CHAPTER-1

INTRODUCTION

1.1 COOLING OF ELECTRONIC EQUIPMENTS:

In general, the sole objective of improving the cooling of electronic systems is to increase cooling capacity. The failure rate of electronic equipment increases exponentially with temperature. Heat removal in an efficient way is necessary in order to maintain reliable operation of electronic devices. The trend in the electronic industry is packing more and more circuits in a given space. With the trend towards further microminiaturization of electronic packages the thermal design problem is **recognized as one of the factors limiting the achievement of higher** packaging densities. A recent trend of electronic systems is the rapid reduction of size with greater capability and processing rate. To attain this purpose, the connection length between chips should be shorter and integration rate of components should be higher. The electric power consumption increases considerably while the size diminishes. It results in significant increase of power density.

The reliability of equipments is, therefore, becoming more critically dependent on the accuracy of heat transfer analysis, which traces the heat flow from chips to the surroundings. High power dissipation may require new cooling techniques, but wherever possible, direct air cooling still remains an attractive method because of its mechanical simplicity.

The modern microprocessors for computers are realized in fact integrating on a surface of an order of magnitude equal to a square centimeter, a very high number of modular computing units. An increment of performances causes a more elevate dissipation of heat as a consequence of the number of single modules integrated in the CPU. The heat generated, in addition to the risk of physically damaging the electronic components, reduces the global performance of the system, so limiting the chance of technical improvements.
The importance of ever more effective heat exchangers is so much needed to cope up with the advancements of electronics. In order to increase the speed of the circuits; the circuit power has to be increased, which leads to temperature augmentation. The accumulation of large amount of heat flux can create considerable quantities of heat stress on chips, substrate, and its package. Therefore, it is necessary for employing effective heat sink module to maintain the operating temperature of electronic components at a safe level. If there is appropriate and effective heat sink design, it will critically affect the reliability and life span of chip function. Extended surfaces of fins, or so-called heat sinks, are in common use in the electronic industry and serve to enhance the thermal capability of convective cooling with air.

Heat sinks are often used to enhance the rate of heat dissipation from printed circuit boards (PCBs) and other power sources within computers and electronic enclosures. These PCBs incorporate a large number of electronic components connected by a network of metal tracks that transport the electric charge. Although the electronic components are usually the source of most of the heat generated in the PCB, the heating of the tracks by dissipation of electric charge is not negligible. Moreover, part of the heat generated in the electronic components is transferred to the tracks nearby.

Hence the design of cooling systems is more significant, and thermal management of electronic equipment has become an important issue. The options for such systems should be carefully investigated. Such options include heat transfer by conduction through materials, heat transfer by convection to an external cooling agent, and radiation heat transfer. However, often these modes of heat transfer are tied together, thus the heat transfer problems become more challenging.

Cooling can be categorized as: a) Passive cooling i. e. Natural Convection, b) Active cooling i. e. Forced Convection. Passive Cooling is done with natural fluid movement and by conduction and / or by radiation. Natural convection is a widely preferred method of cooling, and air-cooling is one of the most traditional methods. The prime reason for that may be its availability in desired amounts. Moreover the design of natural convection air-cooling systems is simple and economic, the systems have high reliability and easy maintenance and there is no
acoustic noise. The most common techniques for enhancing natural convection air-cooling are using parallel plate channels and various fin configurations.

In recent years, the study of heat sinks under both forced and natural convection has received much attention in view of the consistent trends in microelectronic design aiming toward higher packaging densities and higher power dissipation rates. Due to their inherent simplicity, reliability, and low long-term costs, natural convection heat sinks have proven to be instrumental in cooling single or multiple-chip circuit boards.

In Active cooling fluid motion is assisted by an external source like (i) a fan in a forced air-cooled system, (ii) Pump and fan in an immersion or refrigeration cooled system. In Active or forced cooling, increase in cooling capacity can never be accomplished without corresponding increases in fluid friction loss, which induces an increase in fan/blower power consumption and acoustic noise level, both of which are disadvantageous in electronic systems.

One of the primary goals in the design of modern thermal systems for cooling of electronic components is the achievement of more compact and, hence, energy efficient devices. This requires the employment of surfaces with high heat transfer coefficients and high area compactness. Particular attention has to be paid to the selection/design of heat transfer surfaces if the required energy-carrying fluid turns out to be a gas. It is well known that gases have heat transfer coefficients that are about 100 times lower than those of liquids. This is usually compensated with larger heat transfer areas and it is the aim of the work of engineers to have the surface area reduced by enhancing the heat transfer coefficients. Heat transfer enhancement devices are often employed to increase the rate of heat transfer. For applications in electronics cooling, the objective is to maintain the operating temperatures at a safe level for long term, reliable operation. In most cases, however, the selection of the most appropriate geometry for a particular application is difficult, since by adding a heat transfer enhancement device, not only the rate of heat transfer increases (reducing the heat transfer irreversibility), but also the fluid friction increases (increasing the hydrodynamic irreversibility). This raises the question as to what is the real advantage of the employed enhancement technique. Most of the
breakdowns in electronics results from thermal overstressing and the temperature of semiconductor components should not exceed the manufacturers' recommendations.

1.2 HEAT-SINK TYPES:

Heat sinks can also be classified in terms of manufacturing methods and their final form shapes. The most common types of air-cooled heat sinks include [1]:

1. Bonded/Fabricated Fins: Most air cooled heat sinks are convection limited, and the overall thermal performance of an air cooled heat sink can often be improved significantly if more surface area exposed to the air stream can be provided even at the expense of conduction paths. These high performance heat sinks utilize thermally conductive aluminum-filled epoxy to bond planar fins onto a grooved extrusion base plate. This process allows for a much greater fin height-to-gap aspect ratio of 20 to 40, greatly increasing the cooling capacity without increasing volume requirements.

2. Folded Fins: The heat sink manufactured from corrugated aluminum or copper sheet is attached to either a base plate or directly to the heating surface via epoxying or brazing. It is not suitable for high profile heat sinks due to the availability and from the fin efficiency point of view. However, it allows obtaining high performance heat sinks in applications where it is impractical or impossible to use extrusions or bonded fins.

3. Castings: Sand, lost core and die casting processes are available with or without vacuum assistance, in aluminum or copper/bronze. This technology is used in high density pin fin heat sinks which provide maximum performance when using impingement cooling.

4. Forging: In forged heat sinks, the fin arrays are formed by forcing raw material into a molding die by a punch, which usually weighs about 500 tons. Common problems in forging are the choking of material in the molding die cavity, which could lead to fins of uneven height. Secondary processes may include cutting the fins, machining the base, polishing, or etching. While hot forging is inherently easier, cold forging results in denser and stronger fins. Some of the attractive benefits of forging include high strength, superior surface finish, structural rigidity, close tolerance capabilities, continuity of shape, and high uniformity of material. Aluminum and magnesium alloys are easily
forged, and an important economic advantage is a typically low rejection rate for the process. This process category also includes techniques such as impact extrusion and micro-forging.

Stampings: Copper or aluminum sheet metals are stamped into desired shapes. They are used in traditional air cooling of electronic components and offer a low cost solution to low density thermal problems. Suitable for a high volume production, and advanced tooling with high speed stamping would lower costs. Additional labor-saving options, such as taps, clips, and interface materials, can be factory applied to help reduce the board assembly costs.

5. Extrusions: Allow the formation of elaborate two-dimensional shapes capable of dissipating large wattage loads. They may be cut, machined, and options added. A crosscutting will produce omni directional, rectangular pin fin heat sinks, and incorporating serrated fins improves the performance by approximately 10 to 20% at the expense of extrusion rate. Extrusion limits, such as the fin height-to-gap aspect ratio, minimum fin thickness-to-height, and maximum base to fin thicknesses usually dictate the flexibility in design options. Typical fin height-to-gap aspect ratio of up to 6 and a minimum fin thickness of 1.3 mm are attainable with a standard extrusion. A 10 to 1 aspect ratio and a fin thickness of 0.8 mm can be achieved with special die design features. However, as the aspect ratio increases, the extrusion tolerance needs to be compromised.

6. Machining: Heat sinks are machined out of a metal block by material removal to create the inter-fin spaces. Most commonly they are manufactured by gang saw cutting on a computer numerical control (CNC) machine. The gang saw consists of multiple saw cutters on an arbor with precise spacing, which depends on the heat sink geometry to be machined. Often, during machining, the fins are damaged and distorted, and require extensive secondary operations. Material is also consumed in an unproductive manner by the generation of scrap metal.

These methods of manufacturing are shown in Fig. 1.1.
Fig. 1.1 Schematic of advanced heat sink manufacturing processes [2]
1.3 THERMAL RESISTANCE:

The ability of a designer to minimize the thermal resistance between the source of heat dissipation and the thermal sink is essential in controlling maximum operating temperatures and consequently the long term reliability and performance of electronic components. Typical electronic packages can introduce a complex network of resistive paths as heat passes from the integrated circuit through various laminated structures, bonding adhesives, lead frames or sometimes ball grid arrays. Despite the multitude of materials and interfaces within an electronic package, the largest thermal resistance, and consequently the controlling resistance in the path between the source and the sink, is usually the boundary layer or film resistance. Given the relationship in (1.1), an increase in either the heat transfer coefficient or the surface area for heat transfer results in a reduction in the film resistance.

\[
R_f = \frac{1}{hA} 
\]  

(1.1)

Where \( R_f \) = film resistance
\( h \) = convective heat transfer coefficient
\( A \) = surface area for heat transfer

While the convective heat transfer coefficient could potentially be enhanced with an increase in the approach velocity, the dependence of the heat transfer coefficient on the square root of the velocity in laminar flow results in diminished returns as velocity is increased. In addition, noise constraints associated with many electronics applications restrict flow velocities to a range of 5 m/s or less. The second option for reducing film resistance is achieved by increasing the effective surface area for convective heat transfer. This is typically achieved through the use of heat sinks or extended surfaces.

Heat sinks offer a low cost, convenient method for lowering the film resistance and in turn maintaining junction operating temperatures at a safe level for long term, reliable operation. Unfortunately, the selection of the most appropriate heat sink for a particular application can be very difficult giving many design options available.
1.4 TYPES OF FINS:

A large variety of fins are being used for manufacturing heat sinks. Few of them are shown in Fig. 1.2.
Fig. 1.2. Heat sink types (a) plate fin, (b) strip fin, inline, (c) strip fin, staggered, (d) circular pin fin, inline (e) circular pin fin, staggered, (f) square pin fin, inline and (g) square pin fin, staggered [3]
1.5 FLOW PATTERNS:

Natural convection cooled fin arrays is the broad topic of this research and hence information on flow patterns formed due to buoyancy driven forces over horizontal rectangular heat sinks is given. Three types of flow patterns are reported in the literature and are as described below.

1) Single Chimney,
2) Multiple Chimney or Sliding Chimney and
3) Up and Down pattern.

Figure 1.3(i) shows the single chimney type flow pattern. The surrounding fluid enters the fin region from the two open ends and develops a vertical component of velocity as the air is heated. The resulting chimney is only over a fraction of the length of the fin array. In certain cases the single chimney breaks up into several smaller chimneys as shown in Fig. 1.3(ii). Here, the main inflow is again from the open ends; however, the end flow is not sufficient to enter upto centre of the fin channel. Several chimneys are formed in the middle region. Single chimneys are more efficient in the heat removal compared to multiple chimneys. These different flow configurations help in understanding the results obtained from various fin configurations more easily. Up and down pattern may be present in very long arrays and also when the ends are closed as shown schematically in Fig. 1.3(iii).
Fig. 1.3 Different types of flow patterns observed

(i) Single chimney flow pattern
(ii) Sliding chimney flow pattern
(iii) Up and down flow pattern
1.6 THESIS OUTLINE:

This thesis is an experimental and numerical study of PFHS and its comparison with PFPFHS under natural convection condition. PFHS have been studied experimentally and numerically by a large number of investigators under natural convection. When pin fins are planted in channel of PFHS, it becomes a PFPFHS. No work is reported on such PFPFHS in literature under natural convection conditions.


Chapter II discusses literature review of the work done so far in the area of interest, and potential of research in PFPFHS and scope of the proposed work.

Chapter III on ‘Experimentation’ deals with development of experimental set up, instrumentation, procedure and actual experiments carried out with different configurations. This chapter ends with discussion on configuration wise and comparative experimental results, flow visualization carried out and uncertainty analysis to ascertain the result validation.

Chapter IV on ‘Numerical Formulation’ gives the building of the numerical model, CFD codes, governing equations, geometry creation, meshing and boundary definitions using CFD pre-processor software, Gambit. It also discusses solution strategy, convergence criterion and grid independent and domain size independent solution using the CFD processing software - Fluent. The numerical model is validated with experimental and numerical results available in literature. At the end, the computational results are compared with experimental findings.

Chapter V deals with ‘Computational Results’. The results of various configurations are presented in terms of vector plots, contours of temperature and velocity, path lines and plots of heat transfer coefficients. Parametric study of PFHS and PFPFHS is done by keeping length of array constant as 125 mm and with limiting ratio L/H=5 in order to retain single chimney. The chapter ends with proposing correlations, based on numerical results, between $\text{Nu}_b$, $\text{Nu}_a$ with $S/H$, $L/H$, $Ra$, % Area. Special cases
are also discussed with non-conducting pin fins, pin fins of variable heights, a large pin fin at the centre and smaller pin fins on either sides to observe the behavior of larger pin as a cross fin in PFHS.

Chapter VI deals with conclusions, contribution of the research work and discussion on scope for future work.