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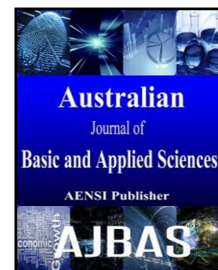

Thermal Analysis of Staggered Pin Fin Heat Sink for Central Processing Unit

[1]Khalil Azha Mohd Annuar, [1]Mohamad Firdaus Mohd Ab Halim, [2]Fatimah Sham Ismail, [1]Madiha Zahari, [3]Siti Halma Johari and [1]Mohamad Haniff Harun

[1]*Department of Electrical Engineering Technology, Faculty of Technology Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia*
[2]*Centre of Artificial Intelligence and Robotics, Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia*
[3]*Department of Electronic & Computer Engineering Technology, Faculty of Technology Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia*

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ABSTRACT

The advancement of microelectronics technology in producing high clock speed and power density's central processor unit (CPU) indirectly related to thermal management issue. This is a major challenge to the manufacturers, designers and researchers to find the optimum design of the cooling system. If the problem is not being tackled, it will become a major setback to the development of electronic components and devices in the next five to ten years. The most popular technique used in the electronic devices is a metal heat sink with high heat transfer rate. The choice and suitable for the optimal heat sink design are needed in order to control and increase the heat dissipation. In this paper, 3D simulation staggered pin fin heat sink is designed and analyzed using COMSOL Multiphysics software. The finding of this study then is used to propose an optimal staggered pin fin arrangement of heat sink design that could give better thermal performance.

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INTRODUCTION

In embedded design, the most difficult challenges to the semiconductor manufacturers are the demand to produce small package size, high speed and high power density CPU processor. There are many cooling techniques such as water cooling, heat pipes, liquid nitrogen and metal heat sink. The heat sink is one of the famous device that widely used as cooling technique in CPU processor unit due to its cost effective, simple and time consuming. The heat sink is a device that allows the transfer of heat away from the heat source (CPU). There are many designs in the market. But for the conventional heat sink model, it can be divided into two types, which are pin fin heat sink and plate fin heat sink.

There are many studies in the design of the heat sink model, especially in conventional arrangement plate fin and pin fin. A lot of questions by researchers and designers related to which type of heat sink that could give best in thermal performance. According to Kim *et al.* (2009), a comparison of the thermal performance between two types of heat sink which are the plate fin and pin fin through an experiment. Various flow rates and width dimension have been used to find the thermal resistance performance. From the result, it is shown that pin fin model with lower heat source power dissipation will provide small thermal resistance. The plate fin model will produce small thermal resistance when the heat source power dissipated is high compared to pin fin type model.

Many criteria need to be considered in choosing and designing the heat sink such as selection of the dimension parameter, material used and others. According to Chen *et al*. (2012) whom performed a simulation using Finite Element Method (FEM) and Genetic Algorithm (GA) optimization technique, the optimal value of the shape of the heat sink dimension for better heat dissipation can be found. The data then is used to develop using a direct adaptive control technique for the CPU heat sink. To provide an excellent performance, fan was used to control the performance of heat thermal in the optimum performance. However, this paper only discusses on the plate fin heat sink only with 2D

Corresponding Author: Khalil Azha Mohd Annuar, Department of Electrical Engineering Technology, Faculty of Technology Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia.
E-mail: khalilazha@utem.edu.my Ph: 06-2346593

simulation.

V.U. Patel and A.J. Modi (2012) study the heat transfer characteristics from fluid flow inside silicon based micro channel heat sink by using Computational Fluid Dynamic (CFD). This is a combination of conduction and convection heat transfer process by using water as a cooling fluid. This technique suitable for small component dimension and could gave optimal thermal problem solution when using micro channel heat sink model.

One of the most significant current discussions in power electronic system thermal management in three different types of heat sink which are extrusion fin, plain fin and cell fin. Lian-Tuu Yeh (2012) reported that by using CFD analysis to characterize each of the heat sink design. In recent years, several studies have focused on high power LED with different heat sink design. Fengze Hou *et al*. (2011) has demonstrated that thermal analysis of high power LED with in line pin fin heat sink. Different design in horizontal and vertical fin heat sink was studied by N. Teeba *et al*. (2011).

Zhou and Yang (2008) presented a radius mounted on sink model as personal computer sent mounts on the CPU of personal computer. The aim of this paper was to study on the aerodynamic shape of cooling fins, to find the best method will reduce flow resistance of the heat sink. Kondo *et al.* (2000) studied zonal approach in optimizing the thermal performance of two types of heat sink with fix pumping power and dimension size. From the result shown, the optimal plate fin heat sink will produce 40% lower thermal resistance compared to pin fin type model heat sink. Based on the results presented from many studies in different type (Kim *et al.*, 2009; Jonsson and Moshfegh, 2001; Zhou and Yang, 2008; Annuar *et al*. 2014; Kondo *et al.*, 2000), mostly they concluded that the thermal performance of the pin fin heat sink will be given a better performance compared to plate fin model. However, the selection of these two types of heat sink is still not obvious.

Therefore, many researchers have been conducted on the heat sink design has been executed in order to solve the thermal problem. There are many factors that affect the performance of the heat sink model design should be considered. The parameters are area, type of material used, airflow velocity and types of the heat sink shapes.

The aim of this study is to develop heat sink with the staggered arrangement of pin fin design by using COMSOL Multiphysics software package. The proposed heat sink models were tested on CPU Intel® Atom™ Processor N450. The simulation results, then proposed an optimal staggered pin fin that able to give better thermal performance compared to the conventional design. All the limitations values clearly are mentioned in this project.

Heat Transfer Equation:

The heat transfer is a part of dynamic process where heat or energy is transferred spontaneously from a hot area to the cool area. The rate of heat transfer is depending between two differences temperature areas. While the difference is increased, it will give high heat transfer rate. There are three types of heat transfer process, which are conduction, convection and radiation. In this study, COMSOL Multiphysics software is used to model the 3D heat sink model and simulation run under the heat transfer module.

Conduction is the process of heat energy transfers between the object that are in physical contact such as copper, aluminium and silver. The equation is described as equation (1).

$$\rho C_p \frac{\partial T}{\partial t} - \nabla.(k\nabla T) = Q \qquad (1)$$

Where ρ is density (kg/m3), *Cp* is the heat capacity (J/Kg°C), *k* is thermal coefficient of the material (W/mK) and *Q* is volume heat source (W/m3).

The second type of heat transfer is convection. Force convection type is the process to improve by adding external power such as airflow from the fan or blower in the heat sink. This technique of heat transfer (use airflow with heat sink) will allow high power processors to be cool in most of applications device. The equation for the air flow across the pin fin can be considered as follows:

$$n \cdot (k\nabla T) = q + h(T_{amb} - T) \qquad (2)$$

Where *n* is the normal vector of the heat flux, *h(Tamb-T)* as known Newton law of cooling, which is used to specify the heat flux cause by forced (airflow) or natural convection process, and *Tamb* is ambient temperature. In this simulation, conduction and convection heat transfer are considered. Any other electronic components radiation effects such as electromagnet heat dissipated by other components near the CPU unit are not considered.

3D Heat Sink Model:

This study proposes 3D simulation, heat sink model with staggered pin fin arrangement using COMSOL Multiphysics software. The proposed heat sink models were tested on CPU Intel® Atom™ Processor N450. The aluminium type of heat sink material is mounted on the top of the CPU processor chip. Various position pin fins of the heat sink are arranged in staggered.

More than 20 models were tested to measure their maximum temperature generation from the temperature profile using conjugate heat transfer modules. Some assumption has been made to minimize the difficulties of modelling such as air box channel dimension, the velocity of air inlet from

the blower fan, heat sink design such as base, pin dimension and total number of pin, power dissipated from the chip and chip dimension.

The operating condition and model parameter values for pin fin heat sink model are listed in Table 1. Figure 1 shows 3D staggered pin fin heat sink model.

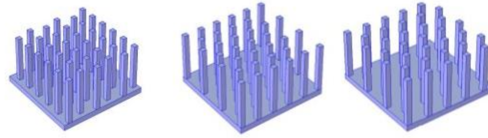

Fig. 1: Example heat sink with staggered pin fin arrangement.

Table 1: Operation Condition and Model Parameter Values for Staggered Pin Fin Heat Sink Model.

Parameter		Values
Air box Channel	Length	6 cm
	Width	5 cm
	Height	2 cm
CPU	Length	2.2 cm
	Height	0.1 cm
	Power dissipated	5.5 W
Pin fin	Height	1.7 cm
	Diameter	0.2 cm
	Number of pin	36
Heat sink base	Base thickness	0.2 cm
	Diameter	4 cm
Air flow inlet	Inlet velocity	10 cm/s
	Inlet temperature	20 °C
Material		Aluminium

a) Geometry of Heat Sink:

Geometrical pin fin of the heat sink model is drawn using COMSOL Multiphysics software. Another alternative way, it is also can be drawn and imported from another software tools such as CAD, Solid Works and others similar type software (.mphbin file).

Figure 2 shows that the heat sink model can be divided into two parts, which is the heat sink base and square pin fins. The heat sink base dimension is fixed to the width, depth and height. The total number of square pin fin selected in this simulation is 36 fins with various staggered positions on the heat sink base.

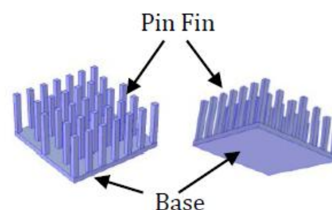

Fig. 2: Example of heat sink geometry.

b) Model Building:

The heat sink is modelled by finite element method using the software package COMSOL Multiphysics under conjugate heat transfer interface module. This module provides a necessary tool to do the analysis the heat sink model under conduction and convection heat transfer. All other properties and parameter related are set by the user as shown in table 1.

The aluminium pin fin heat sink model is placed inside air box channel of a rectangular shape as shown in Figure 3. Airflow position is horizontal to heat sink model plane. It is entering or inlet from one side of the channel and flows out at the other side. The base of the heat sink surface is attached to the heat source with 5.5 watts thermal power dissipated by chip.

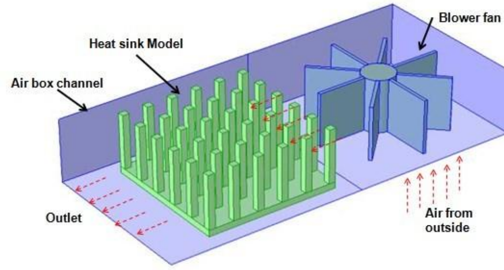

Fig. 3: Actual process for experimental setup with blower.

c) Staggered Arrangement of Pin Fin:

There are about 25 models with a different position or design in staggered arrangement of pin fin heat sink model were tested. Selected four (out of 25 models) staggered position pin fin of heat sink model are shown in Figure 4.

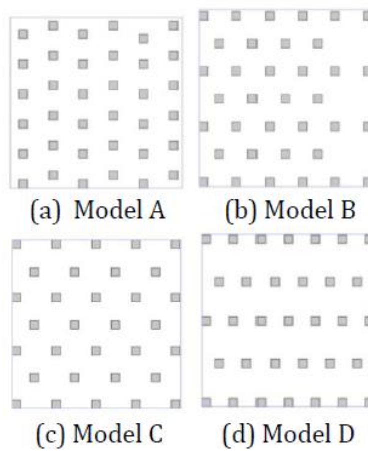

Fig. 4: Example staggered pin fin arrangement design.

Simulation Result & Discussion:

The simulation is done using COMSOL Multiphysics under Conjugate Heat Transfer Interface on a desktop computer equipped with 12 GB RAM and Intel i3-2120 3.30 GHz processor. The best thermal performance produced for this model is 88.83°C shown as Figure 5(b). Figure 6 shows the bottom view temperature distribution for chip processor.

From the result we can observe that different arrangement of pin fin mounted on the base heat sink will give a different thermal performance temperature even though total amount area and volume of each model are similar. These results show that good heat thermal performances depend on the geometry and position of the pin fin in order to create smooth air flowing on the surface of the pin fins heat sink.

Most of the staggered design will create turbulence airflow around the pin fin on the base heat sink. It can be seen in figure 7 (c), which can increase heat dissipated far away from the heat sink. However, for figure 7 (a) turbulence flow has increased the heat around the pin.

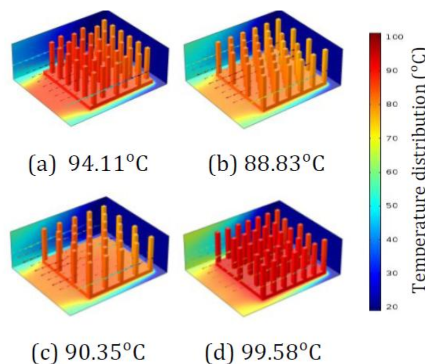

Fig. 5: Example 3D view model staggered pin fin heat sink with highest thermal performance result

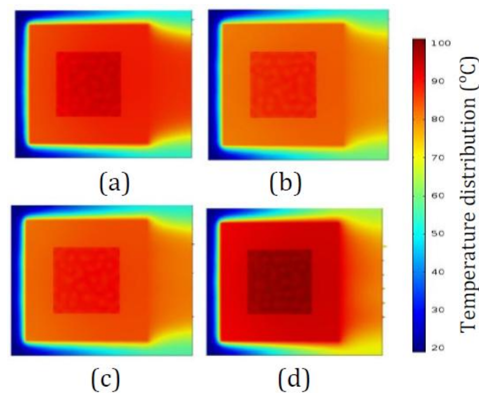

Fig. 6: Bottom view plot of temperature on chip and base of heat sink.

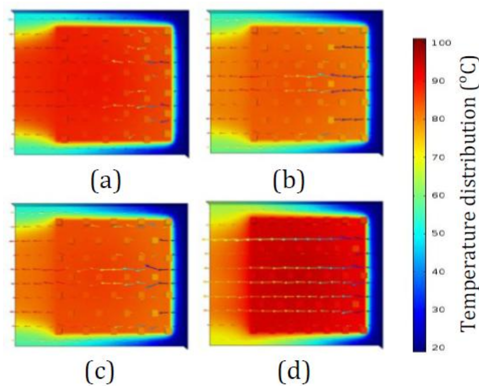

Fig. 7: Top view plot of temperature and airflow.

Conclusions:

This paper has presented thermal performance of various staggered pin fin heat sink design for the CPU processor. The heat transfer phenomena of the various staggered pin fin arrangements are investigated using COMSOL Multiphysics software. Based on the 3D simulation result thermal profile, we can analysed the output thermal performance of the heat sink. Simulation results showed that different design or position of pin fin arrangement will give different heat distribution. Model B design, staggered pin fin heat sink will give better performance which is 88.83°C. The result states that the importance of choosing the suitable arrangement of pin fin as it gives better thermal performance for the CPU processor. Also by knowing the best performance pin fin heat sink will be increase and maintain the performance of the component. For future work can be use by using population based evolutionary algorithm optimization method in finding an optimal arrangement of pin fin.

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