for the two cases of fan-cooling both the DHS and the RHS and fan-cooling only the RHS, and assuming that the heater temperature is equivalent to the CPU case temperature, respective values of R_{ca} were obtained based on these temperature measurements. The results show that R_{ca} = 0.193°C/W for the case of both DHS and RHS working, and R_{ca} = 0.213°C/W for only RHS working. These values were converted using the curve in Figure 3 to heat generation rates that would allow sufficient dissipation, resulting in 155 W for both DHS and RHS working and 141 W for only RHS working. Thus it was demonstrated that in each case the heatsink could cope with the heat generation rate in excess of 100 W.

4. DESIGN BY SIMULATION

Lastly we will describe a design example using simulation. Photo 1 shows an HP-RHS product which was employed in a desktop PC of the 2004 summer model. Four heatpipes are used to transfer the heat to the RHS with dimensions of 120 mm x 120 mm x 60 mm, which is cooled using a 120-mm square fan —25 mm thick, 37 dB in noise level, virtually hidden in Photo in the rear of the heatsink.

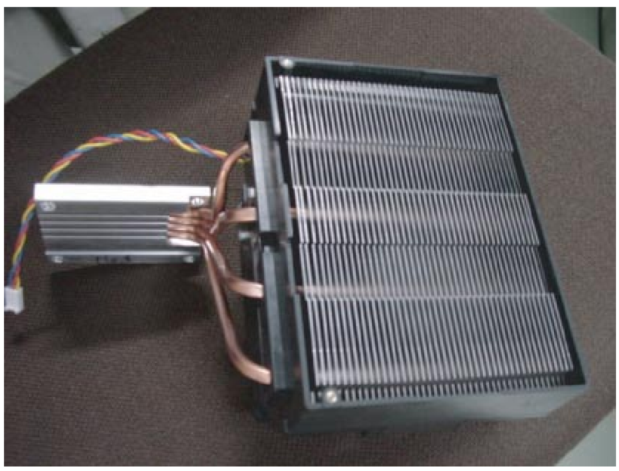
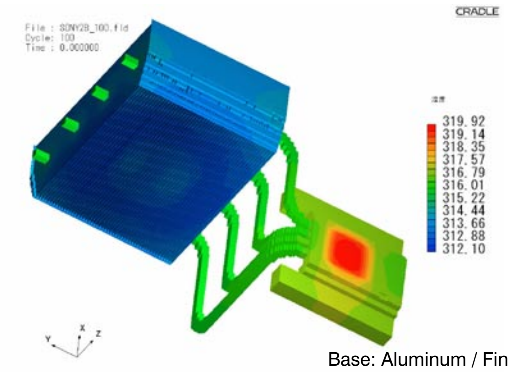


Photo 1 Appearance of an HP-RHS product for desktop PC.

The heatsink was modeled and thermo-fluid dynamics analysis was carried out to calculate the temperature distribution in the heatsink. Figure 11 shows an example of the results obtained under the conditions of: both fin



Base: Aluminum / Fin: Aluminum
Ambient temperature: 308 K
Airflow: 1.67 m³/min
Heat input: 103 W

Figure 11 Temperature distribution of heatsink. (by calculation)

and heat-receiving block is of aluminum; heat input is 103 W; airflow rate to the RHS is 1.67 m^3/min; and ambient temperature is 35°C (308K). Physical properties of the heatpipe itself obtained from the evaluated results of heatpipe elements were used in the calculation model. As can be seen from Figure 11, the highest temperature was reached at the surface of the heat-receiving block corresponding to the center of the incident plane, resulting in a heat-dissipation relationship of R_{sa} = 0.116°C/W, where R_{sa} is defined as the thermal resistance due to the temperature difference between the maximum temperature at the center of the heat-receiving block and the ambient temperature. The calculated value approximately agrees with the experimental result obtained using the same airflow, thus confirming the validity of the calculation model.

When pure copper is used for both the fin and the heat-receiving block aiming at improving the thermal performance, a relationship of R_{sa} = 0.102°C/W is obtained through the use of the same model, thus indicating a reduction of R_{sa} by about 12 %. While materials are to be selected from the standpoint of both thermal performance and weight, use of aluminum was found satisfactory in the current design to achieve the required performance, so that aluminum was employed in consideration of its lightweight for both the fin and the heat-receiving block. Incidentally, ease of integrating dissimilar metals, e.g., copper heatpipe and aluminum fin, is one of the advantageous features of Furukawa Electric's heatsink which employs mechanical jointing.

Lastly, let us compare the thermal performance by converting the values into R_{ca}, into which R_{sa} can be converted by adding the thermal contact resistance for CPU. The resistance is, although slightly subject to change depending on the selection of thermal interface material (TIM), around 0.10°C/W. In the above mentioned case, therefore, R_{ca} =0.216°C/W for aluminum and R_{ca} =0.201 °C/W for copper. Thus referring to Figure 3, it can be seen that the design can deal with the heat generation rates of up to 139 W and 149 W for aluminum and copper, respectively.

5. CONCLUSIONS

As the next-generation heatsink for desktop PCs capable of coping with a heat generation rate exceeding 100 W, the HP-RHS scheme was investigated, in which a heatsink with a sufficient surface area is installed in an open space and the heat is transferred there using heatpipes. It has been clarified that for an HP-RHS using a 120-mm square fan, for example, R_{ca} is about 0.20°C/W; in other words, it is possible to maintain the temperature difference between the CPU case and the ambient not higher than 30°C for heat generation rates of up to around 150 W. Thus we have been successful in demonstrating that the HP-RHS can cope with heat generation rates in excess of 100 W, and also in practically supplying the products to commercial desktop PCs.

Since HP-RHS has practicality, in comparison with other cooling techniques like water cooling, in terms of reliability and cost it is expected to become widespread in desktop PC applications just like in notebook PCs. Future tasks for us would be to build up basic data that are applicable to many cases, and to make more efficient use of the data for design applications.

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2) K. Namba et al.: "Heat-Pipes for Electronic Devices Cooling and Evaluation of Their Thermal Performance," Proceedings of Itherm '98 (1998) 456.