Journal of Electronics and Information Science (2019) 4: 17-25
Clausius Scientific Press, Canada

DOI: 10.23977/jeis.2019.41013
ISSN 2371-9524

High Efficiency Low Profile Heat Sink for Air Cooling of Microelectronics

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Keywords: High efficiency; Low profile; Heat sink; Air cooling; Microelectronics

Abstract: Cooling of electronics has received considerable attention recently. Simplicity and easy maintenance make direct air cooling a most attractive approach in cooling of electronics. Various heat sinks are often mounted to the microelectronic components in order to enhance thermal performance so that the components can be maintained below the respective temperature limits. The high thermal efficiency low profile cell-fins heat sink is developed to meet the need of high power electronics in the limited space between printed circuit boards often occurred in any microelectronic equipment. For the purpose of comparison, convectional heat sinks, including extrusion fins and plain fins are included in the evaluation. A CFD analysis is performed to characterize the performance of the individual heat sinks. A copper heat sink is mounted to a component on the printed circuit board (PCB) which is cooled by the air with the velocities at 1.5, 2.5, 3.5, and 5.5 m/sec, respectively. In order to simulate the real board condition, the flow by-pass which is an important phenomenon to the performance of the heat sink is included in the analysis. The purpose of this study is to evaluate the thermal performance of the individual heat sinks, with special interests in this newly developed cell fin heat sink at various flow velocities. In addition, the effects of the flow by-pass as well as heat sink flow leakage on the heat sink performance will also be examined in details.

1. Introduction

Because of advances in circuit and component technologies, electric circuits have become more efficient, i.e., consumption of less energy, and thus heat dissipation from individual transistors has also become less. However, miniaturization of circuits greatly increases the number of transistors in a single chip. The net result is that the chip heat dissipation has significantly increased in the recent years.

Simplicity and easy maintenance make direct air cooling a most attractive approach in cooling of electronics. Various heat sinks are often mounted to the microelectronics components in order to enhance thermal performance so that the components can be kept below the respective temperature limits.

Three different types of the heat sinks, including extrusion fin, plain fin, and cell fin are under considerations. The extruded heat sink is the most popular because it is inexpensive and easy to

make. However, the fin of this type heat sink is relatively thick which results in the limit number of fins available leading to small surface area available for the convective heat transfer.
The effectiveness of a heat sink is measured by the total heat transfer rate which is defined as follows:

$$Q = \eta\, h\, A_t\, \Delta T \qquad (1)$$

Where

Q = total heat transfer rate

η_o = overall surface efficiency

$= 1 – A_f/A_t\,(1 - \eta_f)$

A_f = fin surface area

A_t = total heat sink surface area for convection

η_f = fin efficiency

h = heat transfer coefficient

ΔT = temperature difference between average heat sink temperature and fluid temperature

A CFD analysis is performed to characterize the thermal performance of the individual heat sinks. A copper heat sink is mounted to a component on the printed circuit board (PCB) which is cooled by the air with the velocities at 1.5, 2.5, 3.5, and 5.5 m/sec, respectively. The flow by-pass which is an important phenomenon to the performance of the heat sink will also be discussed
The additional assumptions for the analysis are as follows

- Inlet air at 30 °C
- Inlet flow rate at 1.5, 2.5, 3.5, and 5.5 m/sec
- Constant physical properties for air and copper heat sinks
  - Thermal conductivity of copper at 385 w/m-°C
- Component power of 80 watts with dimensions of 45 mm x 42 mm x 3 mm
  - Junction to case thermal resistance $\Theta_{j\text{-}c}$ = 0.3 w/°C
  - Junction to board thermal resistance $\Theta_{j\text{-}b}$ = 1.5 w/°C
  - Components mounted on PCB
- Thermal conductivity of TIM between heat sinks and components is 6 w-m/°C (0.5 mm thick)

2. System under Consideration

Three heat sinks along with the respective components are placed in the three separate rectangular channels as Illustrated in Figure 1. The heat sink configurations are presented in Figure 2 and Table 1

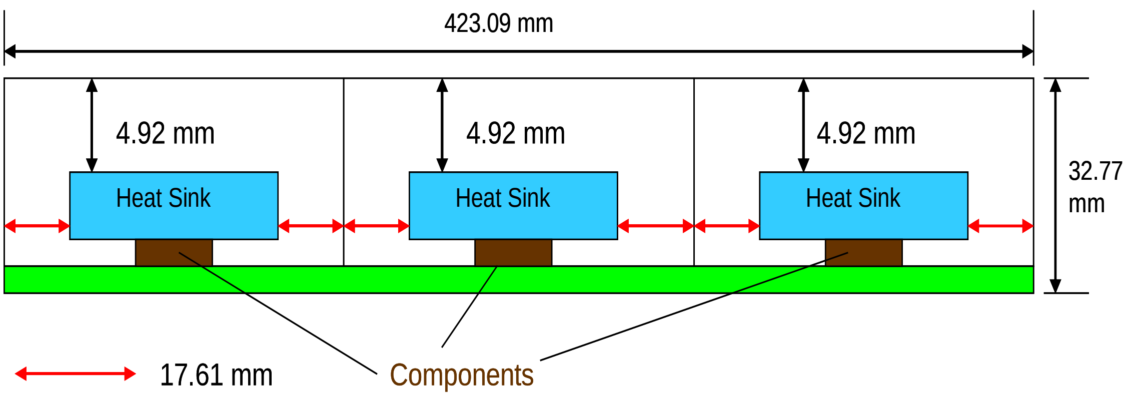


Figure 1 System Thermal Model with 3 Heat Sinks

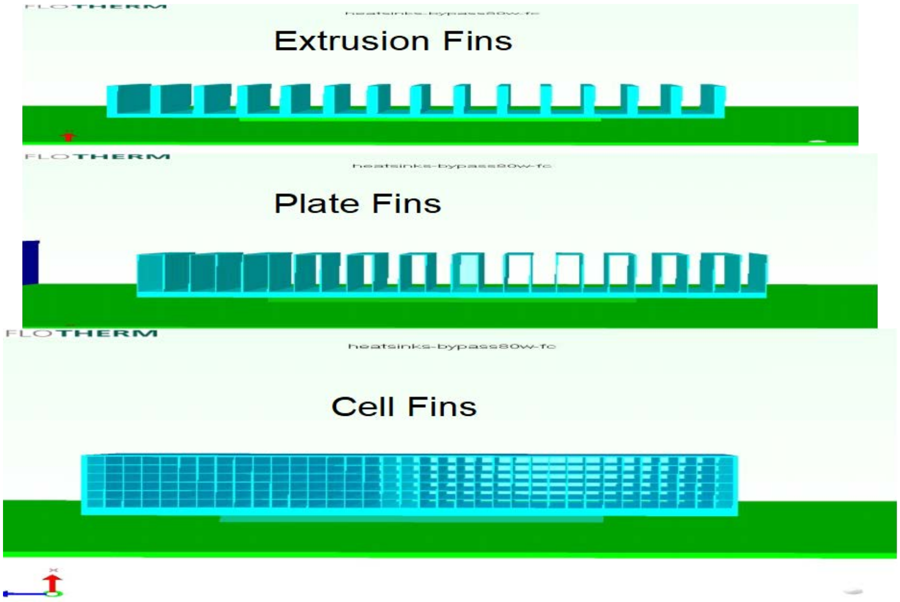


Figure 2 Heat Sink Fin Configurations

Table 1 Fin Configurations of Three Heat Sinks

	Extrusion Fins	Plain Fins	Cell Fins
Heat sink length (L)	60.0 mm	60.0 mm	60.0 mm
Heat sink width (W)	75.95 mm	75.95 mm	75.95 mm
Heat sink height (H)	23.255 mm	23.255 mm	23.255 mm
Base height (Hb)	2.95 mm	2.95 mm	2.95 mm
Fin height (Hf)	20.305 mm	20.305 mm	20.305 mm
Fin thickness (t)	1.3 mm	0.2 mm	0.1 mm
Fin number :	15	25	35

The detailed information of a single fin in the cell fin heat sink is shown in Figure 3. All cell fins are enclosed by the frame with the thickness of 0.5 mm

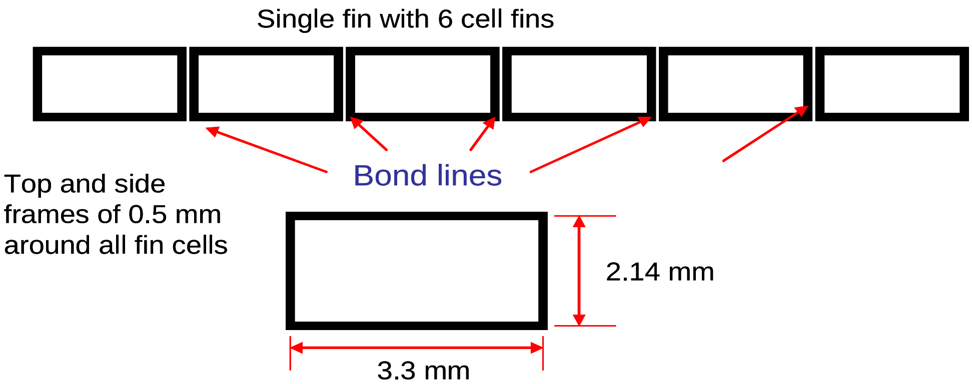


Figure 3 Details of Single Fin for Cell Fin Heat Sink

3. Results and Discussions

A CFD analysis is performed to characterize the performance of the individual heat sinks. The CFD model includes three heat sinks in the separated rectangular channels as shown in Figure 1. The air flow with a constant velocity is provided at the inlet of individual channels. For convenience, the commercial code, Flotherm is employed in the analysis.

To accurately simulate the real board condition, the flow by-pass is included in the thermal model. The heat transfer coefficient and also the thermal resistance of the heat sinks are given in Figures 4 and 5, respectively. The thermal resistance, R of the heat sink is defined as follows

$$R = Q/\Delta T = 1./(h\ At) \qquad (2)$$

Where the ΔT is defined as the temperature difference between the center of the heat sink base and the inlet air.

Figure 4 shows the heat transfer coefficients of the various heat sinks. As can be seen from the figure, the cell-fin heat sink has the lowest value of the heat sink transfer coefficient, and then followed by the plain-fin and the extrusion-fin heat sinks respectively. The opposite trends for the thermal resistance of the heat sinks are found in Figure 5. The value of the thermal resistance represents the effectiveness of the heat transfer. The lower thermal resistance, the higher effectiveness of a heat sink is. This reason for the lowest heat transfer coefficient for the cell-fin heat sink is due to small spacing between the fins. However, it has the largest heat transfer surface area among all heat sinks. Therefore, the cell-fin heat sink has the lowest value of the thermal resistance as shown in Figure 5.

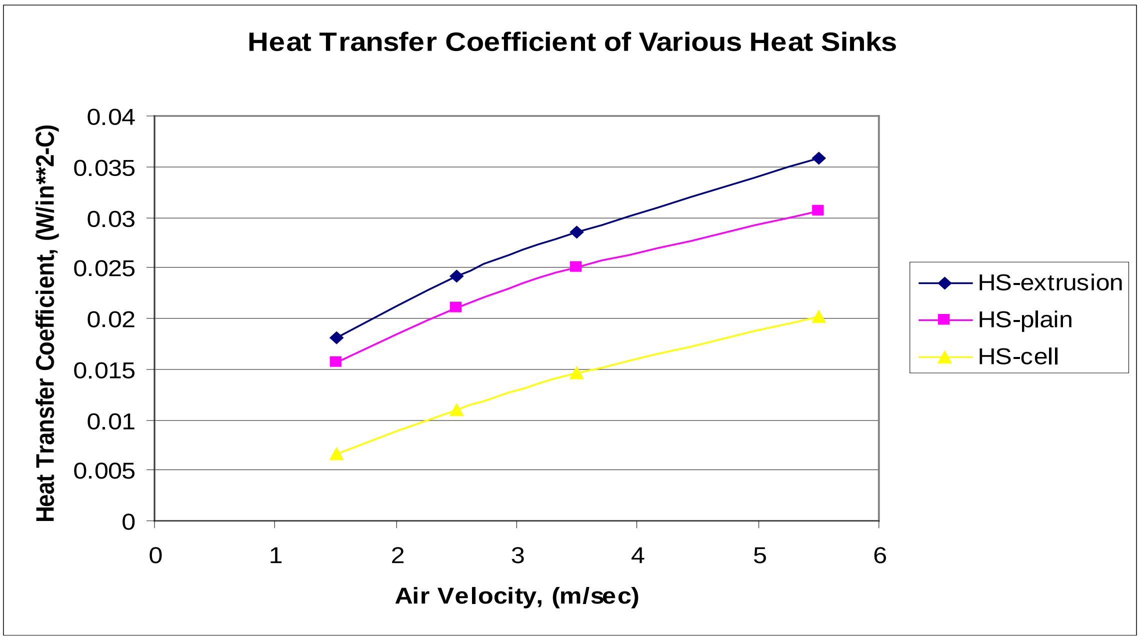


Figure 4 Heat Transfer Coefficient at Various Air Speeds

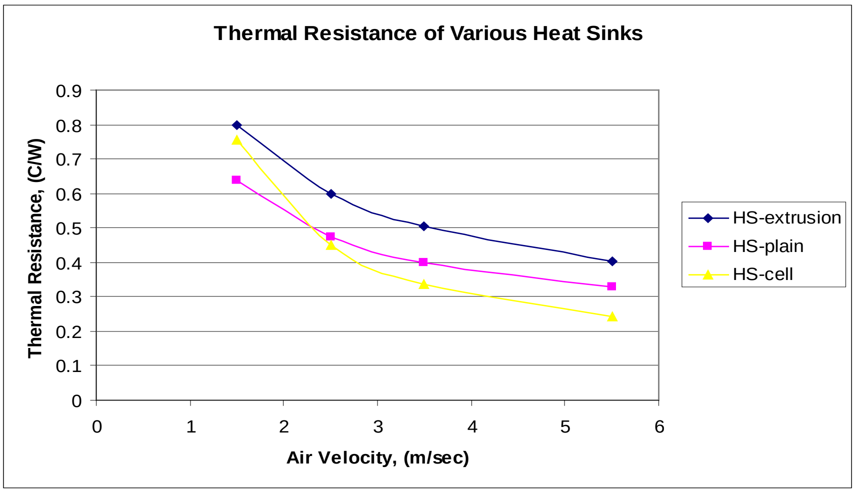


Figure 5 Heat Sink Thermal Resistance at Various Speeds

The heat sink heat transfer surface used to compute the heat transfer coefficient is defined as the total surface area of the heat sink except the bottom of the heat sink base overhanging over the components. The cell-fin heat sink has the largest surface area for the convection but the space between the fins is very small. As can be seen from Figure 5, the thermal resistance of the cell-fin heat sink is across over the other heat sinks for the velocity less than 2.2 m/sec. Because the heat transfer coefficient is so small for the cell-fin heat sink with the velocity less than 2.2 m/sec that the product of the heat transfer coefficient and the surface area is also smaller than those of other two heat sinks at the same velocity which result in the higher thermal resistance

The surface temperatures of the heat sinks at velocity of 3.5 m/sec are presented in Figure 6 for the extrusion-fin, plain-fin and cell-fin heat sinks. The heat sink surface temperature is a function of the thermal resistance, not heat transfer coefficient alone. The trends in Figure 6 are consistent with the results given in Figure 4. In other words, the heat sink with the smallest thermal resistance has the lowest surface temperature. In addition, the component case and junction temperature are given in Figures 7 and 8 respectively.

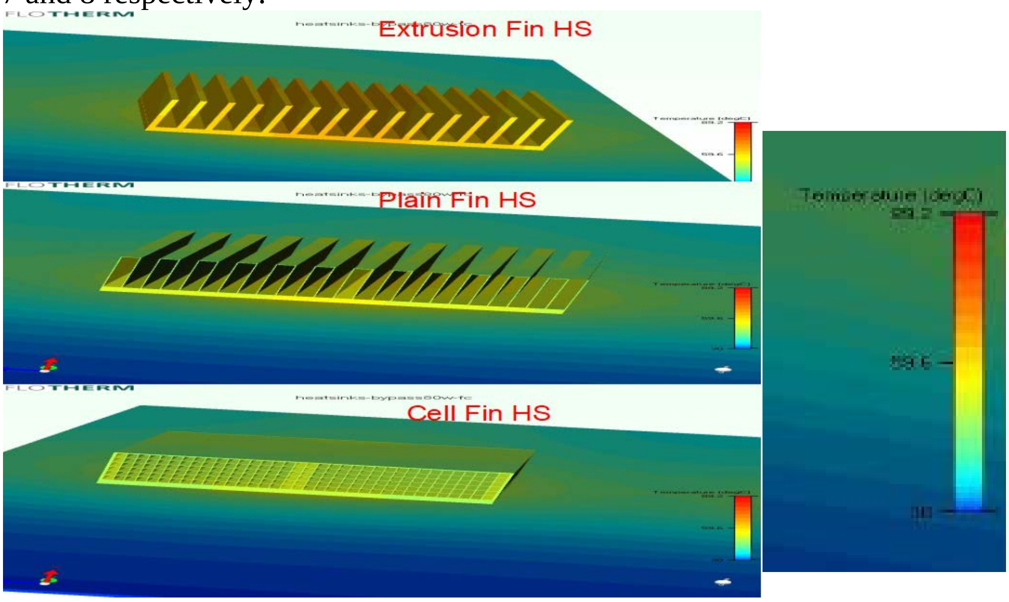


Figure 6 Surface Temperature for Various Heat Sinks at 3.5m/sec

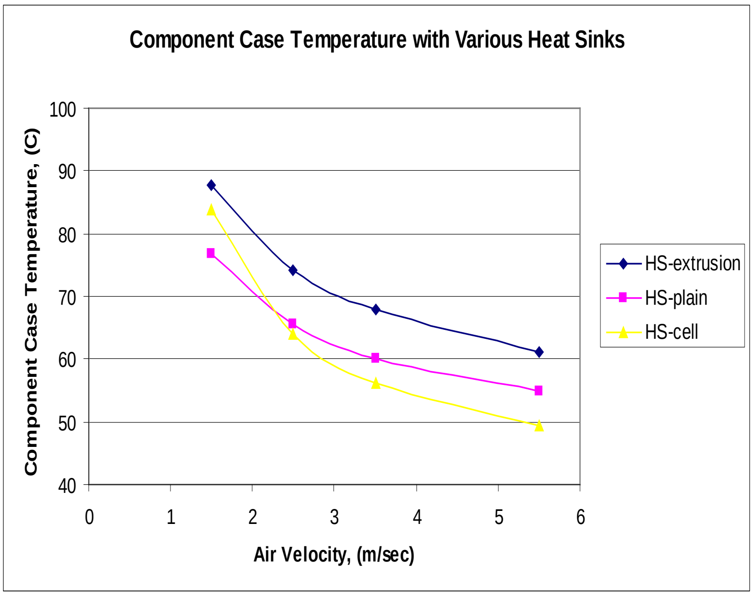


Figure 7 Component Case Temperatures

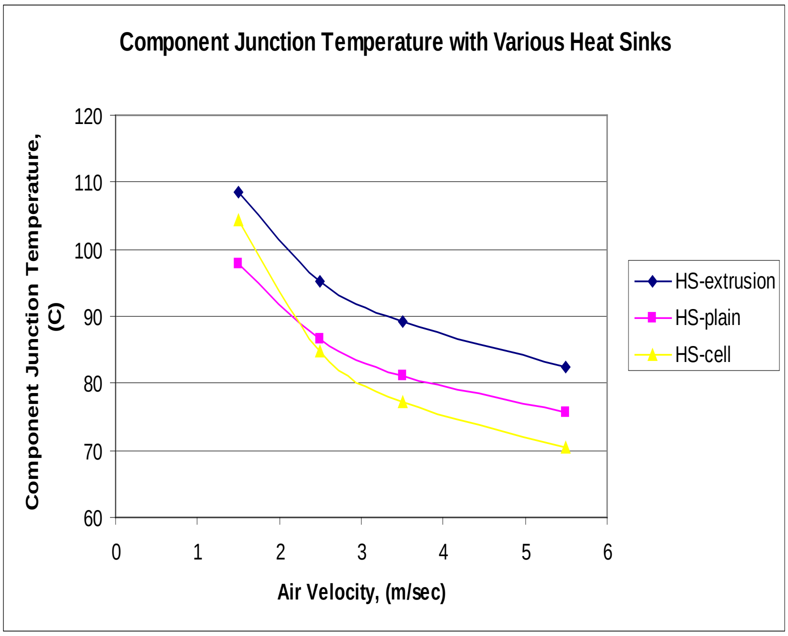


Figure 8 Component Junction Temperatures

It should be noted that the assumption of the junction to case thermal resistance Θ_{j-c} = 0.3 w/°C is well too conservative. With the current advanced component design and manufacturing technologies, the Θ_{j-c} is probably only the one-third of the assumed value. Therefore, the actual component junction temperature will be much lower than the predicted values as shown in Figure 8 The analysis includes the effects of the flow by-pass. This means that the channel cross section is larger than the heat sink cross section area. In other words, not all of the air flow goes through the individual heat sinks. The examples of the flow by-pass over the heat sinks are shown in Figure 9. The narrow spaces between fins restricted the air flow getting into the heat sink.

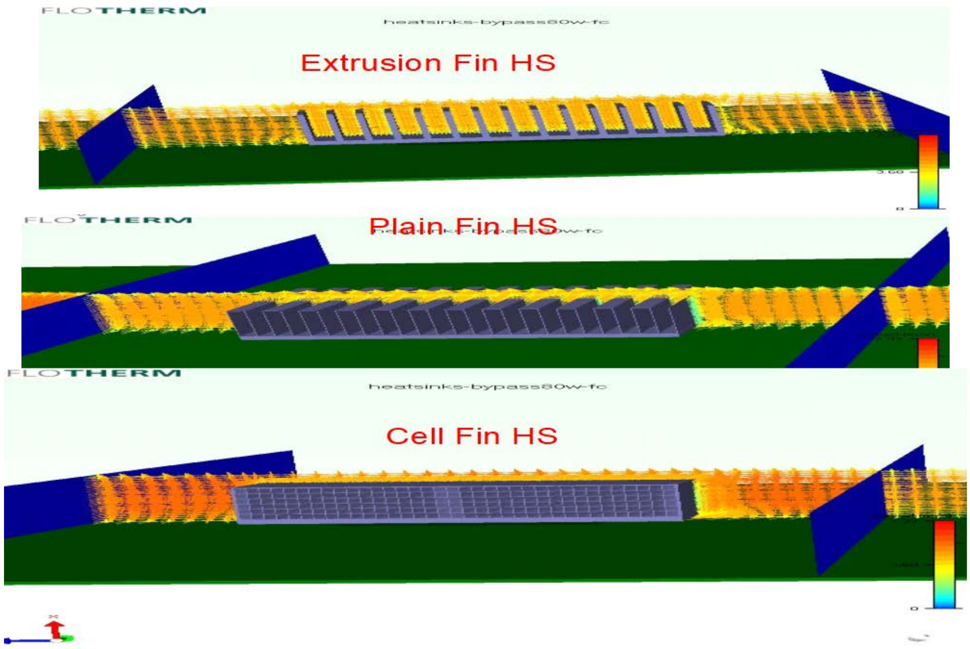


Figure 9 Velocity Profile for Various Heat Sink at 3.5 m/sec

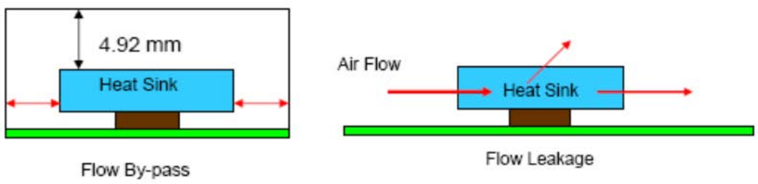
Table 2 shows the heat sink by-pass and leakage over three heat sinks. The amount of the heat sink flow by-pass represents the difference in the flow rates between the channel flow and heat sink inlet flow rates. On the other hand, the heat sink flow leakage corresponds to the difference between the inlet and exit flow rates of the heat sink under consideration. The cell fin heat sink has the largest flow by-pass among these three types of the heat sinks because of the highest flow resistance. However, it has no heat sink flow leakage because the flow is in a confined space. In other words, the air flows internally in the individual cells of the cell heat sink.

Table 2 Heat Sink Flow By-Pass and Leakage

Velocity, (m/sec)	Channel Flow (CFM)	Extrusion Fin HS (CFM)		Plain Fin HS (CFM)		Cell Fin HS (CFM)	
		Inlet	Exit	Inlet	Exit	Inlet	Exit
1.5	13.97	4.4149	3.7294	4.4128	3.6968	2.0627	2.0627
2.5	23.28	7.5561	6.6621	7.7651	6.8018	4.2083	4.2083
3.5	32.60	10.7116	9.6604	11.1854	10.0380	6.6231	6.6241
5.5	51.23	17.0087	15.6888	18.0969	16.6724	11.7902	11.795

Heat sink flow by-pass = Channel flow – Heat sink inlet flow

Heat sink flow leakage = Heat sink inlet flow – Heat sink exit flow



The total pressure drop which consists of inlet loss, exit loss and friction loss over the heat sinks is presented in Figure 10. As expected, the cell fin heat sink has highest pressure drop among all of three different types of the heat sinks because of the smallest free flow cross section area.

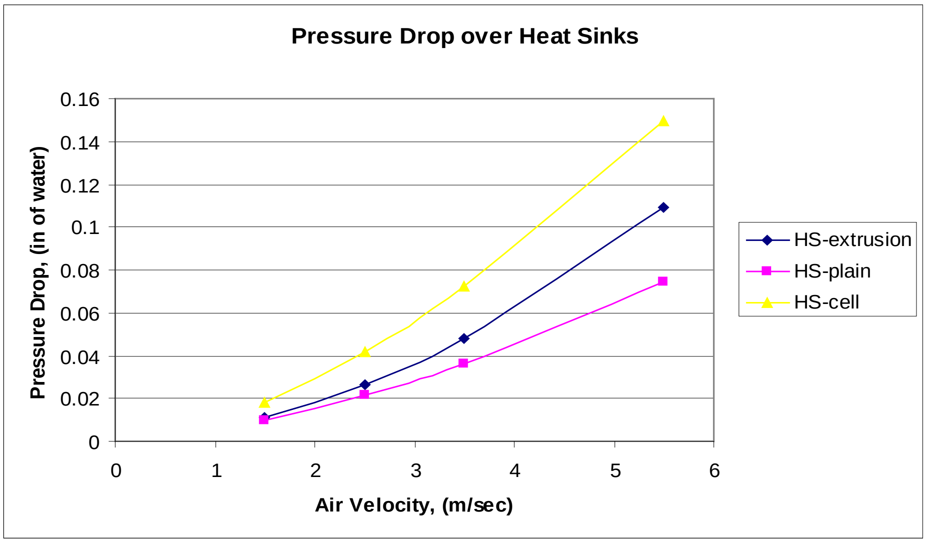


Figure 10 Total Pressure Drop over Various Heat Sinks

The analysis also finds that the flow rate in individual fins of the cell fin heat sink is very uniform and independent of the inlet flow rates as shown in Figure 11.

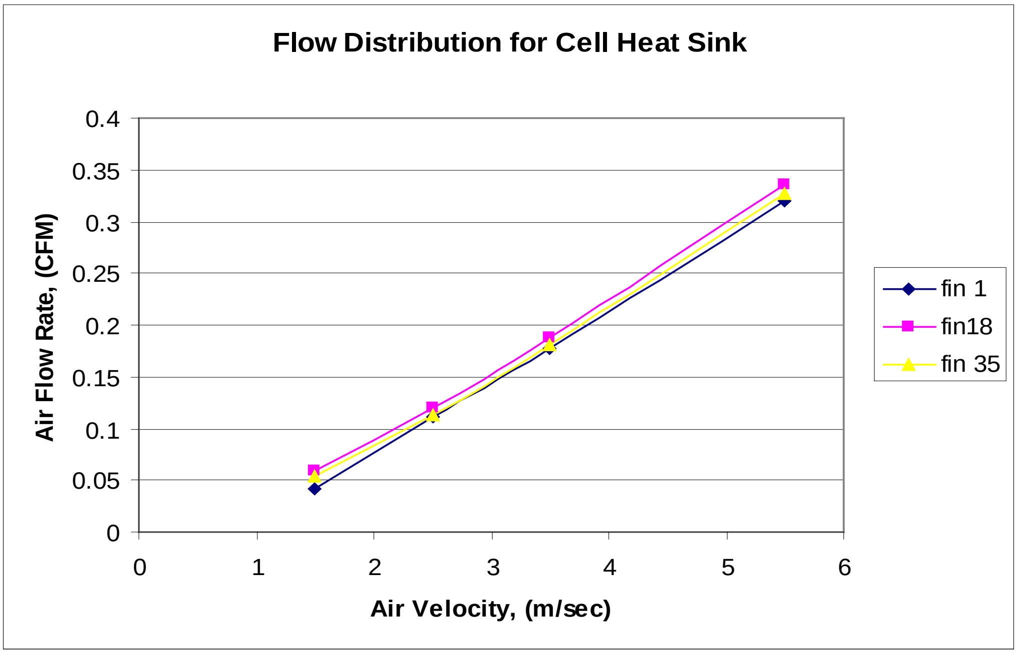


Figure 11 Flow Distribution in Fins for Cell Fin Heat Sink

4. Summary and Conclusion

A high thermal efficiency low profile cell fin heat sink is developed. To evaluate its thermal performance, the conventional extruded heat sink and a thin plain fin heat sink are included in the analysis. A CFD analysis is performed to characterize the thermal performance of the individual heat sinks. The CFD model includes three heat sinks in the separated rectangular channels. In order to simulate the real conditions for a forced air over a PCB (printed circuit board), the flow by-pass must be included in the model.

Figure 12 shows the heat transfer coefficient of the heat sinks at various speeds, ranging from 1.5 to 5.5 m/sec. The cell fin heat sink has the lowest of the heat transfer coefficient because of narrow spacing between the fins which results in the lowest air flow rate entering the heat sink. However, on the other hand, the cell fin heat sink provides the largest surface area available for the heat transfer.

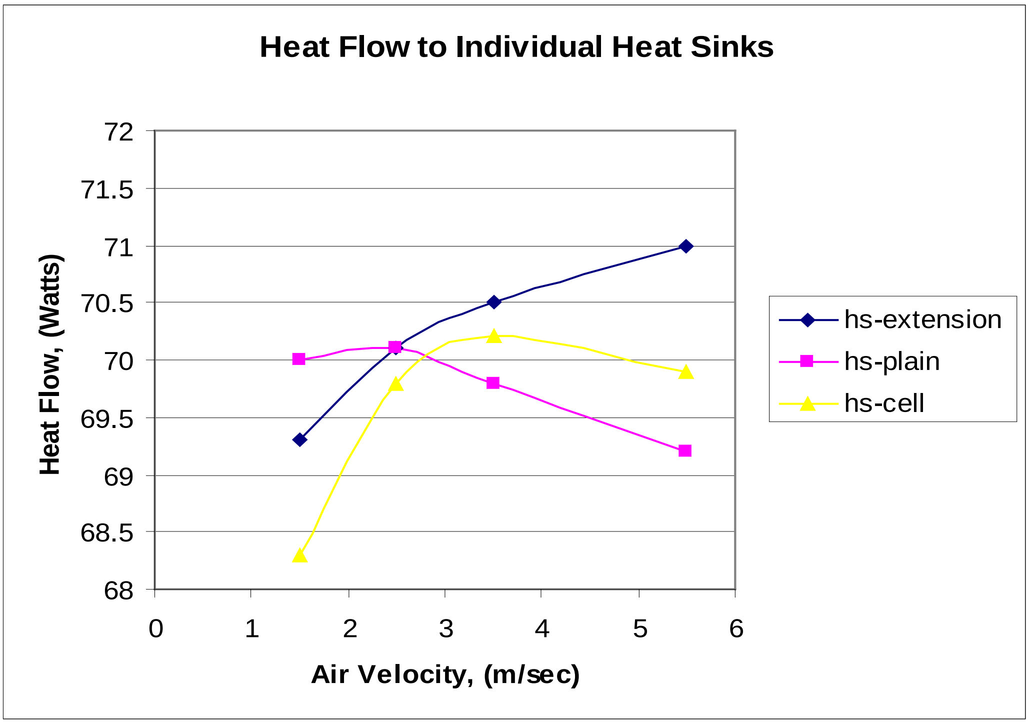


Figure 12 the heat transfer coefficient of the heat sinks at various speeds

The cell-fin heat sink has the largest surface area for the heat transfer but the space between the fins is very small. As can be seen from Figure 5, the thermal resistance of the cell-fin heat sink is across over the other heat sinks for the velocity less than 2.2 m/sec. Because the heat transfer coefficient is so small for the cell-fin heat sink with the velocity less than 2.2 m/sec that the product of the heat transfer coefficient and the surface area is also smaller than those of other two heat sinks at the same velocities.

Two important phenomena associated with the flow over the heat sink are the flow by-pass and the flow leakage. The flow by pass always exists on any PCB and hence, it must be included in the analysis. In summary, the cell fin heat sink is most effective, especially at higher velocities, and is followed by the plain fin heat sink. The extrusion heat sink is the most inefficient because of the least surface area for the heat transfer. However, the plain fin heat sink works well over wide range of the air velocities.

In summary, the thermal performance of the cell fin heat sink is much superior to the convectional heat sinks with the same overall dimensions.

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