White Paper

The Effect of Forced Air Cooling on Heat Sink Thermal Ratings

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ABSTRACT

A heat sink's ability to dissipate thermal energy is determined by its thermal impedance, which is measured in degrees C per watt (˚C/W). This thermal impedance rating is based upon natural "convection air flow" over the heat sink's surface in a still air environment. Generally, the greater the exposed surface area of the heat sink, the lower its thermal impedance and the greater its ability to dissipate thermal energy. However, more surface area often means increased dimensional size as well as cost, even for finned extrusion profiles.

A Heat Sink's thermal rating can also be effectively improved by increasing air flow over its exposed surface area. Closed extrusion profiles or so called "chimney" designs can arguably improve convection air flow verses "open" profiles by virtue of increased convection air velocity through the chimney. However, the most effective means of increasing air flow is through the use of forced air. This paper discusses the effects of forced air flow provided by fans on the thermal impedance ratings of heat sinks.

INTRODUCTION

Solid State Relays dissipate power in the form of heat during their conducting state. This power dissipation is due to the forward voltage drop of the output semiconductor and is directly proportional to the load current. The result is an increase in the operating temperature of the SSRs output devices (s) that must be effectively maintained in the application in order to ensure the reliable operation of the SSR. Aluminum heat sinks, either in the form of a flat chassis panel or extruded profile, are the most common means to achieve the thermal dissipation necessary to reduce the SSRs internal temperature. They are therefore mandatory in most SSR applications with load currents greater than 5 amps.

The typical range of heat sink ratings for common SSR applications is between 3.5 to 0.5 ˚C per watt depending upon load current and ambient temperature. For reference, a flat aluminum plate 2 ft square and .125” thick has a thermal impedance rating of approximately 0.5 ˚C per watt. Its exposed surface area (ignoring the edges) is approximately 1152 square inches or 7435 cm^2. A finned aluminum extrusion of the same thermal rating measures approximately 6” x 6” x 3.5” with an exposed surface area of 694 in^2 or 4480 cm^2. Why the difference in surface area to produce the same thermal rating?

The answer is that the extruded aluminum heat sink is more efficient than the flat plate because of 2 main factors:

1. The extrusion’s design places the source of the thermal energy (the SSR) nearer to the majority of the heat sink’s surface area. The effectiveness of surface area to dissipate energy decreases as the distance from the source increases. In the case of the flat plate, some of the plate is as much as 1.4 ft from the SSR, where as for the extrusion the greatest distance is no more than 0.5 ft.

2. The design of the extrusion’s fins promotes convection air flow due to their parallel placement. Although this example is technically an “open” design and therefore not a “chimney”, convection air flow over the fins is substantially greater than the airflow across the flat plate.

Thus the configuration of the heat sink combined with air flow over its surface can substantially alter the effectiveness of a heat sink.

EFFECT OF FORCED AIRFLOW ON HEAT SINK RATINGS

The primary function of a Heat Sink is to absorb thermal energy generated by a component mounted to its surface and then to dissipate that thermal energy into the surrounding ambient air. For free air convection cooling, surface area and free air flow volume are the primary factors in the heat sinks efficiency as can be seen by the example sited above. Increasing either or both improves the heat sink’s efficiency and reduces its thermal impedance accordingly.

Heat Sink surface area can be increased by adding more fins/material to the extrusion profile, but this usually increases size, weight and cost. Thus free air flow can be modestly increased by design (chimney verses open design) as well as total surface area. However, airflow can be increased substantially by forced air from the addition of fans.

Depending upon several factors including volumetric considerations, fans may provide favorable performance to cost gains. In other words, the additional cost of a fan may be offset by the reduction in size and cost of the heat sink and assembly. However, in higher power applications, fans may provide the only means available to achieve the level of power density required.

CALCULATING THE EFFECT OF FORCED AIR COOLING ON HEAT SINK RATINGS

Fans are commonly rated in CFM (cubic feet per minute) of airflow. However, the parameter used to calculate the impact of forced air on a heat sink rating is LFM (linear feet per minute). The following formula can be used to convert CFM to LFM:

$$\textbf{LFM = CFM / area (ft}^2\textbf{)}$$

The manufacturer's CFM rating is based upon the amount of air that is moved through the fan's external box size, and therefore "area" corresponds to the "footprint" the fan makes when mounted. If the fan is round, then the area can be calculated based upon its external diameter (**d**) as follows:

$$\textbf{Area (ft}^2\textbf{)} = \pi\ (d/2)^2$$

where π = 3.1416 and **d** is in feet

If the fan is square, then the area can be calculated based upon is external dimensions as follows:

$$\textbf{Area (ft}^2\textbf{) = l x w}$$

Where **l** and **w** are the fan's external length and width in feet

Fans are often sized in millimeters, so to calculate area in square feet, the size in millimeters needs to be converted to feet as follows:

1 millimeter = .00328 ft.

The following 2 tables summarize various CFM ratings converted to LFM values for example fans sized in millimeters:

	40 mm Fan	**60 mm Fan**	**80 mm Fan**	**92 mm Fan**	**120 mm Fan**
CFM	**LFM**	**LFM**	**LFM**	**LFM**	**LFM**
5.2	**302**				
6.5	**377**				
7.8	**453**				
14.8		**382**			
15.9		**410**			
17.6		**454**			
21.7		**560**			
22.1		**570**			
27.0			**392**		
34.4			**499**		
36.0				**395**	
37.0				**406**	
41.7			**605**		
42.5			**617**		
76.0					**490**
78.0					**503**
105					**742**
115					**755**
117					**755**

***Table 1*:** CFM to LFM for various size fans.
(Fan specifications courtesy **CST/Crouzet**)

Note: Fan CFM ratings are normally based upon free air delivery and zero back pressure. Most applications will present some degree of back pressure and thus limit the net airflow to some extent. Therefore, it is recommended that the CFM rating be multiplied by a correction factor, typically 0.6 (60%) to 0.8 (80%) to account for this restriction. Table 2 shows adjusted CFM values and resulting LFM ratings based upon the 80% correction factor.

	40mm Fan	60 mm Fan	80 mm Fan	92 mm Fan	120 mm Fan
CFM	**LFM**	**LFM**	**LFM**	**LFM**	**LFM**
4.2	242				
5.2	302				
6.2	362				
11.8		306			
12.7		328			
14.1		363			
17.4		448			
17.7		456			
21.6			314		
27.5			399		
28.8				316	
29.6				325	
33.4			484		
34.0			494		
60.8					392
62.4					403
84.0					542
92.0					594
93.6					604

***Table 2*:** Corrected CFM to LFM for various size fans (using 0.80 factor).

Once the fan's LFM value is calculated, the improvement that it has on the heat sink's thermal impedance rating is calculated by multiplying a correction factor per Table 3 below times the heat sink's free air convection thermal resistance rating.

LFM	Adjustment Factor
100	0.757
200	0.536
300	0.439
400	0.378
500	0.338
600	0.309
700	0.286
800	0.268
900	0.252
1000	0.239

***Table 3*:** Thermal Impedance Adjustment Factor based upon LFM value.
(Adjustment factor data courtesy Aavid Thermalloy)

Using the Table 1 above, a 60mm, 15.9 CFM fan converts to 410 LFM. The corrected LFM value from Table 2 for the same fan is 328. To determine the effect of this fan on a heat sink's thermal impedance rating in °C/W, multiply the free air convection rating of the heat sink by the correction factor of .439 (correction factor for 300 LFM). For example, if the heat sink's free air rating is 2.0 °C/W, the forced air rating with this fan is approximately 0.88 °C/W, a substantial increase in thermal efficiency.

Note: the adjustment factors in Table 3 can be calculated more precisely for LFM ratings which fall between the values listed in the table by interpolation. The correction factor for 328 LFM is actually .422 which would result in a thermal impedance in the above example of 0.84 °C/W.

SOME PRECAUTIONS THAT SHOULD BE CONSIDERED WHEN FANS ARE UTILIZED TO IMPROVE THE THERMAL PERFORMANCE OF HEAT SINKS

1. When forced air cooling with a fan is utilized, the air supply should be free of any oil, grease, water or any contaminant that can adhere to the fan blades or heat sink fins and diminish their heat dissipation efficiency.

2. Fans come in a variety of versions. Care needs to be taken that a fan with a life expectancy suitable for the intended application is chosen. Generally, only ball bearing fans should be specified if the reliability of the SSR/Heat Sink assembly depends upon the fan's continuing function.

3. When forced air cooling is utilized, it is advisable to install an over temperature cut off switch on the heat sink that is wired in series with the SSRs input. The temperature rating of the cutoff switch should be slightly higher than the maximum temperature of the heat sink during normal operation with the fan. Therefore, the switch will remove power from the input of the SSR if the temperature of the heat sink increases due to a failure of the fan (or other causes).

4. Each heat sink will react differently to forced air and the heat sink manufacturer should be consulted to determine the improvement in thermal rating in °C/W based upon their experience with forced air flow.

CONCLUSIONS

Forced airflow is not always required to effectively manage the temperature of a solid state relay mounted to a finned heat sink. The temperature can often be maintained through normal convection airflow due to low ambient temperatures, minimal power dissipation of the relay, low duty cycles, or other mitigating circumstances. However, in some cases the use of forced airflow may provide a cost-effective means to reduce the size of a heat sink assembly. In other cases, forced airflow may be the only means available to effectively manage the heat of a solid state relay due to high power dissipation or conditions of the application's environment.

Regardless, it is imperative that all specifications are reviewed and confirmed through evaluation to ensure that the relay operates within it's given parameters. Failure to adhere to the relays and/or heat sinks specifications, or to confirm the effectiveness of the forced airflow on the performance of the assembly, can result in failure of the SSR.

Crydom offers tools on its web site and assistance through it Applications Engineering Department to determine the minimum heat sink rating required for any given SSR application. Visit www.crydom.com for contact information.

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