Heat sinks reduce and maintain device temperature below the maximum allowable temperature of the device in its normal operating environment. In selecting a heat sink to achieve this goal, four fundamental parameters must be known about the application:

- The amount of heat, Q, being generated by the semiconductor device in watts (W).
- The maximum allowable junction temperature, Tj, of the device in degrees celsius (°C): this information is available from the semiconductor manufacturer's data book or fact sheet.
- The maximum temperature of the ambient cooling air, Ta, in °C.
- The type of convection cooling in the area of the device: is it natural or forced? If it is forced convection, the air flow velocity, in linear feet per minute (LFM), must be known.

BASIC FORMULAS:

Heat is a form of energy that flows from a higher temperature location (i.e. the semiconductor junction at Tj) to a lower temperature location (i.e. the surrounding ambient air at Ta). In semiconductor devices, heat will flow from the device to the ambient air through many paths, each of which represents resistance to the heat flow. This resistance is called thermal resistance, denoted as θ in °C/W, and is defined as the ratio between the amount of total heat being transferred and the temperature difference that drives the heat flow. The total thermal resistance of a system for a given device can therefore be expressed as:

$$\theta ja = \frac{Tj - Ta}{Q}$$

where θ is the thermal resistance in degrees C per watt, and where ja represents junction-to-ambient. Thermal resistance is a measure of relative performance. A low thermal resistance represents better performance than a high thermal resistance.

A system that has a lower thermal resistance can either dissipate more heat for a given temperature difference, or dissipate a given amount of heat with a smaller temperature difference.

In cooling electronic devices, heat sinks lower the overall junction to ambient thermal resistance. The actual thermal path runs through the heat sink when it is mounted on the device by means of an attachment mechanism. In this case, the total thermal resistance, θja, is the sum of all the individual resistances which represent the physical aspect of the thermal path. There are three thermal resistances that are commonly used to express the total resistance:

1) the junction-to-case resistance, θjc, to account for the thermal path across the internal structure of the device,

2) the case-to-sink resistance, θcs, which is also called the interface resistance, to account for the path across the interface between the device and the heat sink,

3) the sink-to-ambient resistance, θsa, to account for the thermal path between the base of the heat sink to the ambient air.

It follows that $\theta ja = \theta jc + \theta cs + \theta sa$.

Realistically, a typical thermal designer has no access to the internal structure of the device, and can only control two resistances outside of the device, θcs and θsa. Therefore, for a device with a known θjc obtained from the device manufacturer's data book, θcs and θsa become the main design variables in selecting a heat sink.

Thermal interface between the case and the heat sink is controlled in a variety of manners with different heat conducting materials. The interface resistance between the case and the heat sink is dependent on four variables: the thermal resistivity of the interface material (ρ °C,W–inch), the average material thickness (t, inches), the area of the thermal contact footprint (A, inch^2), and the ability to replace voids due to finish or flatness (sink or chip) with a better conductor than air. The interface thermal resistance is then expressed as:

$$\theta cs = \frac{\rho \cdot t}{A}$$

NOTE: The thermal resistivity (ρ), of any material, is the reciprocal of its thermal conductivity (k). Therefore, if the conductivity is known, its resistivity can be calculated. The expression is:

$$\rho = \frac{273.2}{k}$$ when k is in units of $$\frac{Btu \cdot inch}{hr \cdot ft^2 \cdot {}^\circ F}$$

TYPICAL VALUES FOR THERMAL RESISTIVITY ρ (°C/W-INCH):

copper (pure)	0.10
aluminum (1100 series)	0.19
aluminum (5000 series)	0.28
aluminum (6000 series)	0.17
beryllium oxide	0.32
carbon steel	0.84
alumina	1.15
anodized finish	5.60
silicon rubber	81.00
mica	66.00
mylar	236.00
silicone grease	204.00
dead air	1200.00

Note: These values do not take into account the contact resistance that will depend on the filling of voids with the interface material. i.e. copper is much more conductive than grease, but grease is used since copper will not flow to fill in the voids that may be present.

Once the θcs is calculated, the required thermal resistance from the sink to ambient (θsa) is easily calculated by the following equation:

$$\theta sa = \frac{Tj - Ta}{Q} \;(\theta jc + \theta cs)$$

The above information will allow you to use the catalog's performance graphs in choosing a standard, ready-to-use, heat sink to meet your requirements.

How To Select a Heat Sink

Example A

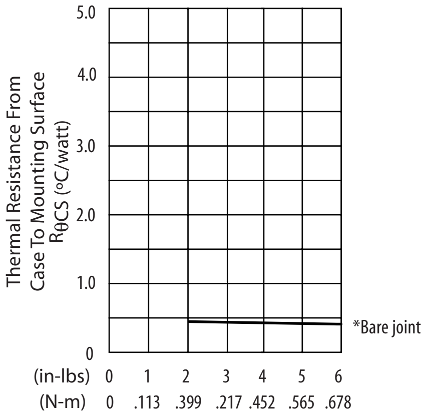
Given: TO-220 case style to dissipate 5 watts:

$R_{\theta JC}$ = 3.0°C/watt
Tj max = 150°C
Ta max = 50°C
Find: The proper heat sink to keep the semiconductor junction from exceeding 150ºC in natural convection.

Equation:

$$P_D = \frac{Tj - Ta}{R_{\theta JC} + R_{\theta CS} + R_{\theta SA}}$$

Assume the device is mounted with Thermalcote™[1] without an insulator. The thermal resistance from case to mounting surface can be obtained from this figure below:



*Bare joint – no finish (with grease)

$R_{\theta CS}$ = 0.5 C/Watt at 0.678 Nm (Newton meter) or 6in. – lbs mounting screw torque, therefore:

$$R_{\theta SA} = \frac{150°C - 50°C}{5\ \text{Watts}} - 3.5 \qquad R_{\theta SA} = 16.5°C/\text{Watt}$$

Part number 6022 on page 47 at 5 watts power dissipation has a mounting surface temperture of 80° C above ambient, therefore:

$$R_{\theta SA} = \frac{80°C}{5\ \text{watts}} = 16°C/\text{Watt}$$

which meets this requirement of natural convection.

Example B

T0-220 to dissipate 13 watts:

Tj Max= 150°C

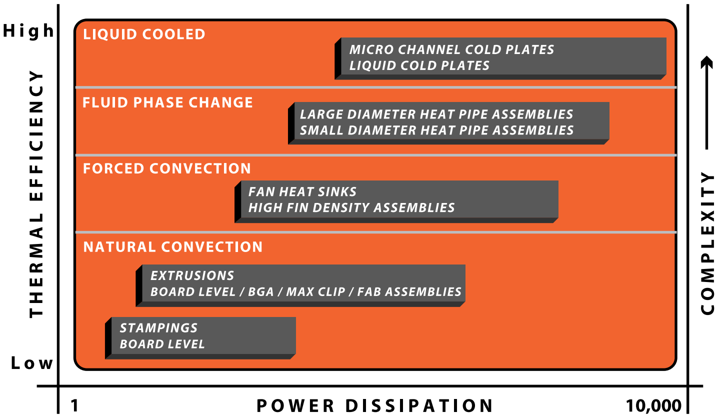
Ta max= 50°C

θjc=3.0°C/W
Air Velocity = 400ft/min
Find a suitable heat sink

Assume the use of a Kon-Dux™[2] pad with a torque of 2 in-lb. From Aavid's data for this type of semiconductor, we know that θcs= 0.5°C/W.

Using the formula above, you will find that Aavid 504222 (see page 39) has a thermal resistance of 4.0° C/Watt at an air velocity of 400 ft/min and therefore will comply with the requirements.

Technical Capabilities



There are 4 primary cooling mechanisms that Aavid Thermalloy takes pride in having expertise and technical capabilities in. The cooling mechanisms include: Natural Convection, Forced Convection, Fluid Phase Change, and Liquid Cooled. This Standard Product Catalog focuses on displaying products that dissipate heat at the board level and various options that can assist in overall performance. The above graph illustrates where the board level products fall in terms of power dissipation and can assist as a starting point to gauge what type of products can be used for your system configuration. For further information realated to our other cooling mechanisms, please contact Aavid Thermalloy at **www.aavidthermalloy.com.**

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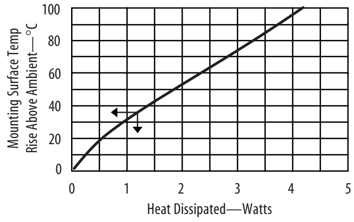
1. See page 113 for information on Thermalcote™
2. See page 86 for information on Kon-Dux™Pads

The performance graphs you will see in this catalog (See graph 579802) are actually a composite of two separate graphs which have been combined to save space. The small arrows on each curve indicate to which axis the curve corresponds. Thermal graphs are published assuming the device to be cooled is properly mounted and the heat sink is in its recommended mounting position.

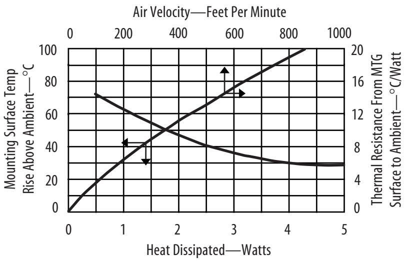
GRAPH A



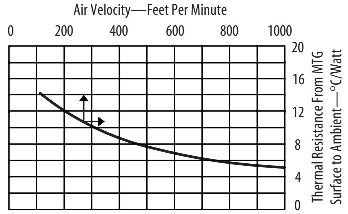
GRAPH A is used to show heat sink performance when used in a natural convection environment (i.e. without forced air). This graph starts in the lower left hand corner with the horizontal axis representing the heat dissipation (watts) and the vertical left hand axis representing the rise in heat sink mounting surface temperature above ambient (°C). By knowing the power to be dissipated, the temperature rise of the mounting surface can be predicted. Thermal resistance in natural convection is determined by dividing this temperature rise by the power input (°C/W).

EXAMPLE A: Aavid Thermalloy part number 579802 is to be used to dissipate 3 watts of power in natural convection. Because we are dealing with natural convection, we refer to graph "A". Knowing that 3 watts are to be dissipated, follow the grid line to the curve and find that at 3 watts there is a temperature rise of 75°C. To get the thermal resistance, divide the temperature rise by the power dissipated, which yields 25°C/W.

579802



GRAPH B



GRAPH B is used to show heat sink performance when used in a forced convection environment (i.e. with forced air flow through the heat sink). This graph has its origin in the top right hand corner with the horizontal axis representing air velocity over the heat sink LFM[1] and the vertical axis representing the thermal resistance of the heat sink (°C/W). Air velocity is calculated by dividing the output volumetric flow rate of the fan by the cross-sectional area of the outflow air passage.

$$\text{Volume (LFM)} = \frac{\text{Velocity (CFM)}}{\text{area (ft}^2\text{)}}$$

EXAMPLE B: For the same application we add a fan which blows air over the heat sink at a velocity of 400 LFM.
The addition of a fan indicates the use of forced convection and therefore we refer to graph "B". This resistance of 9.50°C/W is then multiplied by the power to be dissipated, 3 watts. This yields a temperature rise of 28.5°C.

CONVERTING VOLUME TO VELOCITY

$$\frac{\text{Velocity (LFM)}}{\text{area (ft}^2\text{)0}} = \text{Volume (CFM)[2]}$$

Although most fans are normally rated and compared at their free air delivery at zero back pressure, this is rarely the case in most applications. For accuracy, the volume of output must be derated 60% - 80% for the anticipation of back pressure.

EXAMPLE: The output air volume of a fan is given as 80 CFM. The output area is 6 inches by 6 inches or 36 in^2 or 25 ft^2.
To find velocity:

$$\text{Velocity} = \frac{80}{0.25} = 320$$

Velocity is 320 LFM, which at 80%, derates to 256 LFM.

DESIGN ASSISTANCE

Aavid Thermalloy can assist in the design of heat sinks for both forced and natural convection applications. Contact us for help with your next thermal challenge. For more information, visit our web site at: **www.aavidthermalloy.com**

[1] Linear feet per minute

[2] Cubic feet per minute