ELECTRONIC EQUIPMENTS COOLING THROUGH RECTANGULAR FIN ARRAY BY USING NATURAL CONVECTION: A REVIEW

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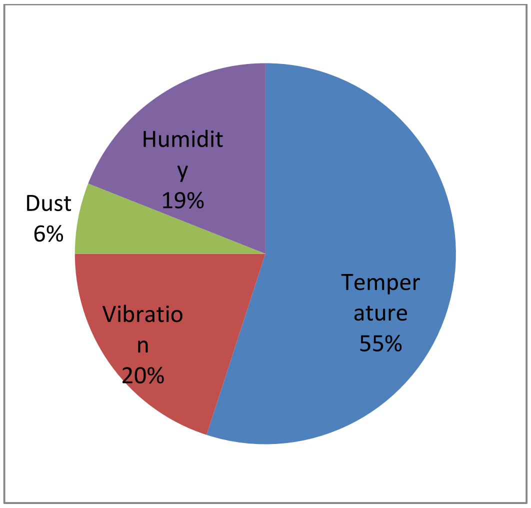
Abstract: High power density electronic equipments during operation generate heat causing temperature rise of the system and if these heat is not dissipated may cause serious overhaeating problem leading to system failure. The design of efficient cooling strategies is essential for reliable performance of high power density electronics. The present paper reviews the literature dealing with various aspects of cooling methods. Among heat transfer augmentation techniques, passive cooling technique found more suitable for electronic cooling than active technique. In this paper, natural convection heat transfer analysis through rectangular fins is reviewed. The paper focus on the various experimental studies has been made to investigate effect of fin height, fin spacing, fin length and fin thickness over convective heat transfer.

Keywords: Rectangular fins, convective heat transfer, heat sink

I. INTRODUCTION

Electornic systems during their operation generate heat. If this generated heat is not dissipated rapidly to its surrounding atmosphere, this may cause rise in temperature of the system Components. This by-product cause serious overheating problems in system and leads to system failure, so the generated heat within the system must be rejected to its surrounding to maintain the system at recommended temperature for its efficient working. The design of efficient cooling strategies is essential for reliable performance of high power density electronics. A number of failure mechanisms in electronic devices, such as inter-metallic growth, metal migration, and void formation, are related to thermal effects. In fact, the rate of such failures nearly doubles with every 10°C increase above the operating temperature (~80°C) of high power electronics. The thermal design of the system is influenced by the key drivers like chip size, power dissipation, junction temperature and ambient air temperature.

It has been found that for every 2 ºC temperature rise, the reliability of a silicon chip will be decreased by about 10 %. The major cause of an electronic chip failure is due to temperature rise (55%) as against other factors which accounts 20 % vibration, 19 % humidity and 6 % dust Fig.(1.1). So it's a great challenge for the packaging engineers to remove the heat from the electronics chips very effectively.



1.1 Major cause of electronic failure

Throughout the past 50 years, cooling and thermal management have played a key role in accommodating increases in power while maintaining component temperatures at satisfactory levels to satisfy performance and reliability objectives. Thermal management will play a pivotal role in the coming decade for all types of electronics products. Increased heat fluxes at all levels of packaging from chip to system to facility pose a major cooling challenge. To meet the challenge, significant cooling technology enhancements will be needed.

II. COOLING TECHNIQUE

In general thermal management is categorized into active cooling techniques and passive cooling techniques. Mechanically assisted cooling sub systems provide active cooling. Active cooling technique offer high cooling capacity. They allow temperature control that can cool below ambient temperatures. In most cases active cooling techniques eliminate the use of cooling fans or they require less cooling. Air/liquid jet impingement, forced liquid convection, spray cooling thermoelectric coolers and refrigeration systems are the examples of active cooling techniques.

Passive cooling methods are widely preferred for electronic and power electronic devices since they provide low-price, noiseless, and trouble free solutions. Some passive cooling techniques include: heat pipes, natural convection air cooling, and thermal storage using phase change materials (PCM). Heat pipes can efficiently transfer heat from heat sources in high power density converter components to a heat sink based on phase change of a working fluid [1, 2]. Air-cooling also is recognized as an important technique in the thermal design of electronic packages, because besides its availability, it is safe, does not contaminate the air and does not add vibrations, noise and humidity to the system in which it is used [3]. Such features of natural convection stimulated considerable research on the development of optimized finned heat sinks and enclosures [4, 5, 6]. Using fins is one of the most inexpensive and common ways to dissipate unwanted heat and it has been successfully used for many engineering applications.

Fins come in various shapes; such as rectangular, circular, pin fin rectangular, pin fin triangular, etc., see Fig. 1.2, depending on the application. Rectangular fins are the most popular fin type because of their low production costs and high thermal effectiveness.

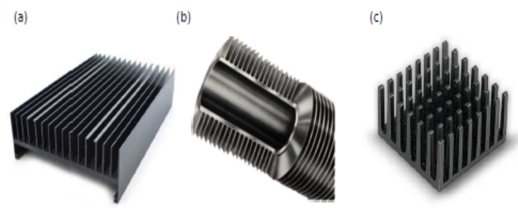


Fig 1.2- Fin Types, a) Rectangular b) Radial c) Pin Fins

Heat sinks are the most common thermal management hardware used in electronics. They improve the thermal control of electronic components, assemblies, and modules by enhancing their surface area through the use of fins. Applications utilizing fin heat sinks for cooling of electronics have increased significantly during the last few decades due to an increase in heat flux densities and product miniaturization. Todays advanced electronic circuits disperse substantially heavier loads of heat than ever before. At the same time, the premium associated with miniaturized applications has never been greater, and space allocated for cooling purposes is on the decline. These factors have forced design engineers to seek more efficient heat sink technologies. Air-cooling also is accepted as an important technique in the thermal design of electronic packages, because besides its availability, it is safe, does not contaminate the air and does not add Vibrations, noise and humidity to the system in which it is used. Using fins is one of the most inexpensive and common ways to dissipate unwanted heat and it has been successfully used for many engineering applications. Rectangular fins are the most popular fin type because of their low production costs and high thermal effectiveness.

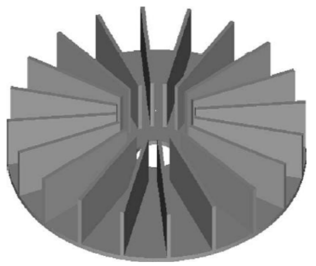


Fig 1.3 Radial heat sink with circular base and rectangular fins

III. REVIEW OF PREVIOUS WORK

F. Harahap, H. Lesmana [7] studied heat dissipation from miniaturized vertical rectangular fin arrays. Experiment was conducted under steady state heat dissipation and dominant natural convection condition for 3mm and 11mm fin spacing. They concluded that effect of the parameter W/L on heat dissipation rate is relatively less for the vertically base array. Also, higher heat dissipation rate was observed for non-square base, same base area and orientation with fins parallel to short side of the base plate than fin parallel to longer side (W/L≤1) of the base.

H. Yuncu [8] performed experiments over thirty different fin configurations with 250 and 340 mm fin length. Optimum fin spacing of aluminum rectangular fins on vertical base was examined. The range of base-to-ambient temperature was kept quiet wide from 30 to 150K for fin height and fin spacing from 5 to 25mm and 4.5 to 85.5 mm, respectively. It was found that optimum fin spacing varies for each fin height which is between 6.1 and 11.9mm. They developed Eq.1 to evaluate the optimum fin spacing value and corresponding maximum heat transfer rate at given fin length and base-to-ambient temperature difference for vertical base fin array. They commented that the larger fin height results in higher convective heat transfer from fin array but for low base-to-ambient temperature difference it was insignificant.

Yongping Chen et al. [9] developed and analyzed numerically a three-dimensional model of heat transfer and fluid flow in noncircular microchannel heat sinks. It is found that Nusselt number has a much higher value at the inlet region, but quickly approaches the constant fully developed value. The temperature both in solid and fluid increases along the flow direction. In addition, the comparison of thermal efficiencies is conducted among triangular, rectangular and trapezoidal microchannels. The result indicates that the triangular microchannel has the highest thermal efficiency.

Abdullatif Ben-Nakhi and Ali J. Chamkha[10] focused on the numerical study of steady, laminar, conjugate natural convection in a square enclosure with an inclined thin fin of arbitrary length. The inclined fin is attached to the left vertical thin side of the enclosure while the other three sides are considered to have finite and equal thicknesses of arbitrary thermal conductivities. The left wall of the enclosure to which the fin is attached is assumed heated while the external sides of the other three surfaces of the enclosure are cooled. The inclined thin fin is perfectly conductive and is positioned in the middle heated surface of the enclosure. Three different finlengths equal to 20, 35 and 50 percent of the heated surface are considered. The problem is formulated in terms of the vorticity-stream function procedure. A numerical solution based on the finite-volume method is obtained. Representative results illustrating the effects of the thin fin inclination angle and length and the thermal conductivity of the thick surfaces on the streamlines and temperature contours within the enclosure are reported. In addition, results for the local and average Nusselt numbers are presented and discussed for various parametric conditions.

Reng-Tsung Huang et. al. [11] experimentally carried out the natural convection heat transfer from square pin fin heat sinks subject to the influence of orientation. A flat plate and seven square pin fin heat sinks with various arrangements are tested under a controlled environment. Test results indicate that the downward facing orientation yields the lowest heat transfer coefficient. However, the heat transfer coefficients for upward and sideward facing orientations are of comparable magnitude.

Hussam Jouhara [12] investigated the comprehensive description of the thermal conditions within a heat sink with rectangular fins under conditions of cooling by laminar forced convection. The analysis, in which increasing complexity is progressively introduced, uses both classical heat transfer theory and a computational approach to model the increase in air temperature through the channels formed by adjacent fins and the results agree well with published experimental data.

Sanjeev D. Suryawanshi et. al. [13] investigated normal and inverted notched fin arrays (INFAs) experimentally and numerically using Commercial CFD software and reported that the values of ha are 50–55% higher for INFAs giving better performance. For smaller spacing, increment in ha is small due to the flow constriction effect. The value of ha increases with spacing giving an optimum value at about S=6 mm. This is in agreement in other investigators. Single chimney flow pattern is retained in INFAs also with a wider chimney zone, which is the possible reason for heat transfer enhancement. When single chimney flow pattern is present, in midchannel stagnant bottom portion becomes ineffective. The modified array is designed in inverted notched form and that has proved to be successful retaining single chimney together with the removal of ineffective fin flat portion. CFD solutions obtained are in good agreement with experimental work.

Seung-HwanYu et.al. [14] experimentally and numerical investigated the natural convection in a radial heat sink, composed of a horizontal circular base and rectangular fins. The general flow pattern is that of a chimney; i.e., cooler air entering from outside is heated as it passes between the fins, and then rises from the inner region of the heat sink. Parametric studies are performed to compare the effects of three geometric parameters.

S.C. Haldar [15] studied numerically the laminar free convection about a single pin fin attached to a horizontal base plate has been reported in this article. Fluid at the far field moves horizontally towards the fin and then rises almost vertically along the fin and finally leaves through the top. With the increase in fin diameter heat transfer increases while the heat flux at fin base decreases establishing the advantage of large number of small diameter fins over fewer fins of bigger diameter.

S.A. Nada [16] investigated experimentally the heat transfer and fluid flow characteristics in horizontal and vertical narrow closed enclosures having a heated finned base plate. The effects of fin length and fin spacing have been studied for both orientations at a wide range of Rayleigh number. It has been found that insertion of fins with any fin array geometries increases the rate of heat transfer. Quantitative comparisons of heat transfer rate and surface effectiveness for both enclosure orientations have been reported. Optimization of fin-array geometries for maximum Nusselt number and finned surface effectiveness has been conducted. It was found that: For a high range of Ra, increasing Ra increases Nusselt number and decreases fin effectiveness.For a small range of Ra and at large S/H, increasing Ra increases both of Nusselt number and finned surface effectiveness. Nusselt number and finned surface effectiveness increases with decreasing S/H until S/H reaches a certain value beyond which the Nusselt number and finned surface effectiveness start to decrease with further decreasing of S/H. The maximum value of Nusselt number and finned surface effectiveness occurs at S/H = 1 for both enclosure orientations. The Nusselt number and finned surface effectiveness increased with increasing fin length. Useful design guidelines and correlations were developed for both enclosure orientations. The predictions of these correlations were compared with the present and previous experimental data and good agreement was found.

IV. CONCLUSION

The high heat flux cooling of electronic equipments and devices with various methods is reviewed. Particularly heat sinks which are used for natural convection and forced convection as passive device is studied. Fins is one of the most inexpensive and common ways to dissipate unwanted heat hence its study is very important for improved design and also improving the heat dissipation rate performance of the plate by using different fin geometry and fin array also by other parameters such as fin height, fin spacing. The challenges of cooling electronic equipments may be expected to continue through the remaining of this decade. As the size of semiconductor is reducing day by day and power dissipation is increasing rapidly, so a breakthrough is needed in advanced cooling to reduce cost without sacrificing effectiveness of cooling.

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