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Simulation Study On The Heat Transfer Rate Of Thermal Modules With Different Fin Array Modes

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Keywords：thermal simulation, thermal management, heat sink, junction temperature.

ABSTRACT

This study uses Flotherm software to investigate the heat transfer rate of thermal modules with different fin array mode. A thermal management system addresses high-power issue in electronic chips. As the chip-power increases, corrective measures can reduce elevating temperatures. The chip powers and different thermal systems are compared including heat sinks and cold-fluid circulation systems. Integrating aforementioned systems can help evaluate each component's trends and clarify the results of the thermal system mechanism. When the power is increased to 45 W, the 15-pin heat sink is the optimal thermal system. A flat-type heat sink is recommended over a square-type heat sink. In addition, fixing the positions within the cold fluid system is the main focus of this study as it is closely related to the sufficient space for faster heat circulation; this implies that the closer it is to the chip center, the higher will be the chip temperature.

INTRODUCTION

Recently, the development of electronic products has become challenging owing to the increased demand for high-performance products that are slim and small; however, it is well known that, the larger the area, the better the thermal efficiency, which is a contradictory condition for thermal systems. Under these circumstances, a more efficient thermal system is required to maintain the proper operation of electronic components. Because of this requirement, a simple module is devised to analyze different thermal systems and to determine the best reference solution. This module is based on a conventional electronic chip design, and a cold fluid pipe that comprises a pipe, and a heat sink. By using the pipe, heat can be conducted in another area, and an unused free area is created.

Heat generation is the most critical factor for an electronic thermal system. If the system is overheated, it will affect the operation, lifespan, and reliability of the products. Because of these adverse effects, a thermal system should be efficiently equipped to dissipate the additional heat energy. First, the geometrics of the heat sink are investigated because the shapes of fins directly affect the conduction and convection (Morrison, 1992; Jousson and Palm, 1998; Yang and Peng, 2008; Morega et al., 1995; Harahap and Setio, 2001; Leon et al., 2004; Alessa et al., 2009). However, a limitation exists and therefore only fins and a fan can be used. Consequently, a significant barrier occurs that requires a different solution to maintain the functions of the chip. The fluid is used to replace air because of its better heat transferring characteristics. Thus, a more robust thermal control system can be obtained using water or another fluid, termed as “cold-fluid circulation system” (Yu and Shiratori, 1997). Moreover, computational fluid dynamics (CFD) approaches have also been developed that could be used to calculate and simulate the heat field of an operating laptop (Kobayashi et al., 1998). In real life, we are accustomed to using technological products with several functions and properties of low weight, slimness, and beauty. Because of these requirements, products face several challenges in thermal control system. The designers need to use minimal space to minimize the rising thermal effect; therefore, every feature of a component is vital in refining products. Although we have applied several different modules to electronic products, they still need to be improved.

The previous conventional thermal module designs could not completely solve heating challenges because the chip power is higher than before. Therefore, it is important to find an alternative solution to the high-power problems. High-powered chips generate more heat energy, which increases the

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chip temperature, thus causing products to shut down. Moreover, slim products are more challenging to design because of the confined inner space. According to the last year's trends in products, it is clear that high-power chips and less thickness will be adopted in the future.

Conventional thermal systems use air as the medium for heat conduction and convection because air is a natural material in our surroundings. A better performance cannot be attained because the unsuitable thermal properties of air limit the entire system. Using a suitable medium like water in a thermal system is the most efficient method. Space is also a challenge in slim designs because the heat fins and fan need a sufficient operating area to release heat energy. To optimally use the entire space of the product, heat transfer to another area needs to be studied to realize a general solution for the heat fin design by studying two types of heat shapes. In summary, analyzing the water cooling pipe and designing the fin's geometrics are the objectives of this study.

METHODOLOGY

Figure 1 shows the module of the thermal model used in this research, which is an electronic chip that uses distinct thermal cooling components. In general, the chip is set up using thermal glue to avoid the air gap between the chip and heat sink. This method is generally used for major high-power thermal cooling systems. By using this method, the heat can be conducted to the heat sink efficiently because of the low thermal resistance of the glue. However, if we only use the glue and heat sink, we cannot obtain a significant effect because the natural flow of heat is unstable. Thus, it is necessary to add a steady component to stabilize the flow rate. Therefore, a fan is added to the electronic chip thermal system, and speed of the fan can be controlled by a computer to avoid temperature increase. Based on this generic thermal module, an extra cooling component is added to improve the performance of the entire system. A cooling pipe is connected to the thermal module containing the chip and the heat sink, such that heat can be conducted along with the pipe's fluid, forming a cyclic thermal loop. In addition, we placed a heat sink along the cooling pipe's path, which simulates the use of another space to design the thermal module because of the limitations of the products. In the proposed system, there are two heat sinks, a fan, and a cooling pipe. We use simulation software to analyze the thermal conditions.

The heat sink material parameters are shown in Table 1.

FloTHERM can help build a 3D module and rapidly perform the CFD calculations by simplifying the features that cause the calculations to converge slowly.

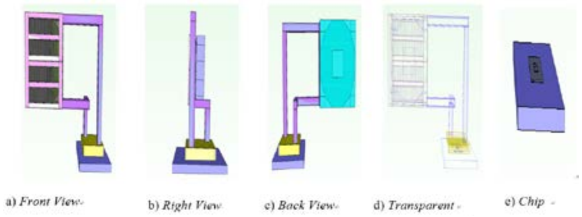

Figure 1. Construction of the proposed module (as viewed from different directions)

Table 1. Parameters of the chip heat sink.

	Plate fin	***Pin fin***
Size (mm)	60*60*9	60*60*9
Material	Aluminum	Aluminum
Base Thickness (mm)	3	3
Fin Height (mm)	6	6
Fin Width (mm)	1	1
Number of Internal Fins	10 / 12 / 15 /17	10 / 12 / 15 /17

The 3D model was divided into hexahedral meshes using FLOTHERM that uses the SIMPLEST algorithm to evaluate the coupled velocity and pressure field. The SIMPLEST algorithm is based on the semi-implicit method for pressure-linked equations.

Similar to heat management technologies, radiators can transfer heat from one location to another; the energy that is transferred from one system to another is called heat. When the temperature gradient changes, conduction occurs in a body or between two objects in physical contact; the heating body contains more heat energy. The heat dissipation problem through the chip and radiator is solved using equation 1.1 to understand the heat transfer of the entire chip and radiator.

$$Q = -kA\frac{dT}{dx} \qquad (1.1)$$

Convection can be defined as the heat transfer between the human body and the fluid in contact with it. If a hotter surface comes into contact with a cooler fluid, heat is first transferred by conduction to the molecules closest to the surface. The hot molecules then rise and are replaced by new molecules with cooler ambient temperatures. Equation 1.2 can be used to describe the heat transfer from a chip and aluminum or copper block, steam chamber, or aluminum or copper radiator to the surrounding air.

$$Q = hA(T_s - T_\infty) \qquad (1.2)$$

Where Q is the convective heat transfer and h is convective heat transfer coefficient. The heat transfer coefficient is affected by many other factors, including fluid composition and velocity. A is the surface area between the human body and fluid, TS is the temperature of the system, and T∞ is the ambient temperature.

Radiation is the heat transfer of electromagnetic waves or photons. It does not require a medium to transmit energy, and the energy transmitted by radiation moves at the speed of light.

$$\boldsymbol{Q = e\,\sigma^{(\Delta T)^4}} \qquad (1.3)$$

We can follow the theory of flow dynamics to obtain the field information that includes velocity, pressure, and temperature. The governing equations can be expressed using the Continuity Equation for the compressibility of the fluid in the Navier-Stokes equations for the momentum conservation and energy equations.

Furthermore, we have to solve these equations, which is challenging because of their nonlinearity.

Nonetheless, each equation will confine other equations because the solutions must match in all the governing equations simultaneously. By using the specialized flow simulation software, i.e., “FloTHERM,” the finite volume method to solve the numerical solution is applied; the space of the field is divided into several small elements, and the elements need to correspond to their surrounding elements because the original equations are not discrete.

Coupled Method is generally used to solve the equations. The coupled solver solves the governing equations of continuity, momentum, energy, and species transport simultaneously. The governing equations for additional scalars are solved sequentially using the procedure described for the segregated solver. Because the governing equations are non-linear, several iterations of the solution loop must be performed before a converged solution is obtained. These calculation steps are continued until the convergence criteria are met.

The algorithm proposed by Patankar (Patankar and Spalding, 1972) is currently the most comprehensive application method for calculating the numerical values of the streamline fields.

RESULTS ANALYSIS AND DISCUSSION

In this study, certain parameters that directly impact the final result are discussed. The thermal components are compared to determine the most influential factors for each thermal component’s condition. Finally, the conclusion inherent in these calculations to determine a better way is adjusted for the advice of readers. First, chip power is considered. Simulations with different power ratings in each thermal system are performed to determine which thermal component combinations can manage the additional heat energy because the conclusions indicate that more high-power chips are required to improve devices. The power is set to 15 W, 30 W, and 45 W as in actual products. Second, the heat sink is considered. There are two types of shapes based on references. Moreover, they are generally applied to different types of thermal modules. Aluminum is used for the heat sink because of its low price and low heat resistance. The thermal convection area can be increased, and consequently the flow releases more heat. However, in the practical case, there is a significant increase in the number of fins because the flow viscosity encases the trailing vortex, which is detrimental to the thermal release, as the air and heat are rotated in the same location. The number of fins is set at 10, 12, 15, and 17 as shown in Figures 2 and 3. Finally, the cooling pipe is considered. According to thermal theory, the closer the heat source is to the connecting point, the better; therefore, the pipe is fixed at three different locations from the heat source (Figure 4). Hence, distances of 1/3, 2/3, and 1 of the length of the diagonal of the heat sink are set, as shown in Figure 5.

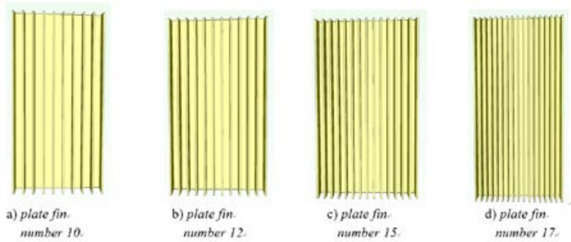

Figure 2. Flat-type heat sink feature

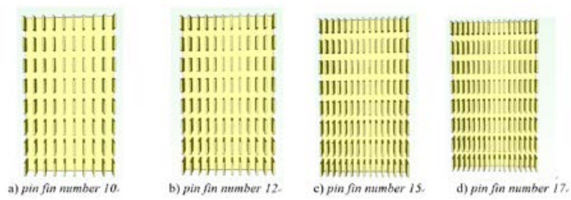

Figure 3. Square-type heat sink feature


Figure 4. Illustration of the cooling pipe fixation points

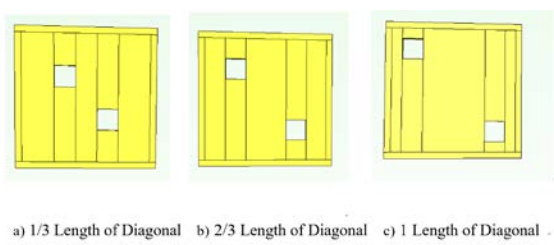

Figure 5. Lengths of the diagonal of the heat sink

Plate-type Heat Sink Simulation

The plate-type heat sink comprises panel fins of the same dimension, therefore the flow passes through them directly. Furthermore, the boundary layer effect is not significant because the boundary layer of the plate flow is the thinnest in thickness at the trailing edge. Following conclusions can be drawn from this simulation:

The heat sink inside the model is mounted on a chip package. The power dissipation from the chip package is set to 15 W. Four basic fin shapes are considered in this study, which aims to evaluate the possibility of improving the heat sink performance. Irrespective of the number of fins used in the thermal module, the same solution was obtained, indicating that the highest temperature of the chip was always 39.9 ℃ (Figure 6). This implies that the module was over-designed, and certain components were unnecessary.

At 30 W and under different fin number conditions, the difference in chip temperature between the lowest and the highest temperature was 2.5 ℃, and the gap between the fins was small; therefore, the boundary layer effect was significant, causing rapid removal of the heat by the flow (Figure 7). This implies that for higher-power chips, a more meticulous design of the number of fins is required because the chip power affects the fin number effect.

When the chip power was increased from 30 to 45 W, the fin numbers had different solutions. We determined that the best choice of fin number was 15, which had the most heat released under high-power conditions. At 45 W and under different fin number conditions, the range of the chip temperature was 4.3 ℃ (Figure 8). The heat transfer effects of the heat sink in electronic cooling applications can be modeled with reasonable accuracy using FloTHERM. This enables the thermal engineer to assess the potential benefit of introducing a heat sink in the design in a timely and cost-efficient manner. This includes feasibility studies in the early stages, as well as design optimization in the later, prototype design stage.

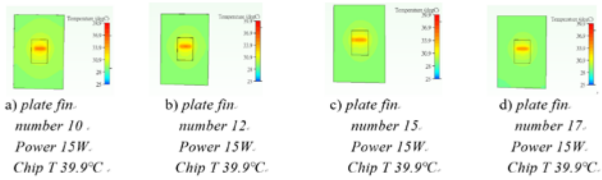

Figure 6. Plate fin with a power of 15 W at varying temperatures

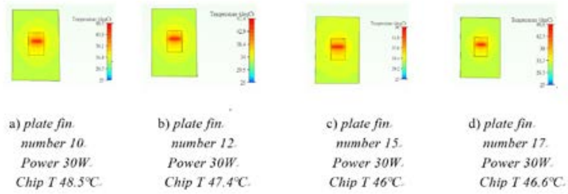

Figure 7. Plate fin with a power of 30 W at varying temperatures

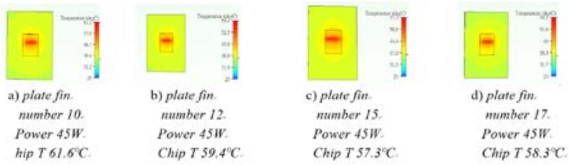

Figure 8. Plate fin with a power of 45 W at varying temperatures

Square-type (pin-type) Heat Sink Simulation

The square-type heat sink is more complex than the flat-type heat sink. The method employed in this heat is to divide the flat to obtain two-dimensional convection flow, which allows the flow to become more directed and improves the convection in some cases. Based on its benefits, the calculations of the numerical solutions are the same as those of the previous flat-type terms. The simulation results are as follows:It has similar features; this means that there is no difference in different fin thermal modules (Figure 9);

Similar to the flat-type heat sink, the chip power is varied from 30 W to ~ 45 W (Figures 10 and 11) and the effect of fin becomes more significant. The range difference from the highest to the lowest is approximately 3 – 4℃;

The 15-fin application is preferred, and its reliability can be confirmed again.

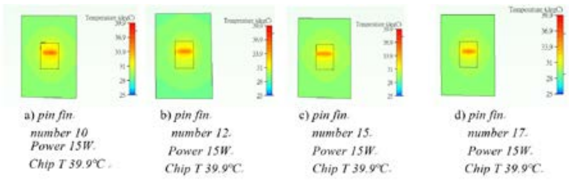

Figure 9. Pin fin with a power of 15 W at varying temperatures

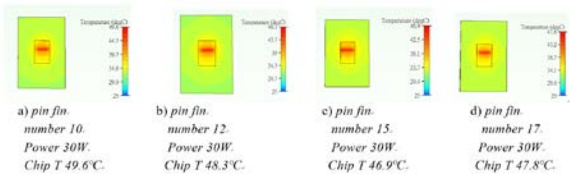

Figure 10. Pin fin with a power of 30 W at varying temperatures

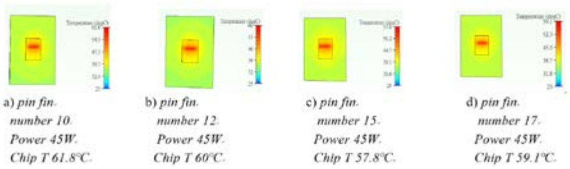

Figure 11. Pin fin with a power of 45 W at temperatures

Comparison of Heat Sink (Flat-type and Square-type)

The characteristics of the flat and square types are summed up as follows:

Under this thermal management system, when the chip power is less than 15 W, it is not important to select the type of heat sink. This module can be removed to avoid wastage of materials.

When the chip power is over 30 W, the thermal module can experience certain effects. Upon calculations, 15 fins are the recommended priority selection.

Following the power increase, a comparison between the flat-type and square-type heat sink shows that under the same 15- fin condition, the flat-type has better thermal performance than the square-type over 0.5℃.

Chip power temperature analysis

In the 45 W condition, the flat type heat sink has a minimum temperature of 57.3℃ by applying 15 fins. In contrast, the 10-fin has a maximum temperature of 61.6℃.

A similar trend is observed for the square type heat sink in the 45 W condition. It has a minimum temperature of 57.8℃ and maximum temperature of 61.8℃ under the 10-pin condition.

When the power is gradually increased, the effect of the fin number becomes increasingly important, which means that different fin numbers of the thermal management should be estimated, and the number of fins required in the system should finally be determined.

Discussion of the Cooling Pipe Location

From the previous discussion, it is observed the heat sink affects the entire system. Then, we analyze the effect of cooling pipe. According to the thermal dynamic flow theory, we found that the closer the connection of the thermal component to the heat source, the better is its performance. In accordance with the theory, we fixed the points at three distances from the heat source and attempted to prove that this thermal module conforms to the theory. The flow rates and pipe dimensions were identical, such that the only difference was the distance. Here, distances of 1/3, 2/3, and 1 of the length of the diagonal of the heat sink were used, as shown in Figure 5.

For the reader to understand the simulation results clearly, we summarized and tabulated the data. The results of the flat-type and square-type heat sink calculations are listed in Tables 2 and 3, respectively. Figure 12 shows the flat-type heat sink at different pipe fixing points. The discussion and analysis of these simulations are provided below.

The results are contrary to the theory; therefore, we are interested in determining the cause of this disparity. By comparing and checking the detailed flow fields, we conclude that this is caused by bad circulation. The pipe flow approaches the heat source; however, because the in-flow and out-flow pipes are placed close to each other, the flow rapidly passes by the heat source. Therefore, the heat transmission time is quite short.

As mentioned in the previous point, the flow requires enough distance for proper circulation of the heat flow such that the outer location has a better effect.

Table 2. Flat-type heat sink calculations

Flat-type heat sink at different pipe fixing points				
Chip Power	Fin number	1/3 length (℃)	2/3 length (℃)	1 length (℃)
15 W	10	39.9	39.1	39.9
	12	39.9	39.1	39.9
	15	39.9	39.1	39.9
	17	39.9	39.1	39.9
30 W	10	49.5	49.4	48.5
	12	51.7	51.4	47.4
	15	47.3	47.3	46
	17	48.1	47.6	46.6
45 W	10	64.2	61.6	61.6
	12	65.0	64.6	59.4
	15	58.4	58.4	57.3
	17	58.9	58.9	58.3

Table 3. Square-type heat sink calculations

Square-type heat sink at different pipe fixing points				
Chip Power	Fin number	1/3 length (℃)	2/3 length (℃)	1 length (℃)
15 W	10	39.9	39.1	39.9
	12	39.9	39.2	39.9
	15	39.9	39.1	39.9
	17	39.9	39.1	39.9
30 W	10	50.0	49.9	49.6
	12	51.9	51.8	48.3
	15	47.4	47.4	46.9
	17	48.0	47.9	47.8
45 W	10	64.9	62.2	61.8
	12	65.2	65.0	60.0
	15	58.2	58.6	57.8
	17	59.5	59.3	59.1

The pipe flow may not be useful in low-power conditions, as it always give same results with different conditions.

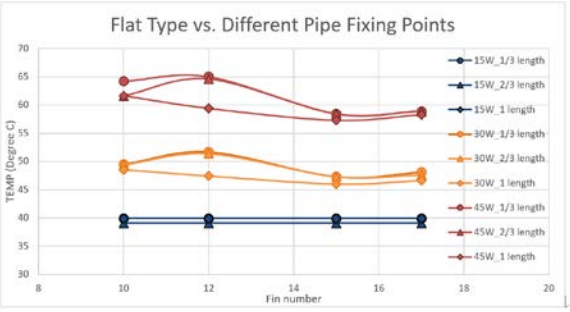

Figure 12. Flat-type heat sink at different pipe fixing points

CONCLUSION

In summary, the results of different conditions can be described as follows. The idea of designing a cooling pipe route and a heat sink is formed. This study focuses on the thermal control of heat sink and cooling pipe. The engineers can design their products' space more efficiently, and keep the cost low by determining the unnecessary materials or components. By following the procedures explained in this study, the chip manufacturers can use alternative methods to develop more high-power products to fulfill customer requests. This study applies the CFD software to simulate different types of thermal components with different conditions, including heat sink types, fin numbers, and cooling pipe fixing points. The conclusions of the study are as follows:

1. In general, the flat-type heat sink is better than the square-type heat sink.
2. Under high-power conditions, the fin number becomes more important.
3. Using 15 fins is recommended.
4. An outer cooling pipe is recommended to provide enough space for internal heat convection with the heat source.

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相異散熱鰭片排列散熱模組之熱傳效率模擬研究

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摘 要

本研究主要分析高功率電子元件的散熱效果，探討 FloTHERM 用於改善熱場的數值解。熱管理系統將解決電子芯片中的高功率問題。隨著芯片功率的增加，比較芯片功率，包括散熱器和冷流體循環系統在內的不同熱系統。將散熱器和冷流體循環系統集成在一起可評估每個組件的趨勢，並闡明熱系統機制的結果。本研究之散熱模組在其條件

下，可達到最佳冷卻效果，然而當瓦數上升時，散熱鰭片及水管位置不同會有明顯差異之結果，其最差與最佳之散熱參數條件可達 5 度差異。