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How to Size Heat Sinks for Semiconductors

As microprocessor speeds increase, their power needs rise proportionally. This also puts higher demands on the voltage regulator that feeds the processor chip. In spite of the increased power, the regulator chip tends to remain the same size, posing a problem of dissipating additional heat.

Consider the production retrofit of a personal computer. An existing microprocessor running at 200 MHz uses a TO-220 style voltage regulator with a passive heat sink. A faster replacement microprocessor drops into the same socket as the 200-MHz model without modification. The higher power voltage regulator also occupies the same area, but dissipates more heat. Another sink must be selected because the original regulator heat sink cannot handle the additional load.

The ideal alternative is to install a regulator heat sink that handles the additional dissipation without modifying the motherboard. The new voltage regulator is also in a TO-220 package and has a peak rating of 15.4 W. Although steady-state operating conditions consume less power than the peak rating, designing around the peak lowers the normal operating temperature and ensures the regulator operates below its maximum temperature rating.

The motherboard sits in an enclosure with little airflow, about 50 linear ft/min with an ambient temperature of 40°C. The regulator data sheet specifies a maximum case temperature of 110°C, and a maximum junction temperature of 150°C. Therefore, the heat sink must maintain the junction temperature at or below the maximum with 50 ft/min of airflow or less.

The mechanical envelope available for the heat sink is 1.95-in. wide by 1.25-in. deep by 1.5-in. high, and the regulator is off center by about 0.25 in. After the designer determines the heat sink requirements, the next step is to calculate the thermal resistance required between the semiconductor junction and the ambient air *qja* with the expression,

$$qja = \frac{(Tj - Ta)}{P} = \frac{(150 - 40)}{15.4} = 7.1^{o}C/W$$

where *Tj* = maximum junction temperature, ºC; *Ta* = maximum ambient temperature, ºC; and *P* = maximum power dissipated, W.

The maximum junction temperature and power dissipated are found in the voltage-regulator data sheet, and the maximum ambient temperature is measured at the motherboard. The thermal resistance for the entire assembly is the sum of resistances of the regulator, heat sink, and the thermal interfaces between them. The resistance of the voltage regulator is the thermal resistance between the semiconductor junction and its case, *qjc*, found by,

$$qjc = \frac{(Tj - Tc)}{P} = \frac{(150 - 110)}{15.4} = 2.6^{o}C/W$$

where *Tc* is the maximum case temperature, ºC.

A high thermal-conductive material placed between the regulator and the heat sink improves mechanical contact at the interface and lowers the total thermal resistance. The thermal resistance of the material, qcs, is rated at 0.1°C/W.

After determining the required resistance for the entire assembly and the resistances of the regulator and thermal material, the heat-sink thermal resistance *qsa* may be solved by

$qja = qjc + qsa + qcs$
$qsa = qja - qjc - qcs$
$= 7.1 - 2.6 - 0.1 = 4.4^{o}C/W$

The next step is to select a heat sink based on the known thermal resistance and available dimensions. Designers need not be stuck with a catalog part that only marginally fits their application. Sink manufacturers often modify standard heat-sink designs to provide the characteristics exactly needed. Thus, the motherboard need not be redesigned.

A catalog heat sink was found for this example that satisfied all conditions – except the location of the regulator on the sink which was off center by 0.25 in. The heat-sink vendor was able to modify the fins and bring the TO-220 device closer to the edge of the envelope. A simulation of the new design showed a thermal resistance less than 4.4ºC/W, and an actual test confirmed it.

Standard TO-220 heat sink selection

PART NUMBER	THERMAL RESISTANCE, 75ºC RISE ABOVE AMBIENT	DIMENSIONS, (IN.) W — D — H
5297	5.5ºC/W	1.65 _ 1.00 _ 1.00
5298	3.7ºC/W	1.65 _ 1.00 _ 1.50
5299	3.4ºC/W	1.65 _ 1.00 _ 2.00