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Modelling and Thermal Analysis of Printed Circuit Board Heat Sink

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Abstract

This study entails the modeling and examination of heat transfer concerning a heat sink on a Printed Circuit Board (PCB). The focus is on an elliptical fin configuration with integrated slits, and the analysis employs Ansys software to evaluate heat transfer dynamics. The utilization of elliptical fins aims to mitigate vortex-induced effects by minimizing pressure losses across the heat sink. This design, often manufactured through the extrusion of plate fins with strategically placed cross-cuts, can be further improved by employing a forging process to shape the fins into ellipses. In comparison to traditional plate fin heat sinks, the elliptical fin design demonstrates enhanced heat transfer efficiency in scenarios characterized by low airflow. Furthermore, when contrasted with Round Pin Heatsinks, the introduction of cross-cuts in the elliptical configuration results in a larger exposed surface area for improved heat dissipation. Particularly noteworthy is the outstanding performance of elliptical fins, capable of lowering temperatures from 350 K to 305 K for a 15W heat load. This configuration proves especially effective in applications involving parallel arrays of heat sinks. By facilitating a substantial airflow between adjacent heat sinks, the fins mitigate air blocking, thereby enhancing the circulation of cool air and optimizing overall ventilation.

Keywords: Heat Transfer; Fins; Temperature; Velocity; AA 6063

1. Introduction

A Heat Sink, often referred to as fins, acts as a passive heat exchanger, transferring the thermal energy produced by electronic or mechanical devices to a fluid medium, typically air or liquid coolant. This process results in the dissipation of heat away from the device, effectively regulating its temperature. Within the realm of computers, heat sinks are strategically employed to cool essential components such as Control Processing Units (CPUs), specific chipsets, and modules like Random Access Memory (RAM). Additionally, heat sinks find utility in high-power semiconductor devices, including power transistors, as well as optoelectronic components like lasers and light-emitting diodes (LEDs), where intrinsic heat dissipation capabilities fall short of maintaining appropriate temperatures.

In the modern computing landscape, CPUs generate substantial heat due to heightened power outputs. This surplus heat introduces unwanted thermal stress to the system, placing central processing units at risk of malfunction or even permanent damage. Addressing this issue requires effective heat management to ensure optimal system performance. An exemplary candidate for experimental investigation is the Raspberry Pi server, given its compact size and over-clocking capabilities. This device emits approximately 15W of heat.

Jha and Kailash [1] investigated heat transfer across extended surfaces, exploring fins with various shapes and cavities. Cavitated fins exhibited heat transfer enhancements of 2% to 21%, with rectangular cavities being particularly effective. Karthikeyan et al. [2] studied heat transfer rates on different fin extensions, emphasizing the efficiency of rectangular extensions. Didwania et al. [3] analyzed pressure loss and heat transfer in a rectangular duct, revealing circular fins' superior heat transfer. Nemati and Samivand [4] developed a novel correlation for efficient annular elliptical fins, optimizing geometry for enhanced heat dissipation. Elliptical fins' complexity was compared to circular fins [5]. Researchers [6-10] employed ANSYS software for intricate PCB heat sink analysis under varying conditions. Yang et al. [11] used nanocomposite materials for effective electronic cooling, lowering temperatures and extending device life. Khairnasov [12] determined optimal thickness for effective heat dissipation in heat-removing layers. LEDs' optimal function using heat sinks was explored by Paul et al. [13]. Korobkov et al. [14] compared cooling methods for electronic devices. Zhan et al. [15] addressed heat issues in integrated electronic chassis using simulations and infrared testing. Lavi et al. [16] introduced a graphene-based coating for effective electronic cooling. Amoroso et al. [17] proposed an experimental-numerical approach for reliable cooling in high-voltage silicon MOSFET modules. PCB thermal performance and reliability were modeled [18]. Kadum et al. [19] investigated air-cooling for PCBs, with horizontal orientation showing better heat transfer. Alshihmani et al. [20] studied phase change materials' impact on PCB cooling efficiency. Pongnot [21] proposed an innovative automotive converter structure, considering geometric parameters for thermal resistance. Hollstein [22] analyzed Quad Flat No-lead (QFN) package heat dissipation. Catalano et al. [23] introduced analytical thermal models for PCB thermal vias and heat sinks. Kang et al. [24] presented an advanced thermal management approach using a micro-pin fin heat sink for GaN power amplifiers, enhancing device performance.

In this work, the focus is on studying and analyzing the heat transfer for elliptical fins in a PCB heat sink using Ansys software.

2. Materials and methodology

2.1. Materials

Aluminium Alloy AA 6063 is an amalgamation of aluminium, containing magnesium and silicon as its principal alloying components. The formulation's adherence to established standards is overseen by The Aluminium Association. This alloy showcases commendable mechanical attributes, is amenable to heat treatment and welding processes, and offers versatile applications.

Notably, AA 6063 stands as the predominant choice for aluminium extrusion. Its characteristics enable the shaping of intricate forms, resulting in exceptionally smooth surfaces that are well-suited for anodizing. Consequently, this alloy enjoys popularity in visible architectural contexts, finding utility in structures such as window frames, door frames, roofs, and sign frames. In instances necessitating heightened strength, alloys like 6061 or 6082 are favored alternatives. The accompanying tables illustrate the composition (Table 1) and properties (Table 2) inherent to Aluminium Alloy AA 6063.

Table 1. Components of AA 6063

Element	Weight Percentage
Aluminium	98.6
Magnesium	0.45
Iron	0.35
Silicon	0.2
Manganese	0.1
Chromium	0.1
Zinc	0.1
Titanium	0.1

Table 2. Properties of AA 6063

Property	Value	Units
Density	2700	Kg/m^3
Thermal Conductivity	202.3	W/m-K
Specific heat capacity	900	J/Kg-K
Melting Temperature	615	^{o}C
Linear Thermal Expansion Coefficient	2.34e-5	K^{-1}
Tensile Yield Strength	214	MPa

The utilization of AA 6063 alloy is motivated by its impressive thermal conductivity, measuring approximately 202.3 W/m K. This thermal conductivity figure outperforms that of any other existing AA alloy, including the AA 2024 alloy. Furthermore, AA 6063 boasts a lower density when compared to the currently employed AA 2024 alloy, which is commonly used in fin manufacturing.

2.2. Design of fin profile

Annular fins find extensive application within industries to amplify heat transfer surfaces. While circular annular fins have undergone comprehensive investigation, elliptical fins remain partially explored, with some research endeavors undertaken. A notable advantage of elliptical fins lies in their ability to yield reduced pressure drops compared to circular fins. Furthermore, their unidirectional extension proves particularly advantageous in scenarios constrained by limited space.

The inverse relationship between fin length and heat transfer rate is evident. Consequently, the optimization imperative revolves around maximizing heat transfer within specified fin volume constraints. This optimization framework has been extensively documented for annular circular fins. However, the domain of shape optimization for annular elliptical fins remains relatively sparse. Within annular elliptical fins, the optimization challenge introduces an additional variable—the radius ratio. Limited experimental efforts have been undertaken to explore the impact of natural convection on predefined elliptical fin geometries.

Nemati et al. [4] presented a straightforward correlation to deduce the efficiency of circular annular fins. Building on this foundation, they extended their analysis to predict the efficiency of elliptical annular fins as well.

Characteristics of the elliptical fin:

- Elliptical fin configuration ensures minimal pressure-drop attributes.
- Constructed using Forged Aluminium alloy 6063 to achieve optimal heat transfer efficiency.
- Particularly well-suited for environments characterized by linear airflow patterns.

The fin's design process is executed within SOLIDWORKS. The fin's geometric profile features an elliptical cross-section, incorporating a strategically positioned slit that is offset from the semi-major axis. This design choice aims to enhance the heat transfer rate across the fin.

Both the fin and the Printed Circuit Board (PCB) are meticulously crafted using SOLIDWORKS software, as depicted in Fig. 1.

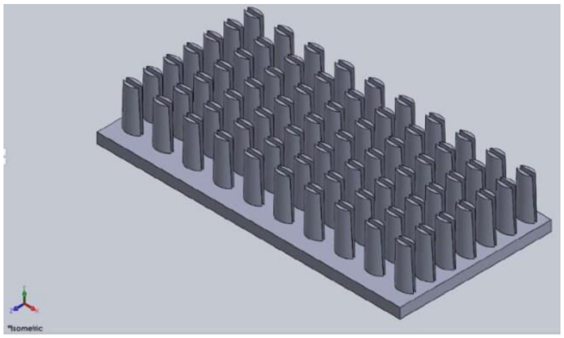

Fig. 1. 3D model of fin profile

3. Results

Fig. 2 illustrates the contour of the velocity profile across the profile's cross-section. The velocity distribution throughout the volume closely mirrors the inlet velocity. The fin's specific design, characterized by strategically placed slits, prevents a complete reduction in velocity across the volume.

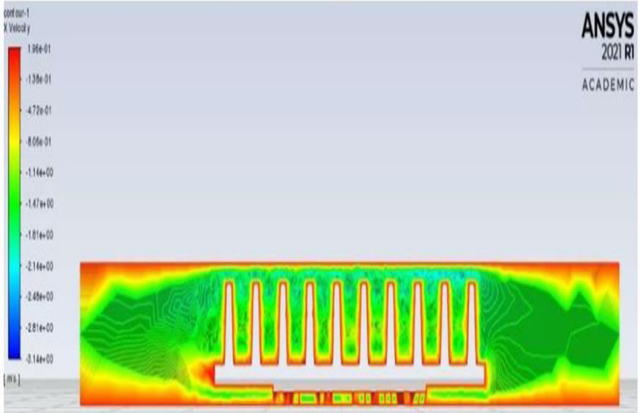

Fig. 2. Velocity contour of cross-section

In Fig. 3, the temperature contour is depicted. Given the nearly consistent airflow rate across the volume, as observed in Fig. 2, the temperature reduction occurs at the PCB's base due to the influence of the surrounding air. Notably, the temperature at the fin's base rests at approximately 305K, indicating an optimal value for efficiently cooling the PCB.

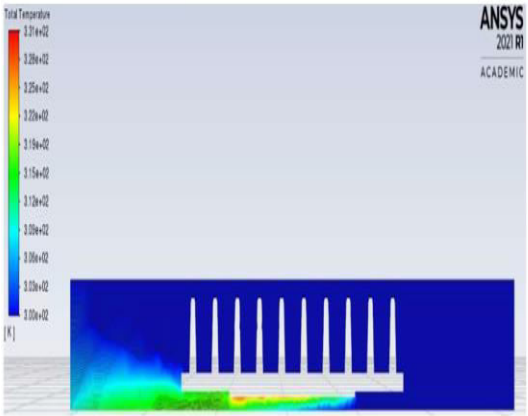

Fig. 3. Temperature contour of cross-section

Fig. 4 illustrates the dispersion of heat across the fins from the PCB. The outcomes of the analysis indicate that the employment of elliptical fins effectively lowered the temperature of the PCB to a range of 300 K to 305 K. This cooling effect was facilitated by utilizing AA 6063 alloy, known for its elevated thermal conductivity, which in turn enhanced the rate of heat transfer.

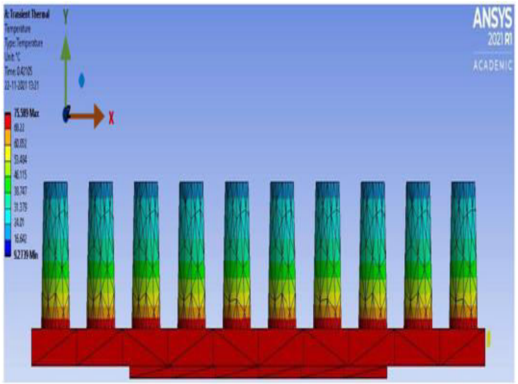

Fig. 4. Temperature profile

4. Conclusion and future aspects

4.1. Conclusion

The Raspberry Pi, currently utilized as a compact CPU for various small-scale applications, gives rise to heat generation within its printed circuit board (PCB) due to current flow. This thermal resistance poses an efficiency challenge for the PCB's functionality. To address this, cooling fins are employed. In the case of cooling the Raspberry Pi 3 PCB, which produces approximately 15W of heat, an innovative approach involves the use of elliptical fins with slits, as opposed to conventional circular pin fins. This modification aims to enhance the rate of heat transfer [2]. The design of these elliptical fins was carried out using SOLIDWORKS, and subsequent computational fluid dynamics (CFD) analysis was performed using Ansys Fluent software to evaluate the effects of fluid flow.

As outlined in the results section, the heatsink comprising the proposed elliptical fin configuration effectively reduced the temperature of the PCB from 350 K to 305 K. This achievement underscores the effectiveness of the chosen design. The analysis was conducted based on a set of assumptions detailed in the corresponding sections.

4.2.Future aspects

- Leveraging the computational speed of modern workstations, we are poised to harness the potential of CFD tools in upcoming endeavors. This will facilitate the modeling of improved design variations that closely mirror real-world PCBs, thereby circumventing the assumptions made in the current investigation.
- Enhanced accuracy in predicting fluid flow and heat transfer attributes of PCB heat sinks can be achieved by implementing finer mesh structures alongside multiphase models.
- In order to attain outcomes that align more closely with real-world scenarios, the following assumptions were adopted in the current investigation:
    - Steady-state heat conditions were assumed.

  - Contact thermal resistance was considered negligible.
  - Heat generation within the fins was disregarded.
  - The material composing the fins was assumed to be homogenous and isotropic.
  - A uniform heat transfer coefficient (h) was assumed across the entire surface of the fins.
  - Heat conduction was assumed to occur in a one-dimensional manner.
- Variations in materials can be explored, coupled with analyses encompassing a broad spectrum of operating temperatures and airflow rates.
- Looking ahead, practical methodologies can be implemented, gradually eradicating assumptions to attain more accurate results.
- The flexibility of altering materials allows for analyses across varying PCB temperatures and air velocity conditions.
- In order to validate the system and delve further into exploration, diverse aspects related to distinct environmental conditions can be examined.

References

[1] N. K Jha, B.A. Kailash, “Heat transfer enhancement and thermal performance of extended surfaces with cavity”, *International Journal of Innovative Research in Science, Engineering and Technology*, 4(10)2015, 9792-9797.

[2] V. Karthikeyan, R. S. Babu, G. V. Kumar,“Design and analysis of natural convective heat transfer coefficient comparison between rectangular fin arrays with perforated and fin arrays with extension”, *International Journal of Scientific Engineering and Technology Research*, 4(2) 2015.

[3] M. Didwania, G. Krishnan, Ravikant, Study and analysis of heat transfer through two different shape fins using CFD tool,*International Journal of IT, Engineering and Applied Sciences Research*, 2(4) 2013, 13-20.

[4] H. Nemati, S.Samivand, “Performance optimization of annular elliptical fin based on thermo-geometric parameters”, *Alexandria EngineeringJournal*, 54(4) 2015, 1037-1042.

[5] N. Nagarani, K. Mayilsami, “Experimental heat transfer analysis on annular circular and elliptical fins”, *International Journal of Engineering Science and Technology*, 2(7) 2010, 2839-2845.

[6] V.Samavi, “Printed circuit board (PCB) thermal analysis”, *International Journal of Innovative*

Science and Research Technology, 3(1) 2018, 350-357.

[7] A. Jain, P. K. Upadhyay, J. Chouhan, "A review on heat transfer from different shaped fins", *Smart Moves Journal IJOSCIENCE*, 2(2)2016, 10-16.

[8] S. Sunil, S. S. Gowreesh, B. R. Veeresh, "Heat transfer enhancement and thermal performance of extended fins", *International Journal of Engineering and Advanced Technology*, 5(5) 2016, 127-131.

[9] F. Shaikh, J.Challa, "CFD analysis on circular pin fin", International Journal of Science Engineering and Research, 4(5) 2016, 47-49.

[10] I. G. Aksoy, "Thermal analysis of annular fins with temperature-dependent thermal properties", Applied Mathematics and Mechanics 34(11) 2013, 1349–1360.

[11] D. Yang, Q. Yao, M. Jia, J. Wang, L. Zhang, Y. Xu, X. Qu, "Application analysis of efficient heat dissipation of electronic equipment based on flexible nanocomposites", *Energy and Built Environment*, 2(2) 2021, 157-166.

[12] K.Z. Khairnasov, "Modeling and thermal analysis of heat sink layers of multilayer board", *Amazonia Investiga*, 8(23) 2019, 664-670.

[13] B. Paul, M. Mathew, P. G. Shripad, "Modelling and thermal analysis of honeycomb heat sink for LEDs in street lighting applications," *International Conference on Inventive Systems and Control (ICISC)*, Coimbatore, India, 2017, 1-5.

[14] M. Korobkov, F. Vasilyev, V. Mozharov, "A Comparative analysis of printed circuit boards with surface-mounted and embedded components under natural and forced convection. *Micromachines*, *13*(4) 2022, 634.

[15] Z. Zhang, Z. Li, H. Cui, J. Guo, Y. Liu, "Thermal analysis and optimal design of artillery integrated electronic case based on FloEFD", *Journal of Physics: Conference Series*, 2023, 2478, 122051.

[16] A.O. Lavi, G.S. Michaely, E. Koronio, Y. Keller, E. Yalon, G. Ziskind, O. Regev, "Graphene-based conformal coating for heat dissipation on printed circuit boards" *Applied Thermal Engineering*, 229, 2023, 120562.

[17] D. M. Amoroso, G. Mauromicale, M. Calabretta, A. A. Messina, G. D'Arrigo, G. Sequenzia, A. Sitta, "Reliability and Thermal Analysis of ACEPACK SMIT Power Module," *PCIM Europe 2023; International Exhibition and*

Conference for Power Electronics, Intelligent Motion, Renewable Energy and Energy Management, Nuremberg, Germany, 2023, 1-7.

[18] Y.Wan, H. Huang, “Thermal performance analysis and prediction of printed circuit boards”, *Journal of Circuits, Systems and Computers*, 32(13) 2023, 2350225.

[19] M.E. Kadum, S.Aljabair, A.A.Imran, “Experimental and numerical study heat transfer performance for printed circuit board”, *AIP Conference Proceedings*, 2023, 2830, 070003.

[20] H. Alshihmani,M. Maghrebi, M. Sardarabadi, “Thermal performance prediction of a phase change material based heat-sink cooling system for a printed circuit board, using response surface method”. *Journal of Energy Storage*, 55, Part B, 2022, 105499.

[21] G. Pongnot, M. Petit, M. C. Duluc, F. Adam, C. Mayet, D. Labrousse, "Thermal analytical modelling of the heat transfer through a power PCB dedicated to a high current density modular converter," *PCIM Europe 2022; International Exhibition and Conference for Power Electronics, Intelligent Motion, Renewable Energy and Energy Management*, Nuremberg, Germany, 2022, 1-9.

[22] K. Hollstein, X. Yang, K.W.Zaage, “Thermal analysis of the design parameters of a QFN package soldered on a PCB using a simulation approach”, *Microelectronics Reliability*, 120, 2021, 114118.

[23] A.P. Catalano, R. Trani, A. Castellazzi, V. d’Alessandro, "Analytical modeling of through-PCB thermal vias and heat-sinks for integrated power electronics," *2019 25th International Workshop on Thermal Investigations of ICs and Systems (THERMINIC)*, Lecco, Italy, 2019, 1-6.

[24] T.Kang, Y.Ye, Y. Jia, Y. Kong, B. Jiao, “Enhanced thermal management of GaN power amplifier electronics with micro-pin fin heat sinks”, *Electronics*, 9(11) 2020, 1778.