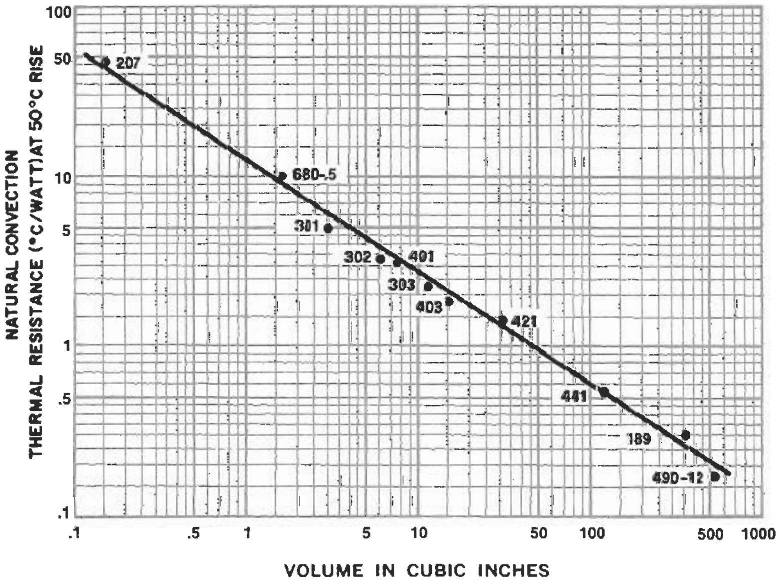
HEAT SINK PERFORMANCE vs. SPACE REQUIRED . . .

Data below . . . Heat Sink Performance vs. Space Required illustrates the fact that natural convection heat dissipation by means of a finned dissipator is a function of the volume contained within the envelope of the dissipator. The curve, a straight line plot on log paper, shows natural convection thermal resistance (°C/watt), at a 50°C rise of the heat sink mounting surface above ambient, versus the volume occupied by the heat sink in cubic inches.

For example, a Wakefield Engineering 441 natural convection heat sink has cross section envelope dimensions of 4.5 x 4.75 inches with a length of 5.5 inches. This means that the total volume occupied by the 441 is 118 cubic inches. The curve shows that a heat sink with 118 cubic inch volume will have impedance of .55 degrees C/watt. The actual test data for the 441 as obtained in the laboratory indicates a thermal impedance of .55 degrees C/watt at a mounting surface temperature rise of 50 degrees C. In calculating the volume of sinks with extruded mounting feet such as 403 and 421, disregard the mounting feet when determining envelope dimensions. For example the 403 should be considered to have envelope dimensions of 1.25 x 4 x 3 and volume of 15 cubic inches.

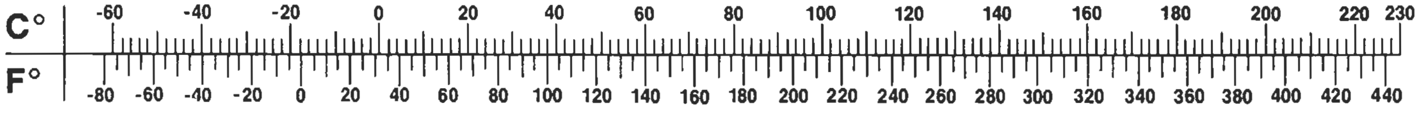
If there is a specific volume of space available for fitting in a heat sink, the thermal resistance of an "optimum" heat sink can be accurately approximated from the curve. By "optimum", it is meant that the ratio of cross-section to length, fin spacing and thickness, finish, and mounting orientation, all meet the high design standards as illustrated in Wakefield Engineering designs.

The curve below is based on performance with one device per heat sink. Thermal resistance with two or more devices per sink may be as much as 20-25% lower since distributing the heat dissipation results in increased efficiency.

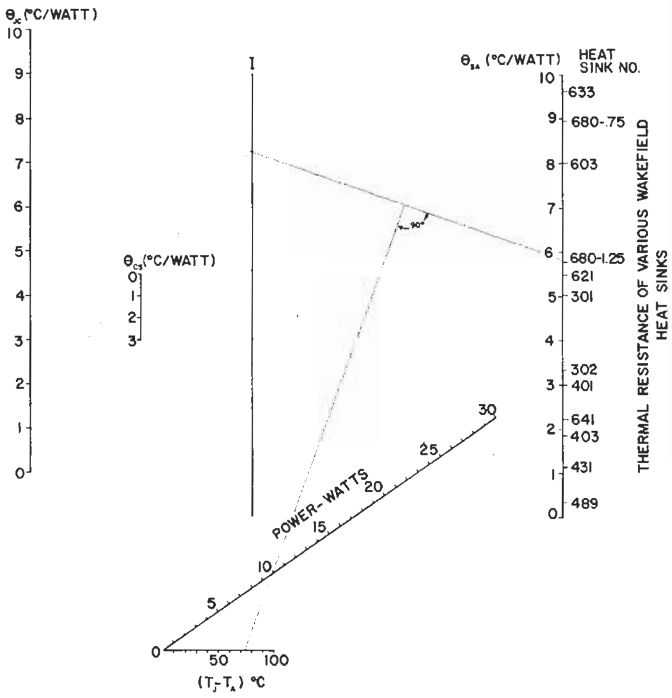


WEIGHTS OF STANDARD HEAT SINKS AND ACCESSORIES

Model No.	Approx. Wt.	Model No.	Approx. Wt.
101	.00067 lbs.	215-A	.0024 lbs.
102	.00031 lbs.	222-C	.0057 lbs.
103	.00014 lbs.	224-C	.0056 lbs.
104	.00014 lbs.	254-D	.012 lbs.
105	.0051 lbs.	254-P	.012 lbs.
106	.0022 lbs.	254-S	.017 lbs.
107	.0033 lbs.	254-SI	.017 lbs.
109	.23 lbs.	254-T	.028 lbs.
111	.054 lbs.	256-D	.00067 lbs.
113	.093 lbs.	256-DM	.00041 lbs.
120-2	.16 lbs.	256-DT	.00055 lbs.
120-5	.33 lbs.	256-ST	.00044 lbs.
120-8	.57 lbs.	259-18-25	.00077 lbs.
120-80	5.5 lbs.	259-18-40	.0010 lbs.
120-320	21.25 lbs.	259-5-50	.0013 lbs.
130-2	.19 lbs.	260-P5	.0013 lbs.
130-3	.30 lbs.	260-P5B	.0015 lbs.
130-4	.36 lbs.	260-4T	.0024 lbs.
130-5	.44 lbs.	260-6SH5	.0037 lbs.
130-A	.36 lbs.	260-10SH5	.0041 lbs.
130-B	.37 lbs.	260-P18	.0070 lbs.
130-C	.40 lbs.	260-P18B	.0030 lbs.
130-D	.41 lbs.	260-2T	.0013 lbs.
130-E	.43 lbs.	260-4SH18	.0017 lbs.
130-F	.44 lbs.	260-6SH18	.0019 lbs.
130-G	.45 lbs.	292-C	.0013 lbs.
130-H	.46 lbs.	292-A	.00049 lbs.
130-J	.49 lbs.	293-1	.0029 lbs.
130-K	.50 lbs.	293-2	.0040 lbs.
130-L	.51 lbs.	293-3	.0056 lbs.
130-M	.53 lbs.	296-1	.0011 lbs.
130-N	.54 lbs.	296-2	.0018 lbs.
130-P	.55 lbs.	296-3	.0025 lbs.
131-4.5	.94 lbs.	296-4	.0029 lbs.
131-F-4.5	.97 lbs.	301	.064 lbs.
131-10	2.01 lbs.	302	.12 lbs.
131-15.5	3.23 lbs.	303	.23 lbs.
132-4.5	1.41 lbs.	310-3.0	1.39 lbs.
132-F-4.5	1.51 lbs.	310-5.5	2.55 lbs.
132-10	2.05 lbs.	310-11.5	5.34 lbs.
132-15.5	3.20 lbs.	401	.16 lbs.
133-4.5	2.78 lbs.	403	.32 lbs.
133-7.5	4.50 lbs.	413	.59 lbs.
133-10	6.00 lbs.	421	.68 lbs.
133-15.5	9.30 lbs.	423	1.20 lbs.
133-16.5	9.90 lbs.	431	.78 lbs.
133-24.5	14.70 lbs.	433	1.36 lbs.
135-1	1.31 lbs.	435	1.25 lbs.
135-2	2.81 lbs.	441	1.78 lbs.
135-3	4.00 lbs.	465	1.77 lbs.
135-B	.98 lbs.	476	2.60 lbs.
151-K-H	.50 lbs.	486	3.68 lbs.
151-Q	3.50 lbs.	489	6.25 lbs.
152-I-A	.10 lbs.	490-3.5	3.00 lbs.
152-K-A	.98 lbs.	490-6	5.25 lbs.
152-G	15.75 lbs.	490-12	10.00 lbs.
153-K-A	1.03 lbs.	501	.52 lbs.
153-Q	4.25 lbs.	502	.93 lbs.
153-G	16.00 lbs.	503	1.89 lbs.
154-K-A	.6 lbs.	504	.43 lbs.
154-Q	3.25 lbs.	505	.71 lbs.
A-4	.49 lbs.	601	.04 lbs.
B-4	.25 lbs.	603	.07 lbs.
C-4	.25 lbs.	621	.10 lbs.
D-4	1.0 lbs.	623	.19 lbs.
H-3	.25 lbs.	631	.02 lbs.
180-10-6	.85 lbs.	632	.032 lbs.
180-10-12	1.75 lbs.	633	.043 lbs.
180-11-6	1.50 lbs.	641	.30 lbs.
180-11-12	2.75 lbs.	671	.010 lbs.
180-12-6	2.25 lbs.	672	.013 lbs.
180-12-12	4.25 lbs.	680-.5	.07 lbs.
170	.0027 lbs.	680-.75	.08 lbs.
171	.0034 lbs.	680-1.0	.09 lbs.
172	.0020 lbs.	680-1.25	.10 lbs.
201-C	.0025 lbs.	690	.07 lbs.
201-A	.0011 lbs.	695	.01 lbs.
202-C	.0020 lbs.		
203-C	.0036 lbs.		
203-A	.0017 lbs.		
204-C	.0015 lbs.		
205-C	.0026 lbs.		
205-A	.0012 lbs.		
207-C	.0037 lbs.		
207-A	.0015 lbs.		
209-C	.0057 lbs.		
209-A	.0022 lbs.		
211-C	.0027 lbs.		
211-A	.0013 lbs.		
213-C	.0034 lbs.		
213-A	.0023 lbs.		
215-C	.0054 lbs.		



Heat Sink Selection and Rating Procedure



NOMOGRAM FOR DETERMINATION OF REQUIRED HEAT SINK PERFORMANCE

HEAT SINK SELECTION

Heat sink selection is often based on a compromise among performance, volume and price considerations. Before examining these three jointly, the performance requirements for a given device (at the expected operating power dissipation level) should be analyzed.

The basic concern in semiconductor operation, from a thermal viewpoint, is the maintenance of a junction temperature level which will not be detrimental to the device. With a semiconductor mounted on a heat sink, the relationship between junction temperature rise above ambient and power dissipated is:

$$q = \frac{T_j - T_a}{\theta_{jc} + \theta_{cs} + \theta_{sa}} \qquad \text{Eq.(1)}$$

where Q = power dissipated — watts

T_j = junction temperature — °C

T_a = ambient (surrounding air) temperature — °C

θ_{jc} = thermal resistance from junction to semiconductor case (given by manufacturer) — °C/watt

θ_{cs} = thermal resistance from case to heat sink

θ_{sa} = thermal resistance from mounting surface of heat sink to ambient — °C/watt

Most of the variables in the equation above are known. Maximum acceptable junction temperature and the junction-to-case thermal resistance (θ_{jc}) for each semiconductor are supplied by the manufacturer. The expected ambient temperature and power (heat) dissipation are specified by the designer. The resistance between the device case and heat sink, θ_{cs}, is the most difficult to obtain. However, estimates for various devices may be found on Pages 5 and 16 of this catalog.

Once having established these parameters equation 1 can be used to determine the required heat sink thermal resistance. In order to simplify this calculation the nomogram at the left can be used. This is done by first extending a line through θ_{jc} and θ_{cs} to Line I. Then trace the "T" shown on the next page on transparent paper. Place it over the nomogram so that Line C-D passes through the desired temperature rise (T_j-T_a) and power dissipated and Line A-D passes through the intersection of I and the θ_{jc}, θ_{cs} line. The intersection of D-B on the θ_{sa} scale yields the required sink thermal resistance.

For convenience the resistance of several Wakefield heat sinks is indicated on the nomogram. These values are for natural convection cooling with a 50°C temperature rise above ambient of the heat sink mounting surface.

If desired, the nomogram can also be used if device case temperature is the basis for selecting a heat sink. Simply use $\theta_{jc} = 0$ and interpret the temperature scale to be (T case $- T_a$.)

In order to illustrate the use of the nomogram consider the following specific example. It is desired to operate a semi-conductor with a TO-3 case such that its junction temperature will not exceed 125°C when it is dissipating 10 watts with ambient temperature at 50°C. The value of θ_{jc} for this device is given by the manufacturer as 1.5°C/watt. Case-to-sink thermal resistance θ_{cs} was assumed to be 0.25°C/watt based on Table I, Page 5 of this catalog. As indicated on the nomogram, extend a line from 1.5°C/watt on the θ_{jc} scale through 0.25°C/watt on the θ_{cs} scale to line I. Then overlay the "T" so that the leg passes through Power = 10 watts and $(T_j - T_a) = (125°C - 50°C) = 75°C$ and the left arm meets line I at the intersection just established. The required heat sink thermal resistance is found at the intersection of the right arm and the θ_{sa} scale to be $\theta_{sa} = 5.8°C/watt$.

As indicated, one sink which provides this performance is the 680-1.25. Examination of the test data throughout the catalog will reveal that there are probably one or more other heat sinks suitable for this application. If so, the choice then becomes dependent on size and price.

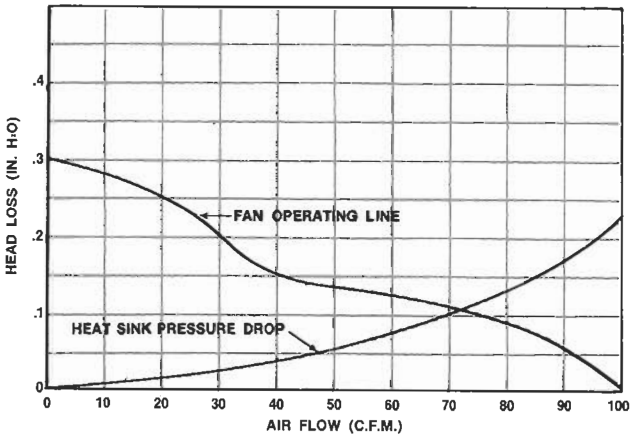
Now that $\theta_{s\text{-}a}$ has been determined a specific heat sink can be selected. If a particular application has a volume restriction then refer to the curve on page 50. Plot the point corresponding to the required $\theta_{s\text{-}a}$, just determined, and the available volume. If the point falls below the curve, it will not be possible to find a heat sink with the desired natural convection thermal resistance. Therefore, it will be necessary to use a heat sink with forced convection or to compromise the performance requirement.

After the required thermal resistance and size are determined it is a simple matter to find a suitable Wakefield heat sink from among those shown in this catalog.

The discussion to this point has considered only heat sinks cooling by natural convection. In most instances in this catalog, particularly for large sinks, forced convection data are also provided.

Forced convection performance is shown in two ways: thermal resistance is presented as a function of the air velocity (feet per second) in front of the fins and also as a function of volumetric flow rate (cubic feet per minute) of air passing through the heat sink. In conjunction with the latter, pressure drop through the heat sink versus air flow is also presented.

FIGURE 1.



In an actual installation one or more heat sinks may be contained within a duct so that all of the fan driven air passes through the sinks. Since the heat sinks were selected on the basis of thermal performance at a particular air flow, their pressure drop versus flow characteristics must be carefully matched to those of the fan to be used. This is done by superimposing the fan operating curve on the sink head loss curve as shown in Figure 1. The intersection of these curves is at the air flow rate which this fan will provide when used with this particular sink. If the thermal resistance corresponding to this air flow is equal to or lower than that required, the combination is acceptable. If not, either a different fan or heat sink must be selected.

If the arrangement above is modified by adding another heat sink in flow series with the first, the airflow will be reduced because of the additional head loss contributed by the second sink. The new air flow rate can be determined by shifting the head loss curve in Figure 1 so that the pressure drop at each flow rate is equal to that of two sinks. The crossover of this new curve and the fan operating curve is the new air flow rate.

Another point which must be considered in a series arrangement is the fact that air entering the second heat sink is at a higher temperature than when it enters the first. This increase, which is caused by the power dissipation in the upstream sink, is given by

$$T = \frac{1.76P}{CFM}$$

Where: T = air temperature leaving sink-air temperature entering sink °C
P = power dissipation watts
CFM — air flow rate CFM

As a result of this one must either accept a slightly higher temperature for the downstream heat sink, or, if this is unacceptable, a small reduction in power dissipation in the downstream heat sink.

RATING PROCEDURE

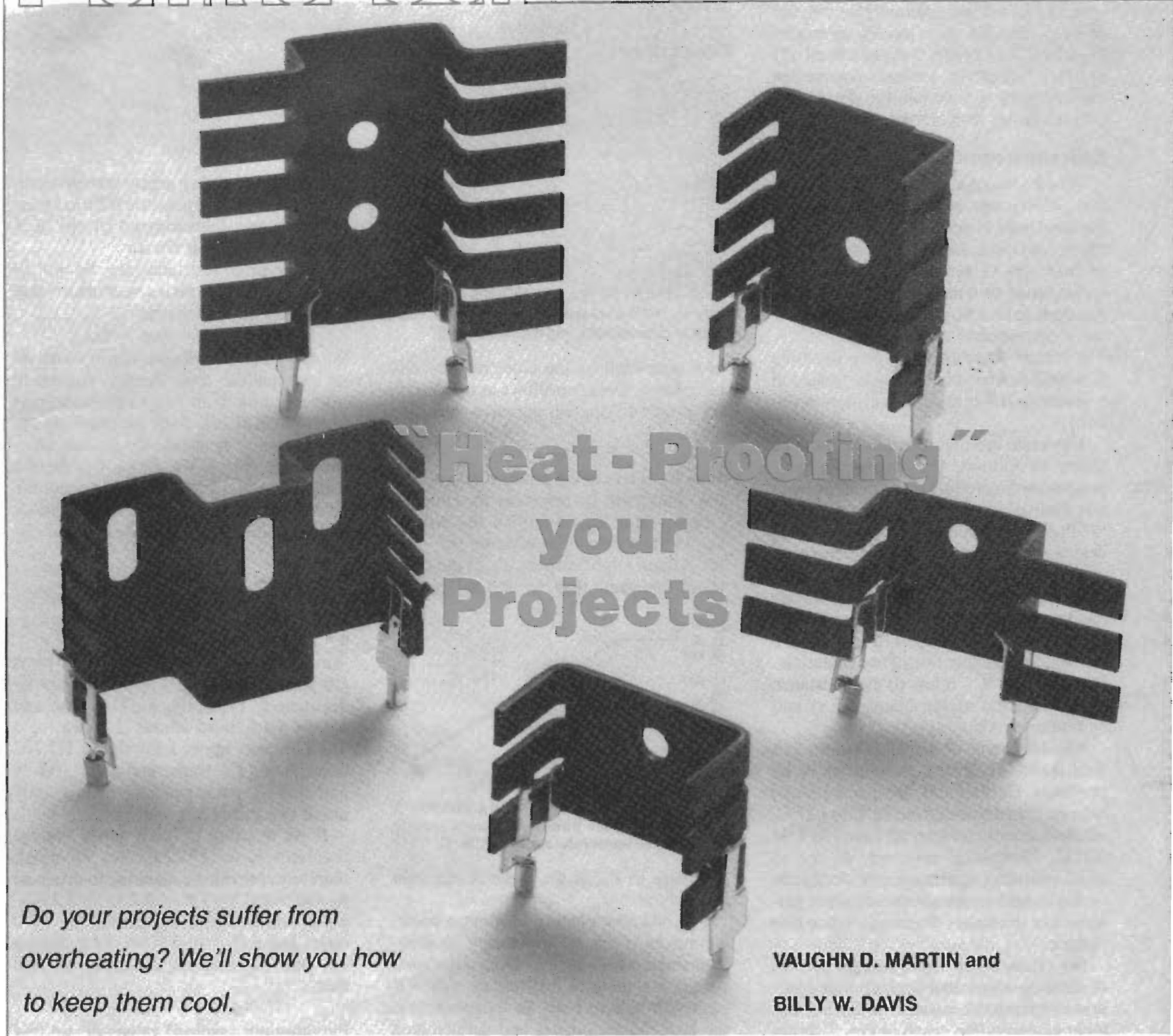
Depending on the particular heat sink, at least one and as many as four curves are presented to describe its performance characteristics.

Natural Convection: Performance of natural convection heat sinks is shown by a curve of temperature rise above ambient versus power applied to the device mounted on it. Observation of a typical curve will show why temperature rise rather than thermal resistance is presented. Thermal resistance is the slope of this curve. Since it is not a straight line, but rather has a slope which decreases with increasing power, a value of resistance cannot be given unless the power at which it applies is also given. The non-linearity of the temperature rise versus power curve is caused by the exponential increase of radiation as temperature increases and from higher convection velocities excited by the fins as they increase in temperature.

Forced Convection: Forced convection performance is expressed in terms of thermal resistance. Two types of installation can be used with forced air coolers. One or more coolers (depending on size) can be situated in a duct such that all of the air flow provided by a fan passes through the sinks. In order to provide a basis for proper selection of a fan in this case, thermal resistance and head loss are presented as a function of volumetric air flow rate (CFM.)

These data are obtained with the test heat sink enclosed in a snug fitting duct, one end of which was sealed into a plenum chamber. Therefore, all of a measured volumetric airflow is forced through the heat sink.

The other possible installation is with the cooler located in a relatively open area supplied with cooling air at a prescribed velocity. For this case thermal resistance is presented as a function of air velocity in feet per minute (FPM).



"Heat-Proofing" your Projects

Do your projects suffer from overheating? We'll show you how to keep them cool.

VAUGHN D. MARTIN and

BILLY W. DAVIS

HEAT CAN DEVASTATE SEMICONDUCTOR components and can make your projects unreliable or short-lived. Fortunately, there are ways to protect your projects from excess heat. We'll show you how it's done. In this article (the first of two parts), we will discuss how electronics designers deal with the flow of heat on a quantitative basis, and how heat may be controlled by using heatsinks and forced-air cooling systems. We will also discuss how thermoelectric devices are used to control heat, and some modern methods of sensing temperature.

In the second part of this article we will examine optical means of sensing and measuring temperature, thermo probes, and Vortex tubes (devices that can produce very low temperatures almost instantaneously without complex drive machinery).

Heat flow

Physicists often talk about three different kinds of heat transfer or heat flow: conduction, radiation and convection. Molecular motion is the cause of *conduction*. Molecules at a higher temperature have higher kinetic energy than do their nearby neighbors, and some of that energy is transferred by those molecules' impinging on one another. Even at the junction of a heatsink's surface and air, energy is transferred via conduction from molecules in the heatsink to molecules in the air.

Heat flow due to *radiation* is caused, not by particle motion, but by the emanation of electromagnetic waves that encompass the spectrum all the way from ultraviolet to infrared light.

In radiation, energy itself is transferred, and in conduction the particles possessing that energy remain in one place. In *convection*, by contrast, the particles themselves move, either of their own accord, or by being forced to move. Convection is related to conduction, in that energy is transferred by means of molecular motion.

Electronics designers must concern themselves with all three types of heat transfer. Conduction is the primary means by which heat is transferred from the internal junction of a semiconductor device to an external surface such as a heatsink, where the effects of both radiation and convection then become noticeable. The size and type of material used for heatsinking has a direct effect on the amount of heat radiated. If a device generates more heat than its heatsink can effectively radiate, forced (or natural) convection must be used to maintain the device at a safe operating temperature.

Heat and electricity

In order to quantify discussions of heat flow, an analogy is often drawn between the units used to describe the flow of electricity, and those used to describe the flow of heat. As shown in Table 1, voltage corresponds to temperature; current corresponds to heat flow; and electrical resistance corresponds to thermal resistance. The circuit diagrams in Fig. 1 illustrate how heat-flow problems may be treated in a manner similar to electrical-flow problems.

The basic thermal relationship may be stated as follows: the change in temperature is the product of dissipated power and thermal resistance, or, in short, $\Delta T = P_D\theta$. The equation reveals that if a device must dissipate a certain amount of power, its thermal resistance must be minimized in order to keep its temperature rise to a minimum. A dual subscript on a thermal resistance is used to indicate the resistance at the junction of two materials. For example, θ_{SA} refers to the resistance at the junction of the heatsink (S) and ambient air (A).

Various kinds of semiconductors can withstand different maximum temperatures. Germanium, for example, can tolerate temperatures from 85°C to 100°C, whereas silicon can tolerate from 150°C to 200°C. Generally, however, we try to avoid operating semiconductor devices at such elevated temperatures, because performance decreases drastically when that is done.

For example, the input leakage current of some op-amps doubles each time junction temperatures increase 10°C. For another example, the graph in Fig. 2 shows the effect that temperature has on the maximum power that a typical power transistor can handle. Below about 25°C, the transistor can handle 90 watts of power. But above that temperature, the maximum power that the transistor can dissipate decreases linearly, until, at 100°C, the transistor becomes inoperable. Clearly, then, the more power we need the transistor to dissipate, the lower we must keep its temperature.

Why does the transistor get so hot? We must remember that both the emitter-base and the collector-base junctions generate heat. However, since the collector-base junction is reverse-biased, it has higher resistance, and it thereby produces more heat. In fact, the collector-base junction produces so much more heat than the forward-biased emitter-base junction that the heat generated by the latter may usually be ignored. Doing so allows us to simplify the power-dissipation equation considerably:

$$P_D = I_C \times V_{CE}$$

Here P_D refers to the power dissipated by the transistor; I_C refers to its collector current, and V_{CE} refers to the voltage across the transistor's collector and emitter. As you might suspect, P_D in this electrical equation may be related mathematically to P_D in the thermal equation cited above.

TABLE 1—ELECTRICAL AND THERMAL UNITS

Electrical			Thermal		
Quantity	**Unit**	**Symbol**	**Quantity**	**Unit**	**Symbol**
Voltage	Volts	V	Temperature	°C	T
Current	Amps	I	Heat Flow	W	P_D
Resistance	Ohms	R	Thermal Resistance	°C/W	θ

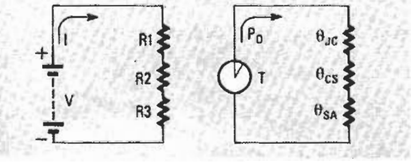


FIG. 1—THERMAL AND ELECTRICAL FLOW are similar conceptually and mathematically.

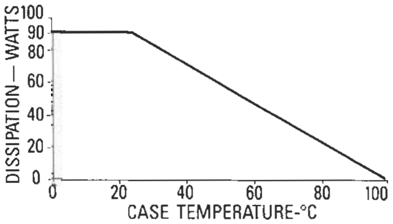


FIG. 2—A TYPICAL POWER TRANSISTOR'S ability to dissipate power decreases rapidly above a case temperature of about 25 °C.

As you know, placing resistors in parallel makes it easier for current to flow. Heatsinks work on the same principle; paralleling thermal resistances makes it easier for heat to flow. So by paralleling the heat-radiating mass and surface area of a semiconductor's case with a heatsink, thermal resistance is lowered, and that allows a more effective path by which heat may flow. Theoretically, in fact, an infinitely large heatsink should reduce thermal resistance to zero. Fortunately, we should never need an infinitely large heatsink—we couldn't manufacture one even if we did need it. What size do we need for a given application? As we'll see, it's rather simple to calculate.

Heatsink calculations

We may rewrite our previous thermal equation in terms of power dissipation as:

$$P_{D(max)} = (T_{J(max)} - T_{A(max)}) \;/\; \theta_{JA}$$

Here T_J is the maximum junction temperature (in degrees Celsius) that we wish our transistor to tolerate, T_A is the maximum ambient air temperature (in degrees Celsius) in which we expect our circuit to operate, and θ_{JA} represents the total thermal resistance encountered by the heat trying to escape our device.

That thermal resistance may be broken down into several series resistances that are merely added together:

$$\theta_{JA} = \theta_{JC} + \theta_{CS} + \theta_{SA}$$

We may state that relationship in words by saying that the total thermal resistance from junction to air (θ_{JA}) equals the sum of the resistances from junction-to-case (θ_{JC}), case-to-heatsink (θ_{CS}), and heatsink-to-air (θ_{SA}). We obtain θ_{JC} from a data book describing the device used; the other two values must be calculated or assumed. Let's see how, given the following:

- $T_{A(max)} = 60°C$
- $T_{J(max)} = 125°C$
- $I_{C(max)} = 0.8$ amps
- $V_{CE(max)} = 10$ volts

We can see immediately that eight watts (10 volts × 0.8 amps) of power must be dissipated. Typically, a TO-3 case can safely withstand about 2.8 watts; a TO-220 case, about 1.8 watts; a TO-202 case, about 1.5 watts; and small TO-39 and TO-92 packages can handle only about two-thirds of a watt.

If we're using a 78XX-series voltage regulator in a TO-220 case, we must, therefore, provide heatsinking to dissipate an additional $8 - 1.8 = 6.2$ watts. Checking the data sheets, we see that the 7800 series has a $\theta_{JC} = 5°C/W$. Rearranging our previous thermal equation, we find that:

$$\theta_{JA} = (T_J - T_A)/P_D$$

Plugging our assumed values in, we find that $\theta_{JA} = (125 - 60)/(0.8 \times 10) = 8.13$ °C/W. The sum of the thermal resistances must equal 8.13, and, since $\theta_{JC} = 5$ °C/W:

$$\theta_{CS} + \theta_{SA} = 3.13$$

Now if we use silicone thermal grease between the heatsink and the case of the transistor, we can approximate that $\theta_{CS} = 0.13°C/W$ (we'll show you why in a minute), so that leaves θ_{SA} to provide the additional 3°C/W of thermal resistance. The nomograph in Fig. 3 may be used to determine the size of an appropriate heatsink. Note that, to achieve a thermal resistance of 3°C/W, a vertically-mounted piece of aluminum 3⁄16-inch thick must have an overall surface area of 22 square inches.

However, surface area is not the only thing to consider when designing heat-

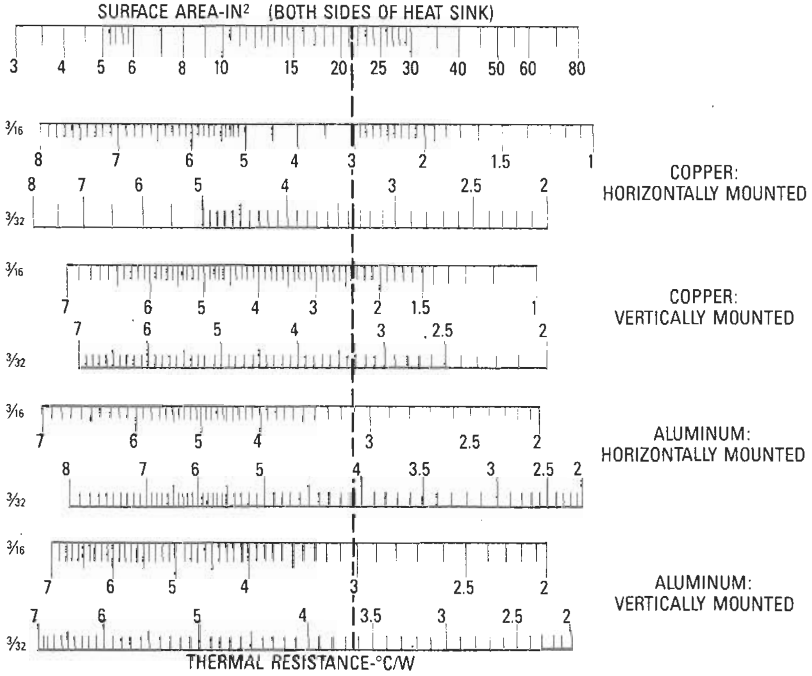


FIG. 3—DETERMINING SURFACE AREA of a heatsink is easy with this nomograph.

sinks. We must also take account of the material the heatsink is made of, the heatsink's surface finish, and the manner in which the heat-generating device is coupled to the heatsink.

The two most popular materials for heatsinks are copper and aluminum. Copper has a thermal conductivity four times that of aluminum, but it also costs much more. Aluminum is, therefore, used more often. Other materials are used to combat special problems. For example, magnesium is very light, and beryllium oxide (BeO) is an excellent insulator.

Emissivity is the term describing the effectiveness with which a given surface radiates energy; in Table 2 we show emissivities of several typical heatsink surfaces. In general, a larger value of emissivity means a better ability to radiate heat. Note that black oil-painted heatsinks radiate most effectively. Commercially available heatsinks are therefore usually painted (or anodized) black.

The third heatsink design consideration is that of device coupling. Often we cannot simply bolt a heat-generating device directly to a heatsink because doing so would cause the device's electrical output to be shorted to ground. To avoid that sort of problem, we usually use a washer that has both low thermal and high electrical resistance. There are three materials commonly used for such washers: mica, anodized aluminum, and beryllium oxide.

Mica is the most commonly used, and anodized aluminum is also fairly widely used, although if the surface of the latter is scratched, an electrical short may result. Beryllium oxide performs better than mica or anodized aluminum, but, unfortunately, it is toxic in powdered form and when vaporized. In Table 3 we compare the thermal resistance of those three insulators to that of an insulator-less junction, both with and without silicone grease. As you can see, the lowest resistance is provided using no insulator and silicone grease; that is what allowed us to assume the value of 0.13°C/W in the discussion above.

TABLE 2—EMISSIVITY OF COMMON HEATSINK SURFACES

Surface	Emissivity (E)
Polished Aluminum	0.05
Polished Copper	0.07
Rolled Sheet Steel	0.66
Oxidized Copper	0.70
Black Anodized Aluminum	0.7—0.9
Black Air Drying Enamel	0.85—0.91
Dark Varnish	0.89—0.9
Black Oil Paint	0.92—0.96

TABLE 3—THERMAL RESISTANCE (°C/W) WITH AND WITHOUT SILICONE GREASE

Insulator	Without	With
None	0.20	0.10
Teflon	1.45	0.80
Mica	0.80	0.40
Anodized aluminum	0.40	0.35

Guide to heatsink use

After all surface-area and thermal-resistance calculations are done, there are a number of practical steps one can take to help increase the effectiveness with which a heatsink dissipates heat:

- Avoid mounting voltage-sensitive devices (power transistors, regulators, etc.) next to other heat-generating components, like power resistors.
- When using heat-sensitive devices in smaller packages (TO-5, TO-39, TO-92), keep lead lengths to a minimum, and maximize copper runs on the PC board.
- Make sure that the heatsink-to-device interface is very flat. With larger heatsinks, that becomes difficult; so, for good thermal conduction, use a thin layer of silicone grease, such as Dow Corning 340, General Electric 662, or Thermalloy's *Thermacote*. Such "grease" is actually a metallic-oxide-filled silicone compound; it effectively increases the surface contact of the two mating devices by filling in air gaps and scratches.
- When a device must be electrically insulated from its heatsink, use an insulating washer 0.003- to 0.005-inch thick. Doing so increases thermal resistance, but that can be partially offset by applying silicone grease to both sides of the washer.
- When using a finned heatsink, maximum heat dissipation will occur when the fins are vertically oriented.
- Be very careful bending the leads of power-sensitive components. Hairline cracks can drastically reduce their heat-dissipating ability.

New heatsinking products

Several manufacturers have introduced products recently in an effort to simplify assembly of heatsinked components. For example, Chomerics Laminates, Inc. (77 Dragon Court, Woburn, MA 01888) has developed a "greaseless" thermal washer, the Cho-Therm *1678*, which is a rugged fiberglass-cloth reinforced, boron-nitride-filled silicone-elastomer material that provides exceptionally good thermal conductivity.

A similar heatsink washer is manufactured by Berquist (5300 Industrial Blvd., Minneapolis, MN 55435); it is shown in Fig. 4 beside a traditional silicone "glob" assembly. The Berquist unit does not require thermal grease, and has a special laminate that helps suppress EMI.

AAVID Engineering (One Kool Path, Laconia, NH 03246) has developed the new heatsink, shown in Fig. 5, for use with plastic DIP's. That slide-on heatsink has two conducting surfaces (one on the

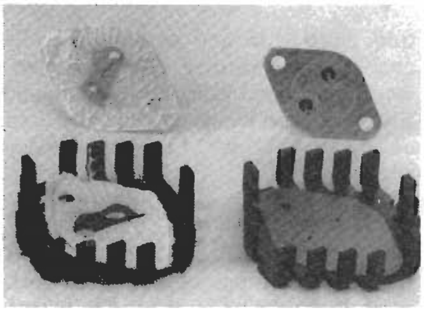


FIG. 4—THE GREASELESS THERMAL WASHER on the right replaces the messy assembly on the left.

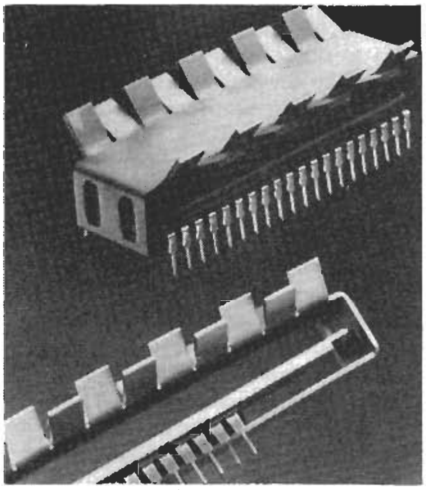


FIG. 5—THIS SLIDE-ON HEATSINK allows an IC to operate 10°C cooler and still dissipate the same amount of power.

top, and one on the bottom) that provide more effective conduction. Fins are slotted and staggered, to provide better convection. The 40-pin DIP shown in the photo dissipates one watt in normal operation; using the heatsink allows the IC to operate 10°C cooler.

So far we have focused our attention mostly on thermal conduction and radiation using heatsinks. At times, however, heatsinks alone cannot provide sufficient cooling; and that forces us to consider the third means of keeping components and assemblies cool: forced-air convection cooling. Basically, there are four convection-cooling methods

- Forced-air convection cooling
- Air-to-air heat exchange
- Air-to-water heat exchange
- Air conditioning

We will discuss convection cooling and air-to-air heat exchangers in this article. The final two cooling methods are not covered here.

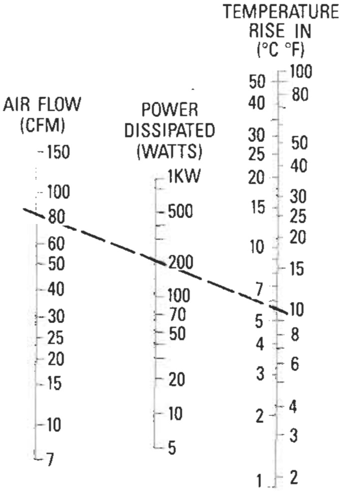


FIG. 6—AIR FLOW IN CFM may be determined easily, given temperature rise and power dissipated.

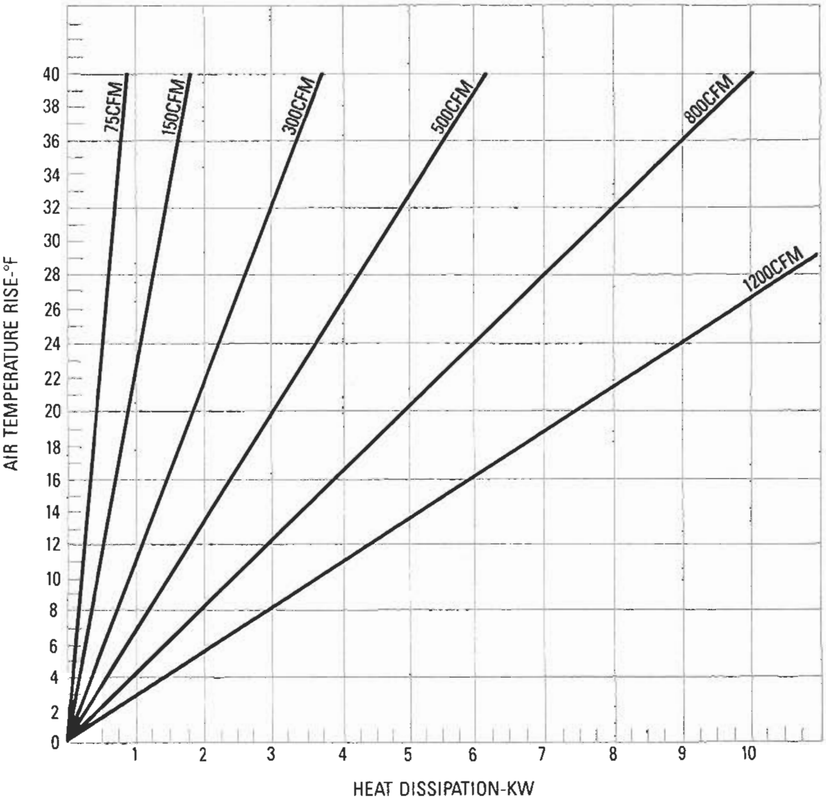


FIG. 7—AIRFLOW is related to temperature rise and heat dissipation for higher-powered units than the nomograph in Fig. 6.

Fans and blowers

The main component of a blower is a wheel that revolves to displace air; blowers are most efficient when operating near maximum static (non-moving) pressure. The main component of a fan is a propeller blade; fans operate best when moving large volumes of low-pressure air.

Cost (and noise) considerations aside, using a blower to pressurize a cabinet by pumping filtered air in is far more desirable than using a fan to exhaust air. The main advantage is that cracks between panels, around doors, etc., are better used as part of the exhaust area than as sources for the intake of dust and dirt.

For forced-air cooling systems:

- The cross-sectional area of the air stream throughout the flow path should be approximately equal to the total effective area of the intake.
- The exhaust area must be located "downstream" from the heat-producing components.
- A baffle may be used to channel a small volume of air across a hot component at high velocity.
- Ducts may be used to maintain even cooling throughout the cabinet. If an even temperature must be maintained throughout a cabinet vertically, place ducts along the sides of the cabinet.

Calculating the size fan necessary to achieve a specific cooling effect is simple. The volume of air required at the inlet equals 1.76 watts × 1.25/°C, or 3.17 watts × 1.25/°F. The power to be dissipated is expressed in watts, and the temperature rise in the cabinet is expressed in the first equation in degrees Celsius, and in the second, in degrees Fahrenheit. The constant 1.25 provides a 25% safety factor. You may calculate air flow using the equation above, or simply use the nomograph in Fig. 6. The graph in Fig. 7 provides a way of determining the air flow for dissipating power in the kilowatt range.

Now let's go through a design example. Assume we have to dissipate 200 watts of power, and that we can only withstand a 10°F rise in temperature in the cabinet. Our formula is: Air flow = (3.17 × power in watts × 1.25)/°F. So (3.17 × 200 × 1.25)/10 = 79.25 cubic feet per minute (CFM). Note that the dashed line in the nomograph in Fig. 6 indicates a flow of approximately 80 CFM.

That's all we have room for now. Next time, we'll look at yet more convection-cooling schemes and then turn our attention to air-to-hear exchangers. **R-E**