Revolution in Fan Heat Sink Air Cooling Technology for Desk Top PCs in the Retail Market

Pakawat Visudthimark[1], *Thang* Nguyen[2], *Tien* Nguyen[2], *Masataka* Mochizuki[2], *Yuji* Saito[2], *Vichan* Kumthonkittikul[1], *Parichart* Sukkasaem[1], *Prasong* Ektummakij[1], *Tanaphan* Sattaphan[1], *Piyawan* Boonsin[1] and *Vijit* Wuttijumnong[3]

This paper describes the overview of revolution on air cooling solutions that have been combined with various heat sink for cooling high power processors in a confined space of PCs., and discusses how to extend the air cooling capability and optimum heat sink performance to against competition of cost in the retail desk top PC market. According to the cost impact, it will influence in the limitation of fan heat sink design. To keep the competition of cost in the market, it will be one of factor to limit the design of air cooling to utilize high cooling technologies at this moment. Included in this paper are the design, data, photos of various fan heat sink air cooling designs showing how the design changes can push the limit of the air cooling capability.

1. Introduction

Thermal management of electronic components is one of the key points for successful product launch as the trend of electronics market was moving fast. According to trend of the processor performance and heat dissipation have been increased significantly every year. In the year 2000, the clock speed of processors used in desk top PC was approximately 1GHz and heat dissipation approximately 20 W, but in the year 2005 the processor's clock speed is higher than 3 GHz and the heat dissipation is approaching 100 ~ 130 W. Meanwhile heat dissipation keeps increasing but the size of die on the processor was reduced or remained the same size and thus the heat flux is critically high. The heat flux is about 10 ~ 15 W/cm^2 in the year 2000 and could reach 100 W/cm^2 in 2005. Passive cooling is no longer appropriate to deliver the cooling requirement. So the active cooling as the heat sink to combine with air blowing devices, have been considered to meet the current demand. The retail market of cooling equipment for desk top PC processors, is general requirement for end users to utilize the processor box package as processor chip included the cooling equipment, on the different of main board, CPU chassis and other devices like a graphics card, memory card, connecting ports card, etc. So the air cooling design will contain some limitation of overall volume, weight, acoustic level to against thermal target specification.

The most of the generated heat in the CPU releases from the processor's small die surface area that's approximates 10 mm × 10 mm and the most case of the die surface is covered with a metal plate called Integrated Heat Spreader (IHS) that will be different size in each processor's design and will be described later. Mostly of thermal performance target will monitor to the temperature of IHS on the top surface of metal plate as Rca (thermal resistance from CPU case surface to ambient [°C/W]). Main development of air cooling design will concentrate on the fan solution and heat sink solution to be optimized under the limitation of overall volume, weight and acoustic level to meet the cooling requirement as thermal target specification.

At this moment, the limitation is availability of high volume manufacturing capability and cost. The cooling technology for heat sink, the majority is still continued with traditional solutions such as aluminum extrusion parallel or radial fin heat sink; combination of aluminum extrusion with aluminum core or copper core. However it might reach to limitation of traditional solution of heat sink in near future, if the trend of the clock speed of processors and heat dissipation still keep increasing, high cooling technologies such as heat pipe, vapor chamber, liquid cooling and thermoelectric cooling will be considered as new generation of air cooling design.

2. Basic Formulas

A basic formulation to calculate the thermal resistance required for the cooling solution as follows:

$$Rja = Rjc + Rca = (Tj - Ta - Tsys)/Q \quad (1)$$

where,

Q = heat dissipation (W)

1 Fujikura (Thailand) Ltd.
2 Fujikura Ltd. Thermal Technology Division
3 Fujikura America,Inc.

Rja = thermal resistance from the CPU die to ambient (°C/W)

Rjc = thermal resistance from the CPU die to CPU case surface (°C/W)

Rca = thermal resistance from CPU case surface to ambient (°C/W)

Ta = ambient temperature (°C)

Tj = junction temperature inside die (°C)

Tsys = temperature rise of the ambient inside of the system due to other heat generating components (e.g. hard disk drive; graphic cards; etc.) (°C)

In the case of CPU packaged with an integrated heat spreader, the Rjc varies depending on the type of CPU and manufacturers. In most cases the Rjc is approximately 0.33 °C/W.[1)2)]

The thermal solution provider could only control the Rca. This thermal resistance consists of the thermal interface material and the cooling solution. Figure 1 shows the required thermal resistance Rja, Rjc and Rca vs. heat dissipation, assuming the maximum CPU's junction temperature of 100 °C, an outside ambient of 35 °C and system temperature rise of 10 °C.

3. Case study

3.1 Summary of air cooling design

This is a summary of design changes to maximize the air cooling capability.

Example 1: The 1st generation of processor design

This processor used Integrated Heat Spreader (IHS) size is 31 × 31 mm. And the loading condition of air cooling design on this processor is 2 points loading on the center of plastic clip on the both ends on the air cooler. For equal comparison, all the designs are within the boundary of a cooling volume of approximately 90 mm × 90 mm × 65 mm (W × L × H). The acoustic level at the maximum specification in general is 45 dBA at 1m from the source. The overall volume and loading condition will be shown in Fig. 2. The heat dissipation on this processor is approximate 65 ~ 85 Watts that will depend on the clock speed of processors.

- Design 1 : Normal parallel fin heat sink with aluminum extrusion with the aspect ratio ~ 16.0 (Fins count approx. 7 fins per inch, 1.2 mm fin thickness, pitch 3.5 mm and 32 mm tall.) and combine with axial fan size 70 × 70 mm, 15 mm in thickness. The Rca range is 0.40 ~ 0.45 °C/W. As shown in Fig. 3.

- Design 2 : High aspect parallel fin heat sink as aluminum extrusion with the aspect ration ~ 24.0 (Fins count approx. 10 fins per inch, 1 mm fin thickness, pitch 2.3 mm and 32 mm tall.) and combine with axial fan size 70 × 70 mm, 15 mm in thickness. In this design extrusion technology had been pushed to the limit capability. It's necessary to have the additional copper block that is soldered on the bottom of aluminum extrusion to be minimize the heat spreading resistance. The Rca range is 0.32 ~ 0.35 °C/W. As shown in Fig. 4.

- Design 3 : The design changes from parallel fin

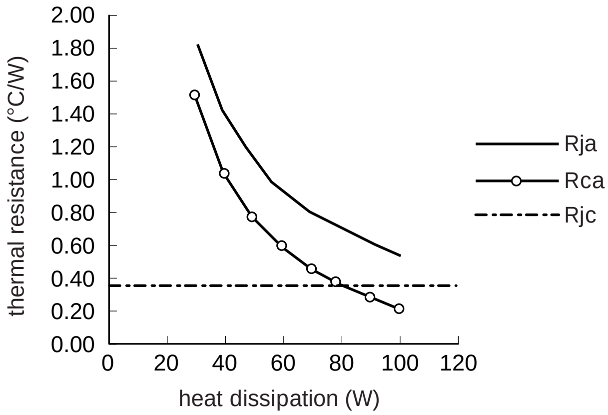

Fig. 1. Rja, Rjc, and Rca vs. heat dissipation.

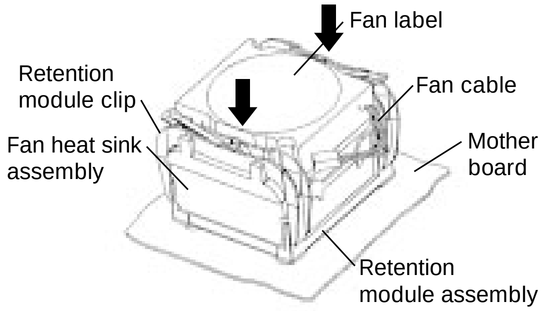

Fig. 2. Loading application for 1st processor.

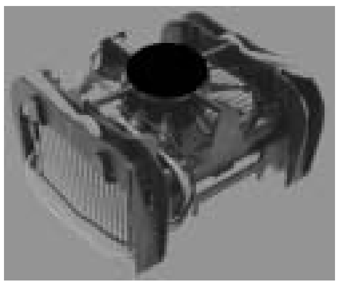

Fig. 3. Normal extrusion HS + Fan 70 × 15 mm.

Fig. 4. High aspect extrusion HS with Cu block + Fan 70 × 15 mm.

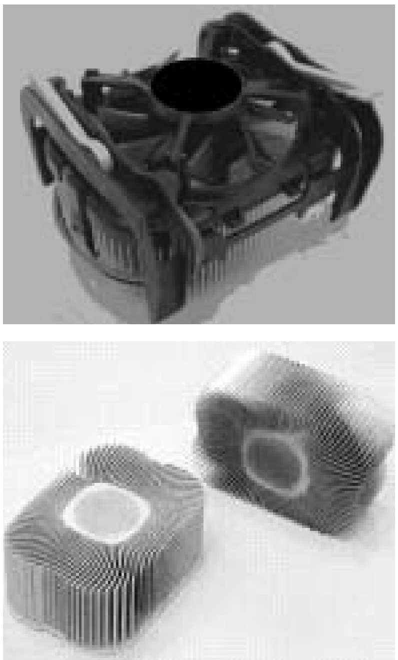

Fig. 5. Radial fin extrusion HS with Cu core + Fan 70 × 18 mm.

extrusion to radial fin extrusion as overall shape as square 70 × 90 mm (Fins count 90 fins, 0.5 mm fin thickness, 40 mm tall). The center of heat sink was integrated with the copper core to improve heat conduction from base to fins. In general radial fin extrusion could capture more air from the fan than a parallel plate fin, thus providing higher fin-air heat transfer coefficient and more efficient cooling. Another advantage is the airflow that pass through the bottom of heat sink is still available to cool the other electronic components around the heat source. Then combine with axial fan size 70 × 70 mm, 18 mm in thickness. The Rca approx. 0.30 ~ 0.32 °C/W. As shown in Fig. 5.

Example 2: The 2nd generation of processor design

This processor used Integrated Heat Spreader (IHS) size is 29 × 29 mm. And the loading condition of the air cooling design on this processor is 4 points loading on the 4 corners of stainless steel X-shape clip that will be assembly on the bottom of the air cooler via plastic fastener to be lock on the motherboard. For equal comparison, all the designs are within the boundary of a cooling volume of approximately cylinder with 90 mm diameter and 65 mm in height. The acoustic level at the maximum specification in general is 45 dBA at 1m from the source. The overall volume and loading condition is shown in Fig. 6. The Heat dissipation on this processor is approximate 85 ~ 130 Watts that will depend on the clock speed of processors.

- Design 1 : Radial fin extrusion with bi-furcating fin within the cylinder volumetric as 90 mm diameter (Fins count 104 fins, 0.5 fin thickness and 30 mm

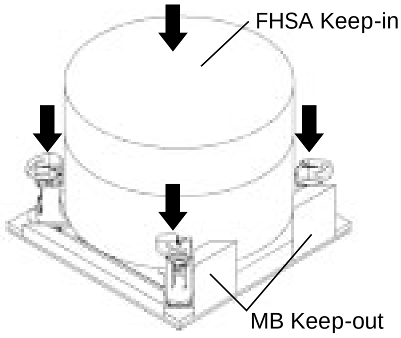

Fig. 6. Loading application for 2nd processor.

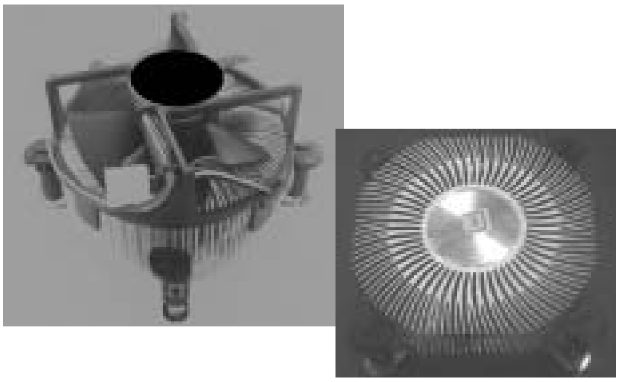

Fig. 7. Bi-furcating radial fin extrusion HS (104 fins) with Al core + Fan 70 × 15 mm.

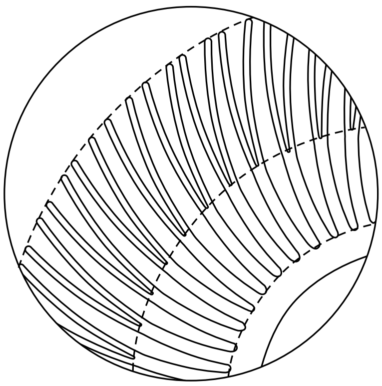

Fig. 8. Bi-furcating radial fin extrusion.

tall). And the center of heat sink was integrated with aluminum core, 33 mm diameter, to improve heat conduction from base to fin as low weight proposal (Fins count 104 fins, 0.5 fin thickness and 30 mm tall) and this heat sink was combined with axial fan size 90 × 90 mm, 15 mm in thickness. The Rca range is 0.30 ~ 0.32 °C/W. As shown in Fig. 7 and 8.

- Design 2 : The extrusion is still continued with radial fin extrusion with bi-furcating fin within the cylinder volumetric as 90 mm diameter (Fins count 104 fins, 0.5 fin thickness and 30 mm tall). And the center of heat sink was integrated with copper core, 33 mm diameter, to improve heat conduction from base to fin. Because heat conductivity of the copper core is better than Al core. To maintain the total weight with requirement, the copper core needs to be

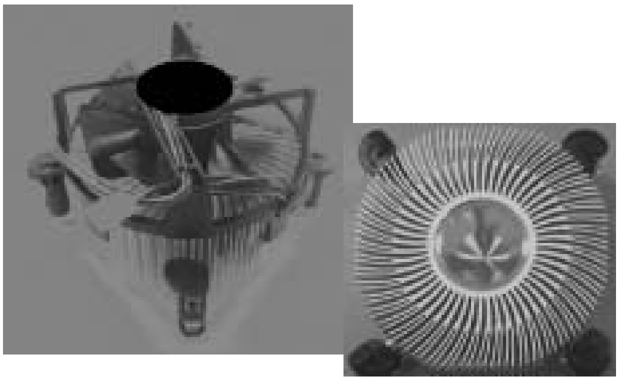

Fig. 9. Bi-furcating radial fin extrusion HS (104 fins) with Cu core + Fan 70 × 15 mm.

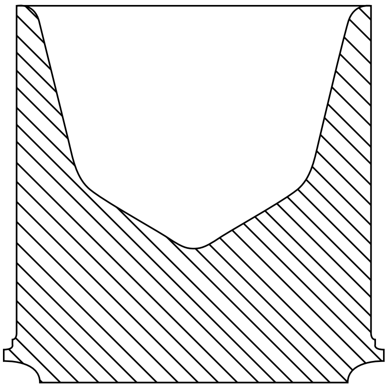

Fig. 10. Bi-furcating radial fin extrusion HS with Cu core + Fan 70 × 15 mm.

design as convex shape. Then this heat sink was combined with axial fan size 90 × 90 mm, 15 mm in thickness. The Rca range is 0.29 ~ 0.30 °C/W. As shown in Fig. 9 and 10.

- Design 3 : The high aspect radial fin extrusion with bi-furcating fin within the cylinder volumetric as 90 mm diameter (Fins count 120 fins, 0.5 fin thickness and 30 mm tall). And the center of heat sink was integrated with larger copper core, 40 mm diameter with the convex shape, to improve heat conduction from base to fin. Then combine with axial fan size 90 × 90 mm, 15 mm in thickness. The Rca range is 0.23 ~ 0.25 °C/W. As shown in Fig. 11.

3.2. Effect of acoustic requirement

According to the air cooling design, the heat sink will conduct the heat from CPU processor. But the air blowing device is also one of important factor to convect the heat from heat sink. Generally we can utilize the airflow in each air blowing device that we will call it as " Fan" to be maximum speed of fan capability in each design. It will help to enhance the fin efficiency of heat sink to reach the limitation of thermal resistance in each heat sink design. However the acoustic requirement will be the limitation of air cooling design to run the fan speed at maximum of fan capability. The trend of acoustic requirement is also getting lower to satisfy the end user of PC computer.

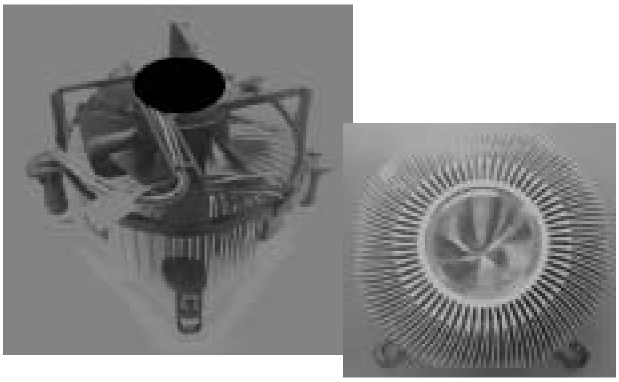

Fig. 11. High aspect bi-furcating radial fin extrusion HS with larger Cu core + Fan 70 × 15 mm.

The main factors that concern to the acoustic level of air cooling design that will call as "Noise (dBA)" was shown as below.

3.2.1. The noise of airflow

Most of the airflow noise will be conduct from the airflow that flow from the fan parts through the heat sink and it have 2 locations that concerned to the noise of airflow as below details.

- The gap between impeller of fan and the top of fin area on the heat sink
- The gap between impeller of fan and the fan spoke on the name plate (PCB) of fan

3.2.2. The noise of rotation of shaft on the bearing

Most of this noise will be the abnormal condition that will concerned with unbalancing.

3.2.3. The noise of electric components

Most of this noise is very small and difficult to distinguish by human hearing like a switching noise of IC, etc.

3.3. Effect of cost competitiveness

Fig.12 shows Rca (Rca: case of CPU to ambient temperature) against cost of the solutions that are the current and future expectation for lap top, desk top PCs, and the server units.[1,2] For the lap top PC, if the thermal solution is considered to use a heat pipe with remote heat exchangers, it is able to deliver Rca performance of approx. 1.5 ℃/W. Further performance improvement would need to consider using the vapor chamber solution. The estimated cost for lap top PC solution including fan is in the range of 5 ~ 15 $US depending on the performance requirement. For the desk top PCs and servers, the majority still use traditional solutions such as high aspect aluminum extrusion parallel or radial fin heat sinks; aluminum or copper plate fins soldered to aluminum or copper metal base. However, as the performance requirement tightens, the trend is moving towards using heat pipes and vapor chambers to maximize the performance and to extend the air cooling capability to the limit.

However the current retail market of the desk top PCs is high competition on the cost. So it can't be available to provide the high cost solution to complete in the market. Most of the air cooling design were monitored on the traditional parallel and redial fin extrusion with some additional of block and core with various of material like a copper or aluminum.

4. Conclusion

The paper will describe the summary of design changes to extend the air cooling capability to meet the demand of each processor's generation. The CPU package with the integrated heat spreader (IHS) was reference thermal resistance of air cooling design as Rca performance (°C/W) vs. heat dissipation (Watts).

According to the cost competition in the retail market of desk top PC, most of the air cooling design will utilize the traditional parallel fin and radial fin extrusion heat sink with block or core to minimize heat spreading resistance and improve heat conduction from base to fin. But the limitation of control volume, maximum weight and the acoustic level of air cooling will be considered the design to meet the requirement in each processors.

However it might reach to limitation of traditional extrusion technology in near future. If the trend of the clock speed of processors and heat dissipation still keep increasing, thus requires lower thermal resistance (Rca), the cooling solution technology tendency to maximize and extend air cooling will move towards more use of heat pipes and vapor chambers. Therefore to provide adequate cooling it is essential to continue research and develop superior heat pipes and vapor chambers having high heat flux capability, and minimal possible thermal resistance between heating and cooling ends

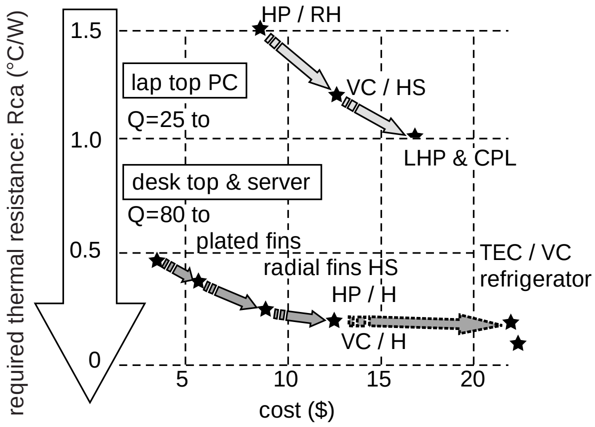

Fig. 12. The thermal solution trend against the cost of solution.

References

1) M. Mochizuki, K. Mashiko, Y. Saito and T. Nguyen: Update Cooling Technology for Personal Computer Using Heat Pipes and Vapor Chamber, Kuala Lumpur, Malaysia, 2004
2) M. Mochizuki, Y. Saito, Thang Nguyen, Tien Nguyen, V. Wuttijumnong and X. Wu: Revolution in Fan Heat Sink Cooling Technology to Extend and Maximize Air Cooling for High Performance Processor in Labtop / Desktop / Server Application, San Francisco and California, USA, 2005