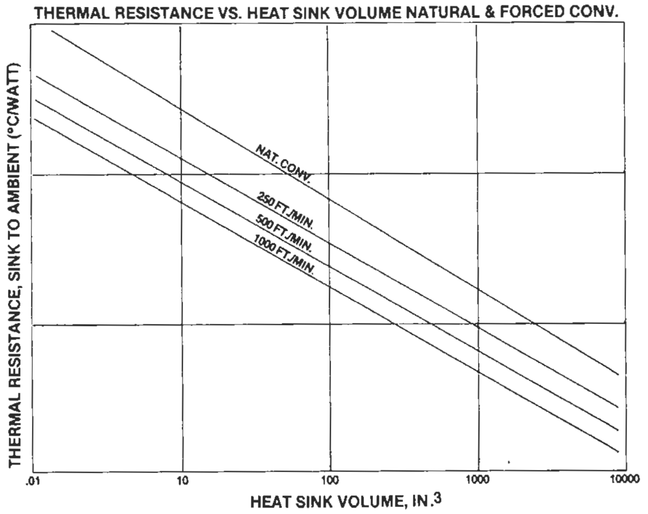
Selecting the Correct Heat Sink



The four curves show the relationship of volume to thermal resistance for natural convection cooling, based on 50°C sink temperature rise above ambient, and forced-convection cooling at velocities of 250, 500, and 1,000 feet per minute.

Before a heat sink is ordered, it is important to make sure that the optimum sink has been selected. In most insances, the best heat sink is not necessarily the largest or the most expensive, but rather the one that provides the best price/performance ratio and still meets the cooling requirement.

To help you make the correct selection we have provided definitions of the most common terms used in Catalog #1.

1. **Heat sink** - a heat dissipator that operates as a result of the temperature difference and thermal resistances between the heat source (semiconductor) and the ambient air.
2. **Function of Heat Sinks** - to increase the surface area available for heat transfer from the semiconductor, thus increasing the amount of heat that can be dissipated.
3. **Thermal Resistance** - like electrical resistance is a measure of the ability of a device or interface to enhance or impede the flow of heat. It is a function of heat sink surface area and convection co-efficient, and is generally expressed in °C/watt.
4. **Natural Convection** - when the movement of ambient air over, around or through a heat sink is induced by temperature differences and buoyancy effects alone.
5. **Forced Convection** - when the movement of air is induced by mechanical means (typically a fan or blower).
6. **Heat Sink Performance** - the amount of heat that can be removed with a specified temperature difference between the heat sink and the air. It is most often characterized by thermal resistance, i.e. the lower the thermal resistance, the better the performance. The only way thermal resistance can be reduced is by either increasing the physical size of the heat sink (i.e. changing surface area) or by moving more air across the sink (i.e. changing from natural convection to forced convection coefficients.)

The figure to the left illustrates the volume required for several heat sinks for a range of thermal resistances, for both natural and forced convection applications. Typically to reduce the thermal resistance by 50% the heat sink volume must be quadrupled.

Basic Considerations

The selection of a heat sink to maintain a semiconductor at a desired operating temperature requires knowledge of:

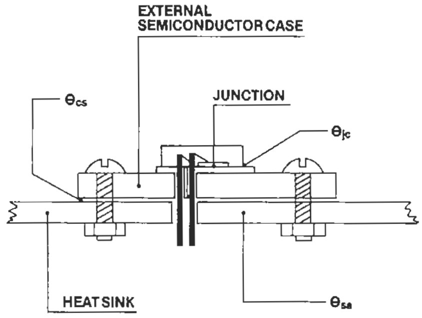
(1) The available volume of space to be occupied.
(2) The maximum allowable device junction temperature.
(3) The power dissipated by the device.
(4) The device configuration.
(5) Ambient conditions (temperature, air flow).

Heat Sink Performance as a Function of Power Dissipation

As stated before, the main function of a heat sink is to protect the semiconductor from the heat it produces as a byproduct of its normal operation. If not removed, this heat will cause the semiconductor to exceed its safe operating temperature. In this circumstance, semiconductor performance, life and reliability are tremendously reduced. The basic objective then is to hold the junction temperature below the maximum temperature specified by the semiconductor manufacturer.

Junction temperature is a function of the sum of the thermal resistances between the junction and the ambient air, the amount of heat being dissipated and the ambient air temperature level.

The Figure below is a simplied drawing of a semiconductor mounted on a heat sink. The following three thermal resistances are readily identified:



1. Thermal resistance between the semiconductor junction and its external case. This resistance is designated Θ_{jc} and is expressed in °C/watt. This resistance is a function of design and manufacturing methods and is specified by the manufacturer for each semiconductor device. Its value is **not** influenced by the use of heat sinks or otherwise controllable.

2. Thermal resistance from case to heat sink. This resistance is designated Θ_{cs} and is expressed in °C/watt. It is a somewhat controllable variable which can be minimized by the application of a thermal grease or paste such as the Series 120 or 121 Thermal Joint Compounds. These compounds reduce the high thermal impedance of the air gap between the case and the sink. See page 40 for specifications on the Series 120 and 121 and values for Θ_{cs} resulting from use of these compounds.

3. Thermal resistance from heat sink surface to the ambient air. This resistance is designated Θ_{sa} and is also expressed in °C/watt. This is the most important resistance of the three in terms of controlling junction temperature level, and plays a significant role in the selection of the proper heat sink. The smaller this value, the more power the device can handle without exceeding its maximum junction temperature.

The thermal resistance from sink to air (Θ_{sa}) is a function of the convection heat transfer coefficient (h_c) and the surface area (A) of the heat sink as shown in the following formula:

$$\Theta_{sa} = \frac{1}{h_c A} \qquad \text{(Equation \#1)}$$

As this formula indicates, (Θ_{sa}) is the reciprocal of the product of the heat transfer coefficient and the sink surface area. Thus increasing the surface area of a sink (A) reduces (Θ_{sa}). In similar fashion, increasing the heat transfer coefficient (h_c) also reduces the thermal resistance. Again, a small value of Θ_{sa} is very desirable.

In most applications involving natural convection, the only way to reduce Θ_{sa} is by increasing the surface area.

If making the sink area larger is not possible because of space limitations, then a similar reduction in Θ_{sa} can be achieved by increasing the heat transfer coefficient (h_c) by forced convection methods.

With a semiconductor mounted on a heat sink, the relationship between junction temperature rise above ambient temperature and power dissipation is given by

$$Q = \frac{T_j - T_a}{\Theta_{jc} + \Theta_{cs} + \Theta_{sa}} \qquad \text{(Equation \#2)}$$

where Q = power dissipated, watts
T_j = junction temperature, °C
T_a = ambient air temperature, °C
Θ_{jc} = thermal resistance from junction to semiconductor case, °C/watt
Θ_{cs} = thermal resistance from case to heat sink, °C/watt.
Θ_{sa} = thermal resistance from surface of heat sink to ambient air, °C/watt

In most applications values for all these parameters are known or can be found except that for the maximum thermal resistance from heat sink surface to air (Θ_{sa}). The value of this parameter then becomes the basis for sink selection.

Equation #2 is the basic equation and is correct for either natural or forced convection cooling. Data for heat sink selection with forced convection is generally presented in terms of Θ_{sa}, but for natural convection, data is presented in terms of ΔT_{sa} (temperature difference between sink and air). This results in the following simplified form of equation #2:

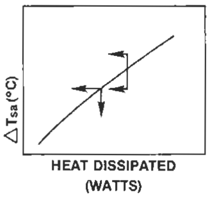
$$\Delta T_{sa} = \left(T_j - T_a\right) - Q(\Theta s + \Theta a) \qquad \text{(Equation \#3)}$$

Heat Sink Performance as a Function of Power Dissipation

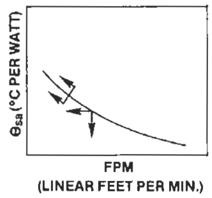
It eliminates the requirement of multiplying Θ_{sa} by Q to obtain the maximum allowable $\triangle T_{sa}$ and thus gives that parameter for direct comparison with data as presented on most natural convection graphs.

To summarize, natural convection data is presented as Heat Sink Temperature Rise vs. Heat Dissipated ($\triangle T_{sa}$ vs. Q) as shown below (figure a). Forced Convection data is usually presented as either Θ_{sa} vs. linear air velocity (figure b) or as Q_{sa} vs. volumetric flow rate (figure c).

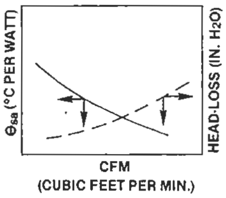
a.



b.



c.



For example, assume a semiconductor with a TO-3 case must be operated so that its junction temperature will not exceed 125°C when it is dissipating 10 watts to ambient air at a temperature of 50°C. The value of Θ_{jc} for this device established by the manufacturer is 1.5°C/watt and Θ_{cs} is estimated to be 0.09°C/watt because Series 120 Thermal Joint Compound is being used. (As shown in the table on Page 40).

The thermal schematic of this example would look like this:

Max. semiconductor junction temp. (T_j) 125°C

$\Theta_{jc} = 1.5$°C/W

Case Temp. (T_c)

$\Theta_{cs} = 0.09$°C/W

Sink temp. (T_s)

$\Theta_{sa} = ?$

Ambient air temp. (T_a) 50°C

Solving Equation #2 above for the unknown value of Θ_{sa} (thermal resistance from sink to air) produces the following equation:

$$\Theta_{sa} = \frac{T_j - T_a}{Q} - (\Theta_{jc} + \Theta_{cs}) \qquad \text{(Equation \#4)}$$

Inserting known values into Equation #4 as follows

$$\Theta_{sa} = \frac{125\text{-}50}{10} - (1.5 + .09)$$

produces a value of 5.9° C/watt for Θ_{sa}. This is the largest value of Θ_{sa} that can be used. Heat sinks providing smaller values of Θ_{sa} are also acceptable since the resulting junction temperatures will be less than the 125°C specified.

With this value of Θ_{sa}, we could then proceed to the data presented for various heat sinks and locate one which will provide this performance. To use the value of Θ_{sa} directly, we would have to specify air flow characteristics as well. In this case, any of the 680 series heat sinks with forced convection cooling would be suitable.

The method for arriving at an acceptable sink for natural convection is to determine the maximum mounting surface (heat sink) temperature allowed or the sink surface to ambient air temperature rise ($\triangle T_{sa}$). This value of temperature rise, $\triangle T_{sa}$ is found from Equation 3 as follows:

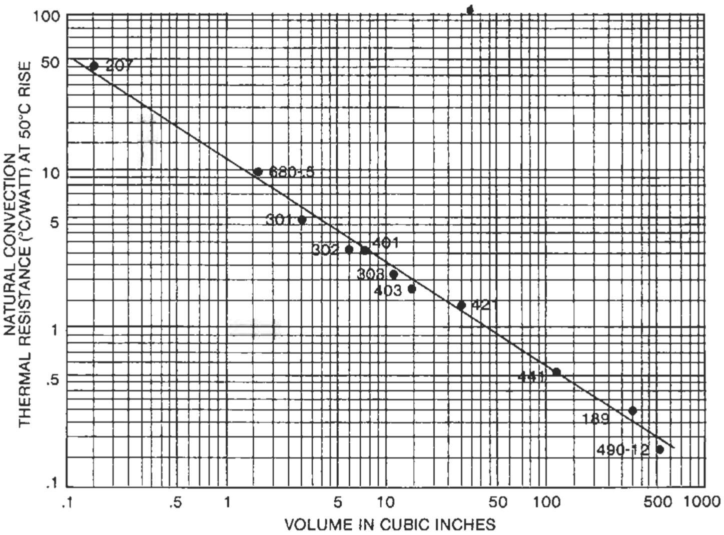
$$\triangle T_{sa} = (125\text{-}50) - 10(1.5 + 0.09) = 59.1\,°C$$

With this value and that of the heat dissipated, reference to the 680 Natural Convection Characteristics data on page 22 indicates that only the 680 - 1.25 would be suitable. (The 680-1.0 mounted horizontally would be marginal).

Of course, further examination of the data in this catalog will show that there are several other sinks suitable for the application. In such cases, the final choice will depend upon size, price, semi-conductor type, mounting requirements and other factors.

Natural Convection Considerations

Correlation of experimental data indicates that the cooling capabilities of extruded heat sinks under natural convection conditions are a function of their volume. This data is shown in the figure below.



For example, an EG & G Wakefield Model 441 heat sink measuring 4.5 by 4.75 by 5.5 inches (excluding mounting feet) has a volume of 118 cubic inches. From the curve, the natural convection thermal resistance of this sink is 0.55°C/watt at a 50°C rise in mounting surface temperature.

For a specified volume of mounting space, the thermal resistance of an 'optimum' heat sink can be approximated from the curve. The data is based on heat sink performance with one semiconductor. Thermal resistance with two or more devices per sink may be reduced by as much as 20 to 25 per cent since the distribution of heat dissipation increases efficiency.

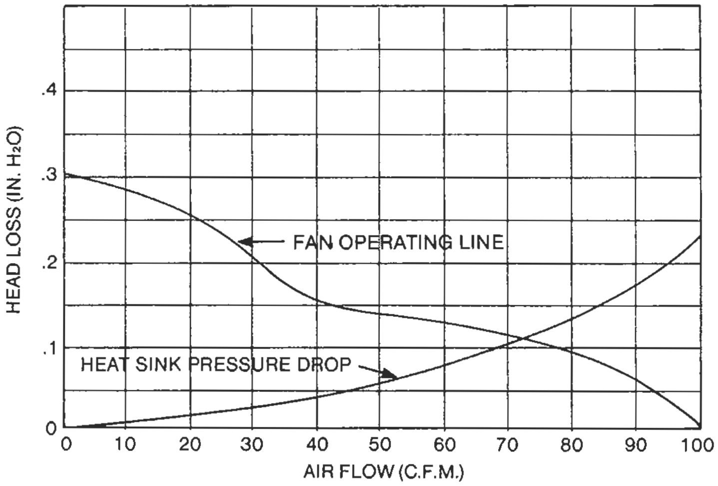
"Watch what you say—Harold's rigged his hearing aid to get fringe reception."

Forced Convection Considerations

Up to this point, almost all discussions in selecting heat sinks have been predicated on using natural convection heat transfer where the only way to reduce the sink to air thermal resistance (Θ_{sa}) was to increase the surface area of the sink. But, as briefly stated in previous discussions, similar reduction in Θ_{sa} can be obtained if the thermal coupling between the heat sink and the ambient air is improved, i.e. increase in heat transfer coefficient, h_c. This can be achieved by forced convection methods using blowers, fans and ducts.

The forced-convection performance of EG & G Wakefield heat sinks is shown in two ways: a) Thermal resistance as a function of linear air velocity (ft/sec) in front of the heat sink and b) thermal resistance as a function of volumetric flow (cfm) passing through the heat sink (used for duct-mounted heat sinks). In conjunction with the latter, pressure drop through the heat sink, ΔP vs. volumetric flow rate (cfm), is also presented to permit selection of an appropriate matching fan or blower.

In an actual installation, one or more heat sinks may be contained within a duct so that all of the fan driven air passes through the sinks. Since the heat sinks were selected on the basis of thermal performance at a particular volumetric flow, their pressure drop vs. flow characteristics must be carefully matched to those of the fan. This can be done by superimposing the fan operating curve on the heat sink pressure drop curve as shown in the figure below.



The intersection of these curves is at the volumetric flow rate which this fan will provide when used with this particular heat sink. If the thermal resistance corresponding to this volumetric flow is equal to or lower than that required, the combination is acceptable. If not, either a different fan (to provide more air flow) or heat sink (to provide more surface area) must be selected.

If the arrangement is modified by adding another heat sink in flow series with the first, the volumetric flow rate delivered by the fan will be reduced because of the additional pressure drop contributed by the second heat sink. It is difficult to predict the flow rate reduction except to say that it will generally be much less than would be estimated by doubling pressure drop versus flow rate data for a single heat sink and finding the new crossing of fan curve and this doubled data. Air flow reduction of only 10% is typical for doubling the number of heat sinks in flow series when using axial flow fans with extruded aluminum heat sinks. It is the inlet and outlet discontinuities which usually dominate the pressure drop, with flow friction through fins and duct playing a relatively minor part in restricting airflow.

Another point which must be considered in a series arrangement is the fact that air entering the second heat sink is at a higher temperature, (i.e. the effective ambient temperature for the second heat sink is higher.)

This temperature increase, caused by the heat dissipation of the upstream sink, is given by

$$\Delta T = \frac{1.76Q}{V} \qquad \text{(Equation \#5)}$$

ΔT = increase in ambient air temperature, °C
Q = heat dissipation, watts
V = volumetric flow rate, cfm
1.76 constant is based on a 25°C ambient air temperature

As a result, with a series arrangement of heat sinks, there will be either a correspondingly higher temperature rise above ambient (relatively slight) or a small reduction in the permitted heat dissipation of the downstream heat sink.