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Optimal Pin Fin Heat sink Arrangement for Solving Thermal Distribution Problem

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Abstract – *Due to the advanced development in semiconductor technology, the size of electronic component and devices become smaller while the performance becomes significantly greater. The increased of power density in the system causes the system components to either operate at higher temperature which led to thermal problem. This thermal problem will reduce the performance and efficiency of the electronics package. The most popular device used for electronic cooling is heat sink. In order to improve the heat transfer process, various type of heat sink with different shapes, materials and dimensions have been designed. This study aims to provide the optimal heat transfer of heat sink to minimize electronic package thermal distribution. This study only focuses on circular and square types of pin fin heat sink with various arrangements. In this study, COMSOL Multiphysics software will be used to simulate various pin fins arrangement design of the heat sink model. The results have proposed a new arrangement of the pin fin that able to give better thermal performances which are 4.1% and 0.5% for circular type and 0.2% and 0.4% for square type compared to inline and staggered arrangement.*

Keywords: Heat sink, Thermal analysis, Heat transfer, Optimization

1.0 INTRODUCTION

Nowadays, the demand of using electronic devices such as computers, laptops and others are very high. Recent advances in semiconductor technology have given rise to a size-reduced, high-tech device with an ever-greater system performance [1]. This tendency of development inevitably leads to the significant increase in power densities encountered in microelectronics equipment. It is also increased the heat generation rate per volume of the device. If the heat generation not appropriately removed, it would affect the normal operation of the device that will leads to device malfunctioning and the device lifetime can be substantially reduced or might be severely damaged.

The result of studies for major causes of electronic failure made by electronic company (AI Technology Inc). It shows that there are four major causes which are dust, humidity, vibration and temperature. The least factor that contribute the cause of electronic failure is dust (6%) followed by humidity (19%) and vibration (20%) meanwhile the major cause of electronic failure is temperature (55%). It can be conclude that poor thermal management leads to more than 50% of electronic failures. Thus it is essential to improve the transfer and dissipated heat generated from electronic devices.

There are many cooling technique that have been used in order to reduce thermal problem from electronic devices. Some of the cooling technique that has been used are heat pipes [2,3], water cooling, nitrogen liquid and heat sink. Yongling et al. [4] used heat pipe technology into the design of the hydraulic motor pump to solve the heat dissipation problem. Heat pipes technique is very efficient when transfer heat in large scale. However, it is not suitable to use for small electronic devices because of space constraint. Anbin et al. [5] used liquid nitrogen test system for cooling high temperature superconductive (HTS) synchronous motor. However, liquid nitrogen has never been used as cooling technique for electronic devices and the cost of liquid nitrogen is very expensive.

Heat sink is commonly used as cooling technique for electronic devices. Heat sink is the most simplest and effective way to dissipate the generated heat of a device compared to other techniques. Heat sink is a device that allows the transfer of heat away from the heat source. There are several types of heat sink but only two that are commonly that widely used in the industry which is pin fin heat sink and plate fin heat sink. Besides that, there are lot of criteria that need to be considered in choosing the optimal heat sink such as selection of type of heat sink, material used, the heat sink dimension parameter and others.

According to the previous researchers, the common heat sinks that have been used are pin fin heat sink and plate fin heat sink. Between this two types of heat sink, the pin fin heat sink give more heat transfer than plate fin heat sink. The common arrangements of pin fin heat sinks that have being used are inline and staggered.

Some researchers have been conducted for enhancing the thermal performance or characteristics of heat sinks. Andrea and Stefano used optimal configuration for natural convection in finned plated [6]. The study expressed the simplified relation of the fins heat exchange to determine the optimum value of fins spacing, which can increased the heat flux densities by 20. But the method only applied on the plate heat sink by using convection and radiation types of heat transfer.

The study of zonal approach in optimizing the thermal performance of two types of heat sink with fix dimension size and pumping power by Kondo et al. [7] show that the optimal plate fin heat sink will produce 40% lower thermal resistance compared to pin fin heat sink. Based on many studies that compared the performance of plate fin and pin fin heat sink, most of the result state that pin fin heat sink give better thermal performance compare to plate fin heat sink.

Kim et al. [8], experimentally compared the thermal performance of two types of heat sink which are plate fin and pin fin heat sink. This study used various flow rate and width dimension to find the thermal resistance performance. The result shown that pin fin model with lower heat source power dissipated will provide small thermal resistance while the plate fin model will produce small thermal resistance when heat source power dissipated is high. Other research on performance of different type of heat sink is by Nawaf Hamadneh et al. [10]. These researchers studied the effect of governing parameters on thermal performance with different pin fin geometries using PSO.

There are many different approaches for the optimization of heat sink designs and various methods have been employed for optimizing the heat transfer in the heat sink. Shih and Liu

[11] proposed a formal systematic optimization process to plate fins heat sink design for dissipating the maximum heat generation from electronic component by applying the entropy generation rate to obtain highest heat transfer efficiency. Chen et al. [12] demonstrated by using Finite Element Method (FEM) and Genetic Algorithm (GA) optimization technique can be used to find an optimal value of the heat sink shape and dimension for better heat dissipation. Zhang and Liu [13] performed a study of in line shape and structure to achieve maximal performance of heat transfer for basic plate heat sink. This research was done through theoretical analysis and numerical solution only.

According to Zainolarifin et al [14], a single and multi-objective evolutionary algorithm can be used for solving thermal problem on heat sink design. The objective of this research is to find plate fin heat sink shapes which maximize the heat dissipation. The result obtain the suitable dimension will increase the heat dissipation with area percentage is about 27.15%.

Mohan and Govindarajan [15] used Computational Fluid Dynamics (CFD) to identify a cooling solution for a CPU. This research only considers the optimal plate fin heat sink design and cylindrical fin heat sink design. Patel & Modi [16] also using CFD method to study fluid flow and heat transfer characteristics in silicon-based micro channel heat sink. Combination of conduction and convection heat transfer process by using water as a cooling fluid. From this research, this technique gives optimal thermal solution and suitable for small component dimension.

In the present work, David and Ivan [17] have performed heat sink optimizations using Particle Swarm Optimization (PSO) and Genetic Algorithm (GA) method. Results from PSO method were compared with GA method. For this paper, two different types of straight fin heat sinks were used which were smooth surface fins and scale-roughened surface fins. In terms of heat sink thermal resistance, both optimization methods deliver equivalent optimized heat sinks designs. But a PSO method provides solutions significantly more quickly than GA method which is several minutes compared to around an hour for GA method. Hanafi and Ismail [18] study the used of heat transfer model and PSO for heat sink design. For optimization, the thickness and the length of fins for plate fin heat sink are considered to maximize heat dissipation of optimal heat sink design.

Therefore, this project will introduce the new arrangement of pin fin heat sink with different geometry. This project is expected to develop a simple and effective arrangement of pin fin heat sink for optimal heat transfer of heat sink design to minimize electronic package thermal distribution.

2.0 MODEL DEVELOPMENT

2.1 Model Building in COMSOL Multiphysics Software

Heat sink is modeled using COMSOL multiphysics software under conjugate heat transfer interface module using finite element method. This module provides a necessary tool to do analysis of heat sink model under conduction and convection heat transfer.

All parameter and properties such as dimension, material used, airflow inlet, number of pin fin and others are setting by the user. The simulation of pin fin heat sink model is run under the operating condition and physical properties parameter listed in the Table 1 [19]. The aluminium pin fin heat sink model is placed inside the air box channel of rectangular shape. Airflow position is horizontal of the heat sink model plane. The air flow from one side of the channel and flow out at the opposite side. The heat source with thermal power dissipated by chip is placed at the bottom of the base of heat sink surface. The heat sink model with the air box channel is shown in the Figure 1.

Table 1: Operation condition and model parameter for pin fin heat sink

Parameter		Values	Description
Airbox channel	L_channel	6cm	Channel length
	W_channel	5cm	Channel width
	H_channel	2cm	Channel height
Chip (heat source)	L_chip	2.2cm	Chip size
	H_chip	0.1cm	Chip height
	P_tot	5.5W	Total power dissipated by electronic package
Pin fin	L1	1.5cm	Pin height
	L2	0.2cm	Pin length/diameter
	Number of pin	36	Inline, staggered or random arrangement
Heat sink base	H_size	0.2cm	Base height
	L_size	4cm	Base length (square)
Air flow inlet	U0	10cm/s	Mean inlet velocity
	T0	20°C	Inlet temperature
Material		Aluminium	

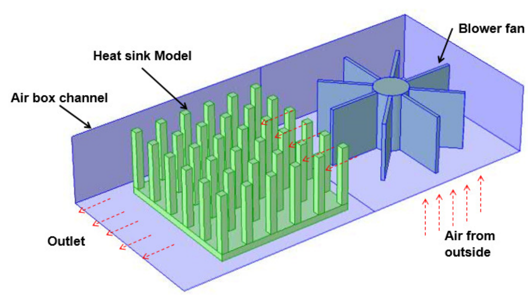


Figure 1: Simulation design set up

2.2 Pin Fin Heat Sink Arrangement Method

The proposed method for two types of pin fin heat sink; square type and circular type are arranged in inline and staggered. Each of the models is designed using COMSOL multiphysics software. The thermal profile of each model will be examined. For both type of pin fin heat sink, the pin fin will be rearranged manually in inline and staggered until the maximum temperature of the model is the lowest.

After the best thermal performance of both type of pin fin heat sink for inline and staggered arrangement is proposed, the new model of circular and square type of pin fin heat sink for random arrangement is tested. The thermal profile of each model for random arrangement will be examined. Both type of pin fin heat sink will be rearranged randomly and manually until the maximum temperature is lower than the best thermal performance of both type of pin fin heat sink for inline and staggered arrangement. Figure 2 shows the flow chart of the approach used.

This simulation will focuses on two shapes of pin fin heat sink, which are circular and square type. The geometrical pin fin of heat sink model will be drawing using COMSOL multiphysics software. The total number of pin fin is fixed to 36 fins. All 36 fins where placed on the heat sink base. The arrangement of pin fin of the heat sink are in inline, staggered and random for both shape of pin fin heat sink. There are three type of arrangement for pin fin on the base of heat sink which is inline, staggered and random arrangement.

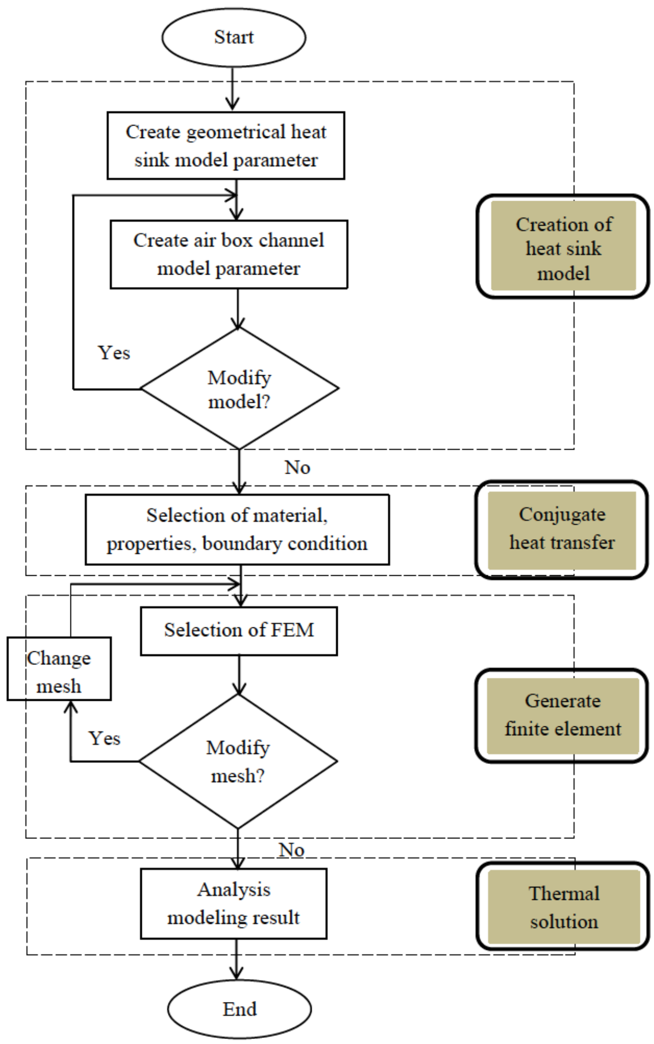
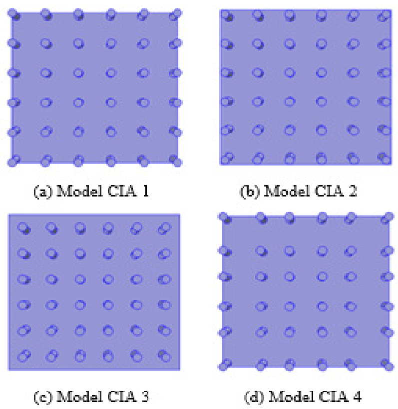


Figure 2: Modelling approach

2.1.1 Circular Type Pin Fin Heat Sink

Circular inline arrangement (CIA) of pin fin heat sink models where all pin fin is arrange uniformly with different distance between the pin fins for each models. Figure 3 shows the top view of the CIA pin fin heat sink model. Table 2 shows the CIA arrangement for pin fin heat sink model.



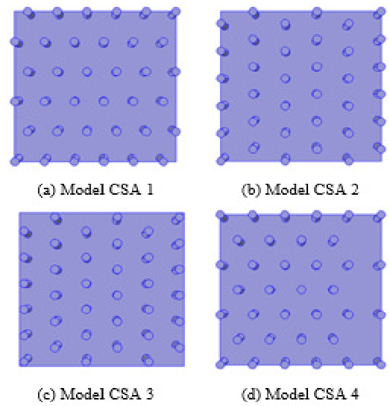


Figure 3: Top view of CIA pin fin model

Figure 4: Top view of CSA pin fin model

The circular staggered arrangement (CSA) of pin fin heat sink models where all pin fins are arranged with irregular arrangement for staggered arrangement with different distance between the pin fins for each model. Figure 4 shows the top view of the CSA pin fin heat sink models. Table 3 shows the CSA set up for pin fin heat sink model.

For the new best thermal performance, the circular random arrangements (CRA) of heat sink models are shown in Fig. 5. Table 4 shows the CRA set up for pin fin heat sink model.

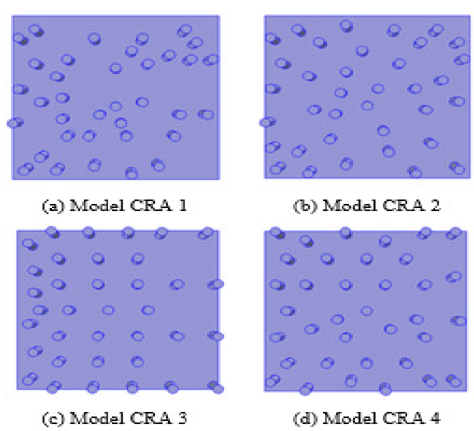


Figure 5: Top view of CRA pin fin models

Table 2: CIA set up for pin fin model

	Model Circular Inline Arrangement 1		Model Circular Inline Arrangement 2		Model Circular Inline Arrangement 3		Model Circular Inline Arrangement 4	
	x(cm)	y(cm)	x(cm)	y(cm)	x(cm)	y(cm)	x(cm)	y(cm)
Pin 1	0.1	0.1	0.2	0.2	0.4	0.4	0.1	0.1
Pin 2	0.1	0.86	0.2	0.92	0.4	0.64	0.1	0.96
Pin 3	0.1	1.62	0.2	1.64	0.4	1.68	0.1	1.62
Pin 4	0.1	2.38	0.2	2.36	0.4	2.32	0.1	2.38
Pin 5	0.1	3.14	0.2	3.08	0.4	2.96	0.1	3.04
Pin 6	0.1	3.9	0.2	3.8	0.4	3.6	0.1	3.9
Pin 7	0.86	0.1	0.92	0.2	0.64	0.4	0.96	0.1
Pin 8	0.86	0.86	0.92	0.92	0.64	0.64	0.96	0.96
Pin 9	0.86	1.62	0.92	1.64	0.64	1.68	0.96	1.62
Pin 10	0.86	2.38	0.92	2.36	0.64	2.32	0.96	2.38
Pin 11	0.86	3.14	0.92	3.08	0.64	2.96	0.96	3.04
Pin 12	0.86	3.9	0.92	3.8	0.64	3.6	0.96	3.9
Pin 13	1.62	0.1	1.64	0.2	1.68	0.4	1.62	0.1
Pin 14	1.62	0.86	1.64	0.92	1.68	0.64	1.62	0.96
Pin 15	1.62	1.62	1.64	1.64	1.68	1.68	1.62	1.62
Pin 16	1.62	2.38	1.64	2.36	1.68	2.32	1.62	2.38
Pin 17	1.62	3.14	1.64	3.08	1.68	2.96	1.62	3.04
Pin 18	1.62	3.9	1.64	3.8	1.68	3.6	1.62	3.9
Pin 19	2.38	0.1	2.36	0.2	2.32	0.4	2.38	0.1
Pin 20	2.38	0.86	2.36	0.92	2.32	0.64	2.38	0.96
Pin 21	2.38	1.62	2.36	1.64	2.32	1.68	2.38	1.62
Pin 22	2.38	2.38	2.36	2.36	2.32	2.32	2.38	2.38
Pin 23	2.38	3.14	2.36	3.08	2.32	2.96	2.38	3.04
Pin 24	2.38	3.9	2.36	3.8	2.32	3.6	2.38	3.9
Pin 25	3.14	0.1	3.08	0.2	2.96	0.4	3.04	0.1
Pin 26	3.14	0.86	3.08	0.92	2.96	0.64	3.04	0.96
Pin 27	3.14	1.62	3.08	1.64	2.96	1.68	3.04	1.62
Pin 28	3.14	2.38	3.08	2.36	2.96	2.32	3.04	2.38
Pin 29	3.14	3.14	3.08	3.08	2.96	2.96	3.04	3.04
Pin 30	3.14	3.9	3.08	3.8	2.96	3.6	3.04	3.9
Pin 31	3.9	0.1	3.8	0.2	3.6	0.4	3.9	0.1
Pin 32	3.9	0.86	3.8	0.92	3.6	0.64	3.9	0.96
Pin 33	3.9	1.62	3.8	1.64	3.6	1.68	3.9	1.62
Pin 34	3.9	2.38	3.8	2.36	3.6	2.32	3.9	2.38
Pin 35	3.9	3.14	3.8	3.08	3.6	2.96	3.9	3.04
Pin 36	3.9	3.9	3.8	3.8	3.6	3.6	3.9	3.9

Table 3: CSA set up for pin fin heat model

	Model Circular Staggered Arrangement 1		Model Circular Staggered Arrangement 2		Model Circular Staggered Arrangement 3		Model Circular Staggered Arrangement 4	
	x(cm)	y(cm)	x(cm)	y(cm)	x(cm)	y(cm)	x(cm)	y(cm)
Pin 1	0.1	0.1	0.1	0.1	0.2	0.2	0.1	0.1
Pin 2	0.1	1.62	0.1	0.8	0.2	0.65	0.1	1.366
Pin 3	0.1	3.14	0.1	1.5	0.2	1.5	0.1	2.632
Pin 4	0.4	0.86	0.1	2.2	0.2	2.15	0.1	3.898
Pin 5	0.4	2.38	0.1	2.9	0.2	2.8	0.5	0.733
Pin 6	0.4	3.9	0.1	3.6	0.2	3.45	0.5	1.999
Pin 7	0.8	0.1	0.86	0.4	0.92	0.55	0.5	3.265
Pin 8	0.8	1.62	0.86	1.1	0.92	1.0	0.86	0.1
Pin 9	0.8	3.14	0.86	1.8	0.92	1.85	0.86	1.366
Pin 10	1.1	0.86	0.86	2.5	0.92	2.5	0.86	2.632
Pin 11	1.1	2.38	0.86	3.2	0.92	3.15	0.86	3.898
Pin 12	1.1	3.9	0.86	3.9	0.92	3.8	1.26	0.733
Pin 13	1.5	0.1	1.62	0.1	1.64	0.2	1.26	1.999
Pin 14	1.5	1.62	1.62	0.8	1.64	0.65	1.26	3.265
Pin 15	1.5	3.14	1.62	1.5	1.64	1.5	1.62	0.1
Pin 16	1.8	0.86	1.62	2.2	1.64	2.15	1.62	1.366
Pin 17	1.8	2.38	1.62	2.9	1.64	2.8	1.62	2.632
Pin 18	1.8	3.9	1.62	3.6	1.64	3.45	1.62	3.898
Pin 19	2.2	0.1	2.38	0.4	2.36	0.55	2.02	0.733
Pin 20	2.2	1.62	2.38	1.1	2.36	1.0	2.02	1.999
Pin 21	2.2	3.14	2.38	1.8	2.36	1.85	2.02	3.265
Pin 22	2.5	0.86	2.38	2.5	2.36	2.5	2.38	0.1
Pin 23	2.5	2.38	2.38	3.2	2.36	3.15	2.38	1.366
Pin 24	2.5	3.9	2.38	3.9	2.36	3.8	2.38	2.632
Pin 25	2.9	0.1	3.14	0.1	3.08	0.2	2.38	3.898
Pin 26	2.9	1.62	3.14	0.8	3.08	0.65	2.78	0.733
Pin 27	2.9	3.14	3.14	1.5	3.08	1.5	2.78	1.999
Pin 28	3.2	0.86	3.14	2.2	3.08	2.15	2.78	3.265
Pin 29	3.2	2.38	3.14	2.9	3.08	2.8	3.14	0.1
Pin 30	3.2	3.9	3.14	3.6	3.08	3.45	3.14	1.366
Pin 31	3.6	0.1	3.9	0.4	3.8	0.55	3.14	2.632
Pin 32	3.6	1.62	3.9	1.1	3.8	1.0	3.14	3.898
Pin 33	3.6	3.14	3.9	1.8	3.8	1.85	3.9	0.1
Pin 34	3.9	0.86	3.9	2.5	3.8	2.5	3.9	1.366
Pin 35	3.9	2.38	3.9	3.2	3.8	3.15	3.9	2.632
Pin 36	3.9	3.9	3.9	3.9	3.8	3.8	3.9	3.898

2.1.2 Square Type Pin Fin Heat Sink

Square inline arrangement (SIA) of pin fin heat sink models where all pin fin is arrange uniformly with different distance between the pin fins for each model. Figure 5 shows the top view of SIA of pin fin heat sink models. Table 5 shows the SIA set up for pin fin heat sink model. The square staggered arrangement (SSA) of pin fin heat sink models are shown in Fig. 7. All pin fins is arrange with irregular arrangement for staggered arrangement with different distance between the pin fins for each model. Table 6 shows the SSA set up for pin fin heat sink model.

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Table 4: CRA set up for pin fin model

	Model Circular Random Arrangement 1		Model Circular Random Arrangement 2		Model Circular Random Arrangement 3		Model Circular Random Arrangement 4	
	x(cm)	y(cm)	x(cm)	y(cm)	x(cm)	y(cm)	x(cm)	y(cm)
Pin 1	0.1	1.4	0.1	1.4	0.3	0.3	0.2	0.3
Pin 2	0.2	2.2	0.2	0.8	0.4	0.98	0.3	1.366
Pin 3	0.2	3.4	0.2	2.2	0.3	1.66	0.3	2.632
Pin 4	0.3	0.3	0.2	3.4	0.5	1.99	0.3	3.898
Pin 5	0.5	3.6	0.3	0.3	0.4	2.42	0.5	0.733
Pin 6	0.6	0.6	0.4	2.8	0.4	2.95	0.5	1.999
Pin 7	0.6	1.9	0.7	0.7	0.3	3.6	0.5	3.265
Pin 8	0.6	2.8	0.7	3.6	0.76	0.1	0.86	0.1
Pin 9	0.9	0.3	0.9	0.2	0.86	0.73	0.96	1.566
Pin 10	0.9	2.5	0.9	2.5	0.86	1.36	0.86	2.632
Pin 11	1.0	1.5	1.0	1.7	1.06	1.99	0.86	3.698
Pin 12	1.0	2.0	1.1	3.3	0.86	2.62	1.26	0.733
Pin 13	1.1	1.1	1.3	1.0	0.86	3.25	1.46	1.799
Pin 14	1.1	2.9	1.4	1.6	0.74	3.9	1.26	3.265
Pin 15	1.5	1.1	1.5	2.1	1.52	0.1	1.72	0.3
Pin 16	1.6	0.4	1.6	0.4	1.62	0.73	1.62	1.366
Pin 17	1.6	3.4	1.6	2.6	1.62	1.36	1.62	2.632
Pin 18	1.7	1.6	1.6	3.7	1.82	1.99	1.62	3.898
Pin 19	2.0	1.8	1.9	3.1	1.62	2.62	2.02	0.733
Pin 20	2.0	2.7	2.0	1.8	1.62	3.25	2.02	1.999
Pin 21	2.1	1.4	2.2	2.2	1.44	3.89	2.02	3.265
Pin 22	2.2	1.1	2.3	1.2	2.28	0.1	2.38	0.1
Pin 23	2.3	0.2	2.4	0.7	2.38	0.73	2.48	1.566
Pin 24	2.3	2.8	2.5	3.6	2.38	1.36	2.38	2.632
Pin 25	2.3	3.0	2.6	2.8	2.58	1.99	2.38	3.698
Pin 26	2.5	1.8	2.9	0.2	2.38	2.62	2.78	0.733
Pin 27	2.5	3.4	2.9	2.2	2.38	3.25	2.98	1.799
Pin 28	2.8	0.4	3.0	3.3	2.2	3.89	2.78	3.265
Pin 29	3.0	3.0	3.1	1.7	3.04	0.1	3.24	0.3
Pin 30	3.1	1.1	3.2	0.9	3.14	1.36	3.14	1.366
Pin 31	3.2	1.6	3.3	3.6	3.14	2.62	3.14	2.632
Pin 32	3.3	3.6	3.4	2.4	2.84	3.88	3.14	3.898
Pin 33	3.4	2.9	3.7	0.3	3.9	0.1	3.7	0.3
Pin 34	3.5	3.3	3.7	1.9	3.9	1.36	3.8	1.766
Pin 35	3.7	1.6	3.7	3.3	3.9	2.62	3.7	2.832
Pin 36	3.8	2.9	3.8	2.9	3.7	3.88	3.7	3.898

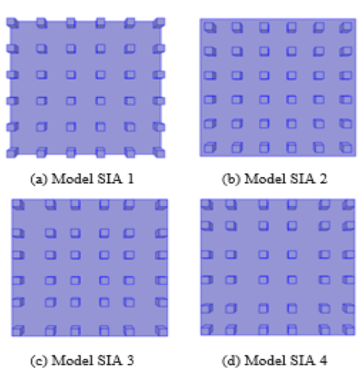

Figure 6: Top view of SIA pin fin model

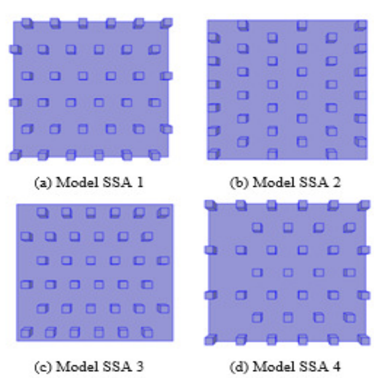

Figure 7: Top view of SSA pin fin model

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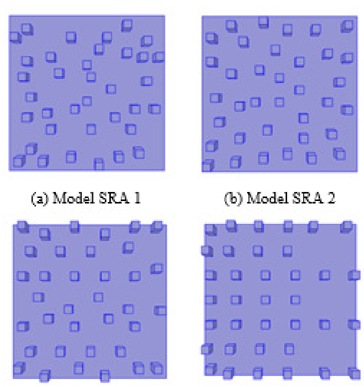
Table 5: SIA set up for pin fin model

	Model Square Inline Arrangement 1		Model Square Inline Arrangement 2		Model Square Inline Arrangement 3		Model Square Inline Arrangement 4	
	x(cm)	y(cm)	x(cm)	y(cm)	x(cm)	y(cm)	x(cm)	y(cm)
Pin 1	0.1	0.1	0.3	0.3	0.2	0.2	0.2	0.2
Pin 2	0.1	0.86	0.3	0.98	0.2	1.02	0.2	0.82
Pin 3	0.1	1.62	0.3	1.66	0.2	1.64	0.2	1.64
Pin 4	0.1	2.38	0.3	2.34	0.2	2.36	0.2	2.36
Pin 5	0.1	3.14	0.3	3.02	0.2	2.98	0.2	3.18
Pin 6	0.1	3.9	0.3	3.7	0.2	3.8	0.2	3.8
Pin 7	0.86	0.1	0.98	0.3	1.02	0.2	0.82	0.2
Pin 8	0.86	0.86	0.98	0.98	1.02	1.02	0.82	0.82
Pin 9	0.86	1.62	0.98	1.66	1.02	1.64	0.82	1.64
Pin 10	0.86	2.38	0.98	2.34	1.02	2.36	0.82	2.36
Pin 11	0.86	3.14	0.98	3.02	1.02	2.98	0.82	3.18
Pin 12	0.86	3.9	0.98	3.7	1.02	3.8	0.82	3.8
Pin 13	1.62	0.1	1.66	0.3	1.64	0.2	1.64	0.2
Pin 14	1.62	0.86	1.66	0.98	1.64	1.02	1.64	0.82
Pin 15	1.62	1.62	1.66	1.66	1.64	1.64	1.64	1.64
Pin 16	1.62	2.38	1.66	2.34	1.64	2.36	1.64	2.36
Pin 17	1.62	3.14	1.66	3.02	1.64	2.98	1.64	3.18
Pin 18	1.62	3.9	1.66	3.7	1.64	3.8	1.64	3.8
Pin 19	2.38	0.1	2.34	0.3	2.36	0.2	2.36	0.2
Pin 20	2.38	0.86	2.34	0.98	2.36	1.02	2.36	0.82
Pin 21	2.38	1.62	2.34	1.66	2.36	1.64	2.36	1.64
Pin 22	2.38	2.38	2.34	2.34	2.36	2.36	2.36	2.36
Pin 23	2.38	3.14	2.34	3.02	2.36	2.98	2.36	3.18
Pin 24	2.38	3.9	2.34	3.7	2.36	3.8	2.36	3.8
Pin 25	3.14	0.1	3.02	0.3	2.98	0.2	3.18	0.2
Pin 26	3.14	0.86	3.02	0.98	2.98	1.02	3.18	0.82
Pin 27	3.14	1.62	3.02	1.66	2.98	1.64	3.18	1.64
Pin 28	3.14	2.38	3.02	2.34	2.98	2.36	3.18	2.36
Pin 29	3.14	3.14	3.02	3.02	2.98	2.98	3.18	3.18
Pin 30	3.14	3.9	3.02	3.7	2.98	3.8	3.18	3.8
Pin 31	3.9	0.1	3.7	0.3	3.8	0.2	3.8	0.2
Pin 32	3.9	0.86	3.7	0.98	3.8	1.02	3.8	0.82
Pin 33	3.9	1.62	3.7	1.66	3.8	1.64	3.8	1.64
Pin 34	3.9	2.38	3.7	2.34	3.8	2.36	3.8	2.36
Pin 35	3.9	3.14	3.7	3.02	3.8	2.98	3.8	3.18
Pin 36	3.9	3.9	3.7	3.7	3.8	3.8	3.8	3.8

Table 6: SSA set up for pin fin model

	Model Square Staggered Arrangement 1		Model Square Staggered Arrangement 2		Model Square Staggered Arrangement 3		Model Square Staggered Arrangement 4	
	x(cm)	y(cm)	x(cm)	y(cm)	x(cm)	y(cm)	x(cm)	y(cm)
Pin 1	0.1	0.1	0.2	0.2	0.3	0.3	0.1	0.1
Pin 2	0.1	1.62	0.2	0.65	0.3	1.66	0.1	1.366
Pin 3	0.1	3.14	0.2	1.5	0.3	3.02	0.1	2.632
Pin 4	0.4	0.86	0.2	2.15	0.7	0.98	0.1	3.898
Pin 5	0.4	2.38	0.2	2.8	0.7	2.34	0.86	0.1
Pin 6	0.4	3.9	0.2	3.45	0.7	3.7	0.86	1.366
Pin 7	0.8	0.1	0.92	0.55	0.9	0.3	0.86	2.632
Pin 8	0.8	1.62	0.92	1.0	0.9	1.66	0.86	3.898
Pin 9	0.8	3.14	0.92	1.85	0.9	3.02	1.26	0.733
Pin 10	1.1	0.86	0.92	2.5	1.3	0.98	1.26	1.999
Pin 11	1.1	2.38	0.92	3.15	1.3	2.34	1.26	3.265
Pin 12	1.1	3.9	0.92	3.8	1.3	3.7	1.62	0.1
Pin 13	1.5	0.1	1.64	0.2	1.5	0.3	1.62	1.366
Pin 14	1.5	1.62	1.64	0.65	1.5	1.66	1.62	2.632
Pin 15	1.5	3.14	1.64	1.5	1.5	3.02	1.62	3.898
Pin 16	1.8	0.86	1.64	2.15	1.9	0.98	2.02	0.733
Pin 17	1.8	2.38	1.64	2.8	1.9	2.34	2.02	1.999
Pin 18	1.8	3.9	1.64	3.45	1.9	3.7	2.02	3.265
Pin 19	2.2	0.1	2.36	0.55	2.1	0.3	2.38	0.1
Pin 20	2.2	1.62	2.36	1.0	2.1	1.66	2.38	1.366
Pin 21	2.2	3.14	2.36	1.85	2.1	3.02	2.38	2.632
Pin 22	2.5	0.86	2.36	2.5	2.5	0.98	2.38	3.898
Pin 23	2.5	2.38	2.36	3.15	2.5	2.34	2.78	0.733
Pin 24	2.5	3.9	2.36	3.8	2.5	3.7	2.78	1.999
Pin 25	2.9	0.1	3.08	0.2	2.7	0.3	2.78	3.265
Pin 26	2.9	1.62	3.08	0.65	2.7	1.66	3.14	0.1
Pin 27	2.9	3.14	3.08	1.5	2.7	3.02	3.14	1.366
Pin 28	3.2	0.86	3.08	2.15	3.1	0.98	3.14	2.632
Pin 29	3.2	2.38	3.08	2.8	3.1	2.34	3.14	3.898
Pin 30	3.2	3.9	3.08	3.45	3.1	3.7	3.54	0.733
Pin 31	3.6	0.1	3.8	0.55	3.3	0.3	3.54	1.999
Pin 32	3.6	1.62	3.8	1.0	3.3	1.66	3.54	3.265
Pin 33	3.6	3.14	3.8	1.85	3.3	3.02	3.9	0.1
Pin 34	3.9	0.86	3.8	2.5	3.7	0.98	3.9	1.366
Pin 35	3.9	2.38	3.8	3.15	3.7	2.34	3.9	2.632
Pin 36	3.9	3.9	3.8	3.8	3.7	3.7	3.9	3.898

For the new best thermal performance, the square random arrangement (SRA) of pin fin heat sink models are shown in Figure 8. Table 7 shows the SRA set up for pin fin heat sink model.



(a) Model SRA 1 (b) Model SRA 2
(c) Model SRA 3 (d) Model SRA 4

Figure 8: Top view of SRA pin fin models

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Table 7: SRA set up for pin fin model

	Model Square Random Arrangement 1		Model Square Random Arrangement 2		Model Square Random Arrangement 3		Model Square Random Arrangement 4	
	x(cm)	y(cm)	x(cm)	y(cm)	x(cm)	y(cm)	x(cm)	y(cm)
Pin 1	0.2	0.2	0.2	0.2	0.2	0.3	0.2	0.2
Pin 2	0.2	3.4	0.3	0.7	0.3	1.366	0.1	0.73
Pin 3	0.4	2.4	0.3	2.8	0.3	2.632	0.2	1.36
Pin 4	0.5	0.5	0.3	3.4	0.3	3.898	0.2	1.99
Pin 5	0.5	1.4	0.4	1.9	0.5	0.733	0.2	2.62
Pin 6	0.5	2.8	0.5	1.3	0.7	2.099	0.1	3.25
Pin 7	0.5	3.6	0.8	2.5	0.5	3.265	0.66	0.1
Pin 8	0.6	1.9	0.8	3.7	0.86	0.1	0.71	0.73
Pin 9	0.9	0.3	0.9	0.3	0.96	1.566	0.86	1.36
Pin 10	1.0	1.5	1.0	0.9	0.86	2.632	0.86	1.99
Pin 11	1.1	1.1	1.0	1.7	0.86	3.698	0.86	2.62
Pin 12	1.1	2.9	1.1	3.3	1.26	0.733	0.66	3.25
Pin 13	1.3	2.5	1.4	1.8	1.46	1.799	1.42	0.1
Pin 14	1.6	0.4	1.5	2.6	1.26	3.265	1.47	0.73
Pin 15	1.6	3.4	1.6	0.4	1.72	0.3	1.62	1.36
Pin 16	1.7	1.6	1.6	3.8	1.62	1.366	1.62	1.99
Pin 17	2.0	1.8	1.7	1.1	1.62	2.632	1.62	2.62
Pin 18	2.0	2.7	1.9	3.1	1.62	3.898	1.42	3.25
Pin 19	2.1	1.1	2.0	1.8	2.02	0.733	2.18	0.1
Pin 20	2.1	2.4	2.0	2.4	2.22	2.099	2.23	0.73
Pin 21	2.3	0.2	2.2	0.5	2.02	3.265	2.38	1.36
Pin 22	2.3	3.1	2.2	3.6	2.38	0.1	2.38	1.99
Pin 23	2.5	3.4	2.5	2.1	2.48	1.566	2.38	2.62
Pin 24	2.6	2.1	2.5	2.8	2.38	2.632	2.18	3.25
Pin 25	2.7	1.4	2.6	0.9	2.38	3.698	3.14	0.1
Pin 26	2.8	0.4	2.6	1.4	2.78	0.733	2.84	3.88
Pin 27	3.0	3.0	2.8	0.4	2.98	1.799	3.14	1.36
Pin 28	3.0	3.7	2.9	3.6	2.98	3.365	1.44	3.89
Pin 29	3.1	1.1	3.2	1.8	3.24	0.3	3.14	2.62
Pin 30	3.2	1.6	3.2	3.0	3.14	1.366	0.74	3.9
Pin 31	3.3	0.5	3.3	1.0	3.14	2.632	3.9	0.1
Pin 32	3.4	2.9	3.5	0.5	3.14	3.898	3.7	3.88
Pin 33	3.5	2.3	3.5	2.3	3.7	0.3	3.9	1.36
Pin 34	3.5	3.3	3.7	1.6	3.8	1.766	2.2	3.89
Pin 35	3.7	1.6	3.7	2.9	3.7	2.832	3.9	2.62
Pin 36	3.8	2.9	3.7	3.7	3.7	3.898	0.2	3.8

3.0 RESULTS AND DISCUSSION

For the fact that the main objective was to analyses the performance of the heat sink design based on the thermal image profile using heat transfer profile. The simulation has been done using COMSOL Multiphysics software under conjugate heat transfer interface module. From the simulation, the model provided the thermal profile for the heat sink and air inlet flowing inside the channel box through the heat sink.

The thermal energy is transfer through conduction from the chip processor which is at high temperature to the aluminium pin fin heat sink which is at low temperature. For convection process, the heat energy transfer between the surface of pin fin heat sink and moving fluid at different temperature. All data operation condition and model parameter values for pin fin heat sink model are shown in Table 1. There are 120 models that have been tested from different pin fin arrangement on the base heat sink.

3.1 Thermal Profile of Circular Type Pin Fin Heat Sink

There are 60 models of circular pin fin of heat sink with different arrangement that have been tested and simulated. The models are divided into three type of pin arrangement which is inline, staggered, and random. Fig. 9 shows the thermal performance result from the COMSOL multiphysics software. From the result, it can be observed that different inline arrangement give different thermal performance. It is also observed that when the length and width become smaller, it reduce the thermal performance of the heat sink. The best thermal performance for CIA of pin fin heat sink model is 101.03°C as shown in Figure 9(a). From the figure, it can be seen that the smooth airflow inside the channel box for inline arrangement.

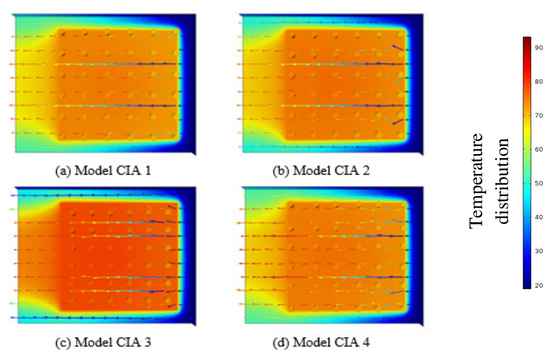

Figure 9: Top view plot of temperature and airflow for CIA of pin fin heat sink models. (a) Model CIA 1 (max temp: 101.03°C); (b) Model CIA 2 (max temp: 102.41°C); (c) Model CIA 3(max temp: 107.43°C); (d) Model CIA 4(max temp: 102°C)

For circular staggered arrangement (CSA) of pin fin heat sink model, there are 20 models that were tested and simulated in this project. The selected four staggered pins arrangement of pin fin heat sink is shown in Figure 10 for CSA of pin fin heat sink models. The pin fin were arranged in staggered with different arrangement as long as only 36 pins were placed on the base of heat sink. The details coordinate of pin fins are shown in Table 3. Figure 10 shows the thermal performance result of circular pin fin heat sink for staggered arrangement. The best thermal performance for staggered arrangement is 97.366°C for circular type of heat sink model as shown in Figure 10(b). It can be seen from the figure that most of the staggered arrangement of pin fin will created turbulence airflow around the pin fin.

Inline and staggered arrangement of pin fin are the commom pin fin heat sink design that available in the market. The purposed of this study to design a new arrangement that can give better thermal performance compared to the conventional arrangement which are inline and staggered. The new arrangement of pin fin heat sink will create both advantage between inline and staggered arrangement.

There are 20 models of circular random arrangement (CRA) of pin fin heat sink were tested and simulated using COMSOL multiphysics software. The random arrangement for pin fin is design based on the best thermal performance model in inline and staggered arrangement of

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circular type of pin fin heat sink. The pin were rearranged until the thermal performance of random arrangement is better than thermal performance of inline and staggered pin fin arrangement for circular type pin fin heat sink.

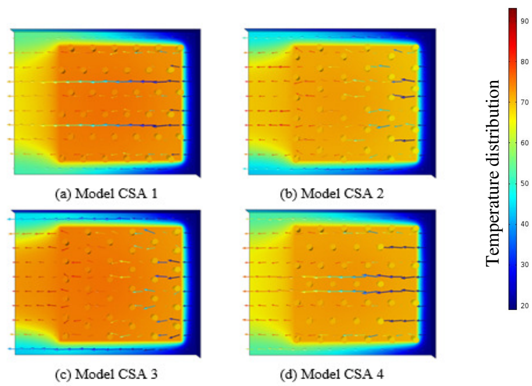

Figure 10: Top view plot of temperature and airflow for CSA of pin fin heat sink models. Model CSA 1 (max temp: 102.08°C); (b) Model CSA 2 (max temp: 97.366°C); (c) Model CSA 3 (max temp: 101.85°C); (d) Model CSA 4 (max temp: 98.189°C)

Based on simulation result shown in Fig. 11, the best thermal performance for CRA of pin fin heat sink is 96.904°C as shown in Fig. 4.11(c).

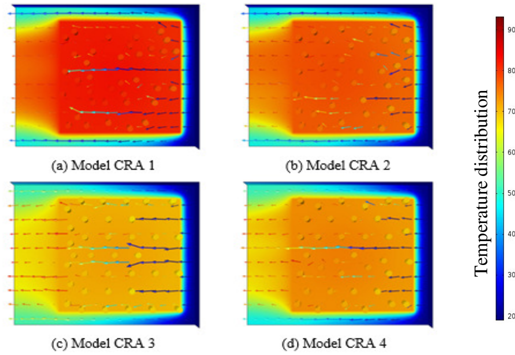

Figure 11: Top view plot of temperature and airflow for CRA of pin fin heat sink models. (a) Model CRA 1 (max temp: 111.62°C); (b) Model CRA 2 (max temp: 106.19°C); (c) Model CRA 3 (max temp: 96.904°C); (d) Model CRA 4 (max temp: 100.4°C)

3.2 Thermal Profile of Square Type Pin Fin Heat Sink

There are 60 models of square pin fin of heat sink with different arrangement that have been simulated. The models are divided into three type of pin arrangement which is inline, staggered, and random. Figure 12 shows the thermal performance result for inline arrangement of square pin fin heat sink models (SIA). From the result, it can be observed that different inline arrangement give different thermal performance. The best thermal performance for SIA of pin fin heat sink model is 90.211°C as shown in Figure 12(a).

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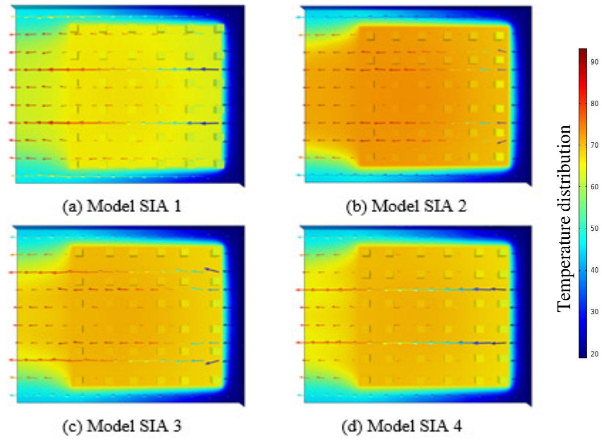

Figure 12: Top view plot of temperature and airflow for SIA of pin fin heat sink models. (a) Model SIA 1 (max temp: 90.211°C); (b) Model SIA 2 (max temp: 98.637°C); (c) Model SIA 3 (max temp: 95.385°C); (d) Model SIA 4 (max temp: 95.152°C)

For square staggered arrangement (SSA) of pin fin heat sink model, there are 20 models that were tested and simulated. The selected four staggered pins arrangement of pin fin heat sink is shown in Figure 13 for square type of pin fin heat sink model. The pin fin were arranged in staggered with different arrangement as long as only 36 pins were placed on the base of heat sink. The details coordinate of pin fins in Figure 13 shows in Table 6.

It shows the thermal performance result of square pin fin heat sink for staggered arrangement. The best thermal performance for square type of heat sink model for staggered arrangement is 90.399°C as shown in Figure 4.19(a). Figure 4.20 shows the top view plot of temperature and airflow for square type of heat sink model. It can be seen from the figure that most of the staggered arrangement of pin fin will created turbulence airflow around the pin fin on the base heat sink.

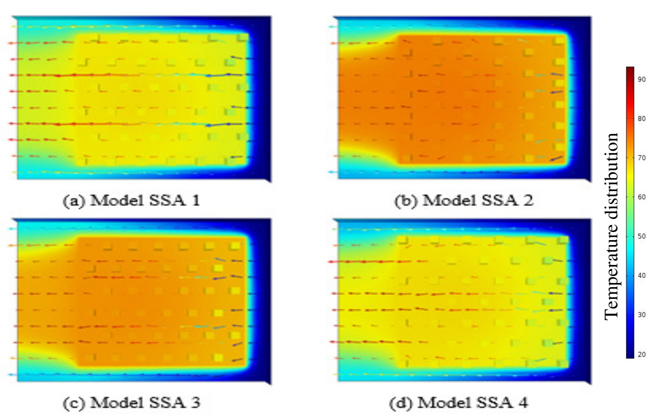

Figure 13: Top view plot of temperature and airflow for SSA of pin fin heat sink models. (a) Model SSA 1 (max temp: 90.399°C); (b) Model SSA 2 (max temp: 101.2°C); (c) Model SSA 3 (max temp: 98.702°C); (d) Model SSA 4 (max temp: 91.023°C)

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There are 20 models of square random arrangement (SRA) of pin fin heat sink were tested and simulated. The random arrangement for pin fin is design based on the best thermal performance model in inline and staggered arrangement of square type of pin fin heat sink. The pin were rearranged until the thermal performance of random arrangement is better than thermal performance of inline and staggered pin fin arrangement for square pin fin heat sink. Based on simulation result as shown in Figure 14, the best thermal performance for square type of pin fin heat sink is 90.044°C as shown in Figure 4.23(d).

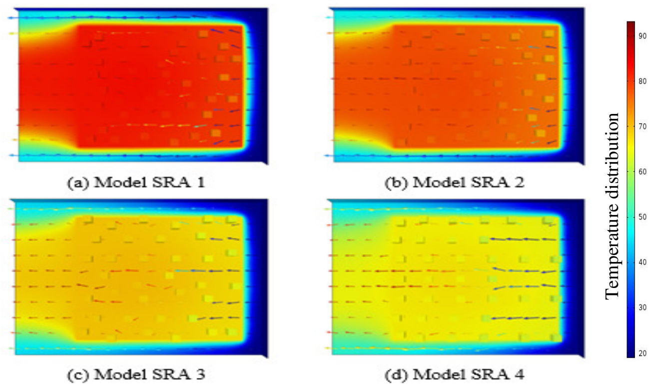

Figure 14: Top view plot of temperature and airflow for SRA of pin fin heat sink models. . (a) Model SRA 1 (max temp: 111.9°C); (b) Model SRA 2 (max temp: 106.01°C); (c) Model SRA 3 (max temp: 94.383°C); (d) Model SRA 4 (max temp: 90.044°C)

3.3 Thermal Performance Analysis

From the simulation result observed, the different arrangement of pin fin mounted on the heat sink base will provided different thermal performance. Besides that, the type of pin fin also affects the thermal performance of heat sink.

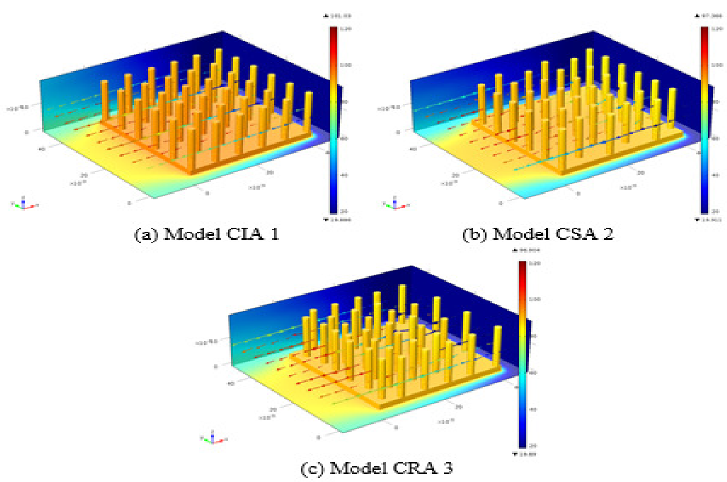

Figure 15: 3D circular pin fin heat sink models with different arrangement. Model CIA 1 (max temp: 101.03°C); (b) Model CSA 2 (max temp: 97.366°C); (c) Model CRA 3 (max temp: 96.904°C)

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Figures 15 and 16 shows the best thermal performance from the three types of arrangement for circular and square type of heat sink respectively. Figure 15(c) shows that the thermal performance for new arrangement of circular type of pin fin heat sink is 96.904°C which is lower than other arrangement. The thermal performance for new arrangement of square type of pin fin heat sink is 90.044°C which is lower than other arrangement as shown in Figure 16(c).

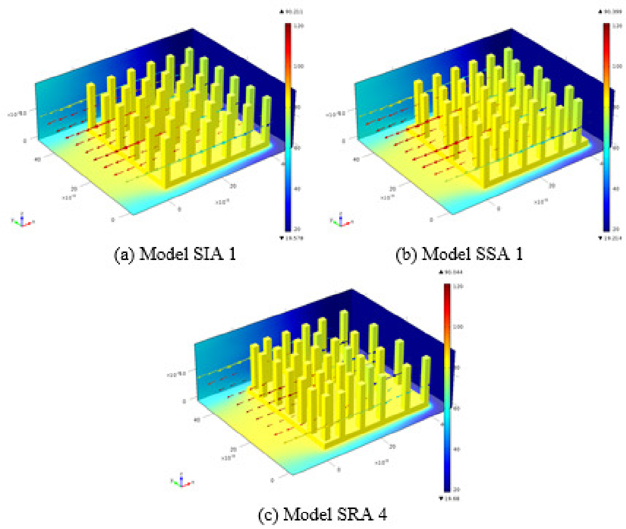

Figure 16: 3D square pin fin heat sink models with different arrangement. Model SIA 1 (max temp: 90.211°C); (b) Model SSA 1 (max temp: 90.399°C); (c) Model SRA 4 (max temp: 90.044°C)

Table 8: The best thermal performance of each type of pin fin heat sink with different arrangement

	Circular	Square
Inline	101.03°C	90.211°C
Staggered	97.366°C	90.399°C
Random	96.904°C	90.044°C

Table 8 shows the best thermal performance of each type of pin fin heat sink with different arrangement. From the Table 8, it shows that square type of pin fin heat sink gives better thermal performance compare to circular type. Table 9 shows the thermal performance comparison between inline and staggered arrangement with the new arrangement for both circular and square type of pin fin heat sink model. From the Table 9, it shows that the new arrangement of the pin fin were able to give better thermal performances which are 4.1% and 0.5% for circular type and 0.2% and 0.4% for square type compared to inline and staggered arrangement respectively.

Table 9: Percentage of thermal performance comparison between inline and staggered arrangement with the new (random) arrangement.

	Circular	**Square**
Inline	4.1%	0.2%
Staggered	0.5%	0.4%

4.0 CONCLUSSION

This study was carried out to analysis the thermal performance of various arrangement of circular and square type of pin fin heat sink using COMSOL multiphysics software. Based on the simulation the various pin fin models with different arrangement have been analysed to see the thermal performance of the heat sink. The conventional arrangement of pin fin which is inline and staggered have been compared with the new arrangement which is random arrangement to find the best thermal performance. From the result, it can be concluded that the new arrangement of pin fin heat sink for circular and square type of pin fin heat sink would give better thermal performance compare to the conventional arrangement. The new arrangement of the pin fin were able to give better thermal performances which are 4.1% and 0.5% for circular type and 0.2% and 0.4% for square type compared to inline and staggered arrangement respectively. It is important to choose the best arrangement and type of pin fin heat sink in order to provide the best thermal performance. For better result in finding the optimal arrangement of pin fin, further study needs to be done by using population based evolutionary algorithm optimization method such as Particle Swarm Optimization (PSO), Genetic Algorithm (GA), Firefly Algorithm (FA) etc. In addition, this study was done with only two types of pin fin which is circular and square. It is recommended to further this study with other different type of pin fin such as rectangular, elliptical and etc.

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REFERENCES

[1] L.C. Jenkins, A. Bennett, 21st century challenge: thermal management design requirements. Digital Avionics Systems Conference, DASC04, 2004, pp. 1-7.

[2] P. Ravibabu, K. Rajshekar, K.R. Gupta, Heat pipes - integrated circuit coolers. Nanoelectronics Conference (INEC), 3rd International 260-264 (2010).

[3] M.C. Zaghdoudi, A. Teytu. Use of heat pipes for avionics cooling. Electronics Packaging Technology Conference 425-430 (2000).

[4] F. Yongling, Z. Meng, Q. Haitao, A. Gaocheng, Application of heat pipe technology in the design of hydraulic motor pump. Electronic and Mechanical Engineering and Information Technology (EMEIT) 1033-1036 (2011).

[5] C. Anbin, X. Fengyu, L. Xiaokun, H. Yubao, W. Zonglin, Z. Yingshun, Sub-Cooled Liquid Nitrogen Test System for Cooling HTS Synchronous Motor. Applied Superconductivity, IEEE Transactions 22 (2012) 4701304-4701304.

[6] D.L.V. Andrea, G. Stefano, G. Franco, Optimum design of vertical rectangular fin arrays. International Journal of Thermal Sciences (1999) 525-529.

[7] Y. Kondo, H. Matsushima, T. Komatsu, Optimization of Pin-Fin Heat Sinks for Impingement Cooling of Electronic Packages. Journal Electronic Packaging 122 (2000) 240-246

[8] D.K. Kim, J.K. Bae, S.J. Kim, Comparison of Thermal Performances of Plate-Fin and Pin-Fin Heat Sink Subject to an Impinging Flow. International Journal of Heat and Mass Transfer (2009) 3510-3517.

[9] K.A.M. Annuar, M.F.M. Ab Halim, F.S. Ismail, M. Zahari, S.H. Johari, M.H. Harun. Thermal Analysis of Staggered Pin Fin Heat Sink for Central Processing Unit. Australian Journal of Basic & Applied Sciences 9 (2015) 68-73.

[10] N. Hamadne, W.A. Khan, S. Sathasivam, H.C. Ong, Design Optimization of Pin Fin Geometry Using Particle Swarm Optimization Algorithm. PLoS One 8 (2013) pe66080H

[11] C.J. Shih, G.C. Liu, Optimal design methodology of plate-fin heat sinks for electronic cooling using entropy generation strategy. IEEE Transactions on components and packaging technologies 27 (2004) 551-559.

[12] C.T. Chen, C.K. Wu, C. Hwang, Optimal Design and Control of CPU Heat Sink Processes. IEEE Transaction on Component and Packaging Technologies 31 (2008) 184-195.

[13] X. Zhang, D. Liu, Optimal geometric arrangement of vertical rectangular fin arrays in natural convection. Energy conversion and management 51 (2010) 2449-2456.

[14] M.Z.M. Hanafi, F.S. Ismail, Multi-objective optimal thermal heat sink design using evolutionary method. Jurnal Teknologi 72 (2015) 1-6

[15] R. Mohan, P. Govindarajan, Thermal analysis of CPU with variable heat sink base plate thickness using CFD International Journal of the Computer 18 (2010) 27-36.

[16] V.U. Patel, A.J. Modi, Optimization of heat sink analysis for electronic cooling. Proceeding of a National Conference on Advances in Mechanical Engineering (NCAME-2012) 64-69 (2012).

[17] D. Geb, I. Catton, Nonlocal Modeling and Swarm-Based Design of Heat Sinks. Journal of Heat Transfer 136 (2014) 011401

Advanced Research in Fluid Mechanics and Thermal Sciences | Vol. 11, No. 1. Pages 11-28, 2015
ISSN (online): 2289-7879

[18] M.Z.M. Hanafi, F.S. Ismail, Heat Sink Model and Design Analysis Based on Particle Swarm Optimization. IEEE Innovative Smart Grid Technologies –Asia (ISGT ASIA) (2014) 726-731.

[19] K.A.M. Annuar, F.S. Ismail, Optimal Pin Fin Arrangement of Heat Sink Design and Thermal Analysis for Central Processing Unit. 5th International Conference on Intelligence and Advance Systems (ICIAS14) (2014) 1-6.