HEAT SINK DESIGN FOR OPTIMAL PERFORMANCE OF COMPACT ELECTRONIC APPLIANCES - A REVIEW

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ABSTRACT.

The ever rising transistor densities and switching speeds in microprocessors have been accompanied a dramatic increase in the system heat flux and power dissipation. In this context the rising IC densities combined with even more stringent performance and reliability requirement have made thermal management issues ever more prominent in the design of sophisticated microelectronic systems. So in order to achieve a high degree power dissipation extruded heat sinks, a number of research works have been done in last two decades. It is observed that components of modern portable electronic devices with increasing heat loads with decrease in the space available for heat dissipation. The increasing heat load of the device needs to be removed for maintaining the efficient performance of the device. The exponential increase in thermal load in air cooling devices requires the thermal management system to be optimized to attain the highest performance in the given space. In the present paper a review report on comprehensive description for thermal conditions for cooling purpose within the heat sink for electronic devices has been summarized.

Keywords: Heat sink, CFD, Heat transfer, Cooling system, Heat pipe.

INTRODUCTION AND LITERATURE SURVEY

In the present time of scientific era, the rapid development of electronic technology, devices and appliances takes an important place in our daily lives. However, as the component size shrinks there is a dramatic increment in the heat flux per unit area, due to which the working temperature of the electronic components may exceed the desired temperature level. And therefore, by promoting the heat transfer rate and maintaining the die at the desired operating temperatures, the condition for a reliable electronic component can be made into existence. Electronic components and assemblies tend to be of a small scale and they are typically cooled by air flowing at moderate velocities. The combination of small dimensions, the use of air as the cooling fluid and low velocities normally results in laminar convection and hence correspondingly low values for heat transfer coefficients.

Heat sink research and development has had a long history which is still ongoing with efforts to improve design and performance. "With heightened concern for energy Conservation, there has been a steady and substantial increase in activity. A focal point of this work has been heat transfer enhancement, which includes the search for special heat exchanger surfaces through which enhancement may be achieved." One Recent development in cellular materials allow for the consideration of designs previously not possible. Cellular materials allow for the construction of very small heat sinks with passageways for fluid to pass through on the order of several millimeters thick. Their superior properties, when compared with conventional materials, make cellular materials very desirable for a wide range of applications where size, weight, and efficiency are important. The decision to investigate optimal geometries for heat sinks was inspired by these recent developments.

Optimal geometries have enhanced heat transfer surfaces which allow devices to take advantage of one of the following options consisting size reduction, increased thermodynamic process efficiency which leads to lower operating costs, increased heat exchange rate for fixed fluid inlet temperatures, or reduced pumping power for fixed heat duty. There are number of methods in electronic cooling to maintain the unwanted heat dissipation during the operation of such devices, which have been studied and investigated by different researchers. Chung and Luo, (2002) have analyzed for unsteady heat transfer by using jet impingement cooling system. Turbulence statics in the stagnation region for an axis symmetric impinging jet cooling system was arranged (Nishino et al., 1996). Heat pipe cooling technology for desktop PC and CPU has been used by Kum et al., (2003). An experimental investigation for the thermal performance of an asymmetrical flat plate heat pipe has been conducted (Wang and Vafai, 2000). CPU with variable heat sink base plate thickness has been analyzed thermally (Mohan and Govindarajan, 2010) by using CFD. Further by the same authors, an experimental and CFD analysis of heat sinks with base plate for CPU cooling has been conducted (Mohan and Govindarajan, 2011) and was observed that the velocity field around the heat sink was affected by the presence of the other components inside the chassis as well as the chassis walls which redirect the hot air back into CPU heat sink.

A numerical study was presented on six CPU heat sinks of the same model, namely a copper heat sink, aluminium heat sink and graphite-metal heat sinks to analyze the temperature distribution and thermal resistance (Liu et al., 2012) and was concluded that the heat dissipation effect of graphite-copper heat sink is better than that of copper one and far better than that of aluminium one, which on further come to the final conclusion that a reasonable design need to consider material and thickness of the base, height and thickness of the fin along with the heat transfer area of sink. It was the basis of the references for the design of CPU heat dissipation and some necessary theoretical basis for the cooling design of the electronic equipments.

A heat sink was designed on geometry based optimization tool with the principle of superposition, whose analysis can be simplified by using a repeating cell (Stadler, 2008). The majority of this work was done with a constant surface temperature boundary condition which had consistently led to designs with one large square channel located closed to the hot surface being shown as the best solution, which resulted in contrast to current designs. Ayli et al., (2013), have investigated for cooling of electronic equipments to design vortex promoters. Different shapes of vortex promoters were used in the experimental study for turbulent flow and the results were used to validate the previous computational works. The work was related to experimental and computational analysis of heat transfer in electronic systems. An analysis and modeling for heat sink with rectangular fins with through holes was done for efficient cooling of electronic devices for optimal performance (Sukumar et al., 2013) and was observed that in the sense of junction temperature interrupted fins are efficient than continuous and was also found that through holes for the interrupted fins has better performance than interrupted rectangular fins of heat sinks and reduction in weight due to more material removal from the standard.

Light emitting diode (LED) is a modern lighting device in which if the heat dissipation mechanism is not well designed, the induced high temperature will cause the reduction of illumination and life time of lamp. Therefore, the heat sink design has become a key technology for LED lighting device. It was designed and analyzed by Chu et al., (2015), for LED cooling purpose. By using CFD software FLUENT, heat flux and temperature around the heat sink were analyzed, and the surface temperature distribution was also investigated. Liu and Garimella, (2004), have analyzed for optimal thermal performance of micro-channels heat sinks and the results obtained by them were demonstrated that the models developed offer sufficiently accurate predictions for practical designs, while at the same time being quite straightforward to use. The comparative study of heat sink having fins of various profiles namely rectangular, Trapezoidal, rectangular Interrupted, square, circular inline and staggered, has been thermally analyzed by using CFD (Kansal and Laad, 2015) and was observed that the optimum cooling is achieved by the heat sink design which contains circular pin fins.

An experimental analysis of radial heat sink was proposed by Abhijit et al., (2016) for cooling performance of 3 conductor profiles, namely LM sort pin-fin conductor, heat sink with staggered form pin-fins and heat sink with tallest fins on outside. The recent review report summarized by Kumar et al., (2017) is also helpful to the researchers seeking to more idea about importance of cooling systems in electronic field.

DIFFERENT COOLING APPROACHES

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. The passive cooling sub systems are not assisted by mechanical equipments. The conventional passive cooling techniques include applying effective heat spreaders and heat sinks to the electronic package. For a module with spatial limitation, passive cooling technique is often more practical than active cooling. But it is limited to what it can achieve. Therefore recent technologies include the use of thermal energy storage with phase change materials and integration of the heat pipes to the electronic packages that are commonly used to achieve high cooling capacity. So, some of the important cooling approaches have been summarized as follows:-

Air cooling- It is the simplest and principal method of thermal control most widely used for variety of electronic systems ranging from portable electronics to large business systems. The advantages of air cooling are its ready availability and ease of application. Before 1964, all IBM computers were cooled solely by forced air. In many cases air moving devices are installed at the bottom or top of a column of boards to provide sufficient cooling. For high heat flux, a push-pull air flow arrangement with air moving devices at both the bottom and top of the column of boards was used to provide high pressure drop capability. Low-power electronic systems are conveniently cooled by natural convection and radiation. When natural convection is not adequate, the forced convection is adopted by a fan or blower to blow the air through the enclosure that houses the electronic components.

Natural convection and radiation- Natural convection and radiation cooling is desirable because of its simplicity. Circuit boards that dissipate up to about 5 W of power can be cooled effectively by natural convection. It is familiar in consumer electronics like TV, VCD, etc. by providing a sufficient number of vents on the case to enable the cooled air to enter and the heated air to leave the case freely.

Fins- A fin is a thin component or appendage attached to a larger body or structure. Fins typically function as foils that produce lift or thrust, or provide the ability to steer or stabilize motion while traveling in water, air, or other fluid media. Fins are also used to increase surface areas for heat transfer purposes, or simply as ornamentation. Fins are often used to enhance the rate of heat transfer from heated surfaces to environment. They can be placed on plane surfaces, tubes, or other geometries. These surfaces have been used to augment heat transfer by adding additional surface area and encouraging mixing. When an array of fins is used to enhance heat transfer under convection conditions, the optimum geometry of fins should be used, provided this is compatible with available space and financial limitations. Advantages in printed circuit boards have yielded increasing power dissipation from surfaces in a channel. Rectangular fins are used extensively to increase the rates of convection heat transfer from systems, because such fins are simple and cheap, to manufacture. Providing adequate cooling of printed circuits boards has recently motivated experiments on the use of longitudinal fins to enhance heat transfer in rectangular channels. The heat transfer, to the fluid flowing through a channel by the heat dissipating surfaces can be obtained mainly by using the mechanisms of heat transfer by forced convection, natural convection and by radiative heat transfer.

Forced convection- When natural convection cooling is not adequate, forced convection is provided by external means such as a fan, a pump, a jet of air, etc. In electronic systems cooling, fan is a popular means of circulating air over hot surfaces. For forced convection the hot surfaces are characterized by their extended surfaces such as fins in heat sinks.

IMPORTANCE OF HEAT SINKS IN ELECTRONIC CIRCUITS

A heat sink is a passive heat exchanger, and it is designed to have large surface area in contact with the surrounding (cooling) medium like air. The components or electronic parts or devices which are insufficient to moderate their temperature, require heat sinks for cooling. Heat generated by every element or component of electronic circuit must be dissipated for improving its reliability and preventing the premature failure of the component.

It maintains thermal stability in limits for every electrical and electronic component of any circuit or electronics parts of any system. The performance of the heat sink depends on the factors like the choice of a material, protrusion design, surface treatment and air velocity. The central processing units and graphic processors of a computer are also cooled by using the heat sinks. Heat sinks are also called as Heat spreaders, which are frequently used as covers on a computer's memory to dissipate its heat. If heat sinks are not provided for electronic circuits, then there will be a chance of failure of components such as transistors, voltage regulators, ICs, LEDs and power transistors. Even while soldering an electronic circuit, it is recommended to use heat sink to avoid over heating of the elements. Heat sinks not only provide heat dissipation, but also used for thermal energy management done by dissipating heat when heat is more. In case of low temperatures, heat sinks are intended to provide heat by releasing thermal energy for proper operation of the circuit.

BASIC PRINCIPLE OF HEAT SINK

Fourier's law of heat conduction states that if temperature gradient is present in a body, then the heat will transfer from a high-temperature region to allow- temperature region. And, this can be achieved in three different ways, such as convention, radiation and conduction.

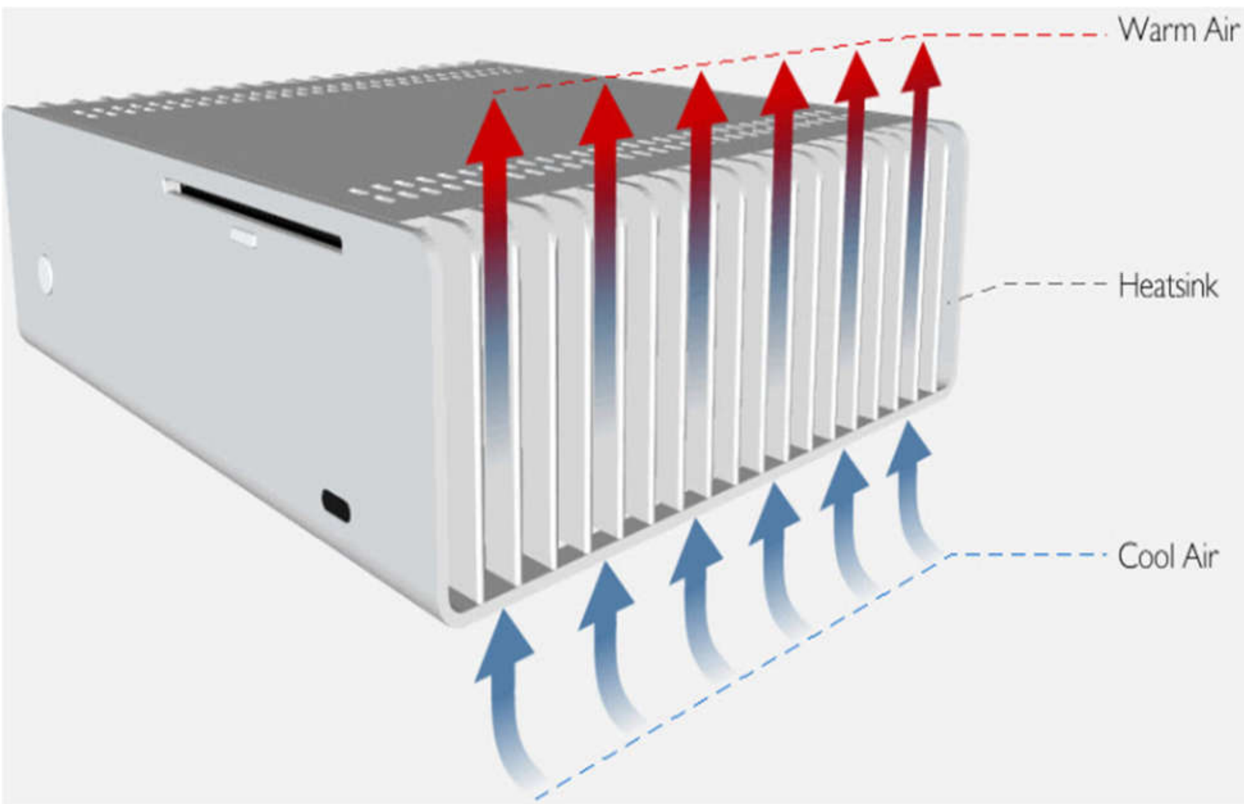

Fig.1. Heat sink with air flow arrangement

A heat sink is an object that transfers thermal energy from a higher temperature 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. If the fluid medium is water, the 'heat sink' is frequently called a cold plate. To understand the principle of a heat sink, consider Fourier's law of heat conduction. Joseph Fourier was a French mathematician who made important contributions to the analytical treatment of heat conduction. Fourier's law of heat conduction, simplified to a one-dimensional form in the *x*-direction, shows that when there is a temperature gradient in a body, heat will be transferred from the higher temperature region to the lower temperature region. The rate at which heat is transferred by conduction, q_k, is proportional to the product of the temperature gradient and the cross-sectional area through which heat is transferred.

$$q_k = -KA.\frac{dT}{dx} \quad (1)$$

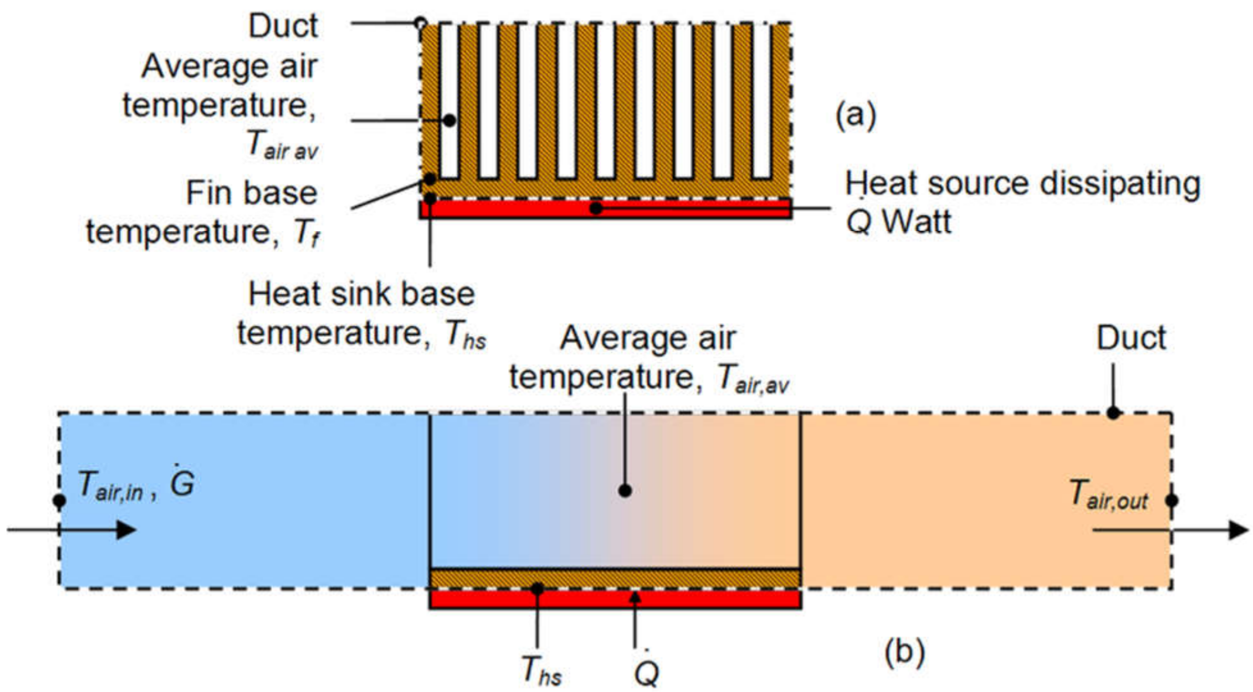

Fig.2. Sketch of a heat sink in a duct used to calculate the governing equations from conservation of energy and Newton's law of cooling

Let us consider a heat sink in a duct, where air flows through the duct, as shown in Fig. 2. It is assumed that the heat sink base is higher in temperature than the air. Applying the conservation of energy, for steady-state conditions, and Newton's law of cooling to the temperature nodes shown in Fig. 2 gives the following set of equations.

$$\dot{Q} = \dot{m}C_p(T_{air,out} - T_{air,in}) \quad (2)$$

$$\dot{Q} = \frac{T_{hs} - T_{air,av}}{R_{hs}} \quad (3)$$

$$\text{Where, } T_{air,av} = \frac{T_{air,out} + T_{air,in}}{2} \quad (4)$$

Using the mean air temperature is an assumption that is valid for relatively short heat sinks. When compact heat exchangers are calculated, the logarithmic mean air temperature is used. $\dot{m}$ is the air mass flow rate in kg/s. The above equations show that when the air flow through the heat sink decreases, this results in an increase in the average air temperature. This in turn increases the heat sink base temperature. And additionally, the thermal resistance of the heat sink will also increase. The net result is a higher heat sink base temperature. The increase in heat sink thermal resistance with decrease in flow rate will be shown in later in this article. The inlet air temperature relates strongly with the heat sink base temperature. For example, if there is recirculation of air in a product, the inlet air temperature is not the ambient air temperature. The inlet air temperature of the heat sink is therefore higher, which also results in a higher heat sink base temperature. Therefore, if there is no air or fluid flow around the *heat sink*, the energy dissipated to the air cannot be transferred to the ambient air. Therefore, the heat sink functions poorly. Furthermore, a heat sink is not a device with the "magical ability to absorb heat like a sponge and send it off to a parallel universe. Other examples of situations in which a heat sink has impaired efficiency:

- Pin fins have a lot of surface area, but the pins are so close together that air has a hard time flowing through them.
- Aligning a heat sink so that the fins are not in the direction of flow.
- Aligning the fins horizontally for a natural convection heat sink. Whilst a heat sink is stationary and there are no centrifugal forces and artificial gravity, air that is warmer than the ambient temperature always flows upward, given essentially-still-air surroundings; this is convective cooling.

DESIGN OF A HEAT SINK

Every electrical and electronic component in a circuit generates some amount of heat while the circuit is executed by providing power supply. Typically high-power semiconducting devices like power transistors and the opto electronics such as diodes, lasers generate heat in considerable amounts and these components are inadequate to dissipate heat, as their dissipation capability is significantly low. Due to this, heating up of the components leads to premature failure and may cause failure of the entire circuit or system's performance. So, to conquer these negative aspects, heat sinks must be provided for cooling purpose. A heat sink is a passive heat exchanger that transfers the heat generated by an electronic or a mechanical device to a fluid medium, often air or a liquid coolant, where it is dissipated away from the device, thereby allowing regulation of the device's temperature at optimal levels. 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 component itself is insufficient to moderate its temperature. Fig.3 shows a typical heat sink design.

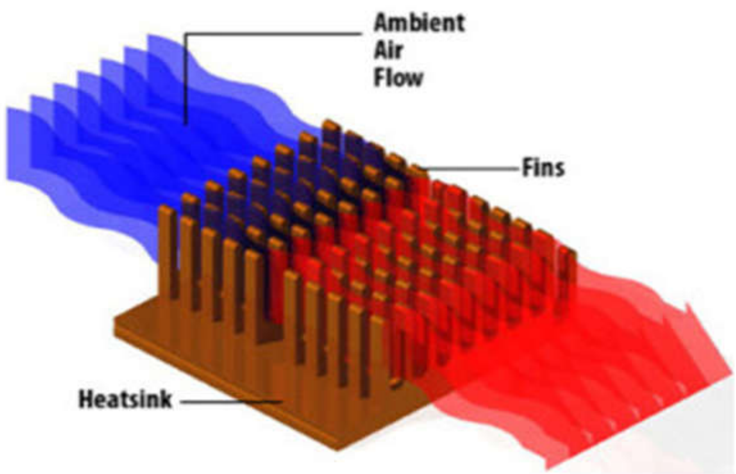

Fig.3 A typical heat sink

Diodes, transistors, and integrated circuits generate considerable amounts of heat during operation. Extreme heat can damage or significantly affect the performance of semiconductor devices, and therefore, supplemental cooling is necessary to maintain the temperature within the limits specified by a manufacturer. Whereas some electronic components can dissipate heat on their own, most optoelectronic devices—like lasers and power transistors such as MOSFETs and IGBTs—cannot sufficiently dissipate heat without a heat management solution. This is where a well-thought-out heat sink design can make a big difference.

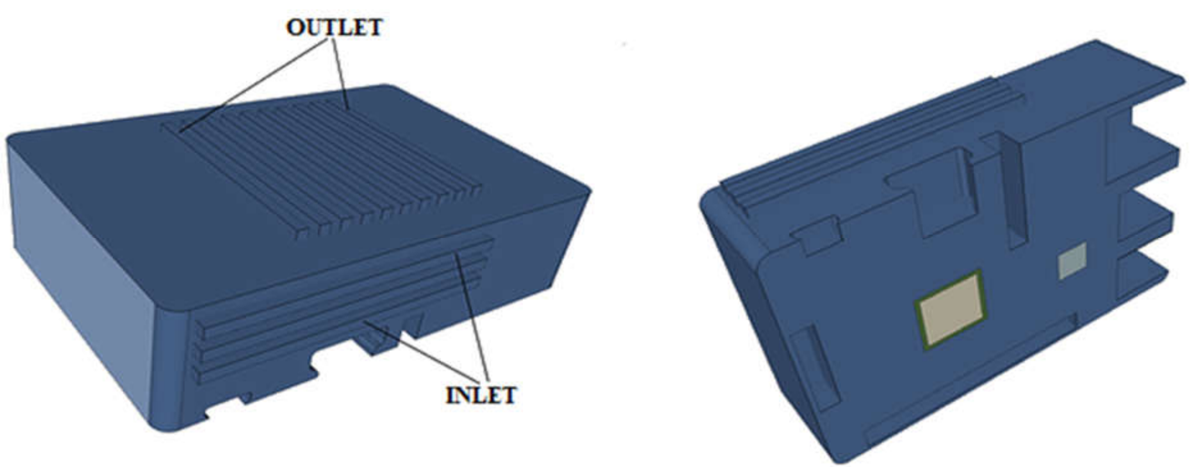

Fig.4. CAD geometry of a heat sink

A heat sink transfers the thermal energy generated by an electronic assembly or component into a cooling medium. The heat is transferred from a higher temperature region (electronic component) to a lower temperature region (fluid medium) by conduction, convection, radiation or by a combination of these heat transfer methods. The performance of this passive heat exchanger is determined by many factors including the velocity of the coolant fluid, the thermal conductivity of the material, the thermal interface material, and the attachment method. For a specific application, the parameters of a heat sink can be precisely determined through modeling and analysis. Following are the factors upon which design of heat sink depends:-

Thermal Resistance- Thermal resistance refers to the sum of resistances to heat flow between the die and the coolant fluid. These heat flow resistances include the resistance between the die and the component casing, the resistance between the casing and the heat sink (thermal interface resistance), and the resistance between the heat sink and the fluid in motion. Thermal resistance does not factor non-uniform heat distribution and it is unsuitable for modeling systems that are not in thermal equilibrium.

Fig.5. A typical thermal resistor

Although the thermal resistance value is an approximation, it enables the modeling and analysis of thermal characteristics of semiconductor devices and heat sinks. Analyses of different heat sink designs are used to determine heat sink geometries and parameters that enable maximum heat dissipation. Complex modeling of thermal characteristics can be achieved by meshing heat sinks using 3D thermal resistances. The Hex-dominant Parametric (only CFD) mesh was used to generate the mesh for the 4 volumes (3 solids and 1 fluid). This is used to create refinements and maintain the volumes as different regions to later define interfaces.

Material- Heat sinks are designed using materials that have high thermal conductivity such as aluminum alloys and copper. Copper offers excellent thermal conductivity, antimicrobial resistance, befouling resistance, corrosion resistance, and heat absorption. Its properties make it an excellent material for heat sinks but it is more expensive and denser than aluminum. Diamond offers a high thermal conductivity that makes it a suitable material for thermal applications. Its lattice vibrations account for its outstanding thermal conductivity. Composite materials such as AlSiC, Dymalloy, and copper-tungsten pseudo-alloy are also commonly used in thermal applications.

Arrangement, Shape, Size, and Location of Fins- The flow of the coolant medium is greatly impacted by the arrangement of fins on a heat sink. Optimizing the configuration helps to reduce fluid flow resistance thus allowing more air to go through a heat sink. The heat sink's performance is also determined by the shape and design of its fins. Optimizing the shape and size of the fins helps to maximize the heat transfer density. Through modeling, the performance of different fin shapes and configurations can be evaluated.

Fin Efficiency- A heat sink fin receives heat from an electronic device and dissipates it into the surrounding coolant fluid. The heat transferred by a fin to the coolant medium decreases as the distance from the base of the heat sink increases. Using a material that has a higher thermal conductivity and decreasing the aspect ratio of the fins help to boost the fins' overall efficiency.

Fig.6. Typical heat sink fins

Thermal Interface Material- Surface defects, roughness, and gaps increase thermal contact resistance thereby reducing the effectiveness of a thermal solution. These defects increase heat flow resistance by reducing the thermal contact area between an electronic component and its heat sink. Thermal resistance is reduced by increasing interface pressure and decreasing surface roughness. In most cases, there are limits to these resistance reduction methods. To overcome these limits, thermal interface materials are used. The electrical resistivity of a material, contact pressure, and size of the surface gaps should be considered when selecting a thermal interface material for a given thermal application.

Heat Sink Attachment Methods- The thermal performance of a heat sink can be enhanced by selecting an appropriate method of attaching a heat sink to an electronic device or component. The selection process should factor in both the thermal and the mechanical requirements of the thermal management solution. Common heat sink attachment methods include standoff spacers, flat spring clips, epoxy, and thermal tape.

CONCLUSIONS

On the basis of above description and literature review following major conclusions have been made:

1. Heat sinks are essential parts of most electronic assemblies, power electronic devices, and optoelectronic components.
2. These passive heat exchangers dissipate heat generated by electronic devices to ensure that they are operating within the limits specified by manufacturers.
3. Some of the key factors that should be considered when designing a heat sink include thermal resistance, material, fin configuration, fin size and shape, fin efficiency, heat sink attachment method, and thermal interface material.
4. Geometries and parameters that provide maximum heat dissipation are obtained by analyzing different heat sink models.

REFERENCES

1. *Y.chung and K. Luo, 2002. Unsteady heat transfer analysis of an impinging jet. Journal of Heat Transfer, 124, 1039-1048.*
2. *K. Nishino et al., 1996. Turbulence statistics in the stagnation region of an axisymmetric impinging jet flow, Int. J. Heat Fluid Flow, 17, 193-201.*
3. *K. Kim et al., 2003. Heat pipe cooling technology for desktop - PC and CPU, Appl. Therm. Engg., 23, 1137-1144.*
4. *Y. Wang and K. Vafai, 2000. An experimental investigation of the thermal performance of an asymmetrical flat plate heat pipe, J. Heat Mass Transfer, 43, 2657-2668.*
5. *Dr. Ashwini Kumar, R. Kumar and Dr. A. K. Behura, 2017. A review of electro thermal cooling systems with heat sink, IJERM, 4, (8), 19-23.*
6. *Abhijit Game, P. S. Desale and V. S. Kulkarni, 2016. Experimental analysis of radial heat sink for high power LED application, IJIFR, 3, (9), 3338-3345.*
7. *Santosh Kanshal and piyush Laad, 2015. Performance & thermal analysis of heat sink with fins of different configuration using CFD, IJSER, 6, (6), 1487-1495.*
8. *Dong Liu and Suresh V. Garimella, 2005. Analysis and optimization of the thermal performance of micro-channel heat sinks, Int. J. for Numerical Method in Heat & Fluid Flow, 15, (1), 7-26.*

9. *Li-Ming Chu, Wei-Chin Chang and Ting Hsuan Huang, 2015. A novel heat sink design and prototyping for LED desk lamps, Hidawi Publishing Corporation Mathematical Problems in Engineering, Article ID 765969, 8 pages.*
10. *R. S. Sukumar, G. Sriharsha, S. B. Arun, P. D. Kumar and C. S. Naidu, 2013. Modelling and analysis of heat sink with rectangular fins having through holes, IJERA, 3, (2), 1557-1561.*
11. *E. Ayli, C. Trunk and S. Aradag, 2013. Experimental investigation of cooling of electronic equipment, IJMMM, 1, (2), 153-157.*
12. *M. B. de Stadler and H. H. Hariri, 2008. Optimization of the geometry of a heat sink, University of Virginia, Charlottesville, VA 22904.*
13. *Y. P. Liu, Z. P. Xu and Q. Zhu, 2012. The simulation and optimization of the CPU heat sink for a new type of graphite, JEET, 1, (3), 8-11.*
14. *R. Mohan and Dr. P. Govindarajan, 2010. Thermal analysis of CPU with variable heat sink base plate thickness using CFD, 18, (1), 27-36.*