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Thermal Performance Analysis for Optimal Passive Cooling Heat Sink Design

Nur Warissyahidah Badrul Hisham[1], Fatimah Sham Ismail*[2], Muhammad Azmi Ahmed Nawawi[3]
Control & Mechatronics Engineering Department, Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 UTM, Johor Baharu, Malaysia
*Corresponding author, e-mail: fatimahs@utm.my

Abstract

Recent advances in semiconductor technology show the improvement of fabrication on electronics appliances in terms of performance, power density and even the size. This great achievement however led to some major problems on thermal and heat distribution of the electronic devices. This thermal problem could reduce the efficiency and reliability of the electronic devices. In order to minimize this thermal problem, an optimal cooling techniques need to be applied during the operation. There are various cooling techniques have been used and one of them is passive pin fin heat sink approach. This paper focuses on inline pin fin heat sink, which use copper material with different shapes of pin fin and a constant 5.5W heat sources. The simulation model has been formulated using COMSOL Multiphysics software to stimulate the pin fin design, study the thermal distribution and the maximum heat profile.

Keywords*: pin fins heat sink, thermal profile, and heat transfer process*

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1. Introduction

Most electronic companies are towards designing more functionality but smaller packages of electronic components with high power density. However, when the electronic components become smaller, heat generation rate per volume of the component increased [1, 2]. In this case, the temperature of the component will affect its normal operation and performance. Furthermore, this will lead to malfunction of the device and it might severely damage. Example, it can cause the transistor to delay to change which can caused the threshold voltage to drop. The worse case can lead variety of reliability problem such as electromigration, oxide breakdown or negative temperature bias instability [3]. An electronic company (AI Technlogy Inc) has studied about major causes of electronic failure, which are dust (6%), humidity (19%) followed by vibration (20%) while another 55% caused by temperature. Thus it is extremely important to improve the process of heat transfer and the heat dissipation from the electronic devices. In producing the high performance of an integrated circuit, thermal consideration should be one of the important roles. The selected heat sink must have higher thermal resistivity as it have higher heat transfer rate.

Heat sink transfers heat from heat source to surroundings. In a past few years, many reseachers have studied on how to enhance the thermal performance and characteristics of heat sinks. Basically, heat sinks can be divided into two categories, which is active and passive heat sink. Passive heat sink used natural convection application such as fan [4]. Active heat sink need external fan to force air to flow over the fins while passive heat sink has no external force to circulate an air over fin [5]. The innovative pin fin designs play an important role in cooling process of power electronic cpmponents [5, 6]. Pin fin is an extended surface, which has been design to increase the area for convection of heat transfer process.

Many cooling techniques have been used in order increase the heat transfer rate of one component such as heat pipes [7], water cooling, nitrogen liquid [8] and heat sink. Several design examples with different types of cooling methods and manufacturing processes have been analysed and it has been shown that aluminium based rectangular heat sink with straight fins has an optimum design configuration [9].

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Two common types of heat sink that widely used in the industry are pin fin heat sink and plate fin heat sink. Heat sink is preferable choice because it helps to maximize heat dissipation rate, small size, portable and low cost compared to liquid nitrogen. Therefore, this study will simulate and analyse the thermal profile of selected heat sink, which finally can be proposed for optimal dimension with high heat transfer rate.

In order to simulate the thermal profile of the pin fins heat sink, software packages such as COMSOL Multiphiysics [10] and ANSYS [11] can be used. COMSOL Multiphysics package software can stimulate various types scientific and engineering field, as it was build up with plenty of modules using finite element method [12]. This study uses COMSOL Multiphysics version 5.0 for 3D simulation heat sink model. This package software also requires no expertise in mathematical or numerical analysis since the software uses Finite Element Method (FEM) approach. Any complicated geometrical form can be analysed using COMSOL.

2. Research Method

General algorithm for pin fin heat sink model development and optimal dimension selection are shown in Figure 1. There are four stages to develop pin fin heat sink model. The first stage is the creation of heat sink geometrical model. Most parameters values are fixed like air box channel, total power dissipated from the source, heat sink base and air flow inlet. Selection of all the dimensions and parameters of the model are based on the actual heat sink that has been used by our system. All the parameters used in this simulation are tabulated in Table 1.

The shape of pin fins is varied in according to thermal resistance of the heat sink. Total 168 fins are attached on the heat sink based on inline arrangement. After completing the geometrical heat sink model, next is the selection of material properties and defining boundary condition in conjugate heat transfer module. This experiment chooses aluminium as the material.

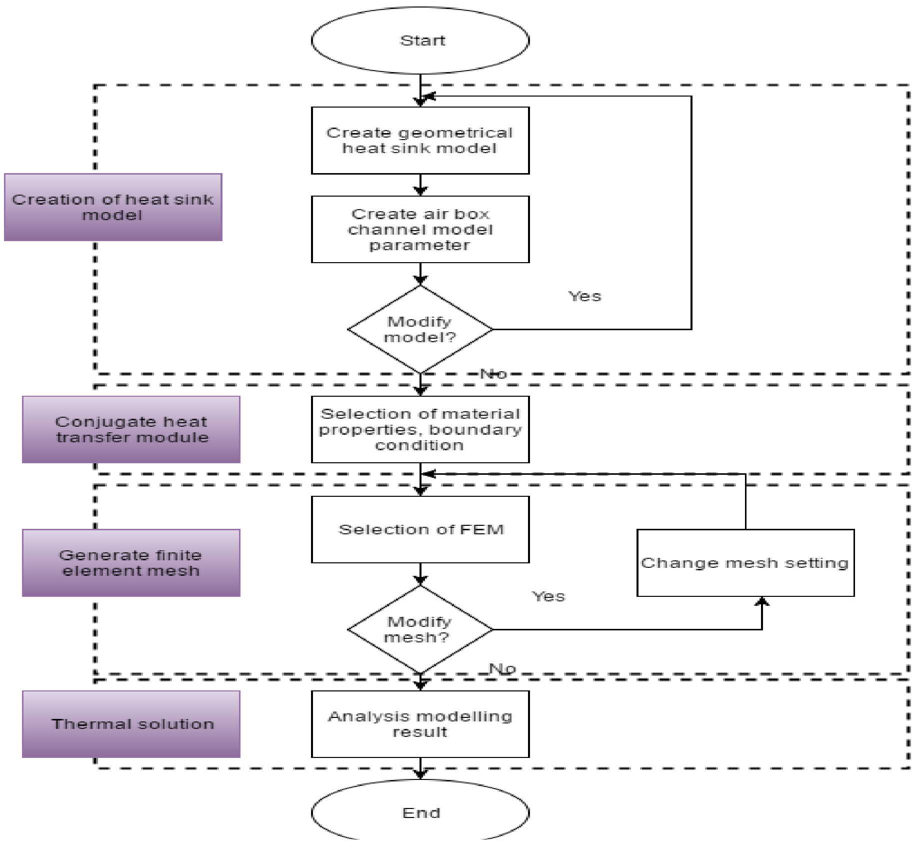


Figure 1. Heat sink thermal modelling algorithm

Table 1. Operating Condition and Model Parameter Values for Pin Fin Heat Sink Model

Name Parameter		Values	Descriptions
Air Box Channel	L_channel	80[mm]	Channel length
	W_channel	60[mm]	Channel width
	H_channel	25[mm]	Chennel height
Heat Sink Base	L_base	46[mm]	Heat sink length
	W_base	45[mm]	Heat sink width
	H_base	5[mm]	Heat sink height
Chip Processor Unit	P_tot	5.5[W]	Total Power Dissipated
Air Flow Inlet	U0	10[cm/s]	Mean Inlet Velocity
	T0	20[^{0} C]	Inlet Temperature
Material (Aluminium)	K	238[W/mK]	Thermal Conductivity
	Cp	900[J/9kg.K)]	Heat Capacity at Constant Pressure

Next step is to generate the finite element mesh on the heat sink model. This process is to divide the geometry into a small unit of a sample shape. This simulation used physics-controlled mesh as the sequence type and extra-coarse is selected as the finite element mesh. Once the selection process has been made, finite element mesh is generated. Process generation of finite element mesh is as shown in Figure 2. Under the mesh setting, sequence type and element size is set.

There are two types of sequence type, which are user-controlled mesh and physics-controlled mesh. For this simulation, physics-controlled mesh is selected as the sequence type. Selection process of finite element shape and finite element size (mesh density) is chose. Extra-coarse is selected as the finite element mesh. Finite element mesh is generated once the selection process has been completed. The result is analysed to determine the performance of the proposed heat sink design. The result analysed to determine the performance of the proposed design as shown in Figure 3.

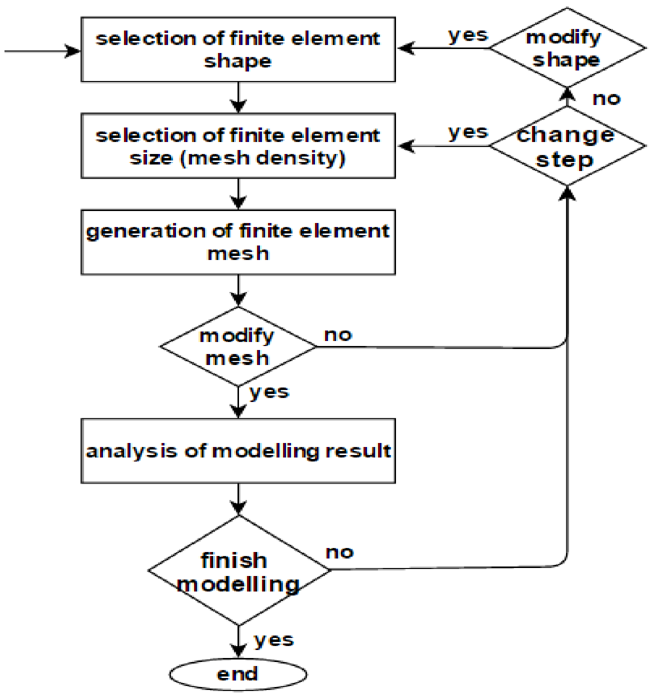
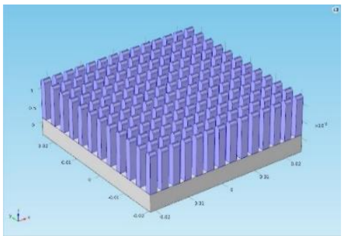
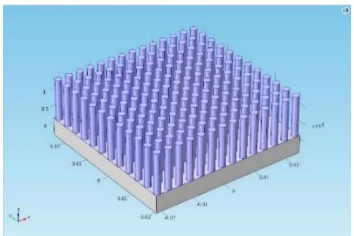


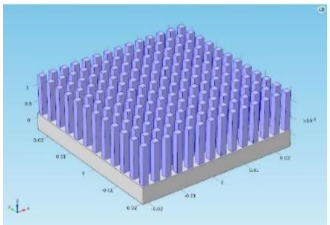
Figure 2. Heat sink thermal modelling algorithm



(a) Design 1



(b) Design 2



(c) Design 3

Figure 3. 3D pin fin heat sinks models with different pin fin shape

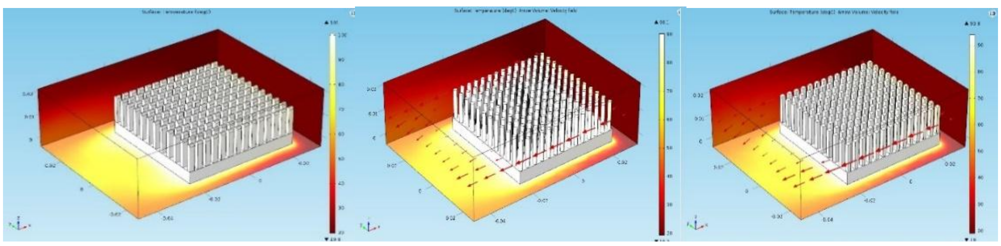
3. Results and Analysis

The simulation was done using COMSOL Multiphysics version 5.0 under Conjugate Heat Transfer Interface Module on a computer equipped with 12.0 GB RAM and Intel® Core^{TM} i5-4200U 2.30 GHz processor. The model solves a thermal profile for heat sink and air inlet flowing inside the channel box. Three different designs made in order to determine the best heat sink for 5.5 Watt heat source. All the data has been recorded as in Table 2 after the heat sink design was simulated.

Two types of heat transfer process will be analysed. First is conduction process and the second is convection. During both process, air with uniform velocity is flowing through heat sink unit. The conduction process occurs when there is a temperature gradient at the inner and outer surface of heat sink. Energy transfers from surface with high temperature, which in this case from the heat sink base as the heat source attached at the bottom of heat sink to low temperature. Convection is a slower method compared to conduction due to it involves transferring of heat energy from heat sink surface to ambient.

Figure 4 shows the simulation results for the optimal design of three types of pin fins design. These optimal results have been selected from 100 random designs. The optimization process is based on random selections, which have been conducted in order to vary the dimension and arrangement of pin fins.

The simulation result with higher thermal resistivity is the best heat sink, which in this case is Design 1. Design 1 showed the highest temperature which is 100.64°C and the average temperature is 100.06°C compared to Design 2 showed the lowest maximum temperature which is 90.064°C and the average temperature is 89.435°C. Based on this thermal profile, it can be concluded that Design 1 is the best heat sink for 5.5W heat source.



(a) Design 1 (b) Design 2 (c) Design 3

Figure 4. 3D Pin fin heat sinks thermal distribution

Table 2. Thermal Distribution for Various Heat Sink Design

Arrangement	Thermal profile	T_{hot} (^{0} C)	T_{ave} (^{0} C)	Q_{total} (KWatt)
Design 1	Thermal resistivity: 7.2^0 C/W	100.64	100.06	8.845
Design 2	Thermal resistivity: 6.2^0 C/W	90.064	89.453	7.677
Design 3	Thermal resistivity: 6.5^0 C/W	93.795	93.22	7.930

4. Conclusion

This paper presented a thermal performance of three different shapes of pin fin heat sink model for computer processing unit (CPU) model. Passive pin fin heat sink has been proved as one of the cooling technique that can be utilized to overcome thermal issues. Moreover, the optimal design even can produce high thermal performance heat sink. In this study, only two factors were considered, which are the arrangement of the pin fin and the surface area of the pin fin. Further research needs to be done using an intelligent optimization technique for optimal heat sink design. The proposed optimal design and the current heat sink design must be analysed. A precise prediction heat sink model is important to ensure the effectiveness and efficiency of heat transfer process.

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