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CFD Analysis of Splayed Pin Fin Heat Sink for Electronic Cooling

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Abstract

Heat dissipation techniques are the prime concern to remove the waste heat produced by Electronic Devices, to keep them within permissible operating temperature limits. Heat dissipation techniques include heat sinks, fans for air cooling, and other forms of cooling such as liquid cooling. Heat produced by electronic devices and circuitry must be dissipated to improve reliability and prevent premature failure. Integrated circuits such as CPUs, chipset, graphic cards, and hard disk drives are susceptible to temporary malfunction or permanent failure if overheated. As a result, efficient cooling of electronic devices remains a challenge in thermal engineering.

The objective of this paper is to present an Optimal Heat Sink for efficient cooling of electronic devices. The choice of an optimal heat sink depends on a number of geometric parameters such as fin height, fin length, fin thickness, number of fins, base plate thickness, space between fins, fin shape or profile, material etc. Therefore for an optimal heat sink design, initial studies on the fluid flow and heat transfer characteristics of a standard pin fin, splayed pin fin and Hybrid pin fin heat sinks have been carried through CFD modelling and simulations. It is observed from the results that optimum cooling is achieved by splayed & hybrid pin fin heat sinks. These heat sink designs promises to keep electronic circuits 20 to 40% cooler than standard pin-fin heat sinks.

1. Introduction

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 pin fins. Applications utilizing pin 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. Today's cutting edge electronic circuits dissipate 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. One of the more powerful cooling technologies that have emerged in recent years is the pin fin technology. The unique pin fin design generates significant cooling power and is highly suitable for "hot" devices and applications that have limited space for cooling[1,7].

Pin fin heat sinks for surface mount devices are available in a variety of configurations, sizes and materials. Pin fin heat sinks, which contain an array of vertically oriented round pins made of copper or aluminium, deliver significantly greater performance than standard heat sinks with flat fins. The aerodynamic nature of the round pins and their omnidirectional configuration enable pin fin heat sinks to transfer heat very efficiently from the heat generating device to the ambient environment. As a result, this superior heat sink style is used in a wide range of applications and industries, wherever difficult cooling challenges takes place.

Fig.1. Standard pin fin heat sink

Even though standard pin fin heat sinks as shown in Fig.1 provide significant levels of cooling, there are applications in which even greater cooling power is required. With these applications in mind, two pioneering derivatives of the pin fin heat sink were developed. Splayed pin fins as shown in Fig.2 and hybrid pin fins as shown in Fig.3 both possess the round pins associated with the standard pin fin heat sink. But as result of their structural and metallurgical enhancements, these two new heat sink styles drive heat sink performance to advanced levels.

Splayed pin fin heat sinks are relatively new derivatives of the standard pin fin heat sink. Unlike standard pin fin heat sinks, which contain an array of vertically oriented pins, splayed pin fins features pins that gradually bend outward. Curving the pins in this way increases the spacing between the pins and allows surrounding air streams to enter and exit the pin array more efficiently without sacrificing surface area. The impact of increased pin spacing on heat sink performance is magnified at lower air speeds because weak air streams have less power to penetrate the array of pins.

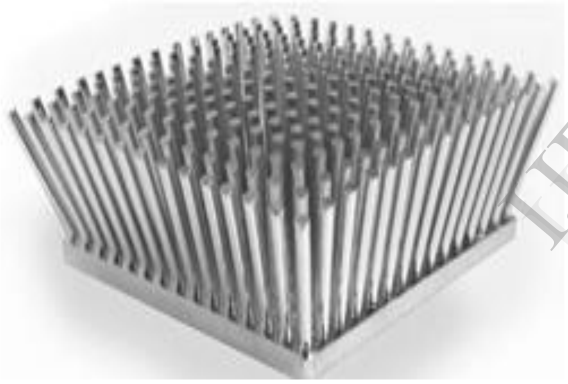

Fig.2. Splayed pin fin heat sink

In low airspeed environments and in natural convection, the increased spacing between the pins reduces the heat sink's thermal resistance by up to thirty percent versus a standard pin fin heat sink. As a result, splayed pin fins are recommended for low and moderate airspeed environments and for natural convection cooling.

Hybrid pin fins shown in Fig.3 feature the same pin configuration as standard pin fin heat sinks, but change the material used in the base. Unlike standard pin fin heat sinks that are either composed of aluminium or copper, hybrid pin fin heat sinks consist of aluminium pin fins that are reflowed onto a copper plate.

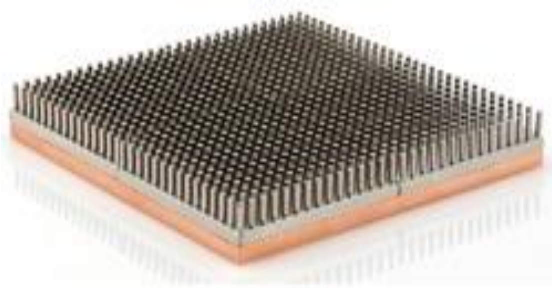

Fig.3. Hybrid pin fin heat sink

Hybrid heat sinks are designed for devices that feature small and focused heat sources. Such devices require heat sinks that are significantly larger than the devices they reside on. These heat sinks are also intended for multi device cooling, in which a single heat sink is used to cool more than one module.

Both of these technologies are becoming more popular as designers try to maximize the space available for cooling purposes. They do so by using application space that is not directly over the heat generating device. In each case, the heat sink must be able to spread the heat quickly along its base to operate efficiently. Otherwise the areas of the heat sink far away from the device will not able to provide any cooling When compared to all copper heat sinks, hybrid heat sinks provide similar spreading power, as the spreading of the heat occurs just along the base. The major advantage of hybrid heat sinks over all copper models is their lighter weight. Copper is approx. 3.2 times the weight of aluminium. So, depending on the size of the heat sink, hybrids may be up to 50% lighter than all-copper heat sinks of the same size.

In the most challenging cooling applications, designers can deploy splayed pin fin heat sinks and hybrid pin fin heat sinks to achieve the required cooling without making excessive tradeoffs in heat sink size or weight. As with vertical pin fin designs, these new variations are highly customizable. Designers can adapt heat sink footprints, pin counts, and other parameters for optimum cooling in their applications.

2. State of the Art

Wirtz et al. reported experimental results on the thermal performance of model pin-fin fan-sink assemblies. They used cylindrical, square, and diamond-shaped cross-sectional pin-fins and found that cylindrical pin-fins give the best overall fan-sink performance. Furthermore, the overall heat-sink thermal resistance decreases with an increase in either pressure rise or fan power and fin height [1].

Jonsson and Bjorn performed experiments to compare the thermal performance of heat sinks with different fin designs including straight fins and pin fins with circular, quadratic, and elliptical cross sections. They evaluated the thermal performance by comparing the thermal resistance of the heat sinks at equal average velocity and equal pressure drop. They recommended elliptical pin-fin heat sinks at high velocities and circular pin-fin heat sinks at midrange velocities [2].

The steady-state thermal and air-flow resistance performances of horizontally based pin-fin assemblies were investigated experimentally by Tahat et al3 .They studied the effects of varying geometrical configurations of the pin-fins and found the optimal Pin fin separation in both stream wise and span wise directions to achieve maximum heat transfer rate[3].

Jung and Maveety performed numerical experiments to investigate the turbulent fluid flow and heat transfer from three pin-fin heat sink geometries over the ReD range from 7800 to 19,700 with air impingement cooling. They used a standard κ– turbulence model to predict the Reynolds stresses. They found that the maximum heat transfer dissipated from a heat sink was obtained under turbulent flow conditions [4].

Behnia et al compared numerically the heat transfer performance of various commonly used fin geometries (circular, square, rectangular, and elliptical).They fixed the fin cross-sectional area per unit base area, the wetted surface area per unit base area, and the flow passage area for all geometries. They found that circular pin fins outperform square pin fins and elliptical fins outperform plate fins. They also found that elliptical fins work best at lower values of pressure drop and pumping work whereas round pin fins offer highest performance at higher values [5].

3. Model Analysis

The modelling of pin fin heat sinks are made by GAMBIT 2.4.6 software.

This analysis is based on the following assumptions:

1) The fins are with adiabatic tip.
2) The fluid, air is assumed to be incompressible throughout the process.
3) The airflow is normal to the fins.
4) Air properties are taken at film temperature.
5) The flow is steady, laminar and two dimensional.
6) There are no heat sources within the fin itself.
7) The radiation heat transfer is negligible.
8) The temperature at the base of the fin is uniform.
9) The heat flow in the fin and its temperatures remain constant with time.
10) The fin material is homogeneous and isotropic.

3.1 Geometry

Heat sinks, used in electronic devices, usually consist of arrays of pin-fins arranged in an in-line manner as shown in Fig 4. The pins are attached to a common base and the geometry of the array is determined by the pin dimensions, number of pins and pin arrangement.

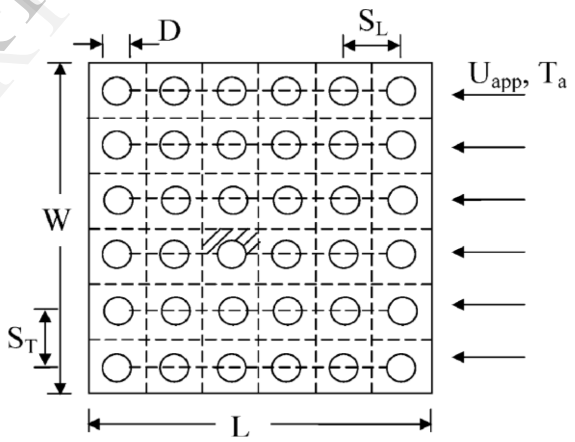

Fig 4: Schematic of in-line pin-fin heat sinks

The geometry of an in-line pin-fin heat sink is shown in Fig 5.The dimensions of the base plate are L × W × t_b, where L is the length in the stream wise direction, W is the width, and t_b is the thickness. Each pin fin has diameter D and height H. The longitudinal and transverse pitches are S_L and S_T respectively. The approach velocity of the air is U_{app}. The direction of the flow is parallel to the x-axis. The base plate is kept at constant heat flux and the top surface (y = H) of the pins is adiabatic. The average local wall temperature of the pin surface is $T_w(x)$. The heat source is idealized as a constant heat flux boundary condition at the bottom surface of the base plate. The mean temperature of the heat source is Ts. It is assumed that the heat sink is fully shrouded and the heat source is situated at the centre of the base plate.

It is assumed that the fluid temperature is averaged over the height of the heat sink, with $T_f = T_f (x)$, so the fluid temperature $T_f (x)$ is the bulk mean fluid temperature. Fully developed heat and fluid flow are assumed in the analysis, and the thermo physical properties are taken to be temperature independent. The overall mesh of the geometry shown in Fig.6.

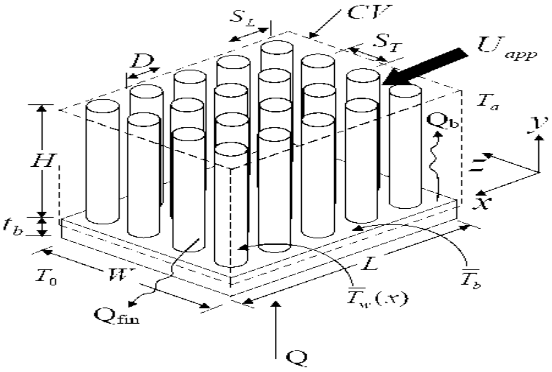

Fig 5. Geometry of In-Line Pin-Fin Heat Sink

Table 1 Dimensions used to determine performance of heat sinks

Quantity	Dimension
Footprint (mm^2)	52×52
Base plate thickness (mm)	3
Overall height of fin(mm)	30
Approach velocity (m/s)	3
Thermal conductivity of solid aluminium(W/m•K) for aluminium	237
Thermal conductivity of solid copper(W/m•K)	401
Thermal conductivity of air (W/m•K)	0.0284
Density of air (kg/m3)	1.086
Specific heat of air (J/kg•K)	1007
Kinematic viscosity (m2/s)	18.15×10^{-6}
Absolute viscosity (Ns/m^2)	19.70×10^{-6}
Prandtl number (Air)	0.6976
Heat load (W)	130
Ambient temperature (K)	297
Base plate temperature (K)	353

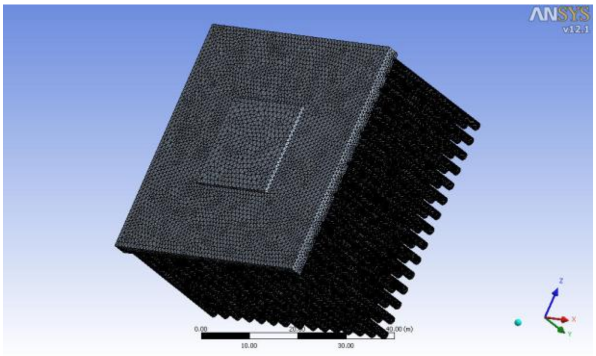

Fig 6. Meshing of In-Line Pin-Fin Heat Sink

3.2 Calculations

To form an appropriate model for calculations, the following assumptions are made.

1. The contact resistance between the heat sink and processor would be negligible when using a high quality thermal paste.
2. The average temperature of the air flowing through the heat sink would be 325 K, and used the values of material properties at 325 K.
3. The Intel, core i7-970 processor is selected as heat source of 130W, to evaluate the pin fin heat sink performance.

3.2.1 Heat transfer coefficient over flate plate

$$\text{Reynolds's number } (Re_L) = (\rho\ v\ L)/\mu \qquad (1)$$

$$Nu = 0.332\ Re_L^{0.5}\ Pr^{0.333} \qquad (2)$$

$$Nu = h_1 L/k \qquad (3)$$

$$h_1 = Nu\ k/L \qquad (4)$$

3.2.2 Heat transfer coefficient across bank of tubes Reference Velocity

The mean velocity in the minimum free cross section between two rows, V_{max}, is used as a reference velocity in the calculations of fluid flow and heat transfer for inline arrangement, and is given by

$$V_{max} = [S_T/(S_T - D)]\ U_{app} \qquad (5)$$

where U_{app} is the approach velocity, S_L, and S_T are the dimensionless longitudinal and transverse pitches,

$$Re_{Dmax} = \rho\ v_{max}\ D \qquad (6)$$

$$Nu = C\ (Re_{Dmax})^{\ n} \qquad (7)$$

For the values of C and n from data book

$$Nu = h_2 D/k \qquad (8)$$

$$h_2 = Nu\ k/D \qquad (9)$$

4. CFD simulation approach

The ANSYS FLUENT 12.1 CFD code was used for the simulations. The simulation procedure was started with pre-processing. The computational mesh was generated using tetrahedral elements. In order to accurately resolve the solution fields in the high gradient regions, the grid was stretched. The discretization scheme was first order upwind scheme. A SIMPLE algorithm was used. For the simulations presented here, depending on the geometry used, fine mesh of up to 3, 33,998 elements were used. The flow field and heat transfer were determined by iteratively solving the governing momentum and energy equations. The under-relaxation factors were first set at low values to stabilize the calculation process, and were increased to speed up the convergence.

The normalized residuals were set at 10^{-4} for velocity components and at 10^{-7} for energy equation, which proved to be adequate.

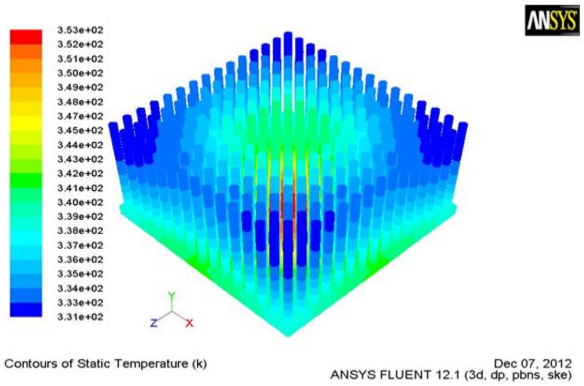

Fig 7. Temperature Contours of Standard aluminium Pin Fin Heat sink with 3 m/s velocity

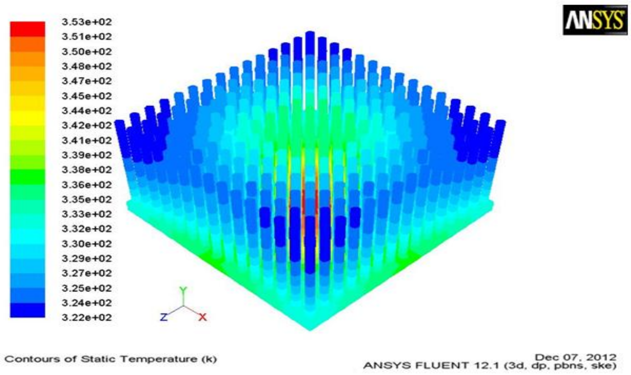

Fig 8:Temperature Contours of Standard copper Pin Fin Heat sink with 3 m/s velocity

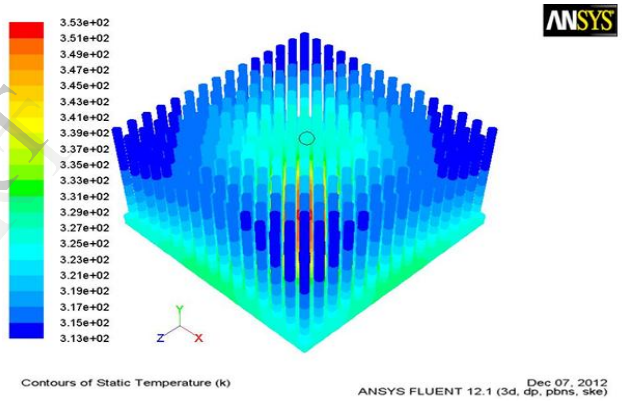

Fig 9.Temperature Contours of Standard hybrid Pin Fin Heat sink velocity (copper base plate with aluminium heat sink)with 3 m/s velocity

Fig.7, Fig.8 and Fig.9 Illustrate the Temperature variation of Standard pin fin heat sinks.

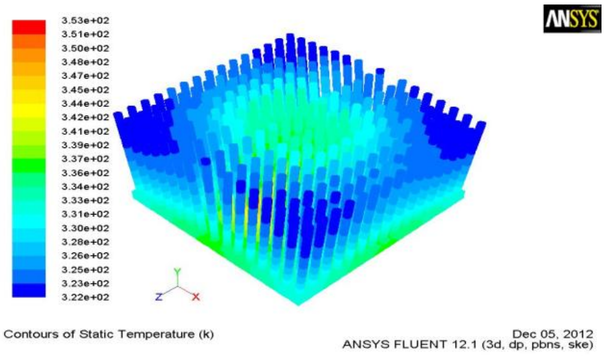

Fig 10:Temperature Contours of Splayed aluminium Pin Fin Heat sink with 3 m/s velocity

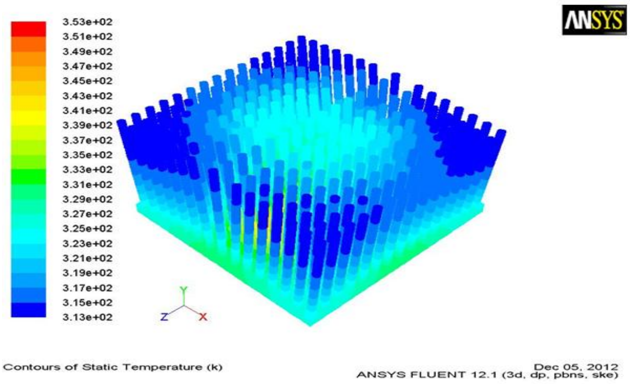

Fig 11:Temperature Contours of Splayed copper Pin Fin Heat sink with 3 m/s velocity

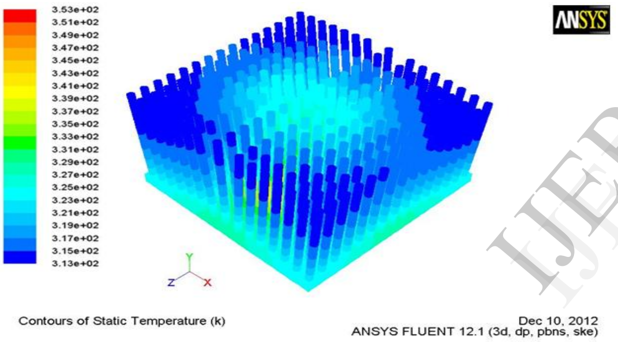

Fig 12:Temperature Contours of Splayed hybrid Pin Fin Heat sink velocity (copper base plate with aluminium heat sink)with 3 m/s velocity

Fig.10, Fig.11 and Fig.12 Illustrate the Temperature variation of Splayed pin fin heat sinks.

5. Results & Discussion

The result obtained from CFD Simulation approach shown in figures 7 to 12 illustrates that copper pin fin heat sinks have lower thermal resistance and superior heat spreading capabilities when compared with aluminium pin fin heat sinks. As a result, copper pin fin heat sinks are generally suitable for two types of design scenarios. The first would be any design with extreme cooling requirements such that aluminium pin fin heat sinks cannot achieve sufficiently low thermal resistance. The other scenario is any application in which the heat sink is significantly larger than the device being cooled. In that case, the ability of copper to spread heat rapidly through the base of the heat sink becomes a necessity to ensure the effectiveness of the fins located far away from the heat generating device. However, the drawback of copper pin fin heat sinks is more cost and more weight than aluminium. In that case hybrid pin fin heat sinks are the best alternative for cooling. Because hybrid pin fin heat sinks exhibits similar characteristics of copper. The comparative temperature values for aluminium, copper and hybrid pin fin heat sinks with standard and splayed structures are shown in Table 2.

	Al	Cu	Hybrid
Standard	342	337	330
Splayed	339	327	324

It is clear analysis that splayed pin fin heat sink enhances the heat transfer, when compared to the standard pin fin heat sink.

6. Conclusion

In the present paper CFD analysis of Splayed pin fin heat sinks for electronics cooling is investigated. Based on the results obtained it can be concluded that in the sense of junction temperature splayed pin fins are efficient .It is also found that Hybrid pin fin heat sinks have better performance than aluminium and copper pin fin heat sinks.

7. Nomenclature

A_b = area of the base plate, m^2
A_C=Area of the Micro processor chip, m^2
t_b=Thickness of the base plate, m
t_c=Thickness of the Microprocessor chip, m
T_a =Ambient Temperature, K
T_s = Surface Temperature, K
T_f =Film Temperature, K
D = pin diameter, m
H = pin height, m
k = thermal conductivity
N = total number of pins in heat sink
L = length of heat sink in flow direction, m
N_L = number of pins in the longitudinal direction
N_T = number of pins in the transverse direction
Nu_D = Nusselt number based on pin diameter
Q = total heat transfer rate, W
Re_D = Reynolds number based on pin diameter
S_L = longitudinal distance between two consecutive pins,m
S_T = transverse distance between two consecutive pins, m
U_{app} = approach velocity, m/s

V_{max} = maximum velocity in minimum flow area, m/s
W = width of heat sink, m

Subscripts
a = ambient
b = base plate
f = film
app = approach

Greek
μ = absolute viscosity of fluid [kg/ms]
ν = kinematic viscosity of fluid [m^2/s]
ρ = fluid density [kg/m^3]

8. References

[1].Wirtz, R. A., Sohal, R., and Wang, H., “Thermal Performance of Pin-Fin Fan-Sink Assemblies,” *Journal of Electronic Packaging*, Vol. 119, March 1997, pp. 26–31.

[2].Jonsson, H., and Bjorn, P., “Experimental Comparison of Different Heat Sink Designs for Cooling of Electronics,” American Society of Mechanical Engineers, Heat Transfer Division, HTD, Vol. 329, No. 7, Association of Mechanical Engineers, New York, 1996, pp. 27–34.

[3].Tahat, M. A., Babus’Haq, R. F., and Probert, S. D., “Forced Steady-State Convections from Pin Fin Arrays,” *Applied Energy*, Vol. 48, No. 4, 1994, pp. 335–351.

[4].Jung, H. H., and Maveety, J. G., “Pin Fin Heat Sink Modeling and Characterization,” *Sixteenth IEEE Semi-Therm Symposium*, IEEE Publications, Piscataway, NJ, March 2000, pp. 260–265.

[5].Behnia, M., Copeland, D., and Soodphadakee, D., 1998, “A Comparison of Heat Sink Geometries for Laminar Forced Convection,” Proceedings of The Sixth Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems, Seattle, Washington, USA, May 27–30, pp. 310–315

[6].Kodandaraman, C.P., Heat and Mass Transfer Data Book.

[7]. http://www.ecnmag.com/articles/2010/01/nextgenerationpin-fin-heat-sinks-provide-superior cooling power