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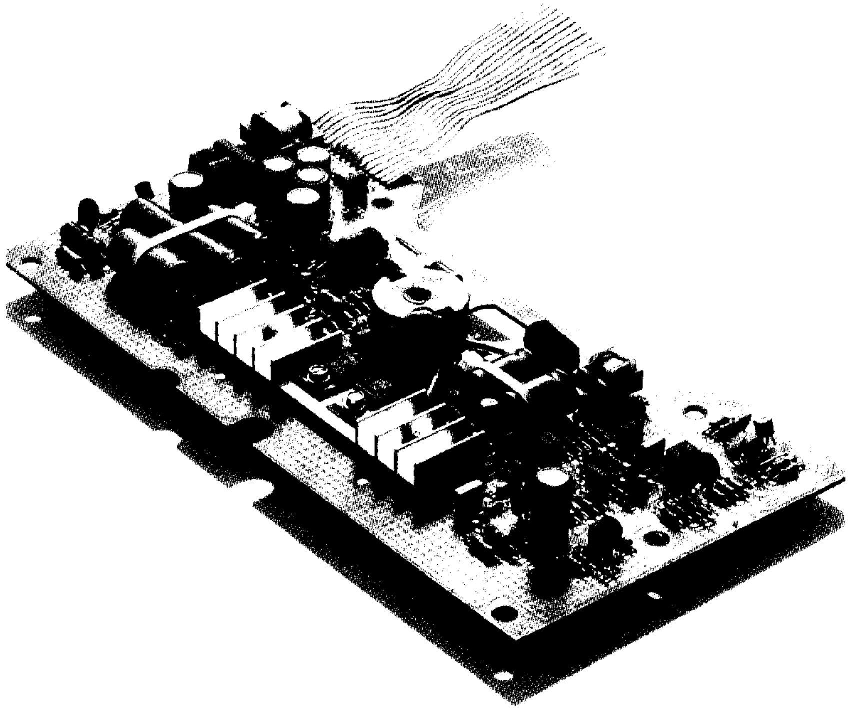
SELECT THE RIGHT HEATSINK

From project design to assembly, two easy equations assure sure-fire cooling!



HEATSINKING IS USUALLY OF LITTLE concern in low-power circuits. Most of the time you can bolt the component's metallic tab to a scrap of metal, or maybe to the chassis, without further concern as to how hot it might get. Low-power applications require minimal thermal mass—a few square centimeters of sheet metal—to transfer the small amount of heat generated by a low-power semiconductor to the air.

Nevertheless, heatsinking is of crucial concern for power components in circuits designed to take full advantage of their capabilities. The power component and its driving components can be destroyed when heat cannot be drawn away fast enough.

Two simple formulae will tell you how hot your semiconductors will get in operation. Using them eliminates guesswork and the accompanying apprehension about guessing wrong and making a mistake.

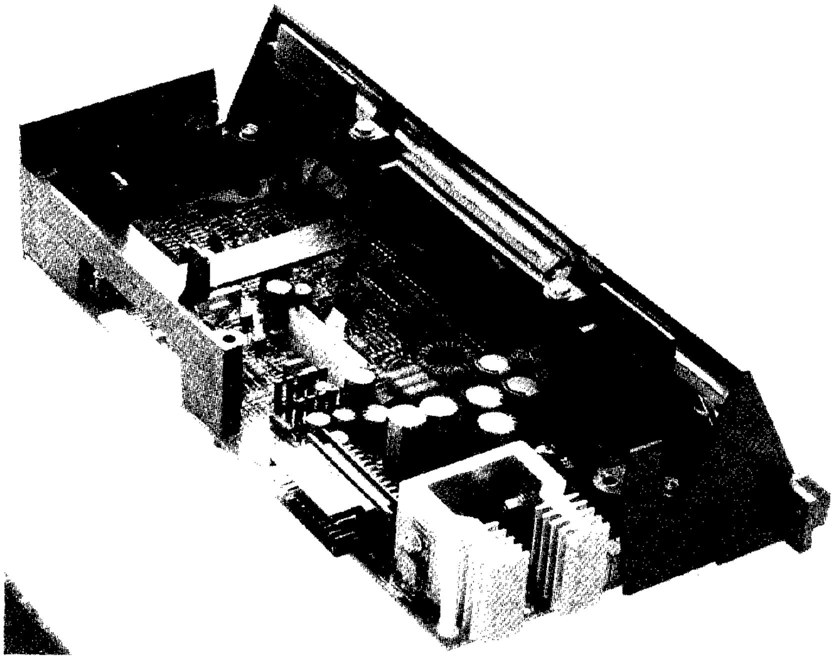
Convection

The design objective for cooling semiconductors is to take advantage of natural convection, which is the transfer of heat by a circulating gas or fluid, in this instance, by ambient air at room temperature. The amount of heat that can be transferred by convection is proportional to the surface area of metal exposed, the velocity of the air passing over the surface, and the temperature difference between the two. This article is limited to the discussion of convective heat transfer to vertical surfaces and natural (as opposed to fan-driven) convective air flow. Nevertheless, even with this limitation, it covers most cooling problems posed by the project designs undertaken by most experimenters.

The power semiconductor is considered a resistive element, as far as the heatsink is concerned. Thus the voltage drop across the device multiplied by the current through it (or I^2R in the case of a power MOSFET) multiplied by the time factor (percent of time it is conducting divided by 100), equals the heat equivalent in watts that the device generates and that must be dissipated into the air by the heatsink. For a simple linear power-supply semiconductor, this is a straightforward calculation. For a semiconductor power switching transistor, the calculation is more involved. For an audio amplifier you might have to estimate dissipation. In any case, make the calculation of the heat to be dissipated equal to the heat in watts as accurate and conservative (on the high side) as you can.

If you have the data sheet for the semiconductor device you will mount on a heatsink, look up its junction-to-case thermal impedance, and case-to-sink thermal impedance. These impedance values are expressed in degrees C per watt, and mean that for every watt of heat power the junction dissipates, it will be a specific number of degrees C hotter than the case—the same applies from the case to the heatsink. If you intend to keep the junction at or below 100° C, and the junction-to-case thermal impedance is 10° C/watt, then 7.5 watts will raise the junction temperature to 100° C, even if the case is kept at a constant 25° C—which might be possible if it were immersed in running water.

Typical junction-to-case ther-



HEATSINKS come in many various sizes and shapes, but the physics of selection is unigue and covered in text. Compare this heatsink with the one on the first page of this story.

mal impedances (Z_{JC}) are 1° C/W for an International Rectifier IRFZ40 MOSFET. and 1.52° C/W for 2N3055. A typical TO-220 case-to-sink thermal impedance (Z_{CS}) is 1° C/W, and for a TO-3 case, 0.12° C/W. Estimate the junction-to-case thermal impedance for your specific semiconductor device using these values for guidance if you do not have the device's data sheet.

Design considerations

What is the maximum temperature the semiconductor's junction should reach? Many circuit designers usually peg the maximum junction temperature at 80° C, because the semiconductor's characteristics will be seriously degraded at higher temperatures, and thermal runaway is a danger for bipolar transistors. Do not take the manufacturer's data sheet claims of maximum watt values and junction temperature seriously. These values are valid only when the device is continuously cooled so that the case is held to a constant 25° C.

Air cooling

What is the ambient air temperature? Remember, the semiconductor device might be inside an enclosure where other heat-producing devices are contributing to the temperature of the ambient air. If you are sure that normal room air can gain free access to the device, you can assume 25° C, but be careful. Recall that the ambient temperature rises in the summer, and 100° F equals 38° C.

Knowing these facts, you can determine ΔT, or the expected temperature difference between the as-yet-unknown heatsink size and the air that will provide the cooling.

$$\Delta T = T_{MaxJ} - [W_J \times (Z_{JC} + Z_{CS})] - T_{AA}$$

where Z_{JC} is the junction-to-case thermal impedance, Z_{CS} is the case-to-sink thermal impedance, T_{AA} is the ambient air temperature, T_{MaxJ} is the maximum junction temperature, and W_J is the junction wattage.

Example: You want to operate a 2N3055 transistor as a motor control, drawing 3 amperes. You will find that the transistor drops 1.2 volts at this current value, and know the maximum duty cycle will be 50%, or 0.5. So, 3 × 1.2 × 0.5 = 1.8 watts. If you decide on a 80° C maximum junction temperature, and 25° C ambient air so that

$$\Delta T = 80 - [1.8 \times (1.52 + 0.12)] - 25$$

$$\Delta T = 52° C$$

The ΔT computation reveals that the estimated heatsink might be 52° C hotter than the air under these conditions. How big, then, must this heatsink be? The answer is calculated as follows:

$$A = W_J \times 5630 \div \Delta T^{5/4}$$

where A = area of the heatsink vertical surface in square centimeters. If you prefer to work with square inches:

$$A = W_J \times 872.6 \div \Delta T^{5/4}$$

In the case of the 2N3055 transistor and using the previous equation for heatsink surface area in square inches, this is

$$A = 1.8 \times 872.6 \div 52^{5/4}$$

$$A = 11.2 \text{ square inches}$$

Thus a heatsink of at least 11.2 square inches of vertical surface area located in free air will do the required cooling job for the transistor.

If you intend to use two or more identical semiconductor devices on the same heatsink, and they are drawing similar currents (e.g. parallel devices), you can do the calculation as if it is for a single device if you calculate the heat power of the combination, and divide the thermal impedances by the number of devices. Dissimilar semiconductor devices should be mounted on different heatsinks.

Example: Two IRFRZ40 power MOSFETs are connected in parallel in a low-voltage switching power supply. The currents are likely to surge to 40 amperes through both devices, and their duty cycles might approach 80%. The on-resistance of the IRFZ40 (the device is conducting) at 80° C is about 0.036 ohm, so the parallel pair will exhibit a resistance of 0.018 ohm to the 40 amperes, giving 0.018 × 40 × 0.8 = 23 watts. Assume a worst case at 38° C as if you were in an Arizona desert during the summer.

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$$\Delta T = 80 - [23 \times (0.5 + 0.5)] - 38$$

$$\Delta T = 19° C$$

The size of the heatsink is then:

$$A = 23 \times 872.6 \div 19^{5/4}$$

$$A - 506 \text{ square inches}$$

The required 506 square inches might seem excessive, but a typical large heatsink that measures 5 × 4 × 2⅝ inches which has 250 square inches of surface area would require another one to adequately dissipate the heat. Of course, those big heatsinks can be expensive, and if they cost more than the device itself, you might want to redesign the circuit with more semiconductor devices in parallel. This will lower the resistance and the heat that must be dissipated.

Experimenter's notes

Your finger is a rather unreliable temperature measuring device. A small thermistor, calibrated on the kitchen stove in a pot of distilled water with a confectioner's thermometer, is a much better approach if you must know how hot things will be for your project's semiconductors.

Be sure to coat the contacting surfaces of the semiconductor and heatsink with thermally-conductive grease before mounting the device on the heatsink. Without adequate heat transfer through the contacting surfaces, the semiconductor will be destroyed regardless of the size of the heatsink. The thermally-conductive grease might be supplied with the semiconductor or the mounting hardware kit or it can be obtained separately.

If you have trouble with the 5/4 exponent of ΔT equation, find the logarithm of this number in a logarithmic table, multiply it by 1.25, and find the antilog of the result. If this doesn't help, a scientific or engineering calculator can provide the numbers. Ω