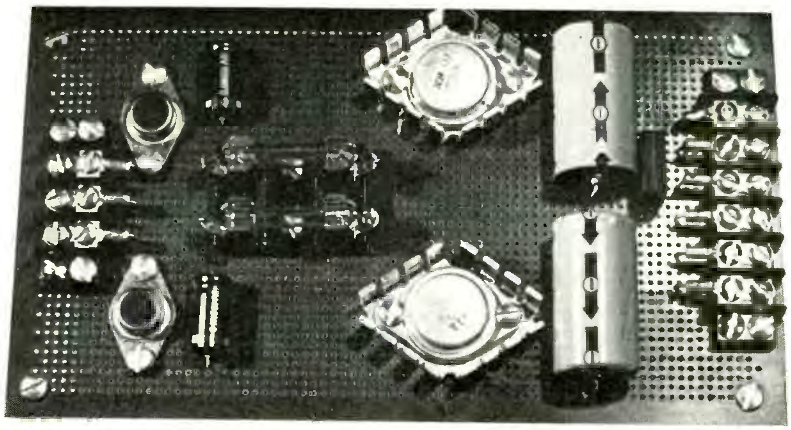
Cool It, Baby!

How to dissipate damaging heat in electronic circuits

By Joseph J. Carr



"Cool it . . . you'll last a lot longer!" Good advice for both hot-tempered people and for electronic equipment, too. Heat is the great killer of electronic equipment, especially solid-state equipment. Many device ratings are based on maintaining certain operating temperatures. One "hobbyist grade" power transistor, for example, offers a seemingly tremendous collector power dissipation (which is prominently advertised!). The catch is that the power is available only at room temperature (25-30 °C). At temperature above 30 degrees Celsius, the transistor must be derated substantially. Almost *anyplace* that the transistor is used inside a cabinet or box the temperature will exceed 30 °C!

Reliability experts measure equipment performance in terms of "Mean Time Between Failure" (MTBF); the MTBF is usually stated in hours. For example, an MTBF of 1000-hours implies that, for a large number of samples of the equipment, the average will be one soul-destroying failure per thousand hours of operation. One source claims that a 10 °C rise in operating temperature will cut the MTBF almost in half.

How important is cooling in electronic equipment? Let's consider some examples. About ten years ago I worked in a university hospital repairing patient monitoring equipment. The oscilloscopes at the nurses' Central Station were a reliability nightmare. About once a week, usually at 3 AM, the nurses would call me to come repair one of the four oscilloscopes. Yet the same model 'scopes at bedside operated reliably. The problem was overheating of the Central Station 'scopes, which were mounted inside of a completely closed desk/console. After cutting ten 1" ventilation holes, and installing a pair of 100-c.f.m. fans, the Central Station instruments became as reliable as the bedside ones.

A second example is a story of tragedy prevented. My first personal computer was a *Digital Group, Inc.* Z80-based machine with 26K of static (2102 chips) memory. In those days, my kilobuck bought (in kit form) a motherboard, three 8K memory boards, a CPU board, a 64 line TV/cassette interface board (with some static memory chips on-board), and several input/output boards. All of those boards contained lots of TTL devices, and they generated a large amount of heat. The builder had to supply the cabinet, a −/+ 12-VDC at 1 ampere dual-polarity power supply and a +5-volt dc at 10 amperes regulated power supply.

At first, all those cards and the two dc power supplies were buttoned up inside an almost unvented aluminum cabinet. Needless to say the temperature of the cabinet rose to egg-frying levels, and the HEP S-7000 power transistor used as the series-pass element in the voltage regulator operated hot enough to take off skin when touched. That computer would have been a reliability headache (with my kilobuck!) if the heat wasn't removed. I installed a pair of 40-50 c.f.m. fans: a 3.5" model blowing across the S-7000 heat sink and a 4.5" model cooling the printed wiring board compartment.

No one with any electronics experience at all, however slight, can deny that heat is the great killer of electronic devices. Projects or equipment that passes or delivers large amounts of either current or power must be kept cool for proper operation. The methods given in this article are simple and sufficient for most reader's applications. While the reliability engineer and the thermodynamicist will flinch at the lack of mathematical ele-

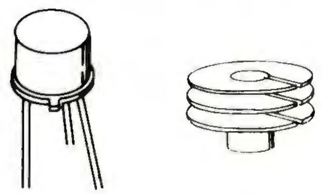

(A) (B)

Fig. 1. A metal TO-5 transistor package as in (A) sometimes requires a "top hat" finned heat sink, as in (B).

gance, the implementations are nonetheless effective.

There is only one simple rule: *where there is excessive heat, remove it.* What's "excessive" mean? If the equipment feels too hot to the touch, or has a history of unexplained failures and/or repairs, then it is probably running too hot. An engineer will have specifications to meet and calculations to make, but they are beyond the scope of this article. The empircal "skin of the thumb" rule, however, suffices for our needs.

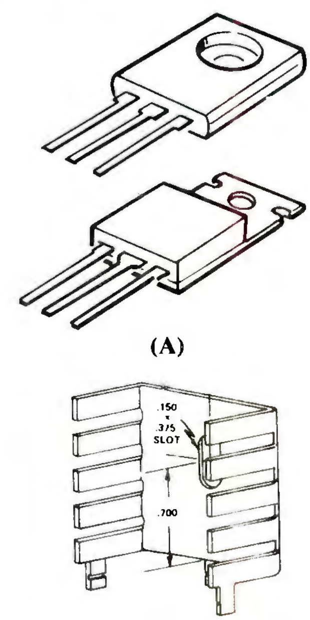
There are three basic tactics that can be used either singly or in combination: (1) radiate more heat, (2) improve natural ventilation, or (3) add or increase forced-air cooling. For most readers, water cooling is not a consideration even though some commercial electronics equipment (e.g. broadcast transmitters) use circulating water for cooling.

Protecting Transistors & IC Regulators

On small projects, where it is not practical (or possible) to use forced-air cooling, you will have to provide heat sinking for the semiconductors. In fact, even most air-cooled projects will need these metal radiators. Figure 1A shows the metal TO-5 transistor package, most of which are mounted on printed-wiring boards, and are low-signal (and low-heat) devices. One would think that heat problems wouldn't occur. But certain TO-5 transistors, such as the 2N3053, operate at moderate power levels in audio drivers. In such instances, a "top-hat" finned heat sink such as in Fig. 1B, is mounted on the TO-5 package to radiate heat. There are also certain other "spring clip" versions of this same kind of heat sink. Should you ever remove such devices, be sure you don't discard the heat sink when you replace them.

Figure 2A illustrates two forms of plastic power package. You will find these packages in power transistors (for instance, 2N5249) and three-terminal IC voltage regulators. In the regulator case, the devices are often rated at 750-mA in free air and 1000-mA when heat sinked. Either vertical or horizontal finned sheet metal heat sinks, such as in Fig. 2B, are used to provide heat dissipation. Be sure to use a thin layer of silicone heat-transfer grease between the metal tab surface on the transistor (or regulator) and the heat sink. Also be certain to tighten the mounting screw properly in order to facilitate heat transfer to the heat sink.

Fig. 2. Two forms of plastic power packages are shown in (A). Finned sheet-metal heat sinks (B) are often used to draw heat away.



(A)

(B)

The lead photograph shows heat sinking for TO-3 transistors and three-terminal regulators. The bent sheetmetal heat sinks pictured here are good for up to about 10 watts of power, or regulators up to 1.5 amperes. For the 3-ampere, 5-ampere and 10-ampere regulators that also use a TO-3 package, it would be better to use a larger finned heat sink.

In much equipment the metal chassis itself is used for heat sinking. In those cases the transistors are bolted either directly to the metal chassis or mounted via mica insulators. In both instances, silicone heat transfer grease is used between the semiconductor device and the chassis. This method is especially successful when the chassis is large or when it is particularly thick.

Some printed wiring boards (PWB) use large areas of unetched copper foil and/or large metal ridges or blocks to provide better heat sinking. This method is used especially where there are not single particular devices that can be individually heat sinked (for example, a TO-220 transistor), but rather when there are a large number of heat-producing devices (such as TTL ICs).

There are many different forms of large, finned heat sink used for TO-3 (and other) transistors, high-current voltage regulators and high-current diodes and SCRs; Figure 3A shows a side view of one of these heat sinks. In this case, the TO-3 transistor (or other device) is mounted on the flat central surface of the heat sink with screws. In most situations, it is wise to use a thin smear of silicone heat transfer grease between the device and the heat sink. This grease is especially needed when a mica insulator is placed between the semiconductor device and the heat sink. Again, it is necessary to make sure that the mounting screws are cinched down tight enough to allow maximum heat

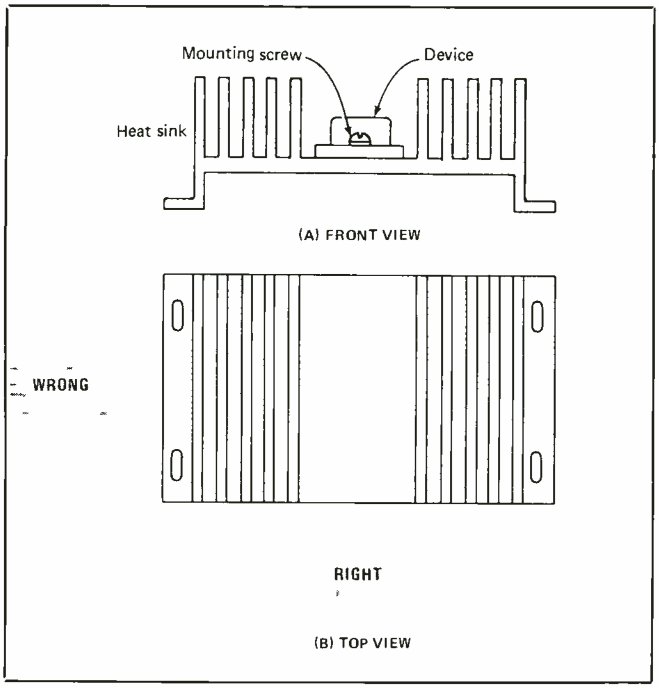


Fig. 3. Another type of heat sink is shown in (A), while (B) illustrates the use of forced air to cool the heat sink.

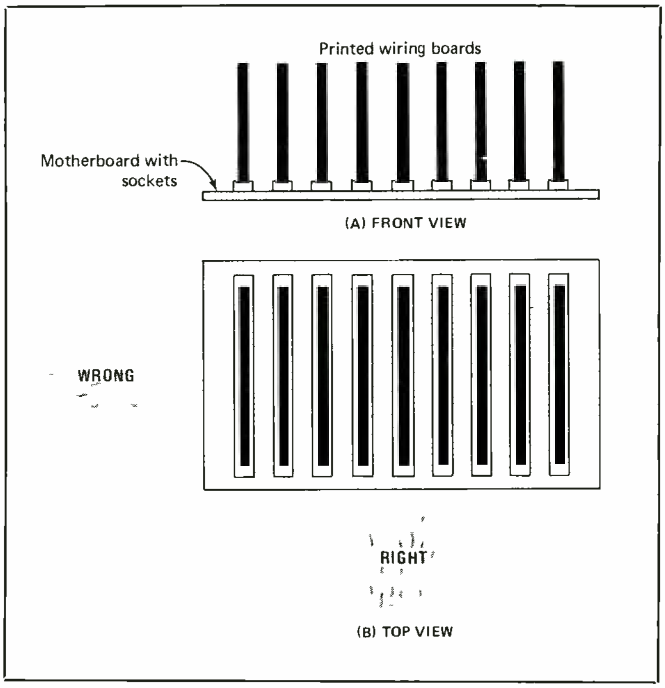


Fig. 4. In (A), plug-in wire boards are shown in a socketed motherboard, while (B) illustrates a top view with correct and incorrect air-flow direction for cooling purposes.

transfer (but not enough to distort the device package).

The big issue in selecting a heat sink is the surface area in square inches. There is a technical discipline used by engineers to calculate the amount of heat sinking needed, and these calculations can be found in various engineering textbooks.

When forced air is used to cool a heat sink—a good idea when the power and/or current is high—then the orientation of the heat sink with respect to the airflow is sometimes important. Figure 3B shows the right and wrong ways to force air over the finned surfaces. Keep in mind, however, that orientation is not always critical, especially when air from the "wrong" direction is sufficient or blows over the entire surface. The designations "right" and "wrong" are merely general considerations for some critical applications.

Other Components

Certain components other than power transistors also generate heat. Rectifier diodes and power resistors are examples, and should be mounted with their bodies 0.125 to 0.250 inch off the PWB. This procedure allows the heat to dissipate into the air instead of the PWB material. I have seen many phenolic and some fiberglass printed wiring boards badly damaged from the effects of a 10-watt power resistor mounted flush to the surface. Some "bargain basement" rectifier diodes can meet their rated forward current only when the rectifier is (a) mounted 0.50″ off the board and (b) has the axial leads cut to 0.75″ or longer. Those diodes are overrated and should be either used only in lower-current applications or shunned entirely.

Layout is important when power components are mounted on the PWB. Try to avoid clustering power components in a small area of the PWB, especially on cheap phenolic boards. Also, avoid placing heat-sensitive parts near power components. For example, never mount 10-watt resistors adjacent to polystyrene capacitors or small transistors.

Large Digital Projects

When I first felt the temperature of my *Digital Group, Inc.* cabinet, I took steps to get rid of the heat—and reliability was improved! Rarely does the homebrew builder have the flexibility that I had with my *Vector Electronics* S-100 cabinet. In most cases, the builder must do with only a single fan and must be clever to make best use of it. Figure 4A shows a typical large-scale digital project—such as a microcomputer—in which plug-in printed wiring boards are installed on a socketed motherboard. Usually, these PWBs will be mounted in a closed cabinet. If we apply air broadside to the PWBs, then only the first one in the line-up will benefit. Figure 4B shows a topview that permits you

(Continued on page 86)

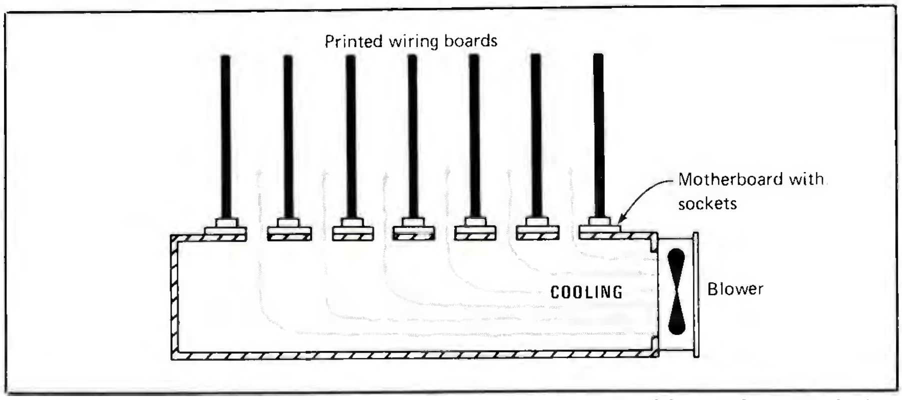


Fig. 5. A home-brew chassis to hold a motherboard with a blower fan circulating cool air, up through openings and across components on PWBs.

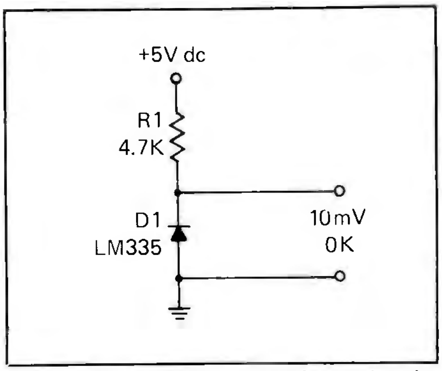


Fig. 6. An LM-335 is used in a simple circuit for monitoring actual operating temperatures.

to see right and wrong airflow directions. Obviously, air coming in from the sides is able to remove heat from more of the PWBs more effectively.

Figure 5 shows a method used by a friend of mine who built a home-designed 6502-based computer. He used a large metal chassis with a motherboard mounted on it to hold the PWBs. There were 0.75″ holes cut in both the chassis top and the motherboard to admit air between the boards. Although only one hole is pictured between each board in this sideview, there were four per row in the actual project. Air from the blower flowed up through the holes and across the electronics components on the PWBs.

Temperature Measurement

In some cases we will want to provide either temperature monitoring on a continuous basis or for temporary measurement of the actual operating temperatures. Although there are elegant methods using thermocouple junctions, we can use a simple, low-cost PN junction temperature sensor. National Semiconductor and others manufacture such devices. Figure 6 shows the simplest circuit for the National Semiconductor LM-335 diode device. The LM-335 will measure temperature over the range − 10 to + 100 °C. In the circuit shown, the output across the diode will be 10 millivolts per degree Kelvin (mV/°K). Degrees Kelvin are the same as degrees Celsius, except they are referenced to "absolute zero" instead of the freezing point of water (note: 0 °C = 273 °K).

If you merely want to measure the temperature, then install the LM-335 "diode" on the PWB and solder-tack the wires to it. The temperature can then be measured with an ordinary voltmeter. Otherwise, mount it permanently on the PWB. Another application is to use the voltage from the LM-335 to turn on a fan or an alarm when the temperature reaches a certain critical limit. One commercial computer uses one of these devices on each PWB, and then monitors all 16 of them in an analog to digital (A/D) converter connected to the computer. A shut-down program turned off the machine in an orderly (data saving) manner when the temperature got too high.

Conclusion

Always keep in mind that heat is the great destroyer of electronic components. If a piece of equipment runs too hot, then the result might well be flakey operation and/or frequent breakdowns. The simple methods shown in this article will permit you to build and/or modify projects to gain the longest and most reliable use possible. **ME**

Commodore's C128 Computer *(from page 33)*

Problems arise only if you start to think in terms of business or advanced educational use because the "heavyweight" programs simply don't exist and how soon they will appear, if ever, is an unknown factor.

On the other hand, if you already work with a CP/M machine and you're happy with the programs, and if the C128 supports your CP/M machine, and you're attracted to the allure of combining C-64 color programming within one machine, the new C128 may be your ticket to two good computing worlds.

Our experience indicates that you're free and clear with Osborne I CP/M programs on double-density disks, and much, but not all of Kaypro's version. Keep in mind, too, that programs with direct calls to the BIOS won't work properly.

Summing up, it's too bad the C128 wasn't here a year or so ago. Now it may be too much too late to duplicate the C-64's wide success. **ME**