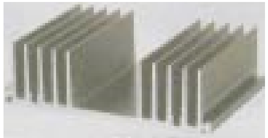
HEATSINK BASICS


All semiconductor devices have *some* electrical resistance, just like resistors and coils, etc. This means that when power diodes, power transistors and power MOSFETs are switching or otherwise controlling reasonable currents, they dissipate power — as heat energy. If the device is not to be damaged by this, the heat must be removed from inside the device (usually the collector-base junction for a bipolar transistor, or the drain-source channel in a MOSFET) at a fast enough rate to prevent excessive temperature rise. The most common way to do this is by using a **heatsink**.

To understand how heatsinks work, think of heat energy itself as behaving very much like an electrical current, and *temperature rise* as the thermal equivalent of voltage drop. We also have to introduce a property of materials and objects known as *thermal resistance*, which behaves in a very similar way to electrical resistance: the more heat energy 'flowing' through it, the higher the temperature rise across it. As you might imagine metals like copper and aluminium have very low thermal resistance, while air tends to have a relatively high resistance. So do many plastics and ceramic materials.

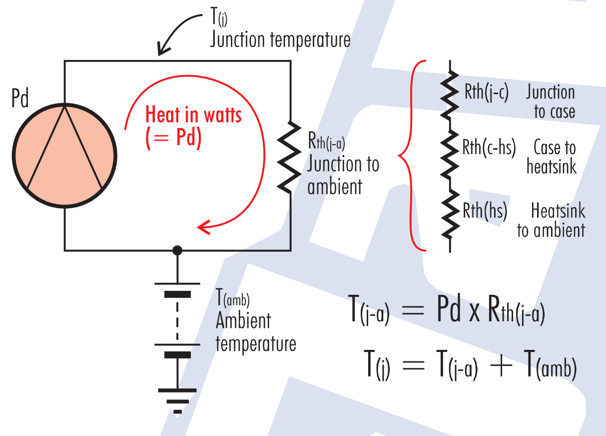
It turns out that there's a thermal equivalent of Ohm's Law, which describes the way heat energy behaves in something like a power transistor:

$$T(j\text{-}a) = Pd \times Rth(j\text{-}a)$$

Here T(j-a) is the temperature rise of the transistor's heat-producing junction, above that of the 'ambient' temperature (i.e., that of the surrounding environment — roughly 'air temperature'); Pd is the power being dissipated; and Rth(j-a) is the **total thermal resistance** between the junction and the surrounding ambient.

Usually T(j-a) is measured in degrees Celsius, Pd in watts and Rth(j-a) in degrees C-per-watt (°C/W). So as you can see the relationship is just like Ohm's Law (E = I x R), except for the units being used and the fact that we're talking about heat.

For example, we can say that if the total Rth(j-a) is 6°C/W and our transistor's junction is dissipating 20 watts, its temperature will rise by (6 x 20) = 120° above the ambient temperature. This means if the ambient temperature rises to 38°C, the transistor's junction temperature will reach (120 + 38) = 158°C.



Power dissipated inside a transistor or other semiconductor device behaves rather like a 'constant current' heat generator, raising the critical inside 'junction' temperature T(j) above the surrounding 'ambient' temperature T(amb) because it has to flow away through the total thermal resistance between the junction and the ambient: Rth(j-a). To keep the device cool, we have to reduce the value of Rth(j-a) — by fitting a heatsink.

Fairly obviously, then, if we want to keep the temperature rise inside the 'works' of a power transistor below its rated safe level, for a given amount of power being dissipated and for a given ambient temperature, the only way to do this is by reducing the value of Rth(j-a), the total thermal resistance between the device's internal source of heat (usually called 'the junction') and the ambient.

Now Rth(j-a) is really made up of *at least two* separate thermal resistances, in series. One is the thermal resistance inside the device package, between the junction and its outside case, called **Rth(j-c)**; the other is the resistance between the case and the ambient, **Rth(c-a)**.

We can't do much about Rth(j-c), but luckily in most power device packages this is fairly small anyway: typically between 0.7 and 4.5°C/W, depending on the package (see Table). But we *can* do something about Rth(c-a), and here's where heatsinks come in.

If a power transistor or MOSFET package is simply supported by its leads above a PC board and surrounded by air, heat energy can mainly flow from the case to the ambient only by two rather inefficient methods: *radiation* and *air convection*. As a result, the thermal resistance to ambient Rth(c-a) is fairly high — typically between 35 and 100°C/W, as you can see from the Table on page 2.

But if instead we bolt the device to a somewhat larger piece of metal, especially a stout piece of aluminium 'heatsink' extrusion with fins, heat can flow much more easily from the case to the ambient: firstly through the aluminium and then to the air via the heatsink's fins — which provide improved surface area to assist both radiation and convection.

Although a heatsink generally provides a much lower thermal resistance to the ambient Rth(hs), when we use one we inevitably introduce additional thermal resistances, each in series with the heat flow: the thermal resistance of the contact between the case and the heatsink Rth(c-hs), which is largely due to tiny amounts of trapped air, and the thermal resistance of any *electrical* insulating washer (mica or plastic) we might need to use between the case and heatsink. Luckily we can minimise these last resistances by using a thin smear of 'thermal compound', a special paste which has very low thermal resistance. This can reduce the total case-heatsink thermal resistance to around 1.5°C/W or less, even when a mica washer is used. (See Table)

Assuming you use thermal compound for the best 'thermal joints', the main way you can reduce the total Rth(c-a) is by using a large enough and efficient enough heatsink — i.e., one with a low enough thermal resistance Rth(hs). Here you have to be guided by the data given by the manufacturer and supplier, as far as the exact Rth(hs) is concerned, but the general 'rule of thumb' is **the larger the heatsink, the lower its thermal resistance**. All of the heatsinks sold by Jaycar have their thermal resistance clearly specified (see Catalogue).

Once you know the maximum safe junction temperature for your power transistor or MOSFET (T_{jmax}), the power it's going to be dissipating (Pd) and the maximum ambient temperature it will be working at (T_{amb}), you can easily work out the maximum total Rth(j-a) from this expression:

Rth(j-a) = (Tjmax - Tamb)/Pd

Usually for silicon devices, it's reasonably safe to assume T_{jmax} is about 150°C. Similarly in many cases, it's reasonable to assume that the maximum ambient temperature inside the equipment's case will be about 50°C. So for a rough but fairly practical rule of thumb calculation, you can find the maximum total Rth(j-a) by dividing 100°C (150° - 50°) by the power being dissipated, in watts.

You can usually find Rth(j-c), the junction-case thermal resistance of the power transistor or MOSFET itself, from the manufacturer's data — or use the typical values for the various common packages, from our Table. Then add the thermal resistance of the thermal compound and/or insulating washer, again from the Table, and this will give you the total junction-to-heatsink resistance. Subtract this from the maximum Rth(j-a) figure, and you'll get the maximum allowable heatsink resistance. You can then select a heatsink which will provide no more than this value of thermal resistance.

Device Package	Junction-Case Rth(j-c), °C/W	No Heatsink Rth(j-a), °C/W	Bolted to Heatsink: Rth(c-hs) in °C/W		
			Direct	Compound	Mica/Comp
TO-220	1.15 - 3.1	62 - 75	1.0 - 1.3	0.5 - 0.8	0.8 - 1.4
TO-202	12.5 - 25	62 - 78	1.5 - 2.0	0.9 - 1.2	1.2 - 1.7
TO-126, SOT-32/82	2.1 - 4.5	100	1.0	0.5	3.0
TO-3	0.7 - 1.75	35	0.5 - 0.7	0.3 - 0.5	0.3 - 0.6
SOT-186 (insul.case)	—	55	5.5 - 7.0	3.6 - 4.5	—
TO-218, SOT-93	0.7 - 1.6	45	0.8	0.3	0.8

Of course if you have the room, it's always a good idea to use a larger heatsink, with an even lower thermal resistance than your safe maximum. Your power transistor or MOSFET will then run even cooler.