Design Example:
MOSFET Thermal Design

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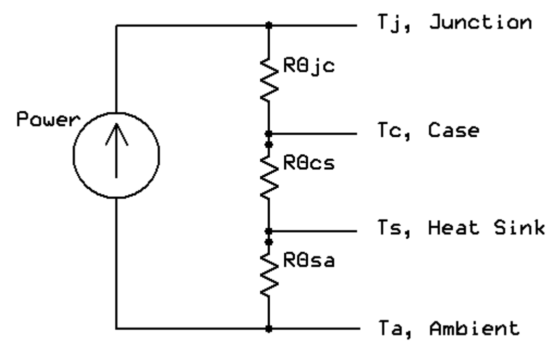
A transistor cannot be run at its maximum rated junction temperature without impacting its long-term reliability. A safe design limit would be 150 °C for a gold-metalization device with a maximum operating junction temperature rating of 200 °C. This will provide a reasonable margin for disastrous events – wrong or no antenna, for instance. The device can then have the thermal margin to withstand the error for the time it takes for the over-current or high SWR protection circuits to react to the fault and shut it off.

Heat sinks come in many forms. Each is rated by its manufacturer for thermal resistance under specified conditions. The thermal rating is called $R_{\Theta SA}$, the thermal resistance between the sink and the ambient environment, i.e. room temperature. For extruded aluminum heat sinks, $R_{\Theta SA}$ is determined, among other things, by the length, depth, number of fins, and the volume and speed of air passing over the fins, if any. The thickness of the base, conductivity of the particular alloy, and whether the fins are part of the extrusion or bonded to it also play on its thermal conductivity. Aluminum is not a particularly good thermal conductor but it's relatively cheap, light and easily extruded into finned shapes. Many amplifier heat sink assemblies employ a copper plate under the transistors as a *thermal spreader* to more effectively distribute the thermal load over the whole area of the sink.

The whole thermal system can be described as shown in the following figure:



The thermal system of a transistor and its heat sink.

The three resistances represent the thermal path of the dissipation power flowing from the transistor's junction out into the ambient environment. The device's $R_{\Theta JC}$ is fixed for a particular device. The case-to-sink $R_{\Theta CS}$ impedance is determined by the surface conditions of the sink and device, and the grease used. The heat sink and its cooling determine the magnitude of $R_{\Theta SA}$. The temperature drop across any of these thermal impedances can be calculated as $\Delta T = P_D \times R_{\Theta xx}$.

Thermal design starts with the device. Say we want 100 W of RF output from a linear amplifier to be used in the output stage of a mobile radio, operating from 13 V. The amplifier is 50% percent efficient so it takes 200 W of dc input power to get it. 100 W goes to the antenna, the other 100 W goes into the heat sink. We look at devices and see that there are none that can do it alone but the RD100HHF1 will give 100 W, half what is needed. De-rated for the real world, we will use two. This is a good idea since a push-pull amplifier is actually easier to make and has less harmonic content to deal with, and since the two transistors are in parallel thermally, their $R_{\Theta JC}$ is cut in half. These transistors are aluminum LDMOS parts so we decide to aim at 150°C for absolute max T_J.

The amplifier will operate mobile and will experience ambient temperatures much higher than normal room temperature of 25°. A hot day in the car could be 130°F or 55°C. If the amplifier is mounted in a confined space where the heat sink does not get full ambient circulation, it could be even hotter than that. The good news is that you are not going to be operating RTTY at 100% duty cycle. It will be more like 50% or even lower for a low duty cycle mode like SSB. So now we have an average dissipation of 50 W at a maximum ambient temperature of 55°C. The RD100HHF1 has a published $R_{\Theta JC}$ of 0.85 °C/W. Two of them in a push-pull circuit places their thermal resistances in parallel so overall thermal resistance is cut in half. The thermal drop at 50 W of dissipation is 50 W x 0.85/2 °C/W = 21.25 °C. With a limit of 150 °C for the maximum junction temperature, this puts the case of the transistors at 150 – 21.25 = 129 °C. A heat sink must now be found to match the remaining thermal drops of $R_{\Theta CS} + R_{\Theta SA}$ = (129-55°C) / 50 W < 1.48 °C/W

This means the sum of the case-to-sink interface plus the sink-to-ambient resistances must be less than 1.48 °C/W or else the junction temperature will go higher than the allowed 150 °C. A quick check of heat sinks [see AAVID or Wakefield] leads us to the conclusion that a simple convection-cooled aluminum extrusion will need to be larger than the amplifier! The solution is to use forced-air cooling.

We find a piece of extrusion that provides 1.3 °C/W of thermal resistance with 2 cfm of air flow. A small 12V fan can force air over the sink making it far more effective. To control noise and reduce dust build-up on the heat sink, a thermal control circuit is used to monitor the sink temperature. It will turn the fan on when the sink reaches 50 °C and disable the PA if it ever reaches 80 °C, meaning something is wrong like a blocked air intake. This is how most small 100 W radios like the Yaesu FT-100, Icom IC-7000, and Elecraft K3 work.