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Fan-less Cooling Technology for Notebook Computers

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Cooling technologies are becoming critical for handling increased heat output in portable computers. This is because the increased heat output of components (elements and modules) used in the latest notebook computers and the miniaturization of cabinets has led to high internal temperatures in equipment and the intensification of partial heat density. The situation has almost reached the point where MPU performance may have to be limited due to higher temperatures, especially for devices with small cabinets, such as sub-notebook computers. This paper extracts a technological problem necessary for achieving the fan-less cooling of notebook computers, and verified the cooling structure and method of solution. The result of thermal fluid simulation on our notebook computers (which incorporate new cooling technology) and measurement values were found to correspond well.

1. Introduction

Until a few years ago, heat output from units was relatively small for notebook computers, and cooling measures were practically unnecessary for mounted parts. A significant increase in heat output from such units as elements and modules, and the use of thinner, miniaturized cabinets in recent models, however, are causing problems involving higher air temperatures inside the cabinet and, in some sections, higher component temperatures (**Figure 1**). When the temperature of a component rises above the permissible value, poor performance and element damage generally result. This not only has considerable impact on product performance and reliability, but also causes major safety-related problems. Consequently, heat radiation technology has assumed greater significance.

This is especially true for sub-notebook computers, which are already limited in terms of cabinet size. Heat conditions may also limit the types of MPUs that can be mounted. Therefore, heat radiation technology represents a key technology for product development.

2. Cooling methods

There are three main methods of cooling electronic equipment. Passive air cooling radiates heat using the airflow generated by differences in temperature, forced air cooling radiates heat by forcing air to flow by using fans, and forced

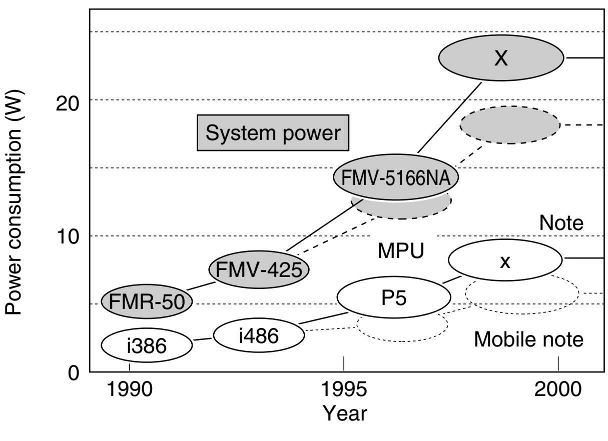

Figure 1.
Power consumption trends for notebook PCs.

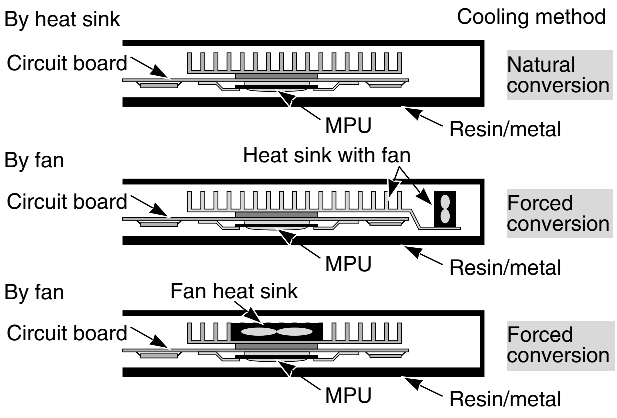

Figure 2.
Cooling methods of notebook PCs.

liquid cooling radiates heat by forcing coolants like water to circulate. Today's notebook computers primarily rely on the passive air cooling and forced air cooling methods shown in **Figure 2**.

2.1 Passive air cooling method

The passive air cooling method employs a convection current to transfer and radiate heat. (This convection current, generated by differences in temperature caused by heat produced by unit parts, circulates in the surrounding air.) To effectively radiate heat using this method, the surface area of parts exposed to the air, as well as the difference in temperature between the heating element surface and surrounding air must be increased.

2.2 Forced air cooling method

This section describes variations of the forced air cooling method.

2.2.1 Miniature axial fan

The miniature axial fan [size:25 to 30 mm^2] method regulates internal unit temperature by using a miniature fan to forcibly discharge air inside the unit. This method enables the cooling of all mounted parts in a unit. In this method, the unit requires an internal air passage with intake and exhaust holes. Therefore, when designing the unit, several factors must be considered. One is how to create air passages in the space afforded by using allowable dimensional tolerances during assembly.

2.2.2 Heat sink with fan

With this method, a heat sink combined with a fan is used to directly lower MPU temperature. The main purpose of the heat sink-fan combination, however, has been to cool the MPU. This is why, in most cases, the capacity to cool other parts within the unit is lacking. Care must also be taken regarding reliability because the fan is most likely to be mounted on the upper section of the MPU and exposed to high temperature.

Table 1. Comparison of cooling methods.

Cooling method	Device used	Reliability	Cooling performance	Noise	Power consumption
Passive air cooling	–	High	Mediocre	No	No
Forced air cooling	Fan	Low (limited service file)	High	Yes	Yes

Table1 compares the cooling methods. As indicated in the table, forced air cooling poses the problems of noise, high consumption of electric power, and limited service life, but offers high cooling performance.

3. Cooling for portable computers

To be portable, computers must be small, light, and thin. Consequently, problems regarding air temperature and the increased temperature of unit parts in some sections of notebook computers have cropped up. Portable computers also require high shock tolerances and long battery operation between recharging, thus making it difficult to use forced air cooling, which has implications regarding cooling mechanism reliability and battery service life.

Our unit, therefore, employs the fan-less cooling method. This decision takes into consideration the overall reduction in thermal resistance related to the unit and high heat-generating sections, as well as the optimization of heat distribution within the cabinet.

The following four points must be considered for the most effective cooling structure for fan-less cooling.

3.1 Cooling structure

This section describes the cooling structure in detail.

3.1.1 Cooling using Micro-Heat Pipe[1)]

Due to restrictions on unit size, it is difficult to mount in notebook computers the multi-vaned heat sink commonly used in desktop computers. Therefore, with the method employed, cooling performance is boosted by enlarging the surface area(The surface area is enlarged by spreading an aluminum plate inside the unit). A thicker plate must be used to diffuse heat through heat diffusion. But a thicker plate makes the unit heavier, thus losing a key feature of a portable computer. To circumvent this problem, a heat pipe using a thin, light aluminum plate high in heat conductivity is employed.

3.1.2 Bare chip direct cooling

Figure 3 shows the typical methods of MPU cooling.

Such semiconductor devices as MPUs are built into packages (e.g., QFP, BGA, TCP), and encased in plastic. Therefore, heat generated in a semiconductor device is not easily released to the package exterior (because the device has high thermal resistance). We tried to reduce thermal resistance by employing such methods as bare chip back surface attachment and inverted TCP mounting.

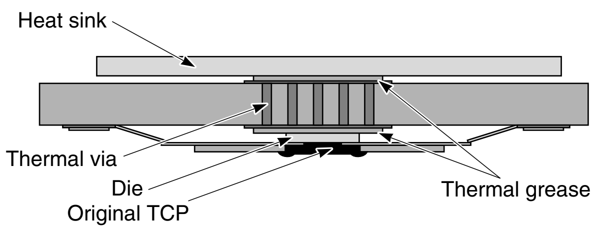

Figure 3.
Typical methods of MPU cooling.

3.1.3 Module structure (e.g., MCM)

By using technology that enables the high-density mounting of bare chips and package parts on a single board, high heat-generating components can be concentrated at a single location. This apparently enables the collective heat radiation of the heat generated. Since it is now easier to separate parts susceptible to heat when positioning parts within a unit, the adverse effects of heat can be minimized.

3.1.4 Metal housing

Resin is generally used for the enclosure of notebook personal computers. Conversely, a metal enclosure with good heat conduction is believed to improve heat radiation from the surface of a device.

4. Methods of testing

The four cooling structures and factors divided roughly above were tested to verify the effects of cooling.

Each method of testing was recorded as follows. In the following testing, the device under test was placed in a box made of paper (1000 × 1000 × 1000 mm in size) to eliminate the effects of wind.

4.1 Verifying effects of cooling using Micro-Heat Pipe with thin aluminum board

Testing was conducted to verify the effectiveness of the Micro-Heat Pipe.

A heater 40 × 40 mm in size was positioned under a radiator plate 210 × 85 × 0.6 mm in size [material: A5020], and enclosed in insulating polystyrene foam 30 mm thick. Then, 10 W of power dissipation was applied and a test conducted to compare differences in cooling performance when using and not using a heat pipe.

Figure 4 shows a 200 mm long, nickel-plated heat pipe 3 mm in diameter attached to three sections of the radiator plate end with a roll clinch in 43 mm intervals. (Grease was not applied to the space between the aluminum and heat pipe

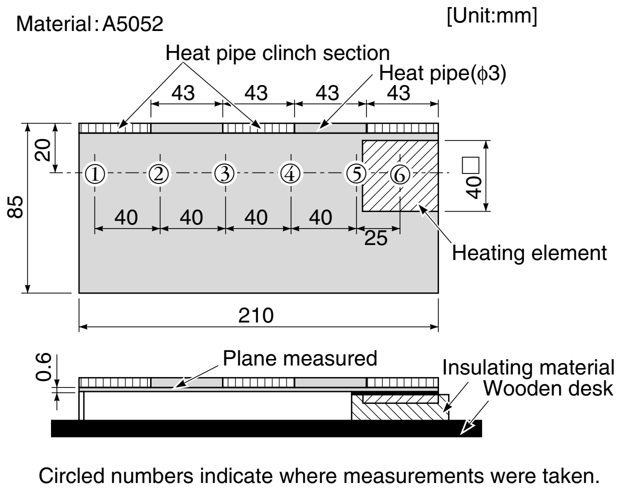

Figure 4.
Test equipment for micro-heat pipe.

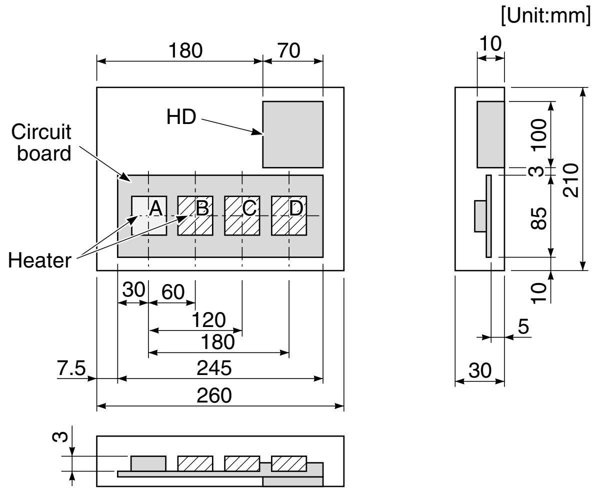

Figure 6.
Test equipment for heat concentration.

in the clinch section.)

4.2 Verifying effects of bare chip direct cooling

Testing was conducted to confirm the results of comparing the conventional TCP package cooling method (with uses a thermal via) with the bare chip direct cooling method.

The heating element had a chip size of 10 × 10 × 0.5 mm, and the same TCP package was used throughout testing. A six-layer test board 100 × 100 × 1 mm in size was used, and 12 × 12 vias 0.25 mm in diameter were positioned under the chip. Two mounting types on the top and bottom were also used. Thermal grease was applied to the space between the chip and test board, as well as between the chip and radiator plate. A radiator plate 45 × 45 mm in size [material: A6063] was used, with a 45 × 45 mm heat sink and fan attached to the upper section as shown in **Figure 5**. Six samples were used for each system, and the diode characteristic embedded in the chip was used to measure chip temperature.

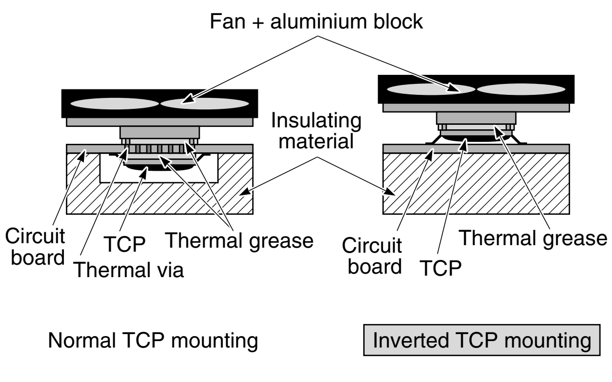

Figure 5.
Test equipment for bare chip direct cooling.

4.3 Effects of cooling on module structure

Two heaters were used in this testing, and the thermal effects of heaters on the HD mounted nearby were investigated based on heater positioning. The testing was conducted as follows: Inside a sealed container 260 × 210 × 30 mm in size (material: ABS 2 mm thick) as shown in **Figure 6**, two ceramic heaters (45 × 45 mm in size) and an HD (2.5-inch HD, 12.5 mm thick) were mounted. This sealed container, equipped with four rubber feet at the corners, was positioned 1 mm above the evaluation desk. One heater was positioned at A at the left end of the PC board; the other heater was moved from position B to C, then to D. The thermal effects on the HD were investigated by observing changes in HD surface temperature when moving the second heater around.

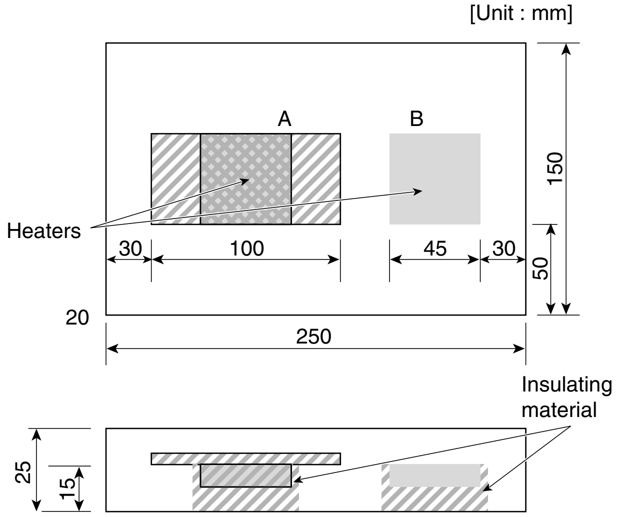

Figure 7.
Test equipment for metalic housing.

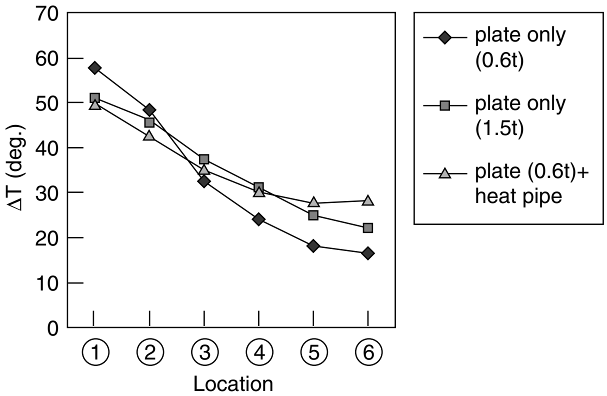

Figure 8.
Test data for micro-heat pipe.

4.4 Verifying effects of cooling on metallic housing

The difference in heat radiation between a resin enclosure and metallic enclosure was verified by the following methods. The enclosure (250 $\times$ 160 $\times$ 25 mm in size) used resin (material: ABS 2 mm thick) and metal (material: aluminum 1 mm thick) as shown in **Figure 7**. Two ceramic heaters are installed in the enclosure. An aluminum heat radiation board 50 $\times$ 100 $\times$ 1 mm in size was connected in the upper surface. The heat of each 3 W was applied to both heaters. The enclosure maintained a height of 5 mm from the evaluation desk.

5. Results and considerations

5.1 Verifying effects of cooling using Micro-Heat Pipe with thin aluminum board

Figure 8 shows that heating element temperature dropped by 8°C when using a heat pipe. Such cooling performance is equivalent to that achieved with a 1.5 t thick radiator plate. In terms of weight, equivalent performance was achieved by using only 31.5 g, or about 45% of the 71.2 g previously required.

5.2 Verifying effects of cooling using bare chip direct cooling

Figure 9 shows the thermal resistance values calculated from the chip temperature and environmental temperature. The average temperature for the conventional method was 5.49°C/W, and 3.99°C/W for bare chip direct cooling. An average reduction of 1.5°C/W in thermal resistance was achieved. This was made possible due to the shortened heat radiation path using the bare chip direct cooling method. In the conventional method, the heat radiation path progresses as follows: Chip → Material of heat conduction section (adhesives, thermal grease) → Thermal via → Thermal grease → Radiator plate. Whereas in the bare chip direct cooling method, the heat radiation path progresses as follows:
Chip → Material of heat conduction section (adhesives, thermal grease) → Radiator plate.

Since a thermal via is used in the conventional method, heat also radiates throughout the PC board, and causes the temperature to rise in other parts mounted on the PC board. The thermal via exclusively uses both surfaces of the PC board, which makes miniaturization more difficult. In bare chip direct cooling, however, parts can be mounted on the side of a PC board where chips are not mounted. Using this method reduces the thermal effects resulting from hot parts contacting the PC board.

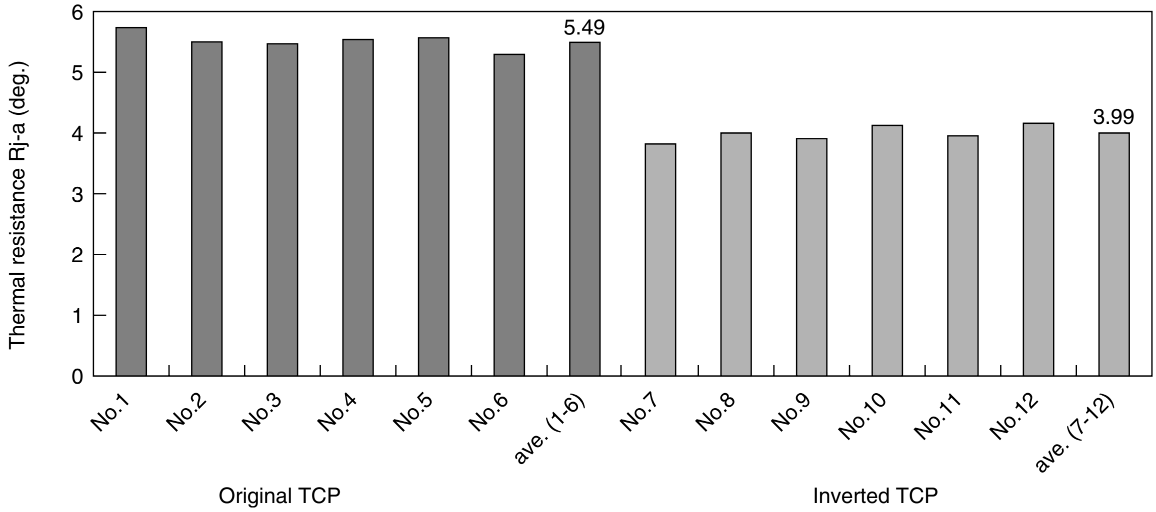

Figure 9.
Test data for bare chip direct cooling.

Thus, we adopted the method shown in **Figure 10** for our notebook personal computers.

5.3 Effects of cooling on module structure

In **Figure 11**, the vertical axis shows the increase in HD temperature; the horizontal axis shows the position of the heater. We confirmed that closer the heater was positioned to the HD, the higher the HD temperature.

This finding suggests that careless positioning of high heat-generating components on a PC board may subject other parts mounted inside a notebook computer to thermal effects.

Accordingly, small space limitations can best be utilized by concentrating high heat-generating components in a small area (for heat radiating purposes) separated from other parts that may be susceptible to the adverse effects of heat. Consequently, we designed the module shown in **Figure 12**, and have applied it to our notebook personal computers.

5.4 Effects of cooling on metallic housing.

Figure 13 compares the heat radiated between a resin enclosure and metallic enclosure.

We confirmed that surface temperature was 6°C to 9°C lower for the metallic enclosure than for the resin enclosure. Moreover, the temperatures of built-in parts were decreased about 3°C lower.

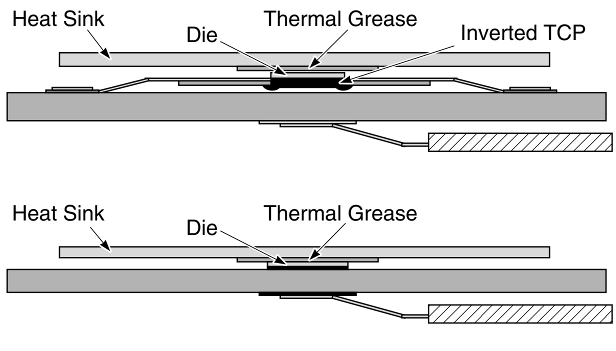

Figure 10.
Bare chip direct cooling methods.

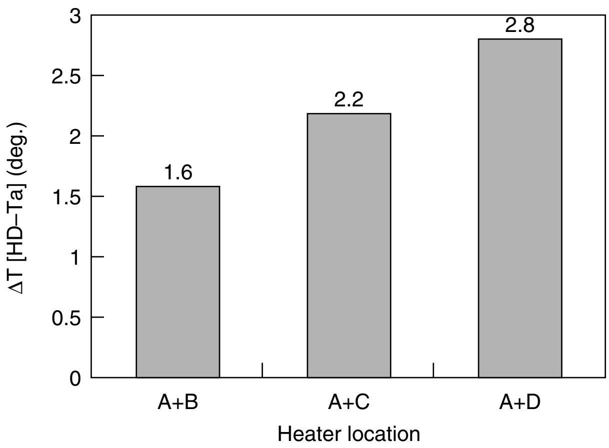

Figure 11.
Test data of heat concentration.

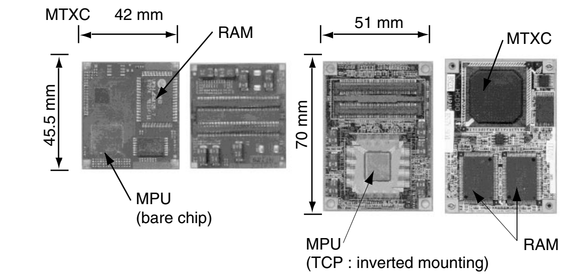

Figure 12.
Structure of module.

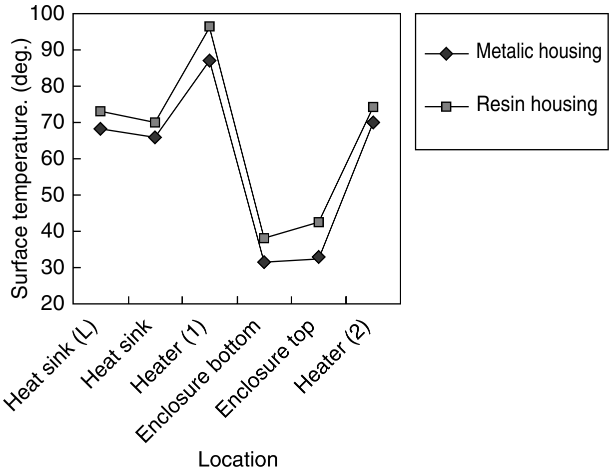

Figure 13.
Test data for metallic housing.

The reasons for this heat reduction is that heat received by the enclosure diffuses because the heat conductivity of aluminum is higher than that of resin, and the effective heat radiation area of the enclosure expanded. Another factor is that thermal resistance decreases when the enclosure is passed.

6. Thermal fluid simulation

Because the air temperature is expected to increase inside a notebook computer and in the components of some sections, thermal fluid simulation was applied as a measure to optimize the internal heat distribution of the cabinet.

6.1 Effects of thermal fluid simulation

By applying thermal fluid simulation, an imaginary unit model can be created on the computer to check measures against heat radiation. This eliminates the need to repeat trial manufacture and evaluation as in the past. **Figure 14** shows where analysis was applied and the effectiveness. For example, by applying analysis when determining the unit specifications or designing

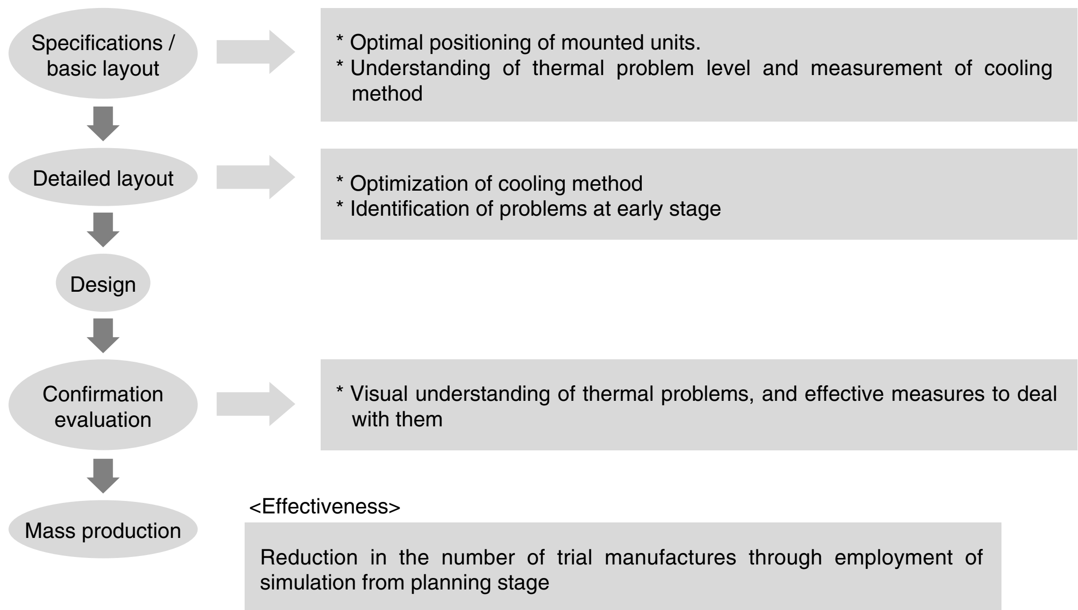

Figure 14.
Effects of application (using simulation).

the unit layout, the cooling method and cooling structure may be optimized. As a result, the number of prototypes to be manufactured can be reduced, and the lead- times required for product development can be shortened.

Thus, simulation can be used from the planning stage to reduce the trial manufacturing required.

6.2 Example of thermal fluid simulation

This section describes an example of thermal fluid simulation for our product, which employs the cooling method above.

6.2.1 Subject unit: FMV-BIBLO-NC

This unit employs MCM including, for example, bare chip mounting for the MPU, as well as a cooling method using a heat pipe and Hybrid Housing.[2] This is an A5-size, lightweight, portable notebook computer with advanced specifications. Total power dissipation within the sealed cabinet is approximately 15 W (excluding heat output from the LCD monitor section), and passive air cooling without using a fan.

6.2.2 Simulation model conditions

To duplicate actual use conditions, the unit was placed on a wooden desk. The surface temperature of a portable computer is a key factor in ensuring compactness and utility. Therefore, space was set accordingly to enable identification.

Small heating components (believed to have little thermal effects) were not used in the model, and the PC board was assumed to generate most of the heat. The total mesh number was put at approximately 150,000, and analysis was performed using a finite-volume method (with about six hours of calculation time for analysis).

6.2.3 Results of simulation[3]

Once the unit was completed, temperature was measured under virtually the same conditions (e.g., placed on a wooden desk) as those created during the simulation.

Figure 15 shows the temperature distribution of the device; **Figure 16** shows the comparison results of measurement and analytical values.

The measurement and analytical values matched well, which is sufficiently accurate for possible practical use in the design examination. Moreover, both temperature levels are assumed to have achieved the target values.

7. Summary

In terms of cooling technology for portable computers, the cooling method described below was applied to this unit. This resulted in a high performance portable computer that is light, thin and not equipped with a fan.

Using a heat pipe with the radiator plate of a notebook computer achieved cooling performance equivalent to that achieved by using aluminum about twice the thickness and weight. The use of bare chip direct cooling achieved a 1.5°C/W reduction in thermal resistance.

The high-density mounting of such high heat-generating components such the MPU reduced the adverse effects of heat on other parts inside

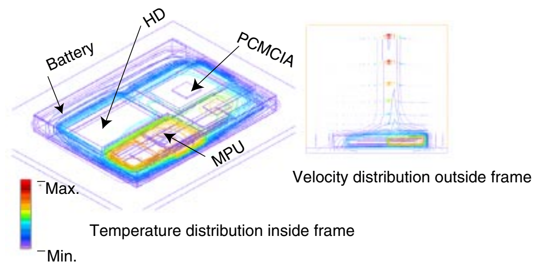

Figure 15.
Temperature distribution.

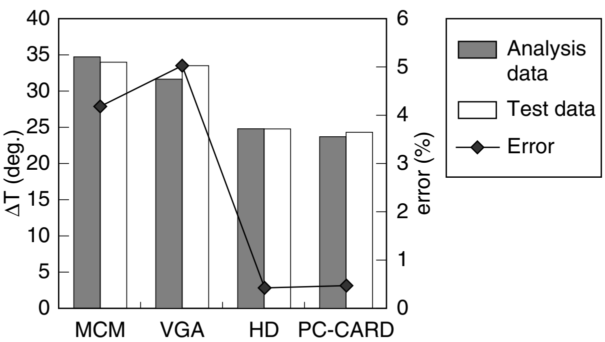

Figure 16.
Comparision of analysis and testing.

the unit.

A metallic enclosure proved superior to the conventional resin enclosure in terms of heat radiation.

The heat analysis result and measurement values of our BIBLO-NC device (which incorporates the new technology) matched well and verified the sufficiency of fan-less cooling.

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