To Enhance the Heat Transfer Rate in Thermoelectric Cooler: A Review

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Abstract - Heat sinks are devices that enhance heat dissipation from a hot surface, usually the case of a heat generating component, to a cooler ambient, usually air. air is assumed to be the cooling fluid. The primary purpose of a heat sink is to maintain the device temperature below the maximum allowable temperature specified by the device manufacturer. There are two ways to increase the rate of heat transfer i) to increase the convection heat transfer coefficient h. ii)to increase the surface area As Thermoelectric cooling, also called "The Peltier Effect". There are many products using thermoelectric coolers, including CCD cameras (charge coupled device), laser diodes, and a new field of thermoelectric coolers for refrigeration effect. The present model study is to be conducted for application of heat sink in thermoelectric can cooler, where in the device shall be used to cool beverage cans. The size of the device is constraint due to the fact that the device is to be used as a portable device hence has to be compact. Thus the study is focused on design development and testing of heat sink with straight and tapered fins to dissipate approximately 35 watt of energy to get a desired refrigeration effect into the cooler system.

Keywords – Heat Sink, Thermoelectric cooler, Peltier Effect, Thermoelectric Module.

I. INTRODUCTION

A heat sink is a component or assembly that efficiently transfers heat generated within a solid material to a fluid medium, such as air or a liquid. Examples of heat sinks are the heat exchangers used in refrigeration and air conditioning systems and the radiator (also a heat exchanger) in a car. Heat sinks also help to cool electronic and optoelectronic devices, such as higher-power lasers and light emitting diodes (LEDs).

In academic text books discussing heat transfer in general, the term "heat sink" is never used. When these text books do mention the objects commonly referred to as heat sinks, they use the term extended surfaces. A heat sink basically uses the extended surfaces to increase the surface area in contact with, for example, the air. A heat sink does not have a "magical ability to absorb heat like a sponge and send it off to a parallel universe". Heat transfer theory helps explain practical aspects of how heat sinks work, and can also help to clear up common misconceptions and design mistakes. Approach air velocity, choice of material, fin (or other protrusion) design and surface treatment are some of the design factors which influence the thermal resistance, i.e. thermal performance, of a heat sink. One engineering application of heat sinks is in the thermal management of electronics, often computer CPU or graphics processors. For these, heat sink attachment methods and thermal interface materials also influence the eventual junction or die temperature of the processor(s). Theoretical, experimental and numerical methods can be used to determine a heat sink's thermal performance.

Fig.1 CPU Heat Sink with Fan attached.

Basic Heat Sink Heat Transfer Principle-

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. 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.

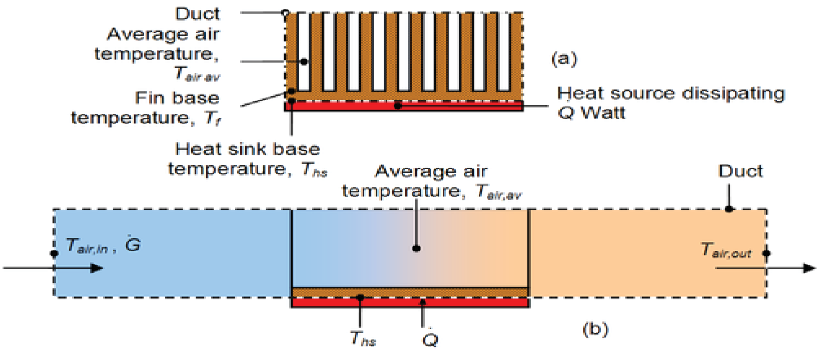

Fig 2: Sketch of a heat sink in a duct used to calculate the governing equations from conservation of energy & Newton's law of cooling.

Consider a heat sink in a duct, where air flows through the duct, as shown in Figure 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 Figure 2 gives the following set of equations.

$$\dot{Q} = \dot{m}c_{p,in}(T_{air,out} - T_{air,in}) \qquad (1)$$

$$\dot{Q} = \frac{T_{hs} - T_{air,av}}{R_{hs}} \qquad (2)$$

$$T_{air,av} = \frac{T_{air,out} + T_{air,in}}{2} \qquad (3)$$

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.

Heat Sink –

The efficiency of various heat-sink types depends mainly on three factors: surface area, structure or shape, and material. Cooling capabilities relate directly to surface area; the larger the surface area, the more heat that can be dissipated. Physical structure is another factor. Proper structure increases turbulent airflow which creates a more efficient heat sink .The heat-sink material is also crucial. Copper, for instance, has superior cooling qualities to aluminum because the thermal conductivity of copper is much higher than that of aluminum. At room temperature, copper has a thermal conductivity of 401 W/m-K while aluminum is 235 W/m-K. Consequently, all other factors being equal, a heat sink made of copper dissipates more heat than a heat sink made of aluminum. A technical term that can be used to compare various heat-sink technologies is volumetric efficiency (VE). VE is the product of thermal resistance and heat-sink volume, where thermal resistance equals temperature increase per watt (°C/W) and heat-sink volume equals footprint area times height .The lower the thermal resistance, the more effective a heat sink is, and the smaller the heat-sink's volume (but larger surface area) the more efficient it will be. Consequently, a low volumetric efficiency number means a more efficient heat sink. As technological development and concern about global warming, the quest for power generation through alternative sources is increasing. Today, electricity is a pretty basic for the development of the population, which improves the quality of life by providing social and economic growth.

Heat Sink Thermal Circuit -

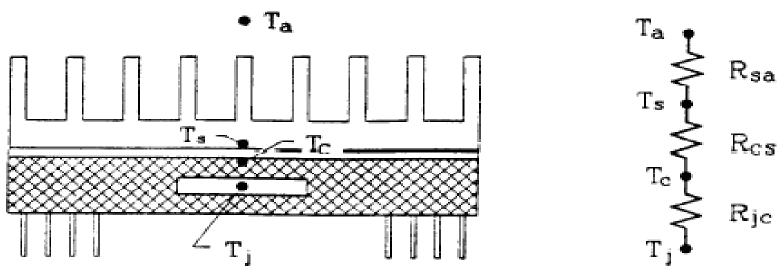

Figure : Thermal Resistance Circuit

Q: Total power or rate of heat dissipation (watt)
Tj : Maximum junction temperature of device ^{o}C
Ts : Sink Temperature ^{o}C
Tc: Case temperature of device ^{o}C
Ta : Temperature of air ^{o}C

II. CONCEPT OF THERMOELECTRIC COOLING

A. Thermoelectricity–

The thermoelectricity is the conversion of thermal energy into electrical energy through a temperature gradient. This phenomenon is reversible and is mainly based on the Seebeck effect and the Peltier effect. The Seebeck effect was discovered in 1821 by Thomas Seebeck, verifying that two conductors of different states at their tips and a temperature difference between them, metal materials made with a needle that was between them. Thomas Seebeck published his findings stating that conductors (or semiconductors) produce a different voltage when they are united with the ends and subjected to a temperature gradient.

B. Seebeck Effect:-

The Seebeck effect is the conversion of temperature differences directly into electricity and is named after the Baltic German physicist Thomas Johann Seebeck. in 1821, discovered that a compass needle would be deflected by a closed loop formed by two different metals joined in two places, with a temperature difference between the junctions.

$$\mathbf{E}_{emf} = -S\nabla T$$

Where, S is the Seebeck coefficient (also known as thermo power), a property of the local material, and delta T is the gradient in temperature .The Seebeck coefficients generally vary as function of temperature, and depend strongly on the composition of the conductor. For ordinary materials at room temperature, the Seebeck coefficient may range in value from −100 μV/K to +1,000 μV/K.

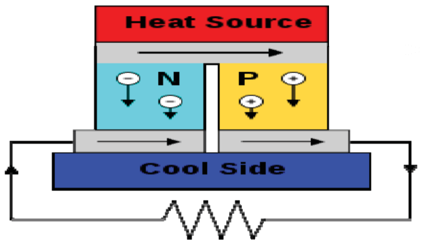

Fig.3 a thermoelectric circuit composed of materials of different Seebeck coefficient (p-doped and n-doped semiconductors), configured as a thermoelectric generator.

C. Peltier effect-

The Peltier effect is the presence of heating or cooling at an electrified junction of two different conductors and is named for French physicist Jean Charles Athanase Peltier, who discovered it in 1834. When a current is made to flow through a junction between two conductors A and B, heat may be generated (or removed) at the junction. The Peltier heat generated at the junction per unit time, $\dot{Q}$, is equal to

$$\dot{Q} = (\Pi_A - \Pi_B) I$$

Where, Π_A (Π_B) is the Peltier coefficient of conductor A (B), and I is the electric current (from A to B). Note that the total heat generated at the junction is not determined by the Peltier effect alone, as it may also be influenced by Joule heating and thermal gradient effects.

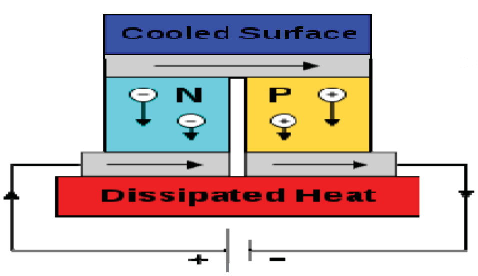

fig.4 The Seebeck circuit configured as a thermoelectric cooler.

D. Thermoelectric cooler –

Thermoelectric coolers (TECs), also known as Peltier coolers, are solid-state heat pumps that utilize the Peltier effect to move heat. Passing a current though a TEC transfers heat from one side to the other, typically producing a heat differential of around 40°C or as much as 70°C in high end devices that can be used to transfer heat from one place to another. When two conductors are placed in electric contact, electrons flow out of the one in which the electrons are less bound, into the one where the electrons are more bound. The reason for this is a difference in the so called Fermi level between the two conductors. The Fermi level represents the demarcation in energy within the conduction band of a metal, between the energy levels occupied by electrons and those that are unoccupied. When two conductors with different Fermi levels make contact, electrons flow from the conductor with the higher level, until the change in electrostatic potential brings the two Fermi levels to the same value. (This electrostatic potential is called the contact potential.)

TECs are constructed using two dissimilar semi-conductors, one n-type and the other P-type (they must be different because they need to have different electron densities in order for the effect to work). The two semiconductors are positioned thermally in parallel and joined at one end by a conducting cooling plate (typically of Copper or Aluminum).A voltage is applied to the free ends of two different conducting materials, resulting in a flow of electricity through the two semiconductors in series. The flow of DC current across the junction of the two semi-conductors creates a temperature difference. As a result of the temperature difference, Peltier cooling causes heat to be absorbed from the vicinity of the cooling plate, and to move to the other (heat sink) end of the device. The heat is carried through the cooler by electron transport and released on the opposite ("hot") side as the electrons move from a high to low energy state.

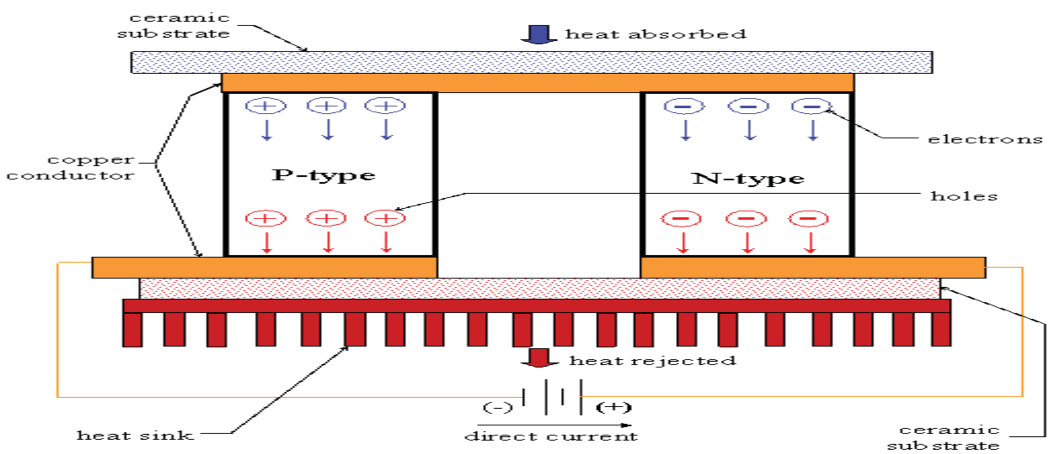

Fig.5 Thermoelectric Cooling System.

E. Thermoelectric Module-

A thermoelectric module converts thermal energy into electrical energy and vice versa consisting of a matrix formed by multiple bimetallic junctions connected in series to increase output voltage, and in parallel to increase output current. These are able to operate as generators temperature gradient or as generators of electricity in direct current. Each bimetallic junction element is constituted by a p-type semiconductor and n-type they are connected in series and grouped in pairs surrounded by a sheath ceramics. The ceramic plates have copper bar that allows linking semiconductors electrically in series and thermally in parallel.
Currently, we use many joints to maximize the power delivered by the module. In Fig presents a series of junctions grouped in matrix form, forming a set, known thermoelectric module. The modules are in their datasheet specifications and temperature information relating to voltage, current and power modules can provide, beyond the dimensions and other characteristics necessary for their use. It is observed that as there is a high temperature gradient, the values of voltage and current increase proportionally.

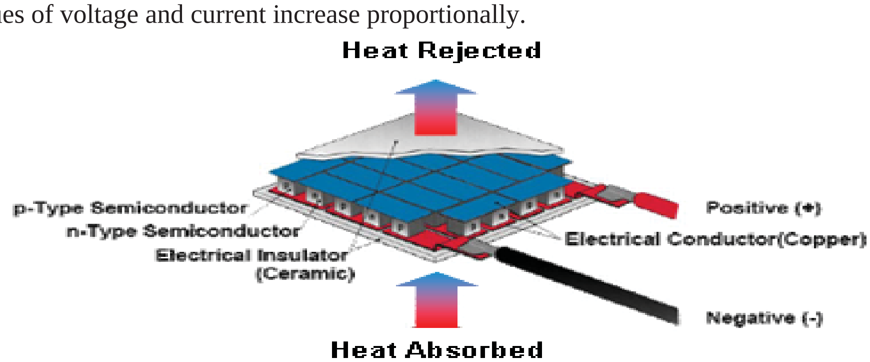

Fig.6 Thermoelectric Module.

III. CONCLUSION

To enhance heat transfer in electronic devices with the use of waveform pin-finned heat sinks. The cooling performance of electronic devices has attracted increased attention owing to the demand of compact size, higher power densities and demands on system performance and re-liability. Pressure drop across heat sink is one of the key variables that govern the thermal performance of the heat sink in forced convection environment the advantages of using a waveform fin heat sink are light weight, low profile and small footprint. There are three

Manufacturing methods for bonding the waveform fin to the base of heat sink: adhesive bonding, soldering, and Brazing. The newly developed comparison method allowed a detailed numerical study of the influence of waveform pin cross-section on the performance of pin fin arrays used in the electronics industry.

REFERENCES

[1] C.K. Loh, Bor-Bin Chou, and Dan Nelson and D.J. Chou, “Study of Thermal Characteristics on Solder and Adhesive Bonded Folded Fin Heat Sink”, the 7th Intersociety Conference ITHERM, 2000

[2] Y. Peles, A. Ko¸sar, C. Mishra, C. J. Kuo, and B. Schneider, “Forced convective heat transfer across a pin fin micro heat sink,” Int. J. Heat Mass Transfer, vol. 48, no. 17, pp. 3615–3627, Aug. 2005.

[3] G. Hetsroni, A. Mosyak, Z. Segal, and G. Ziskind, “A uniform temperature heat sink for cooling of electronic devices,” Int. J. Heat Mass Transfer, vol. 45, no. 16, pp. 3275–3286, 2002.

[4] Z. Li, X. Huai, Y. Tao, and H. Chen, “Effects of thermal property variations on the liquid flow and heat transfer in microchannel heat sinks,” Appl. Thermal Eng., vol. 27, nos. 17–18, pp. 2803–2814, Dec.2007.

[5] E. G.Colgan, B. Furman, M. Gaynes, N. LaBianca, J. H. Magerlein, R. Polastre, R. Bezama, K. Marston, and R. Schmidt, “High performance and subambient silicon microchannel cooling,” J. Heat Mass Trans., vol. 129, no. 8, pp. 1046–1051, 2007.

[6] E.G.Colgan, B. Furman, M. Gaynes, W. S. Graham, N. LaBianca, J. H. Magerlein, R. Polastre, M. B. Rothwell, R. J. Benzema, R. Choudhary, K. C. Marston, H. Toy, J. Walkil, J. A. Zitz, and R. R. Schmidt, “A practical implementation of silicon micro channel coolers for high power chips,” IEEE Compon. Packag. Technol., vol. 30, no. 2, pp. 218–225, Jun. 2007.

[7] M. E. Steinke and S. G. Kandlikar, “Single phase liquid heat transfer with plain and enhanced micro channels,” in Proc. 4th ASME Int. Conf. Nanochann. Microchann. Minichann., Limerick, Ireland, 2006, pp. 943.

[8] M. T. Bohr, “Interconnecting scaling the real limiter to high performance ULSI,” in Proc. IEEE Int. Electron Dev. Meeting, Dec. 1995, pp. 241–244.

[9] P. Lall, M. G. Pecht, and E. B. Hakin, Influence of Temperature on Microelectronic and Reliability. Boca Raton, FL: CRC Press, 1997.

[10] G. O.Workman, J. G. Fossum, S. Krishnan, and M. M. Pelella, “Physical modeling of temperature dependences of SOI CMOS devices and circuits including self-heating,” IEEE Trans. Electron Dev., vol. 45, no. 4, pp. 125–133, Jan. 1998.