

Heat Sink Thermal

Resistance Changes with Length and Width

The increasing power dissipation of ASICs and microprocessors, and their stringent thermal requirements, makes the use of heat sinks a standard industry practice. As processing speeds increase and packaging space shrinks, choosing the right heat sink becomes even more challenging. Specifically, a heat sink's thermal performance acquires a unique condition once it is placed on a PCB in an unducted fluid flow delivery system. While a heat sink may appear structurally simple, the fluid flow through its fin field and thermal coupling with its surrounding create a rather complex problem. As a result, heat sinks are often selected only by considering their total device power dissipation rather than performing a detailed thermal analysis, and thus the common syndrome of "I need a heat sink to cool a 15W device!" The most important characteristic of a heat sink is its thermal resistance value. The following will show the definition and evaluation of this number.

Heat sink thermal resistance (R_{sa}) is defined by the following equation [2],

$$R_{sa} = \frac{1}{\eta h A_{fin}} + \frac{1}{2 \dot{m} C_p} \quad (1)$$

Where,

A_{fin} = heat sink fin area and base area between fins

C_p = specific heat at constant pressure

h = heat transfer coefficient

\dot{m} = mass flow rate, equal to $\rho V_f \Delta$

V_f = fluid velocity in the fin field

η = fin efficiency

ρ = fluid density

Δ = fin channel cross sectional area

R_{sa} = sink-to-ambient thermal resistance

To determine R_{sa} , the heat transfer coefficient (h) and the flow

velocity within the fin field (V_f) must be determined. The heat transfer coefficient is obtained from Equation 2 [1]:

$$Nu = 4.421 + 0.1572(L^*)^{-0.811} \quad (2)$$

Where,

$$Nu = 2hs/k$$

and

$$L^* = L/2D_H Re_D$$

D_H = hydraulic diameter

k = fluid thermal conductivity

L = fin length in the direction of flow

Re_D = Reynolds number, equal to $\rho V_f D_H / \mu$

s = fin-to-fin spacing

The next step is to obtain V_f . Before we do this, it must be noted that calculating the fluid flow through the fin field in an open channel (top and side bypasses) is rather complex because the flow is highly three dimensional. The premature egress of the fluid from the fin field makes the analytical prediction difficult. This is shown in Figure 1, whereby the CFD simulation of the flow through the straight fin (conventional) heat sink clearly exhibits the three dimensionality of the flow and how the flow departs from the fin field in an open channel system (typical of most applications).

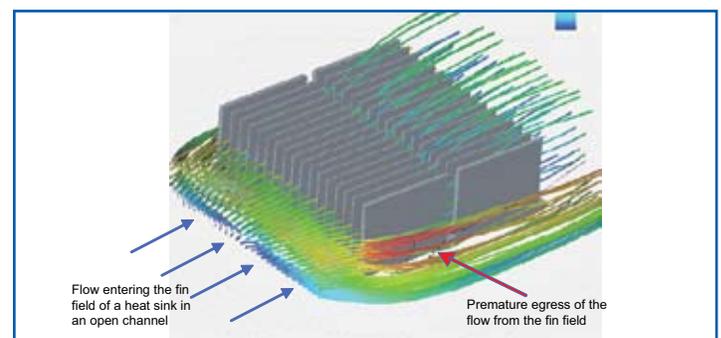


Figure 1. Computational Fluid Dynamics Simulation of Air Flow Through a Straight Fin Heat Sink.

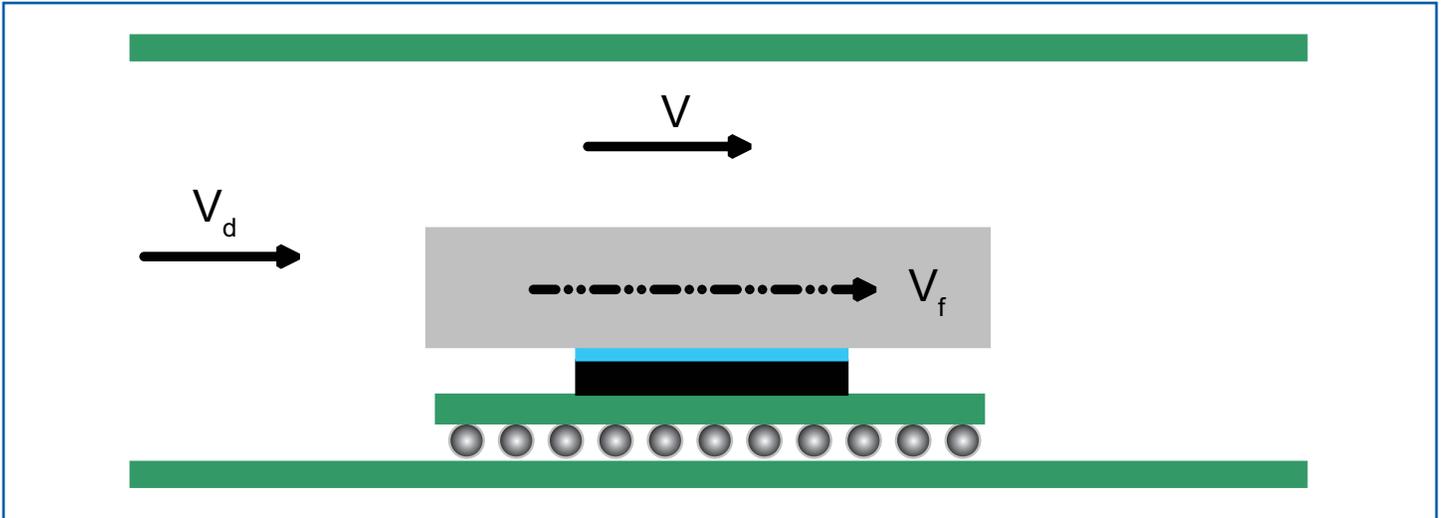


Figure 2. Regional Flow Designation.

Figure 2 shows the flow bypass V , and the flow through the fin-field, V_f

Applying conservation of energy to the heat sink,

$$-\frac{1}{2}\rho V_f^2 + \frac{1}{2}\rho V^2 - \Delta P_{HS} = 0 \quad (3)$$

Applying the continuity equation and assuming the Poiseuille flow in the channels created by the fins, we have;

$$V_d A_d = V_f A_f + V(A_d - A_f) \quad (4)$$

and

$$\Delta P_{HS} = 12 \frac{\mu L V_f}{D^2 H} \quad (5)$$

Where,

A_d = duct cross section

A_f = channel cross section between fins

S = fin to fin spacing

L = fin length in the direction of flow

ΔP_{HS} = heat sink pressure drop

V = bypass fluid velocity

V_d = duct (approach fluid) velocity

V_f = fluid velocity between fins

For a given V_d , simultaneous solution of Equations, 3, 4 and 5 will yield V_f .

A parametric study was undertaken to evaluate the impact of length and width on the thermal performance of the heat sink in an unducted flow. The dimensions of the heat sink were:

$W = 40$ mm

$L = 40$ mm

$H_{fin} = 14.5$

Base thickness = 1.5 mm

N (number of fins) = 10

$V = 2$ m/sec (400 lfm)

Figure 3 shows the thermal resistance as a function of fin length. Thermal resistance decreases from a fin length of 20 mm and starts leveling off at a length of about 80 mm. The resistance stays constant up to 170 mm, and then starts to increase. The increase in pressure drop and the temperature of the air inside the fin-to-fin channels degrades the performance of the heat sink after a certain length. At this point, the air temperature has essentially reached the heat sink temperature, and hence no cooling can take place. One might think that because the surface area has increased the thermal resistance should decrease. But after a certain length, the air temperature inside fins and the fin surface temperatures are essentially the same, so no heat transfer occurs.

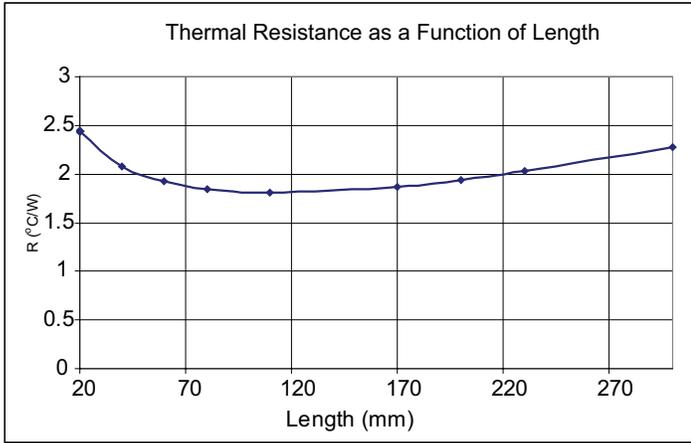


Figure 3. Thermal Resistance as a Function of Heat Sink Length for Uniform Heat Distribution. (Width = 40 mm, Fin Height = 14.5 mm, Velocity = 2 m/s (400 lfm)).

The above argument is based on the assumption that the heat was uniformly distributed at the base of the heat sink, and thus there was no spreading resistance.

Figure 4 shows the thermal resistance of the same heat sink as a function of length, but with the heat distribution fixed at 40 x 40 mm. The graph shows that the thermal resistance goes up much faster than the uniform heat distribution case. It clearly indicates that by increasing the size of the heat sink, the spreading resistance takes its toll. Not only does it not improve the resistance, it actually starts going up very rapidly. For lower flows, the negative effect of increased fin length will be more pronounced, and these effects will start at lower lengths compared to higher flows.

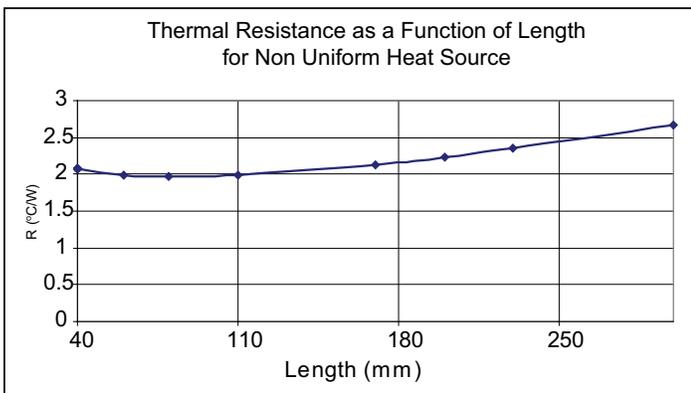


Figure 4. Thermal Resistance as a Function of Length for Non-Uniform Heat Distribution.

Figure 5 shows the thermal resistance as a function of heat sink width for a uniform heat distribution. This figure shows that the thermal resistance continually decreases, although it does this at slower rates with larger heat sink widths. This is because the increase in width does not linearly increase the surface area, and the number of fins are kept constant at 10.

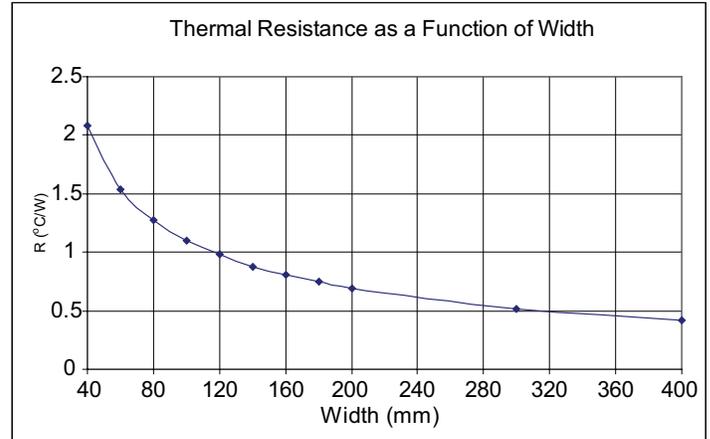


Figure 5. Thermal Resistance as a Function of Heat Sink Width (Length = 40 mm, Fin Height = 14.5 mm, Velocity = 2 m/s (400 lfm)).

The above analysis shows that simply increasing the size of a heat sink might not yield the desired performance results. The thermal engineer should look at different variables, such as flow magnitude and ducted or unducted flow, before choosing a specific heat sink. In this analysis process, it is also very important to consider spreading resistance.

References:

1. Tavassoli, B., Heat Transfer Coefficient Correlation for High Performance Heat Sinks, Internal Paper ATS-08876-99-01, Advanced Thermal Solutions, Inc., 1999.
2. Azar, K., Tavassoli, B., How Much Heat Can be Extracted from a Heat Sink?, Electronics Cooling, May 2003