# Heat Sink Selection Methodology

in Electronics Cooling

Heat sinks are widely used to help remove heat from electronic components with elevated temperatures. As is commonly known, the life of an electronic device is directly related to its operating temperature. Every 10°C temperature rise reduces a component's life by 50%. Heat sinks are important parts of the thermal management systems of most electronic devices, due to their low cost, versatility, durability and high reliability. For low to medium power electronic components in computers, telecommunication devices and embedded devices, heat sinks play an irreplaceable role for removing heat. Even for modern, high-power components like CPUs, video cards and DSP chips, advanced heat sinks combined with enhanced air cooling methods provide an effective cooling method

To select the best heat sink for your application, it is important to understand the basic heat transfer mechanism used to remove heat flux. The heat transfer theory helps explain practical aspects of how heat sinks work. It also helps to clear up common misconceptions and design mistakes. Whenever there is a temperature difference inside an object or between an object and media, heat transfer occurs. There are three basic heat transfer modes: conduction, convection and radiation. Conduction refers to heat transfer within an object or between adjacent objects due to temperature gradient. Convection happens between a solid surface and a moving fluid when they are at different temperatures. Radiation refers to the heat transfer through electromagnetic waves between different objects with finite temperature. In most electronic cooling applications, radiation only transfers a small portion of heat from a heat sink to its environment. Most heat is removed from components by conduction and convection. So, heat radiation is normally neglected when doing thermal analysis for heat sinks, except for high temperature applications (heat sink temperature>100°C) or natural convection.

There are many parameters that affect a heat sink's overall performance. The parameters engineers should pay special attention to are the convection mode (natural convection/ force convection), flow conditions (approach air velocity/flow directions), heat sink thermal resistance, heat sink pressure drop and choice of sink material and cost.
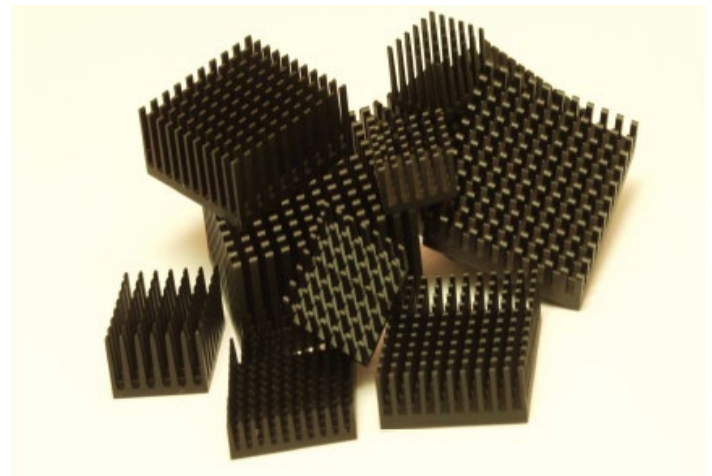
Figure 1. ATS Pin Fin Heat Sinks.

The most widely used air-cooled heat sinks are pin fin, straight fin and flared fin designs. They are simple, low cost, robust and available in thousands of existing profiles and configurations for engineers to use. A pin fin heat sink has pins that extend from its base. These pins can be square, cylindrical or elliptical. Pin fin heat sinks are usually made by metal casting, forging or stamping. They can also be made by cross cutting straight fin heat sinks or by screwing/ pushing pins into a metal base. Figure 1 shows some pin fin heat sinks from Advanced Thermal Solutions (ATS).

A straight fin heat sink is by far the most common type available on the market. Its fins extend from the base and run the entire length of the sink. The fin thickness may vary from base to tip. Straight fins are mostly made by extrusion, which is the most cost effective way to manufacture a heat sink. Straight fins can also be made by bonding or soldering the fins to the base, or by forging or casting. Straight fin sinks can be cut at regular intervals, too, but at a coarser pitch than a pin fin type. Figure 2 shows an extruded straight fin heat sink.
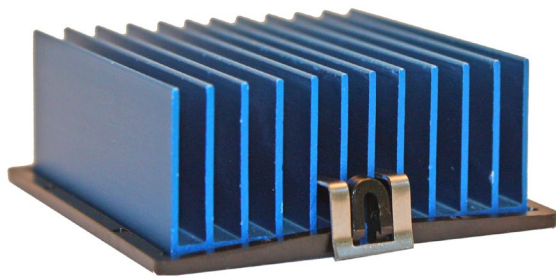

Figure 2. ATS Straight Fin Heat Sink with superGRIP Attachment.

Flared fin heat sinks have fins that are not parallel to each other, as shown in Figure 3. This is a patented heat sink design by Advanced Thermal Solutions, Inc. Flaring the fins creates more convection surface area and also decreases flow resistance. Generally they provide better thermal performance than straight fin heat sinks with the same foot print.

Figure 3. ATS Flared Fin Heat Sink with maxiGRIP™ Attachment.

Figure 4 shows the temperature variation and heat transfer modes for a heat sink sitting on top of a component with a thermal interface material (TIM) compressed in between them.
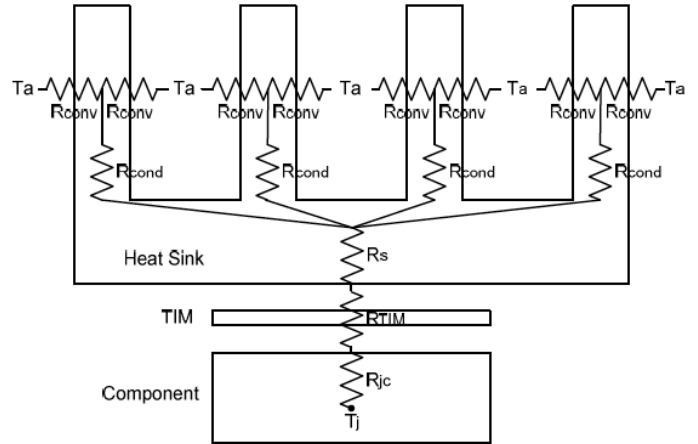

Figure 4. Electrical Package and Heat Sink Thermal Resistance.

The overall thermal resistance from component junction to ambient R_{ja} is,

$$R_{ja} = R_{jc} + R_{TIM} + R_s + R_{cond} + R_{conv} \qquad (1)$$

Where R_{jc} is the thermal resistance from component junction to case, R_{TIM} is the thermal resistance of the thermal interface including contact resistance, R_s is the spreading resistance due to the cross-sectional area change, R_{cond} is the conduction resistance inside the heat sink, and R_{conv} is the convection resistance between fins and air.
The thermal resistance of a heat sink is defined as,

$$R_{hs} = \frac{T_{hs} - T_a}{q} \qquad (2)$$

Where T_{hs} is the heat sink's base temperature and q is the heat removed by the sink.

Generally, the thermal resistance of a heat sink can be calculated by using the following equation,

$$R_{hs} = R_{cond} + R_{conv} = \frac{t}{kA_{base}} + \frac{1}{\eta h A_{fin}} \qquad (3)$$

Where k is the heat sink thermal conductivity, A_{base} is the heat sink base area, t is the base thickness, η is the fin efficiency, h is the convection heat transfer coefficient, and A_{fin} is the total fin surface area.

From Equation 3, it is clear that better thermal conductivity reduces heat sink thermal resistance. The most common heat sink material is aluminum alloy, for example aluminum alloys 6063 with thermal conductivity around 200 W/m·°C. If better thermal performance is required, copper can be used. Copper's thermal conductivity is around 400 W/m·°C, which is twice that of aluminum. Copper can significantly minimize spreading resistance when the component is much smaller than the heat sink base. If the heat sink base is same size as the component, copper is not justified for use because it is three times as heavy as aluminum and about four to six times more expensive.

In general, the more surface area a heat sink has, the smaller its convection thermal resistance. However, this is not always true because densely packed fins will create a large pressure drop, which will force most approach flow to bypass the heat sink if the heat sink is not ducted. This is especially true for low velocity flow and natural convection. So when choosing a heat sink, it is better to evaluate the flow first. Then select the heat sink based on its calculated thermal resistance and pressure drop.

However, before diving into detailed calculations and CFD simulations, engineers should narrow down the best sink selection based on basic heat transfer principles and a heat sink selection guide.

Here are some general rules for selecting a heat sink ...
For natural convection applications:
1) If the heat sink is mounted horizontally, it is recommended to use a pin fin heat sink.
2) If the heat sink is mounted vertically, both a pin fin heat sink and a straight fin can be used. For a straight fin heat

sink, the fin-to-fin spacing has to be at least 6mm to enhance the natural convection flow.
For low velocity force convection (≤ 2 m/s):
1) If the flow direction is unknown or unpredictable, choose a pin fin heat sink whose thermal resistance is less sensitive to flow orientation. A cross cut, flared fin heat sink is also a good choice for such applications.
2) If the heat sink is ducted, a straight fin heat sink is best choice.
3) If the heat sink is in free stream flow, a flared fin heat sink generally provides better performance than a straight fin or pin fin heat sink.
For forced convection (≥ 2 m/s):
1) If the flow is un-ducted, make sure that the straight fins are parallel to the approaching flow, otherwise use a pin fin heat sink.
2) If the heat sink is ducted, both a pin fin and a straight fin heat sink are good choices. When calculating the thermal resistance of the heat sink theoretically or numerically, caution should be paid to choose right equations for flow mode. The flow may be in transition flow or turbulent flow regimes.
For air impingent applications:
If an air jet is impinged from above to a heat sink, a pin fin heat sink generally generates the lowest thermal resistance. But the fin pitch and fin height must be carefully chosen to maximize thermal performance. The same conclusion is applied to a heat sink with a fan on top. However, a straight fin heat sink with cross cuts can also be used for a fan heat sink if cost is the priority.
1) Here are other thumbs-up rules for choosing or designing a heat sink ...
2) In natural convection applications, a heat sink with high aspect ratio fins benefits thermal performance. For high velocity force convection, high aspect ratio fins may not provide extra thermal benefits.
3) If the heat sink is required to have the ability to absorb a heat flux spike, it is better to use copper than aluminum.
4) For extreme performance and reduced weight, a heat pipe or vapor chamber can be embedded in a heat sink.

Heat sinks are not magical devices that can absorb heat from electronic components. They are designed to use basic heat transfer modes to remove heat from a heat source and eject it to the environment with minimum temperature gradients. However, their thermal performance is not only determined by their design, but also affected by the environment they are working in. So the best way to select a heat sink is to choose one that best fits a specific application, not one with the best self- claimed performance. By applying basic heat transfer principles and empirical rules, an engineer can make a better heat sink choice. After all the theoretical and number calculations, the heat sink must be put into the field for experimental evaluation to prove its performance before a product goes into production.