Heat sinks for electronic cooling applications

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Introduction

The previous century brought the miniaturization of electronic components. Overheating of these devices necessitates the need of advanced cooling technologies. The main reason for using these technologies is to eliminate as fast as possible the maximum heat quantity from these systems in order to ensure an increased reliability and functional stability (Kim & Kim, 2007). We know that Using CPU's at high temperatures can cause system to crashes in the short term and in the long term cause to reduce the life of your CPU. In extreme cases the CPU could be burn out or melt onto the motherboard. The dissipation of this large amount of heat cannot be achieved by conventional cooling methods. Thus, the modern electronic component cooling needs proper technology to ensure proper performance.

In electronic systems, a heat sink is a passive heat exchanger that cools a device by dissipating heat into the surrounding medium. In computers, heat sinks are used to cool central processing units or graphics processors. Heat sinks are used with high-power semiconductor devices such as power transistors and optoelectronics such as lasers and light emitting diodes (LEDs), where the heat dissipation ability of the basic device is insufficient for its cooling.

A heat sink, transfers the thermal energy from a higher temperature surface of the electronic component to a lower temperature fluid medium. The fluid medium is frequently air, but can also be water or in the case of heat exchangers, refrigerants and oil. The most common heat sink materials are aluminum alloys. Copper has excellent heat sink properties in terms of its thermal conductivity and corrosion resistance.

A heat sink is designed to maximize its surface area in contact with the cooling medium surrounding it. Fluid velocity, choice of material, protrusion design and surface treatment are factors that affect the performance of a heat sink. Heat sink attachment methods and thermal interface materials also affect the die temperature of the integrated circuit. The use of thermal adhesive or thermal grease can also improve the heat sink's performance by filling air gaps between the heat sink and the device.

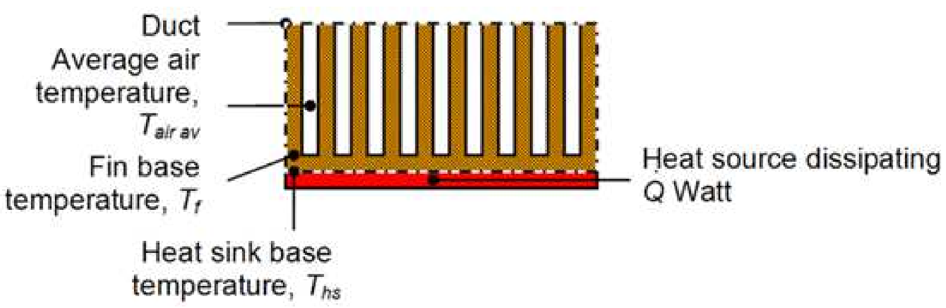

Fig 1: A heat sink.

Heat-Sink Categories

One way to categorize heat sinks is by the cooling mechanism employed to remove heat from the heat-sinks. It can be largely divided into five categories:

1 **Passive Heat Sinks** are used in either natural convection applications or in applications where heat dissipation does not rely on designated supply of air flows. Normal load limit for such type of heat sink is 5 to 50 watts.

2. Semi-Active Heat Sinks leverage off existing fans in the system. Normal load limit for such type of heat sink is 15 to 25 watts

3. Active Heat Sinks employ designated fans for its own use, such as fan heat sinks in either impingement or vertical flows. This type of heat sinks usually involves mechanically moving components and its reliability depends heavily on the reliability of the moving parts. Normal load limit for such type of heat sink is 10 to 160 watts.

4. Liquid Cooled Cold Plates typically employ tubes in-block designs or milled passages in brazed assemblies for the use of pumped water, oil, or other liquids. Normal load limit for such type of heat sink is huge.

5. **Phase Change Recirculating System** includes two-phase systems that employ a set of boiler and condenser in a passive, self driven mechanism, Heat pipe systems incorporate either no wicks in a gravity fed arrangement or wicks that do not require gravity feeds. This category also includes solid-to-liquid systems but those are usually used to moderate transient temperature gradients rather than for the purpose of dissipating heat. Normal load limit for such type of heat sink is 100 to 150 watts.

Heat-Sink Types

Heat sinks can also be classified in terms of manufacturing methods and their final form shapes.

1. 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.

2 Extrusions: Allow the formation of elaborate two-dimensional shapes capable of dissipating large wattage loads. They may be cut, machined, and options added. A cross-cutting will produce omnidirectional, 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.

3. 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.

4. 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.

5. Folded Fins: Corrugated sheet metal in either aluminum or copper increases surface area and, hence, the volumetric performance. The heat sink is then 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.

Different methods of cooling can be implemented for cooling the heat sinks. Methods for cooling used generally are as mentioned below.

1. Liquid Cooling

Liquid computer cooling uses a combination of water blocks, a radiator and a fan linked by tubing. As cool liquid is pumped through water blocks, it draws heat away from the attached component. The warm liquid is pumped into the radiator, where it is cooled using a large fan, and the cool liquid is then re-circulated.

2. Air Cooling

Air cooling in a computer uses a combination of fans and heat sinks. As components heat up, fans draw air through the heat sink, cooling the attached component part. Fans at the rear of a computer exhale the warm air generated by cooling the hot components.

3. Heat Pipe

A heat pipe is a heat-transfer device that combines the principles of both thermal conductivity and phase transition to efficiently manage the transfer of heat between two solid interfaces. It is a hollow tube containing a heat transfer liquid. The liquid absorbs heat and evaporates at one end of the pipe. The vapor travels to the other (cooler) end of the tube, where it condenses, giving up its latent heat. The liquid returns to the hot end of the tube by gravity or capillary action and repeats the cycle. Heat pipes have a much higher effective thermal conductivity than solid materials. For use in computers, the heat sink on the CPU is attached to a larger radiator heat sink. Both heat sinks are hollow, as is the attachment between them, creating one large heat pipe that transfers heat from the CPU to the radiator, which is then cooled using some conventional method. This method is expensive and usually used when space is tight, as in small form-factor PCs and laptops.

4. Fluid impingement jet

A fluid stream issuing from a nozzle at high velocity and hence a high kinetic energy term as Jet. The fluid at high velocity impinges on the plate or a vane through a fluid jet is known as Jet impingement**.** A directed liquid or gaseous flow released against a surface can efficiently transfer large amounts of thermal energy. Jets can be classified as submerged if they discharge into an ambient fluid of similar physical properties (e.g., air in air) and un-submerged if the properties of the two fluids are quite different (e.g., water in air).

Design Parameters

In designing or selecting an appropriate heat sink that satisfies the required thermal and geometric criteria, one needs to examine various parameters that affect not only the heat-sink performance itself, but also the overall performance of the system. Option of choosing a particular type of heat sink depends largely on the thermal budget allowed for the heat sink and external conditions surrounding the heat sink. In any type of heat sink, one of the most important external parameters in air cooling is the flow condition which can be classified as natural, low flow mixed, and high flow forced convection.

A list of design constraints for a heat sink may include parameters, such as

1) induced approach flow velocity
2) available pressure drop
3) cross sectional geometry of incoming flow
4) amount of required heat dissipation
5) maximum heat sink temperature
6) ambient fluid temperature
7) maximum size of the heat sink
8) orientation with respect to the gravity
9) appearance and cost

Given a set of design constraints, one needs to determine the maximum possible performance of a heat sink within the envelope of constraints. The parameters, over which a designer has a control for optimization, typically include,

1) Fin height
2) Fin length
3) Fin thickness/spacing
4) Number/density of Fins

5) Fin shape/profile

6) Base plate thickness

7) Cross-cut patterns

8) Heat sink material

Heat sink analysis

Consider a package with a heat sink used for cooling an electronic component. The overall thermal performance of the system can be measured in terms of the total thermal resistance.

$R_{totat} = R_{th,h} + R_{th,c} + R_{th,sub} + R_{th,cnv}$

Where, $R_{th,h}$ – Conduction Resistance through the chip

$R_{th,c}$ – Contact Resistance at the Chip/Substrate Interface

$R_{th,sub}$ – 3-D Conduction Resistance in the substrate (spreading resistance)

$R_{th,cnv}$ – Convection Resistance from the substrate to the coolant

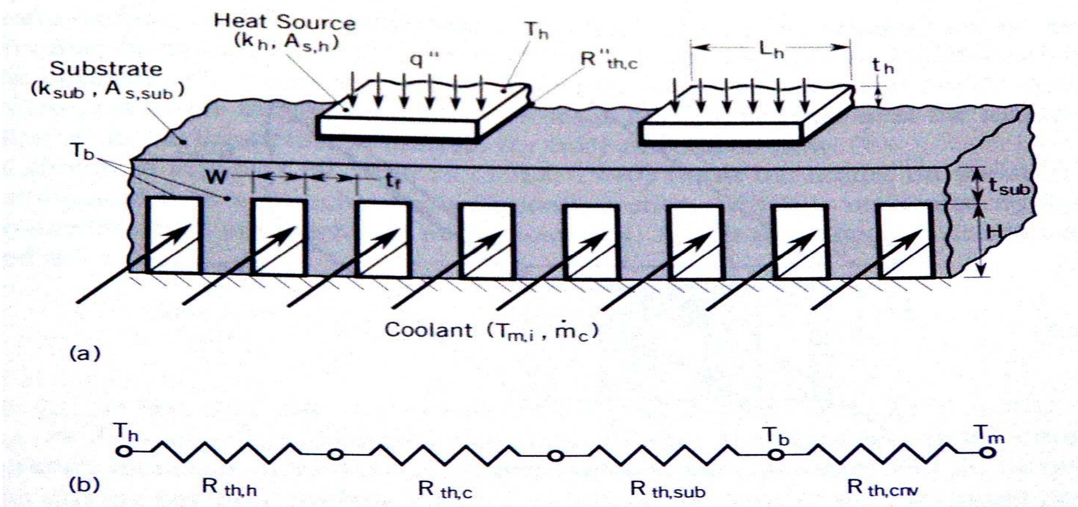

Fig 2: Thermal Resistance network for Heat sink analysis.

Descriptions of projected cooling performance of some of the recent heat sink cooling technologies for CPU cooling (Pautsch, 2005) are mentioned in the Table No.1below. Some additional methods other than those mentioned in Table No. 1 proposed by (Banton & Blanchet, 2004) are as follows.

- Spray cooling with mercury inside
- Hollow core liquid cooled electronic modules
- Microchannel cooling;
- Refrigeration, air chillers;
- Heat pipes;
- Thermo-electric coolers (TEC).

Sr. No.	Cooling Technology	Power [W]	Power Density Removal [W/cm3]
1	Air Cooling – Open loop	40	1270
2	Air Cooling – Closed loop	75	2032
3	Conduction to Liquid – Cold plate	80	4572
4	Conduction to Liquid – Top Hat MTA	100	5080
5	Single Phase Forced convection (immersion)	75	3810
6	Single Phase Impingement	120	7620
7	Heat Pipe Assisted Heat Sink	140	6604
8	Spray Evaporative Cooling	200	10160
9	Film Evaporative Cooling (Spray cooling with Phase Change)	275	13970

Table No.1- projected cooling performance of some cooling technologies for CPU cooling

(Meijer et al., 2009) proposed different possibilities to increase the cooling process efficiency by either operating on TIM or using one of the following:

- Ultra Thin High Efficiency Heat Sinks and Manifold Microchannel Heat Sinks,
- Radially Oscillating Flow Hybrid Cooling Systems,
- Oscillating Flow Liquid Cooling and
- Phonon Transport engineering method.

(Pautsch, 2005) presented limits that can be reached by dissipating the heat flow to the maximum for different cooling methods is as shown in fig. No.3.

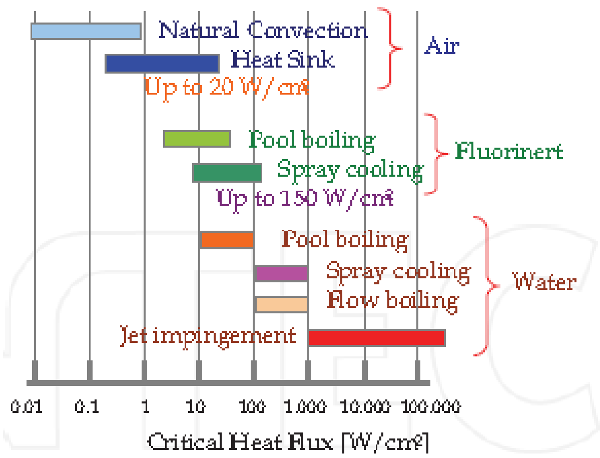

Fig. No. 3- Maximal values of the Critical Heat Flow (Pautsch)

In the future a lot of research is still required for developing the above mentioned cooling technologies in order to enhance the development as per the requirement of more sophisticated cooling applications and they can be made viable and practically implementable.