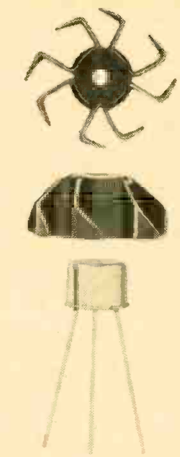
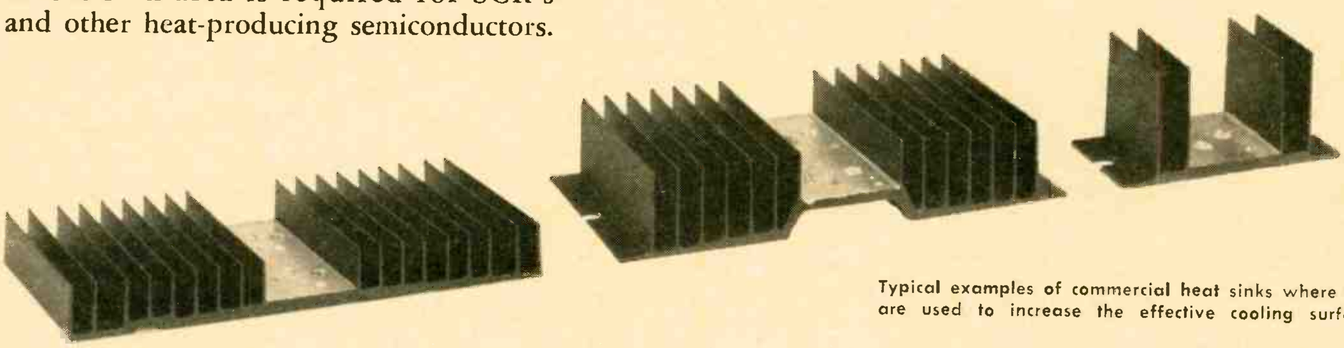
SEMICONDUCTOR HEAT SINK DESIGN CHART



By FRANK D. GROSS

Simple method of determining how large a heat sink area is required for SCR's and other heat-producing semiconductors.



Typical examples of commercial heat sinks where fins are used to increase the effective cooling surface.

HEAT sink information seems to be rarely, if ever, in a usable form, particularly for SCR and other switching circuits. This nomogram directly relates the load an SCR is controlling to the required heat sink area. The nomogram may be extended to apply to any semiconductor.

The heat produced in an SCR is caused by two factors; namely, a brief power pulse during turn on, and the continuous power loss due to the forward drop of the *p-n-p-n* junction. In all power frequency circuits (1 kc. or less), the turn on of the SCR is so fast that only the forward drop need be considered. Put another way, the duty cycle of the turn-on power pulses is very low. The heat produced by the SCR due to forward drop loss is given by $P_{loss} = V_f \times I_{load}$ where V_f is the forward drop which varies with the load current but never exceeds 1.1 volts when the SCR is run within its continuous power rating. Let us make the conservative assumption that the forward drop is always exactly 1.15 volts and that the SCR is on all the time (or half the time in a half-wave circuit). This means we can assume that the power loss in an SCR is equal to 1% of the maximum load power since the load power is given by 115 I_{load} and the forward loss is assumed to be 1.15 I_{load}. This is strictly a worst-case assumption as the power loss will be considerably less when lower conduction angles (less load power due to speed or brightness setting) are chosen.

Heat transfer is accomplished in two ways by the heat sink: convection and radiation. Convection is almost always the stronger of the two transfer mechanisms. Radiation is very much a function of the color and roughness of the heat sink surface and can approach zero for a smooth, highly polished surface. Convection is independent of these parameters. Let us make a second assumption that all of the heat transfer is provided by convection. Again, this is a worst-case assumption.

The physics book says that $Q = H_c \times A \times \Delta T$ where Q is watts of heat transferred by convection, H_c is convection transfer constant, A is surface area, and ΔT is temperature difference between ambient and heat sink.

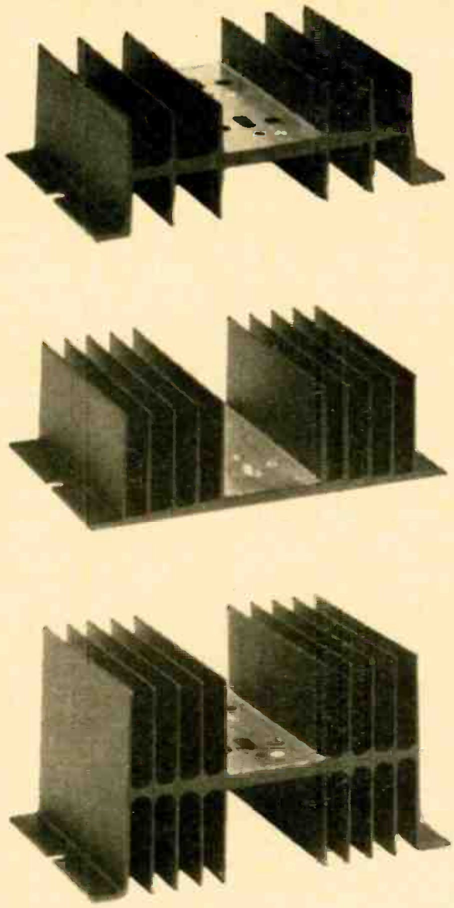
H_c is a constant of heat transfer which is given by $H_c = .0022(L/\Delta T)^{1/4}$ where L is the vertical length of a square metal plate in inches and T is the temperature difference in degrees centigrade between the plate and the ambient air.

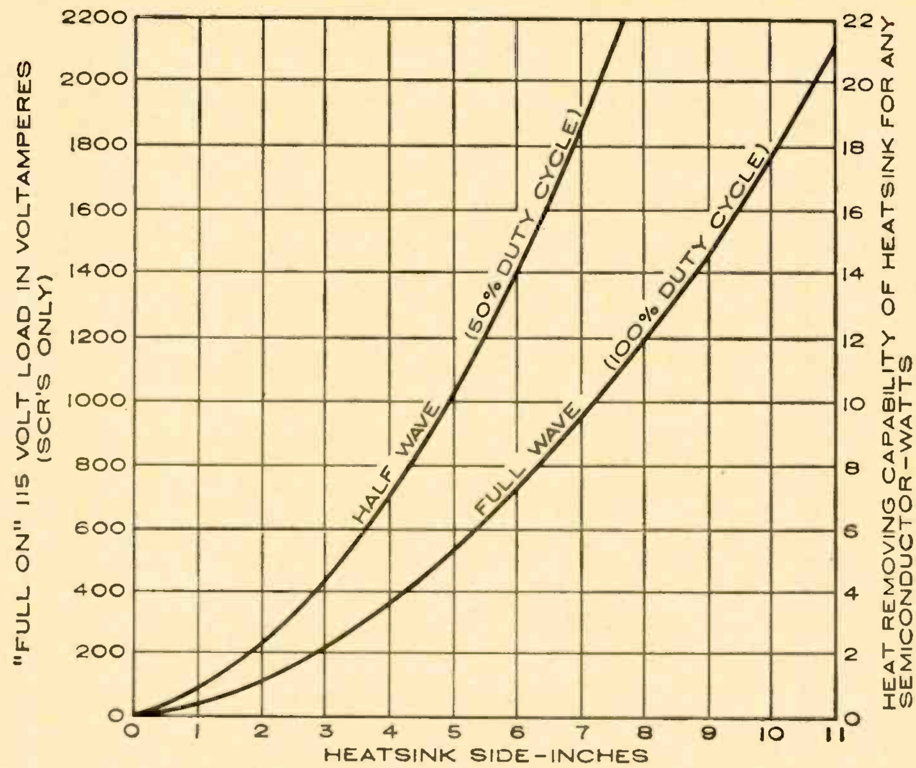
An SCR is capable of safely operating at case temperatures that can cause serious burns to humans. In any SCR control, consideration should be given to what the operator or user of the equipment can stand and not to the ultimate temperature damaging to the SCR. This is especially true in small dimmers and power-tool controls where the case doubles as a heat sink. Operation at heat sink temperatures safe to humans allows the SCR to run well within its ratings, enhancing circuit life and reliability.

A metal plate at 140°F (60°C) may be described as alarmingly hot. No burn damage will occur, but substantial will power is required to hold onto a metal plate at this temperature. Above this temperature, the probability of a burn rapidly increases. A choice of 55°F (13°C) of allowable temperature rise permits the heat sink to stay below the critical temperature for any ambient temperature below 85°F. This is quite reasonable for most SCR applications. The heat sink is normally well below this design temperature except during full-on operation.

The geometry assumed for the nomogram is a vertical, square, ⅛-inch thick piece of aluminum with both sides exposed to the cooling air. A minimum clearance of 1½ inches on either side is assumed. It is also assumed that there is no obstruction to ambient air either above or below the heat sink. A bit of thought will allow this geometry to be distorted into any heat sink geometry required for a specific application.

Generally, the nomogram will give quite conservative re-





These curves will give a 55° F. (13° C) temperature rise of the heat sink above room temperature when using a square, vertical 1/8-inch aluminum plate with a minimum of 1 1/2 inches of side clearance and unobstructed top and bottom access to ambient air. The heat sink may be any color as long as any coatings used on the aluminum are as thin as possible.

sults, *e.g.*, the heat sink temperatures will be less than predicted.

If the SCR is used in a half-wave circuit (or a full-wave circuit in which the alternate half cycles are conducted by a diode or other SCR), only half the normal SCR power is produced since the SCR is only on half the time. Because of this, a heat sink of one-half the area (or a square of .707 *L*) is required.

If only one side of the heat sink is available to the cooling air, then twice the required area (or 1.41 times each side) must be used.

Actually, the nomogram is simply a plot of how many watts a heat sink can transfer and is by no means limited to SCR's. Any semiconductor or, for that matter, any heat producer will provide the same results.

If higher heat sink temperatures are permitted, the reduction in area is proportional to the allowable temperature rise. For instance, if a 110°F rise is permitted, only half the required area for the 55°F case is needed. If higher temperature operation is used, the SCR *must* have a very low thermal resistance to the heat sink. This means that at most a thin mica or anodized-aluminum insulating washer may be placed between SCR and heat sink. The use of silicone grease is mandatory in this case.

Here are some examples that show nomogram use.

1. How large a two-sided heat sink is required for a 1-kw., 115-v.a.c. light dimmer using an SCR in a half-wave circuit?

Answer: The 1000-va. line is followed horizontally across the nomogram till it intersects the half-wave curve. The required size is read vertically downward. The answer is five inches square.

If only one side of the heat sink has access to cooling air, the same area is still required. The area is $2 \times 5 \times 5 = 50$ in.^{2} This is equal to a one-sided square slightly over seven inches on a side. The area need not be calculated if you are using a square geometry. Simply multiply the original side by 1.41, or in this case $5 \times 1.41 = 7$ inches.

2. How large a heat sink is required for a bilateral SCR operating a 2.2-amp. electric drill as a power-tool control?

Answer: The drill voltampere rating is given by $115 \times I$ or $115 \times 2.2 = 253$ va. Following the value horizontally to the full-wave curve and reading downward gives 3½ inches square.

3. Two SCR's are used as a contactor for a 115-v.a.c., 1-h.p. induction motor, both mounted on the same heat sink. What size is required?

Answer: Two half-wave SCR's are the same as one full-wave one, so the full-wave curve must be used. The voltampere load of the motor must be found. One horsepower equals 746 watts. The efficiency of the motor at full load is probably above 90%, and the power factor is most likely to be .8 or better. The voltamperes drawn are then equal to $746/(.8)(.9) = 1036$ va. An 8-inch heat sink is required.

4. A germanium transistor is used in a 400-cps static inverter that draws five amperes from a 28-volt d.c. line. As the circuit is push-pull, the transistor is only on half the time. What size heat sink is required?

Answer: The low frequency of the inverter allows us to assume that most of the heat produced is during the conduction or on time and that we may neglect switching-power losses during on time. The saturation voltage may be found on the transistor data sheet, or it may be assumed to be less than .3 volt. The heat produced is then equal to 5 amps × 3 volt = 1.5 watts. Since the transistor operates on a 50% duty cycle, .75 watt of heat must be continuously removed by the heat sink. The right ordinate of the nomogram and the full-wave curve are used to give an answer of one inch. As this is quite small, it might be better to consider a larger value to account for turn-on losses and starting transients. Three inches would be a good choice. ▲