OPTIMAL HEAT TRANSFER OF HEAT SINK DESIGN BASED ON ELECTRONIC PACKAGE THERMAL DISTRIBUTION USING COMSOL PACKAGE SOFTWARE

RASHIDAH BINTI ROSLI

UNIVERSITI TEKNOLOGI MALAYSIA

OPTIMAL HEAT TRANSFER OF HEAT SINK DESIGN BASED ON ELECTRONIC PACKAGE THERMAL DISTRIBUTION USING COMSOL PACKAGE SOFTWARE

RASHIDAH BINTI ROSLI

A project report submitted in partial fulfilment of the requirements for the award of the degree of Master of Engineering (Electrical – Mechatronics and Automatic Control)

> Faculty of Electrical Engineering Universiti Teknologi Malaysia

> > JUNE 2015

Thanks to ALLAH S.W.T and his Prophet Muhammad S.A.W.

Especially dedicated to my beloved mother, father, siblings and friends who have prayer, supported, encouraged, guided and inspired me throughout my journey of education.

ACKNOWLEDGEMENT

First and foremost, "Syukur Alhamdulillah" to Allah, the Most Gracious and Most Merciful for ensuring myself to be healthy to carry out my study and to complete this project.

Secondly, I would like to express my warmest gratitude to my project supervisor, Dr. Fatimah Sham Ismail for her guidance, professional advice, encouragement and support throughout the period in completing this project. Her remarkable ideas and suggestions will be much appreciated in the long run of my career.

My sincere appreciation also goes to my family especially my parents Rosli bin Abdul Hamid and Wan Mazlina binti Wan Mahmood who has been so tolerant and supportive in all years either morally or financially. Thanks for their continuous encouragement, love and emotional supports that they had given to me all this while.

I also would like to gratefully thank to all my lecturer and all my friends who had given me helps technically and mentally throughout my journey in completing my project. Thanks a lot from the bottom of my heart.

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.

ABSTRAK

Oleh kerana pembangunan yang maju dalam teknologi semikonduktor, saiz komponen elektronik dan peranti menjadi lebih kecil manakala prestasinya semakin meningkat. Peningkatan ketumpatan kuasa dalam sistem menyebabkan komponen dalam sistem untuk beroperasi pada suhu yang lebih tinggi yang membawa kepada masalah termal. Masalah termal ini akan mengurangkan prestasi dan kecekapan pakej elektronik. Peranti yang paling popular digunakan untuk penyejukan elektronik adalah heat sink. Dalam usaha untuk meningkatkan proses pemindahan haba, pelbagai jenis heat sink dengan bentuk, bahan dan dimensi telah direka. Projek ini bertujuan untuk menyediakan pemindahan haba yang optimum dalam heat sink untuk mengurangkan pengagihan haba dalam pakej elektronik. Projek ini hanya memberi tumpuan kepada heat sink jenis bulat dan segi empat dengan pelbagai susunan pin. Dalam projek ini, perisian COMSOL Multiphysics akan digunakan untuk mensimulasikan pelbagai susunan pin di atas permukaan heat sink. Keputusan telah mencadangkan kaedah penyusunan baru pin yang dapat memberikan prestasi termal yang lebih baik iaitu sebanyak 4.1% dan 0.5% untuk jenis bulat dan 0.2% dan 0.4% untuk jenis empat segi berbanding dengan susunan pin sebaris dan berperingkat.

TABLE OF CONTENTS

CHAPTER

1

2

TITLE

PAGE

DEC	LARATION	ii	
DED	ICATION	iii	
ACK	NOWLEDGEMENT	iv	
ABS	ГКАСТ	v	
ABS	ГПАК	vi	
TAB	LE OF CONTENTS	vii	
LIST	OF TABLES	Х	
LIST	OF FIGURES	xi	
LIST	OF ABBREVIATIONS	xiv	
LIST	LIST OF SYMBOLS		
INTI	RODUCTION	1	
1.1	Backgroud	1	
1.2	Problem Statements	3	
1.3	Objectives of Project	4	
1.4	Scope of project	4	
1.5	Thesis Outline	5	
LITH	CRATURE REVIEW	6	
2.1	Introduction	6	
2.2	Heat Transfer	6	
	2.2.1 Conduction	7	
	2.2.2 Convection	10	

	2.2.3 Radiation	11
2.3	Heat Sink	12
2.4	Performance of Different Type of Heat Sink	14
2.5	Heat Sink Optimization Method	15
2.6	Different Material of Heat Sink	17
2.7	Summary	18
RESI	EARCH METHODOLOGY	19
3.1	Introduction	19
3.2	Pin Fin Heat Sink Arrangement Method	20
	3.2.1 Circular Type of Pin Fin Heat Sink	22
	3.2.2 Square Type of Pin Fin Heat Sink	31
3.3	Geometry of heat sink	40
3.4	Model Building in COMSOL Multiphysics Software	42
3.5	Summary	46
RESU	ULTS AND DISCUSSION	48
4.1	Introduction	48
4.2	Thermal Profile of Pin Fin Heat Sink	48
4.3	Thermal Profile of Circular Type Pin Fin Heat Sink	51
	4.3.1 Circular Inline Arrangement (CIA) of Pin Fin	51
	4.3.2 Circular Staggered Arrangement (CSA) of Pin Fin	54
	4.3.3 Circular Random Arrangement (CRA) of Pin Fin	58
4.4	Thermal Profile of Square Type Pin Fin Heat Sink	62
	4.4.1 Square Inline Arrangement (SIA) of Pin Fin	63
	4.4.2 Square Staggered Arrangement (SSA) of Pin Fin	66
	4.4.3 Square Random Arrangement (SRA) of Pin Fin	71
4.5	Thermal Performance Model Analysis	74
4.6	Summary	77
CON	CLUSION AND RECOMMENDATION	78
5.1	Conclusion	78
5.2	Recommendation	79

3

4

5

viii

REFERENCES

80

LIST OF TABLES

TABLE NO.	TITLE	PAGE
2.1	Thermal conductivity of several materials	9
3.1	Inline arrangement set up for circular pin fin heat sink model	24
3.2	Staggered arrangement set up for circular pin fin heat sink mod	el 27
3.3	Random arrangement set up for circular pin fin heat sink model	30
3.4	Inline arrangement set up for square pin fin heat sink model	33
3.5	Staggered arrangement set up for square pin fin heat sink mode	1 36
3.6	Random arrangement set up for square pin fin heat sink model	39
3.7	Operation condition and model parameter values for pin	44
	fin heat sink model	
4.1	The best thermal performance of each type of pin fin	77
	heat sink with different arrangement	
4.2	The thermal performance comparison between inline	77
	and staggered arrangement with the new arrangement	

LIST OF FIGURES

FIGURE NO.

TITLE

PAGE

1.1	Major causes of electronic failure	2
2.1	Types of heat transfer process	7
2.2	One Dimensional (1D) heat conduction	8
2.3	Common type of heat sinks	13
2.4	Other design of heat sinks	13
2.5	Pin fin heat sink with different arrangement	14
3.1	Flow chart for evaluation method approach	21
3.2	Example of circular type pin fin heat sink with	22
	inline arrangement	
3.3	Top view of the inline arrangement of the	23
	circular pin fin heat sink model	
3.4	Example of circular type pin fin heat sink with	25
	staggered arrangement	
3.5	Top view of the staggered arrangement of the	26
	circular pin fin heat sink model	
3.6	Example of circular type pin fin heat sink with	28
	random arrangement	
3.7	Top view of the random arrangement of the	29
	circular pin fin heat sink model	
3.8	Example of square type pin fin heat sink with	31
	inline arrangement	
3.9	Top view of the inline arrangement of the square	32
	pin fin heat sink model	

3.10	Example of square type pin fin heat sink with	34
	staggered arrangement	
3.11	Top view of the staggered arrangement of the	35
	square pin fin heat sink model	
3.12	Example of square type pin fin heat sink with	37
	random arrangement	
3.13	Top view of the random arrangement of the	38
	square pin fin heat sink model.	
3.14	Example of heat sink geometry	40
3.15	Example position of pin fin on the base heat sink	41
3.16	Heat sink modelling algorithm	43
3.17	Model of heat sink with the air box channel	44
3.18	Dimension of heat sink model	45
3.19	Example of material selection	45
3.20	Example of boundary selection	46
4.1	Example of simulation result of of pin fin heat sink model	50
4.2	Example of CIA of pin fin design	51
4.3	Example of 3D view plot of temperature for CIA	52
	of pin fin heat sink models	
4.4	Top view plot of temperature and airflow for CIA	53
	of pin fin heat sink models	
4.5	Bottom view plot of temperature on chip and base for CIA	54
	of pin fin heat sink models	
4.6	Example of CSA pin fin design	55
4.7	Example of 3D view plot of temperature for CSA	56
	of pin fin heat sink models	
4.8	Top view plot of temperature and airflow for CSA	57
	of pin fin heat sink models	
4.9	Bottom view plot of temperature on chip and base for CSA	58
	of pin fin heat sink models	
4.10	Example of CRA of pin fin design	59
4.11	Example of 3D view plot of temperature for CRA	60
	of pin fin heat sink models	

xii

4.12	Top view plot of temperature and airflow for CRA	61
	of pin fin heat sink models	
4.13	Bottom view plot of temperature on chip and base for CRA	62
	of pin fin heat sink models	
4.14	Example of SIA of pin fin design	63
4.15	Example of 3D view plot of temperature for SIA	64
	of pin fin heat sink models	
4.16	Top view plot of temperature and airflow for SIA	65
	of pin fin heat sink models	
4.17	Bottom view plot of temperature on chip and base for SIA	66
	of pin fin heat sink models	
4.18	Example of SSA of pin fin design	67
4.19	Example of 3D view plot of temperature for SSA	68
	of pin fin heat sink models	
4.20	Top view plot of temperature and airflow for SSA	69
	of pin fin heat sink models	
4.21	Bottom view plot of temperature on chip and base for SSA	70
	of pin fin heat sink models	
4.22	Example of SRA of pin fin design	71
4.23	Example of 3D view plot of temperature for SRA	72
	of pin fin heat sink models	
4.24	Top view plot of temperature and airflow for SRA	73
	of pin fin heat sink models	
4.25	Bottom view plot of temperature on chip and base for SRA	74
	of pin fin heat sink models	
4.26	3D circular pin fin heat sink models with different	75
	arrangement	
4.27	3D square pin fin heat sink models with different	76
	arrangement	

LIST OF ABBREVIATIONS

HTS	-	High Temperature Superconductive
1D	-	One Dimensional
2D	-	Two Dimensional
3D	-	Three Dimensional
CPU	-	Computer Processing Unit
FEM	-	Finite Element Method
GA	-	Genetic Algorithm
CFD	-	Computational Fluid Dynamics
PSO	-	Particle Swarm Optimization
CCC	-	Carbon-Carbon Composite
CIA	-	Circular Inline Arrangement
CSA	-	Circular Staggered Arrangement
CRA	-	Circular Random Arrangement
SIA	-	Square Inline Arrangement
SSA	-	Square Staggered Arrangement
SRA	-	Square Random Arrangement

xiv

LIST OF SYMBOLS

Q	-	Heat transfer rate (Watts)
k	-	Thermal conductivity of the material (W/mK)
Α	-	Area of the surface (m^2)
ρ	-	Density (kg/m ³)
C_{p}	-	Heat capacity (J/Kg°C)
ġ	-	Energy generated per unit volume (W/m ³)
Н	-	Convection heat transfer coefficient (W/m ² K)
T_a	-	Ambient temperature (°C @ K)
Ts	-	Surface temperature (°C @ K)
Е	-	Emissivity value
σ	-	Stefan-Boltzmann constant
L_channel	-	Channel length (cm)
H_channel	-	Channel height (cm)
W_channel	-	Channel width (cm)
L_chip	-	Chip size (cm)
H_chip	-	Chip height (cm)
P_tot	-	Total power dissipated by electronic package (Watts)
L1	-	Pin height (cm)
L2	-	Pin length/diameter (cm)
H_size	-	Base height (cm)
L_size	-	Base length (square) (cm)
U0	-	Mean inlet velocity (cm/s)
Т0	-	Inlet temperature (°C)

CHAPTER 1

INTRODUCTION

1.1 Background of study

Nowadays, the demand of using electronic devices such as computers, laptops and others are very high [1]. Recent advances in semiconductor technology have given rise to a size-reduced, high-tech device with an ever-greater system performance [2,3]. 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.

Figure 1.1 shows 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.

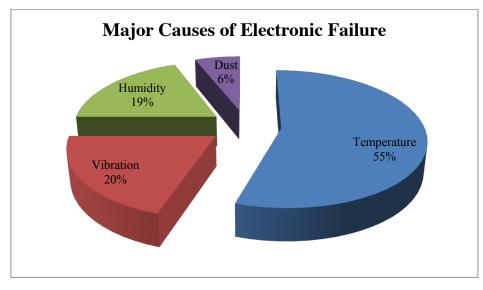


Figure 1.1 Major causes of electronic failure

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 [4,5], water cooling, nitrogen liquid and heat sink. Yongling *et al.* [6] 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 used for small electronic devices because of space constraint. Anbin *et al.* [7] 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 two common type of heat sink 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.

1.2 Problem Statement

Due to the advanced development in semiconductor technology, the size of electronic component and devices become smaller while the performance becomes significantly greater [2]. 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. Thus, it is a big challenge to the manufacturers to design electronic devices in terms of performance, size and functionality. Therefore, heat sink with high heat transfer rate is needed in order to remove the heat generated within the system.

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. 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.

1.3 Objective

The objective of this project can be dividing into three main objectives that are:

- i. To simulate various pin fins arrangement design of the heat sink model using COMSOL Multiphysics software.
- ii. To analyses the performance of the heat sink design based on the thermal image profile using heat transfer model.
- iii. To propose a new arrangement by minimizing thermal distribution with high heat transfer rate.

1.4 Scope of Project

The scopes of this project are:

- i. Literature review on heat sink design, method and analysis.
- ii. Study pin fin heat sink thermal profile using resistance thermal model.
- iii. Use COMSOL Multiphysics software to simulate the thermal profile.
- iv. Study a new arrangement of pin fins by minimizing thermal distribution with high heat transfer rate.
- v. Thermal image analysis for pin fin type heat sink

1.5 Thesis Outline

This thesis consists of five chapters. Chapter 1 introduces the background of the study, problem statement, objective of this project, scope of project and the overall thesis outline. Chapter 2 focuses on literature reviews related to this project based on journals and other references. An introduction on heat transfer and the previous works related on the heat sink model from other researchers are explaining clearly.

Chapter 3 mainly discussed the methodology of the project. The modeling algorithm to create conventional heat sink arrangement and new arrangement are mention in this chapter. The parameter and boundaries are stated clearly in the steps of the modeling process. Details on the progress of the project are explained in this chapter.

Chapter 4 presents the results of the project. The discussion focused on the performance of various heat sink models. The optimal arrangement of pin fin is compared between the conventional arrangements.

Chapter 5 concludes overall about the project. The recommendation for future works also suggested in this chapter.

REFERENCES

- [1] Khalil Azha Mohd Annuar and Fatimah Sham Ismail, "Optimal Pin Fin Arrangement of Heat Sink Design and Thermal Analysis for Central Processing Unit", 5th International Conference on Intelligence and Advance Systems, 2014 (ICIAS14).
- [2] Bar-Cohen A. Thermal management of microelectronics in the 21st century. Electronic Packaging Technology Conference, 1997. Proceedings of the 1997 1st, 8-10 Oct 1997.29-33.
- [3] Jenkins, L. C. & Bennett, A. 21st century challenge: thermal management design requirements. Digital Avionics Systems Conference, 2004. DASC 04. The 23rd, 24-28 Oct 2004. 9.D1-9.1-7 Vol.2.
- [4] P. Ravibabu, K. Rajshekar, and K. Rohit Kumar Gupta, "Heat pipes integrated circuit coolers," in Nanoelectronics Conference (INEC), 2010 3rd International, 2010, pp. 260-264.
- [5] M. C. Zaghdoudi and A. Teytu, "Use of heat pipes for avionics cooling," in Electronics Packaging Technology Conference, 2000. (EPTC 2000). Proceedings of 3rd, 2000, pp. 425-430.
- [6] F. Yongling, Z. Meng, Q. Haitao, and A. Gaocheng, "Application of heat pipe technology in the design of hydraulic motor pump," in Electronic and Mechanical Engineering and Information Technology (EMEIT), 2011, pp. 1033-1036.
- [7] C. Anbin, X. Fengyu, L. Xiaokun, H. Yubao, W. Zonglin, Z. Yingshun, et al., "Sub-Cooled Liquid Nitrogen Test System for Cooling HTS Synchronous Motor," Applied Superconductivity, IEEE Transactions on, vol. 22, pp. 4701304-4701304, 2012.
- [8] Holman, J.P. (2010) "Heat Transfer, Tenth Edition", New York: McGraw-Hill.

- [9] Chen, C.-T. & Jan, S.-H., "Dynamic simulation, optimal design and control of pin-fin heat sink processes," Journal of the Taiwan Institute of Chemical Engineers 2012, vol. 43, pp. 77-88.
- [10] D. L. V. Andrea, G. Stefano and G. Franco, "Optimum design of vertical rectangular fin arrays,"Int. J. Therm. Sci, 1999, 38, 525-529.
- [11] Kondo, Y., Matsushima, H. & Komatsu, T. 2000. Optimization of Pin-Fin Heat Sinks For Implingement Cooling of Electronic Packages. J. Electronic Packaging 122.
- [12] Kim, D.-K., Bae, J.-K. & Kim, S. J. 2009. Comparison of Thermal Performances of Plate-Fin and Pin-Fin HeatSinks Subject To An Impinging Flow. *International Journal og Heat and Mass Transfer*, 3510-3517.
- [13] Hamadneh N, Khan WA, Sathasivam S, Ong HC (2013) Design Optimization of Pin Fin Geometry Using Particle Swarm Optimization Algorithm. PLoSONE 8(5): e66080. doi:10.1371/journal.pone.0066080.
- [14] C. J. Shih and 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, 2004, Vol.27, No. 3.
- [15] Chen, C.-T., Wu, C.-K. & Hwang, C., "Optimal Design and Control of CPU Heat Sink Processes," IEEE Transaction on Component and Packaging Technologies, 2008, pp. 184-195.
- [16] X. Zhang and D. Liu, "Optimal geometric arrangement of vertical rectangular fin arrays in natural convection," Energy conversion and management, 2010, 51, 2449-2456.
- [17] S. Bureerat & S. Srisomporn, "Optimum Plate-Fin Heat Sinks by Using a Multi-Objective Evolutionary Algorithm", Engineering Optimization Vol. 42, No. 4, April 2010, 305–323.

- [18] R. Mohan and P. Govindarajan, "Thermal analysis of CPU with variable heat sink base plate thickness using CFD," Intenational Journal of the Computer, the Internet Management, 2010, Vol. 18 No. 1, pp 27-36.
- [19] 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), 2012. 64-69.
- [20] David Geb, Ivan Catton, "Nonlocal Modeling and Swarm-Based Design of Heat Sinks", Journal of Heat Transfer, JANUARY 2014, Vol. 136.
- [21] Mohd Zainolarifin Mohd Hanafi and Fatimah Sham Ismail, "Heat Sink Model and Design Analysis Based on Particle Swarm Optimization", IEEE Innovative Smart Grid Technologies –Asia (ISGT ASIA), 2014.
- [22] Jabber, A. A. A., Jawad, M. R. & Humadil, A. A. M. 2010. "The Effect of Heat Sink Fins Length and Material on Its Performance". Diyala Journal of Engineering Sciences, 1-11.
- [23] Shankar, N. V. S., Desala, R., Babu, V., Krishna, P. V. & Rao5, M. M. 2012. Flow Simulation To Study The Effect of Flow Type on the Performance of Multi-Material Plate Fin Heat Sinks. [Ijesat] International Journal of Engineering Science & Advanced Technology, 2,233-240.