Number 17 on your Feedback card

CARR'S CORNER

Joseph J. Carr K4IPV
P.O. Box 1099
Falls Church VA 22041

For Long Ham Equipment Life . . . GET THE HEAT OUT!!!

Experienced electronics professionals know that heat is the great killer of electronic devices. Equipment that passes or delivers large amounts of either current or power must be kept cool for proper operation. The methods given in this month's column are simple, yet are sufficient for most applications. While reliability engineers and thermodynamicists will flinch at the lack of mathematical elegance in this approach, the methods are nonetheless effective for most practical ham radio applications.

There is only one simple rule: Where there is excessive heat, remove it.

But, as they say, "the devil is in the details." What does "excessive" mean? If the equipment feels too hot to the touch, or has a history of unexplained failures 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 column. The practical "takes off the skin of the thumb" rule suffices for our needs.

Consider some practical examples. I know of a medical central monitoring station in a hospital that once suffered from heat exhaustion. The monitoring console contained oscilloscopes that were slaved to bedside monitoring sets in the coronary care unit (CCU). The carpenter who built the console was a master craftsman in wood, but did not understand electronics worth a squat. He completely enclosed the monitor—a pretty nice installation, except that there was no ventilation. The service technicians in the hospital had to be summoned in the middle of the night, on the average of once a month. This was not only expensive, but it placed the patients at risk as well.

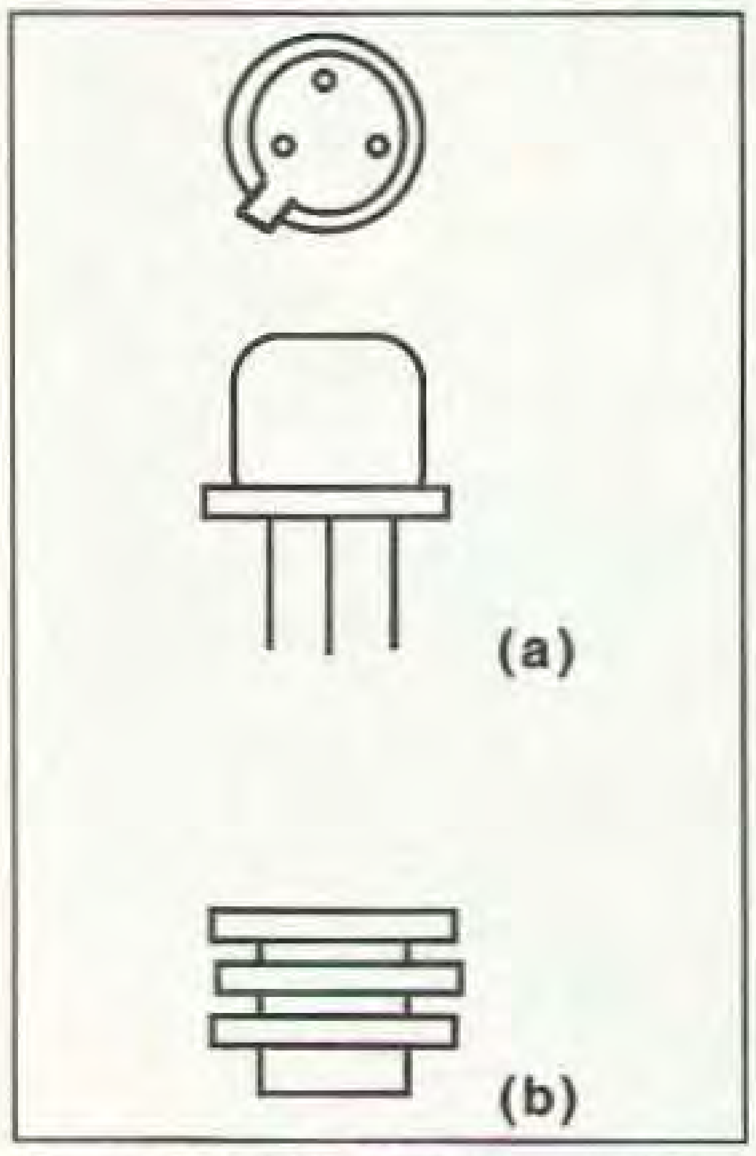

Figure 1. a) TO-5 transistor package; b) TO-5-style top-hat heat sink.

Another example was seen in consumer electronics servicing. A low-cost compact stereo unit from Japan was causing the importer fits because warranty returns were terrible. Shops were awash with returned units. Adding insult to injury, the repaired units often returned again before the original warranty expired. An enterprising technician began installing sheet metal heat sinks on the TO-5 audio output transistors (it was a relatively low-power unit), and his work didn't return. The service manager noted that fact, and issued a service guidance letter to all warranty stations ordering heat sinks installed on all units returned. Subsequent modifications from the manufacturer included heat-sinking.

There are three basic tactics which can be used in any combination to remove heat: 1) radiate more of the heat; 2) improve natural ventilation; or 3) add or increase forced-air cooling. Water cooling is not an issue for most hams, although some commercial broadcast transmitters and high-power industrial electronics devices use circulating water for cooling. (Some broadcasting stations use the waste heat from the transmitter's water radiator to heat the transmitter building).

Protecting Transistors & IC Voltage Regulators

Semiconductors are especially prone to heat damage, so manufacturers often take special care to rid solid-state circuits of heat. In both of the examples presented above the parts causing the problems were the semiconductors. In the case of the hi-fi gear it was obvious, but in the hospital case, analysis of the service records indicated that DC power supplies and cathode ray tube deflection amplifiers were the main printed wiring boards replaced. Further analysis by the manufacturer showed that it was primarily the voltage regulator transistors on the power supply, and the output amplifier transistors on the deflection circuits. Electronic reliability experts note that semiconductors should be operated such that the junction temperatures inside the transistors are kept at 110°C or less, even when rated at 125°C. According to one reliability handbook, the mean time between failure (MTBF) of semiconductors is cut in half for every 10°C increase in junction temperatures. Thus, even small improvements in the temperature situation can make a tremendous difference in the final product.

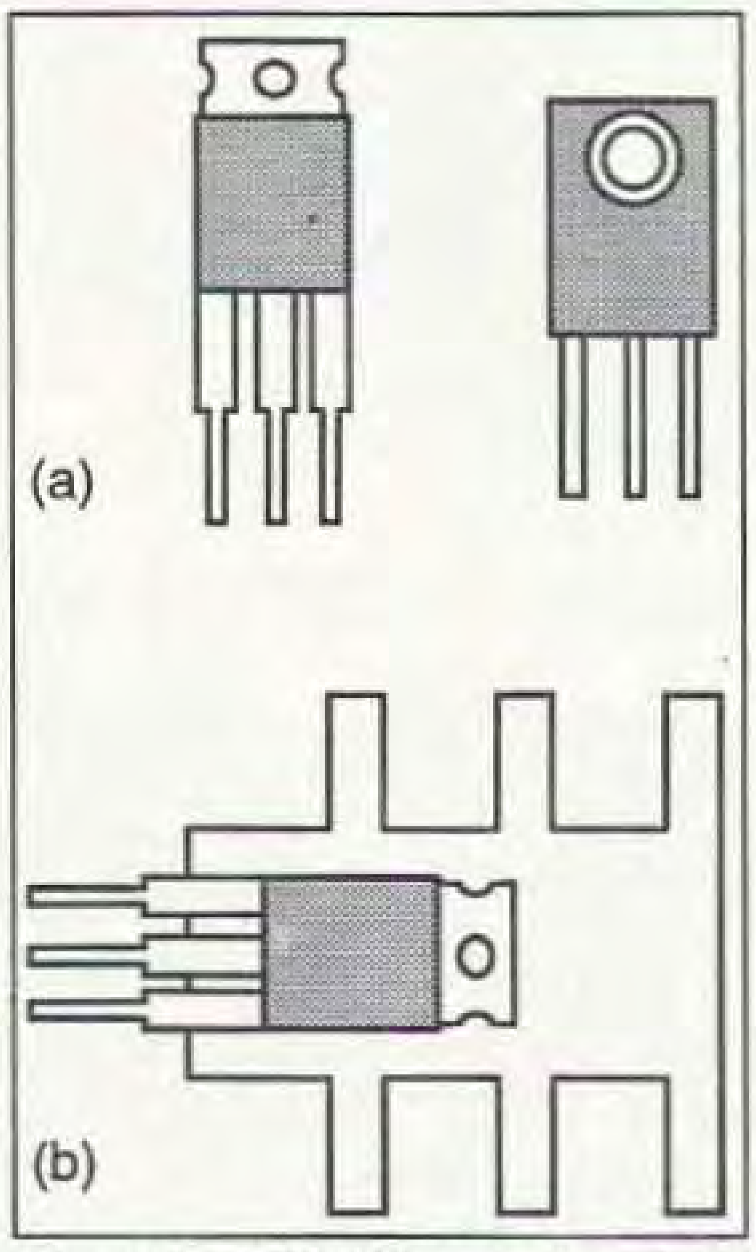

Figure 2. a) TO-220 and other plastic power transistor package; b) TO-220 device mounted to sheet metal heat sink.

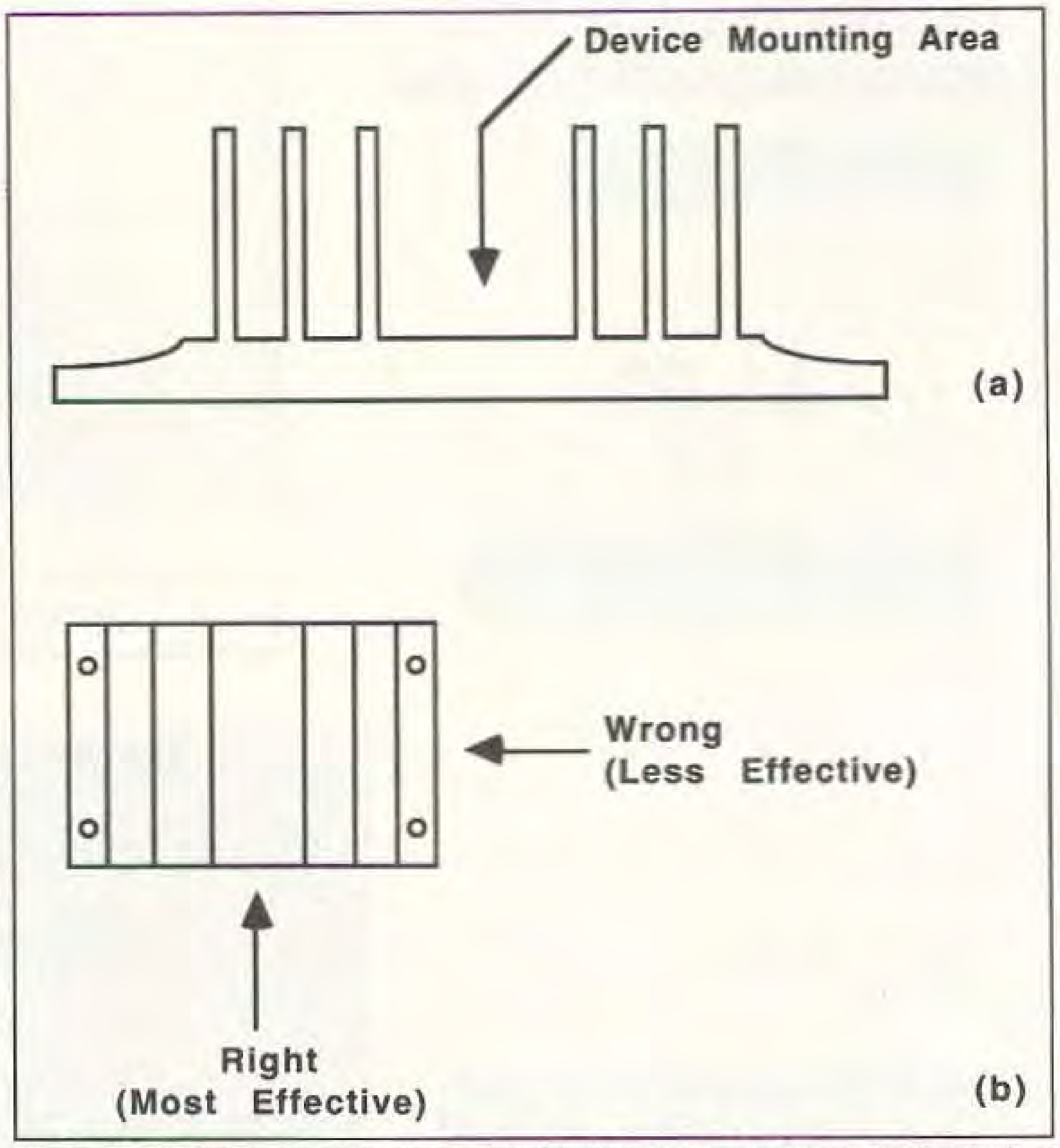

Figure 3. a) Power transistor heat sink; b) right and wrong ways to direct air at heat sink.

On some small equipment it is not practical (or possible) to use forced air cooling, so you will have to provide heat-sinking for the semiconductors. In fact, even in most forced-air cooled equipment the semiconductors will need these metal radiators. Figure 1a shows the metal TO-5 transistor package. Most of these transistors are mounted on printed wiring boards, and are low-signal (and low-heat) devices. But certain TO-5 transistors, such as the 2N3053, 2N5109 and certain 3 to 10 watt RF power transistors, operate at moderate power levels. A "top-hat" finned heat sink, such as that shown in Figure 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.

Figure 2a shows two different plastic power device packages. You will find these packages in audio power transistors (e.g. 2N5249), thyristors and three-terminal IC voltage regulators. In the regulator case, the devices are usually rated at 750 mA in free air and 1,000 mA when heat-sinked. These devices are frequently used at higher power than they are rated for! Either vertical or horizontal finned sheet metal heat sinks, such as that shown in Figure 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 sure to tighten the mounting screw properly in order to fa-

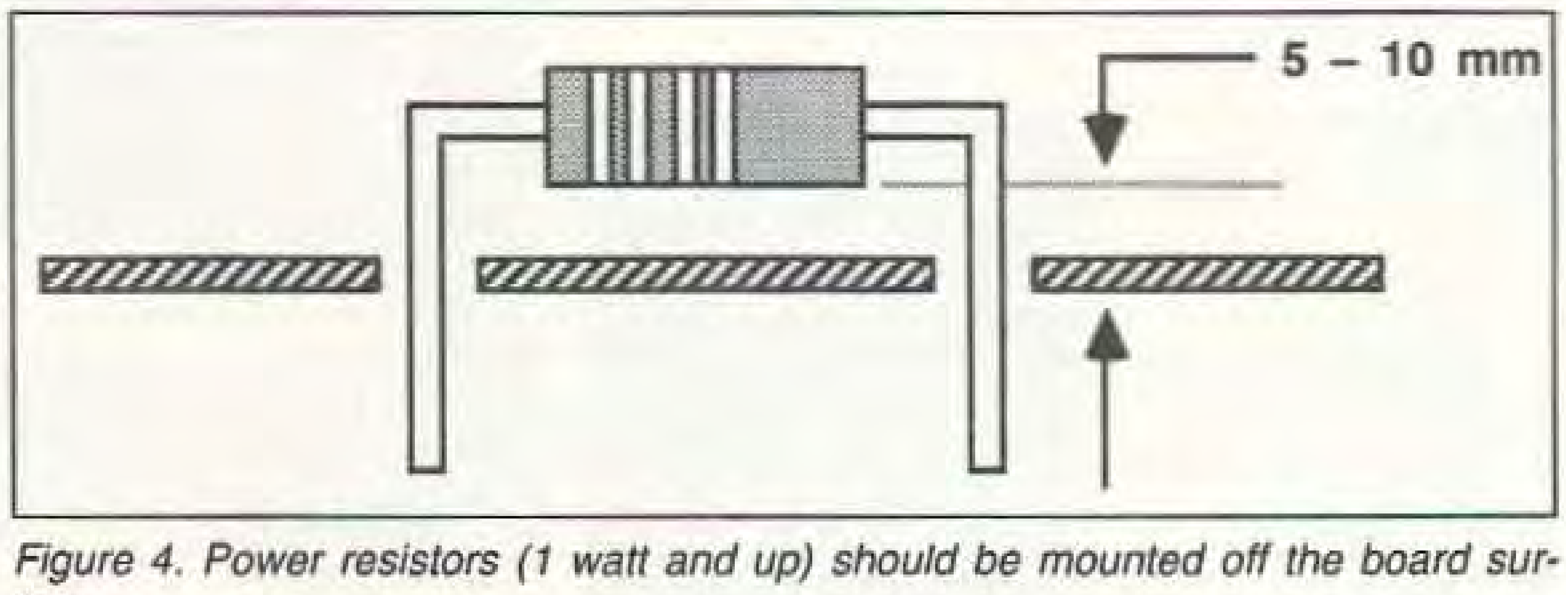

Figure 4. Power resistors (1 watt and up) should be mounted off the board surface.

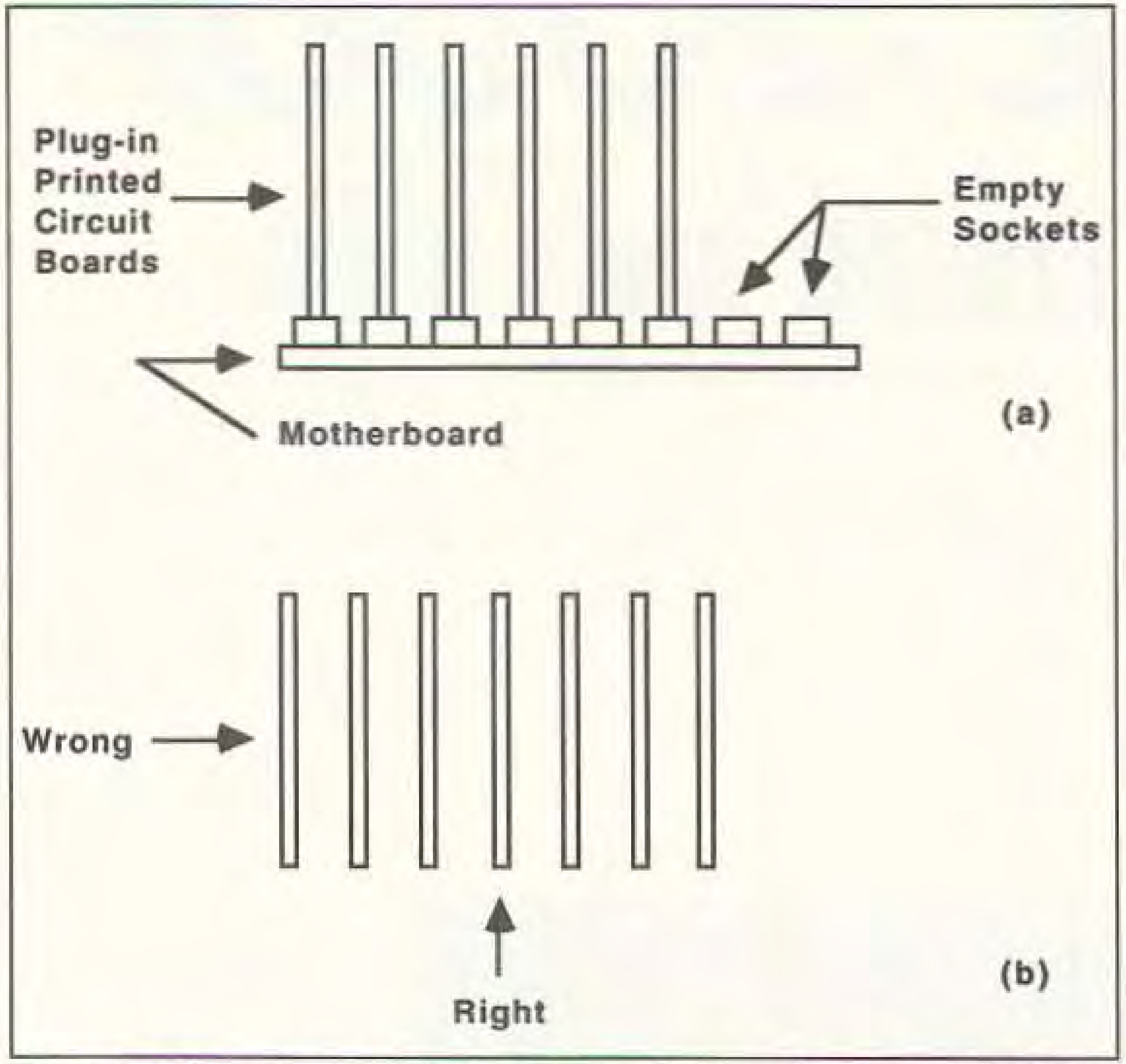

Figure 5. a) Several printed circuit cards mounted in sockets on a motherboard; b) right and wrong ways to direct air over the printed circuit cards.

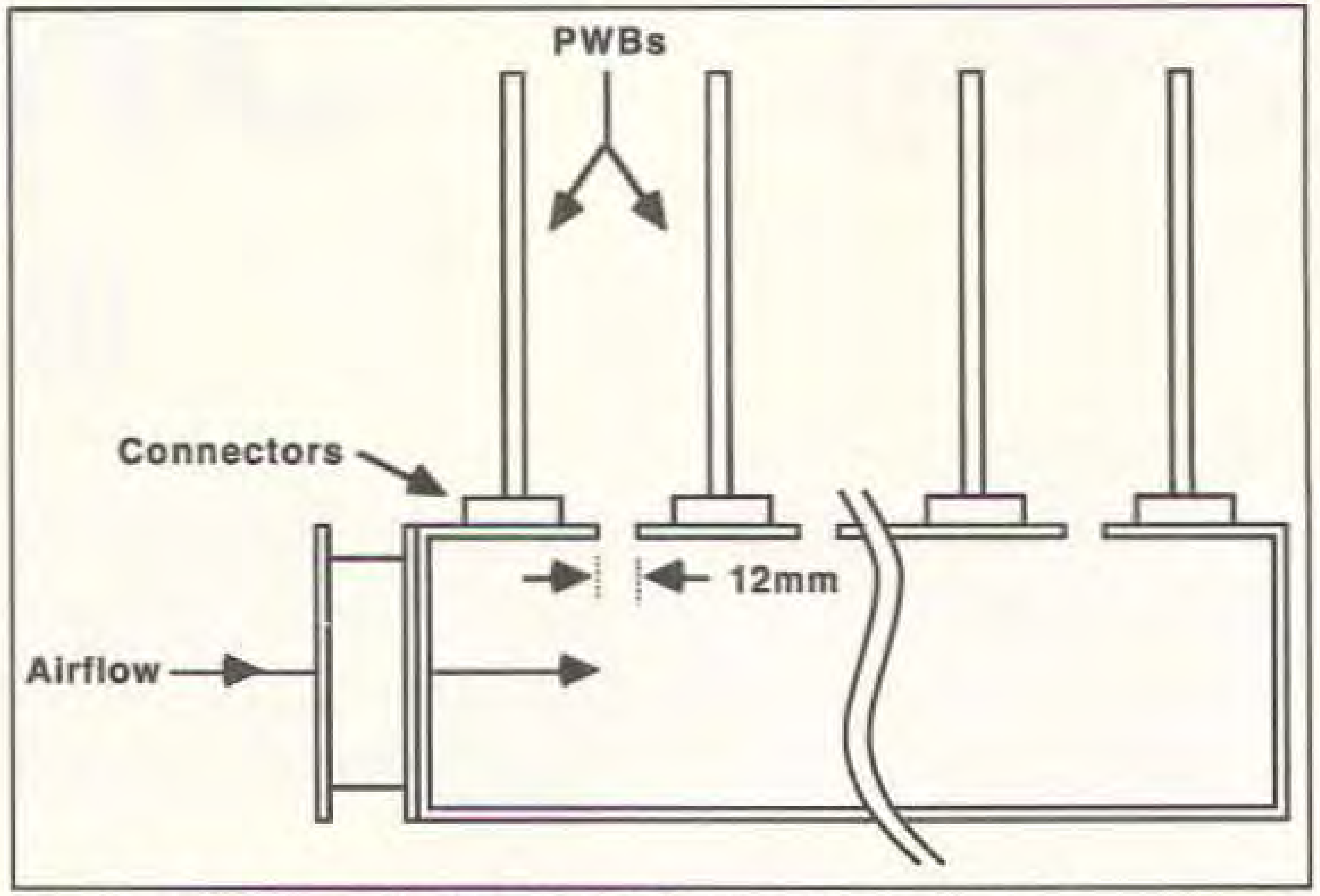

Figure 6. Holes in an otherwise closed chassis were used by one computer manufacturer to direct air over PWB surface.

cilitate heat transfer to the heat sink.

Sheet-metal heat sinks for TO-3 transistors and three-terminal regulators are mounted on a printed circuit board. The bent sheet metal heat sinks are good for up to about 10 watts of power, or voltage regulators up to 1.5 amperes. For the 3 ampere, 5 ampere and 10 ampere voltage regulators that also use a TO-3 package it would be better to use a larger finned heat sink.

In many pieces of equipment the metal chassis is used for heat-sinking. In those cases the transistors are bolted either directly to the metal chassis or mounted via mica insulators if electrical isolation is required. In both cases, 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 (i.e. has a high "thermal mass").

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 no single devices that can be individually heat-sinked (e.g. a TO-220 transistor), but rather a large number of heat-producing devices such as TTL ICs.

There are many different forms of large, finned heat sinks 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 with screws on the flat central surface of the heat sink. In most situations, it is wise to use a thin smear of silicone heat transfer grease

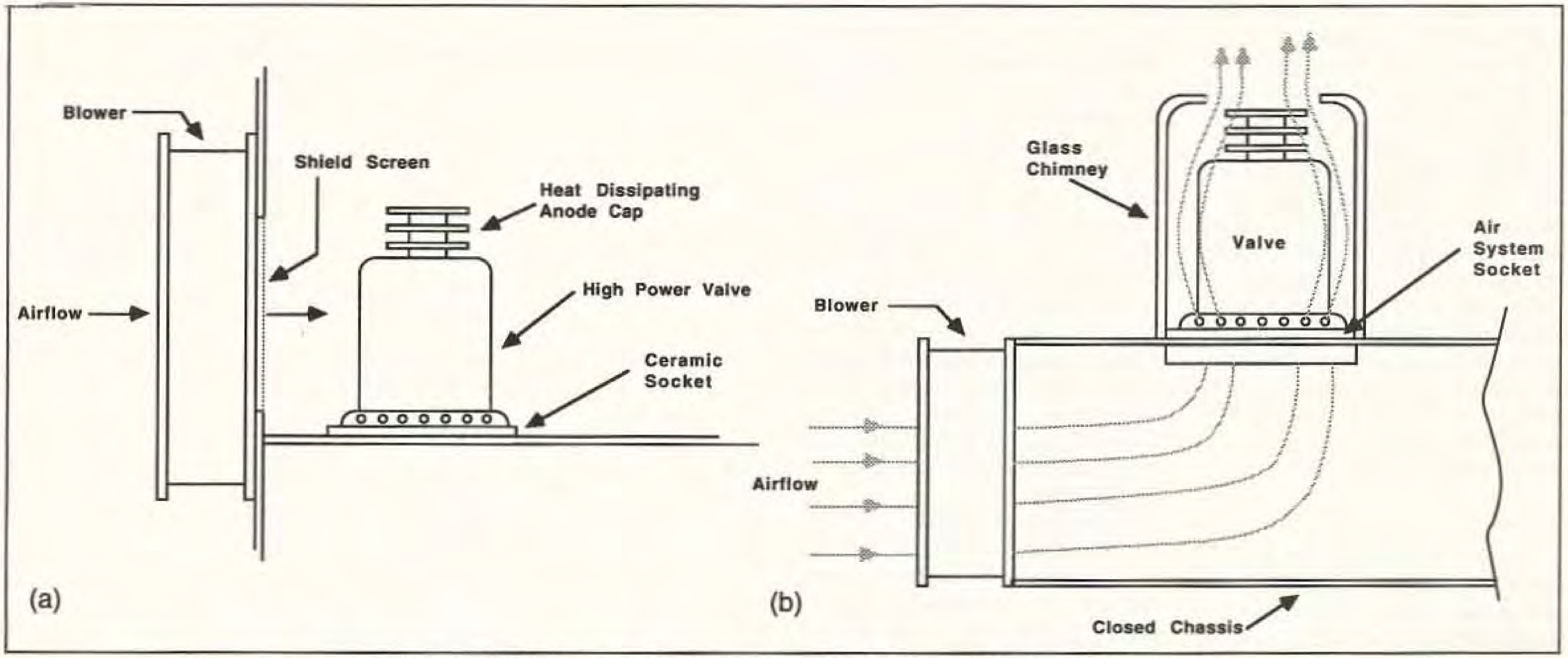

Figure 7. a) Direct method of cooling RF power tubes; b) use of an air system socket.

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 transfer (but not enough to distort the device package). The big issue in selecting a heat sink is the surface area.

When forced air is used to cool a heat sink—a good idea when the power and/or current is high—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.

Microprocessor chips are no different from other semiconductor devices: Heat kills them. To make matters worse, speed beyond the designer's specified speed often generates excessive heat inside the chip. Some low-priced computers operate cheaper lower-speed chips at a higher clock rate, but at the cost of decreased reliability. Even in well-designed computers, reliability improvement is possible by cooling the microprocessor chip.

Some 486 personal computers add a second fan on the back of the cabinet, in addition to the one in the DC power supply, in order to cool the very high-speed chips on the motherboard. Other vendors offer a clip-on fan that mounts above the 486 chip and blows air on it directly. These fans are designed to rob power from one of the computer's disk drive power connectors. In the JDR Microdevices (2233 Samaritan Drive, San Jose CA 95124) catalog there is a "refrigeration" clip-on fan for 486 chips. I suspect that this device has a Peltier-effect solid-state refrigeration unit embedded in the fan block. Some vendors of computing stuff tell me that they won't sell a 486 machine rated at more than 33 MHz clock speed without installing the clip-on fan to cool the main chip.

Other Components

Certain components other than power transistors generate heat. Rectifier diodes, bridge rectifier stacks and power resistors are prime examples. How these components are handled is critical in determining the reliability of electronic equipment.

Rectifier diodes and power resistors should be mounted with their bodies 5 mm to 10 mm from the Printed Wiring Board (PWB). Please see Figure 4. This procedure allows the heat to dissipate into the air instead of into the PWB material. Many phenolic and some Fiberglas printed wiring boards can be badly damaged from the effects of a 10 watt power resistor mounted flush to the surface. Some "bargain basement" or "grab bag" rectifier diodes can meet their rated forward current only when the rectifier is a) mounted 10-15 mm off the board, and b) have the axial leads cut to 20 mm or longer. Those diodes are overrated and should either be used only in lower than the rated current applications or shunned entirely.

Besides reducing the operating life or limiting the power output of circuits, overheating can also decrease performance in other ways. Certain circuits, oscillators for example, are inherently sensitive to heat. There was once a popular two-way radio transceiver that suffered terrible frequency drift because the master oscillator was located right next to the RF/IF strip vacuum tubes. Although that was such a bad design error that nothing would really "fix" the situation, a lot of technicians improved the frequency stability markedly by adding some thermal insulating material between the RF/IF PWB and the aluminum oscillator shielded housing.

Large Multi-Board Equipment

Figure 5a shows a piece of typical large-scale multi-board equipment, 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 for both Electro-Magnetic Interference (EMI) and aesthetic reasons. If we apply air broadside to the PWBs, only the first one in the lineup will benefit. Figure 5b shows a top view that permits you to see right and wrong airflow directions. Obviously, air coming in from the sides is better able to remove heat from more of the PWBs.

Figure 6 shows a method that was used in a minicomputer a few years ago. There is a large metal chassis with a motherboard mounted on it to hold the PWBs. There were several 12 mm holes cut in both the chassis top and the motherboard to admit air between the boards. Although only one hole is shown between each board in this side view, there were four per row in the actual computer. Air from the blower flowed up through the holes and across the electronic components on the PWBs.

Radio frequency power amplifiers and high-power transmitters pose special heat problems. Some linear power amplifiers, for example, are only 45 percent efficient. Therefore, a 1,000 watt linear amplifier delivers 450 watts of usable RF power and 550 watts of waste heat. To make matters even worse, the necessity of keeping harmonics inside the transmitter means buttoning up all that heat inside of a shielded metal cabinet.

Most RF power amplifier tubes used in ham radio transmitters must be forced-air cooled in order to realize their full ratings. (Some are absolutely dependent on cooling.) Figure 7 shows two methods for providing the needed cooling air. In Figure 7a we see the situation where a blower is mounted so that the air flow is directly over the glass envelope. The fan may be mounted either exterior to the RF compartment (as shown) or inside.

The other method, shown in Figure 7b, assumes the use of "air system" tube sockets. A blower or fan supplies air to the bottom side of the socket, and the air is directed upwards through holes in the socket and around the glass envelope. A "chimney" aids in keeping the airflow against the glass. Some air system sockets have plumbing connections for the air hose, while others are dependent upon pressur-ization of the lower compartment. In either case, the reason this socket is better is that the lead seals in the glass are kept cooler. The plate cap lead seal should also be kept cool, if possible. Toward this end some builders use a finned "heat dissipating" plate cap to make electrical connection to the anode.

IC Printed Circuit Boards

The component density possible on modern printed wiring boards (PWB) makes it possible to make very small, high density products such as modern radio communications equipment and digital computers. Unfortunately, as the number of IC devices on a card increases, so does the problem of cooling them off. In some cases, impingement airflow, as discussed earlier, is neither feasible nor desirable, but we still have to remove the heat. One solution is shown in Figure 8. This method uses a ladder heat sink built onto the board.

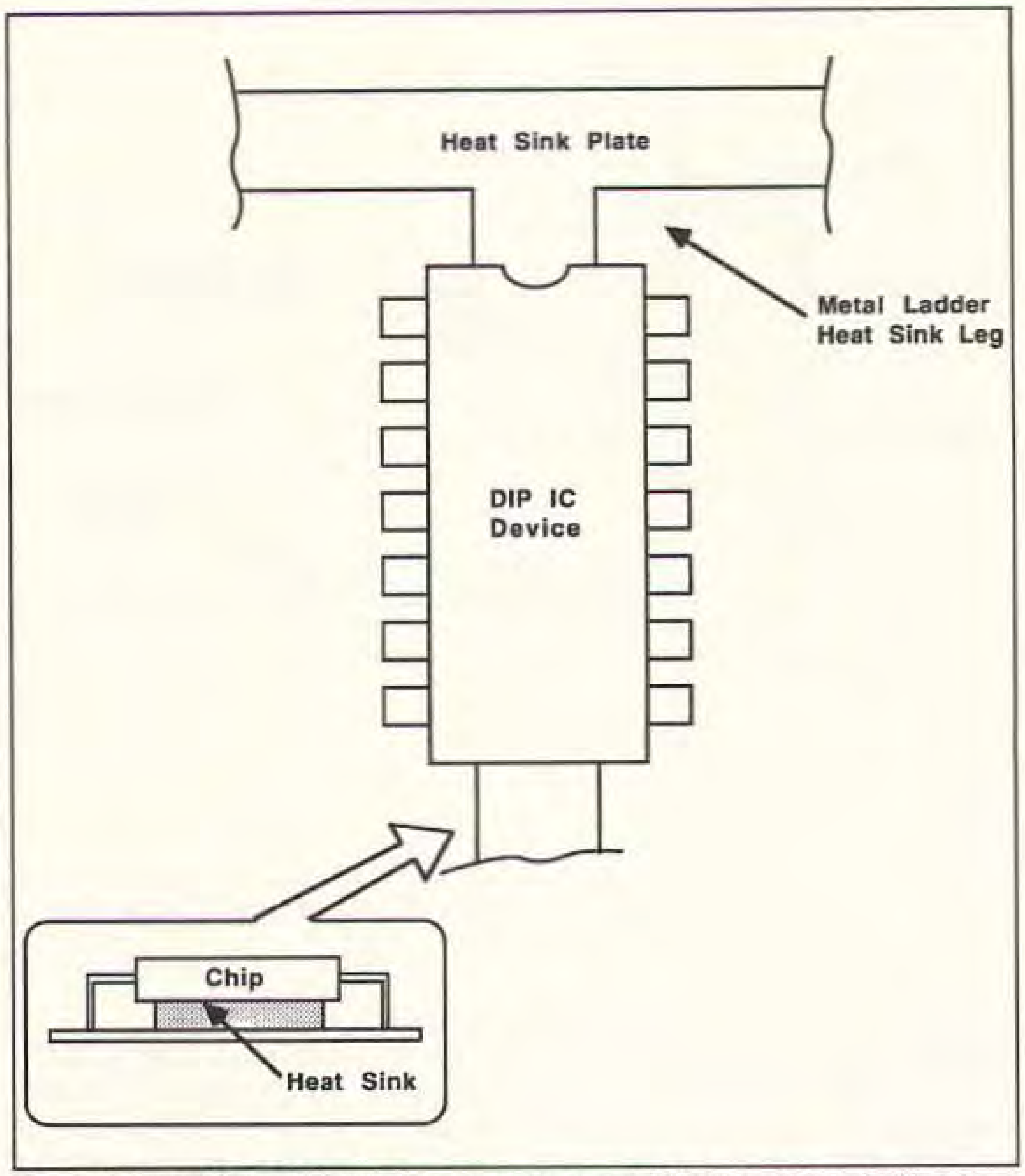

Figure 8. Use of a heat sink ladder network on a printed circuit board with a large number of ICs (particularly important in large TTL boards).

In Figure 8, a heavy metal "ladder" is run underneath each IC device (see inset) and is joined to a large heat sink bar on the card edge. Heat is removed from the IC area by conduction. In some cases, air flow can de directed across the card edge heat sinks. In this type of construction, we usually want to place the most heat producing components as close as possible to the edges of the PWB where the heat sink bar is located.

A neat trick used in some commercial and military equipment, although less practical for hobbyists, is to enclose the chamber containing the printed circuit board and use the conduction ladder method to conduct heat to the walls of the box (Figure 9). The box walls act as a "cold plate" to sink the heat. Forced air is blown through chambers on the outside of the cold plate to carry heat away.

Conclusion

Heat is clearly the great destroyer of electronic components. If a piece of equipment runs too hot the result will be erratic operation, frequent breakdowns and all the headaches that accompany low reliability. Although it is ordinarily unwise to modify equipment without expressly written instructions from the manufacturer, there are sometimes exceptions to this rule. An obviously overheating piece of equipment that can be modified with no adverse effect is a candidate for exception to the rule. The simple methods shown in this column will permit you to modify equipment to gain the longest and most reliable use.

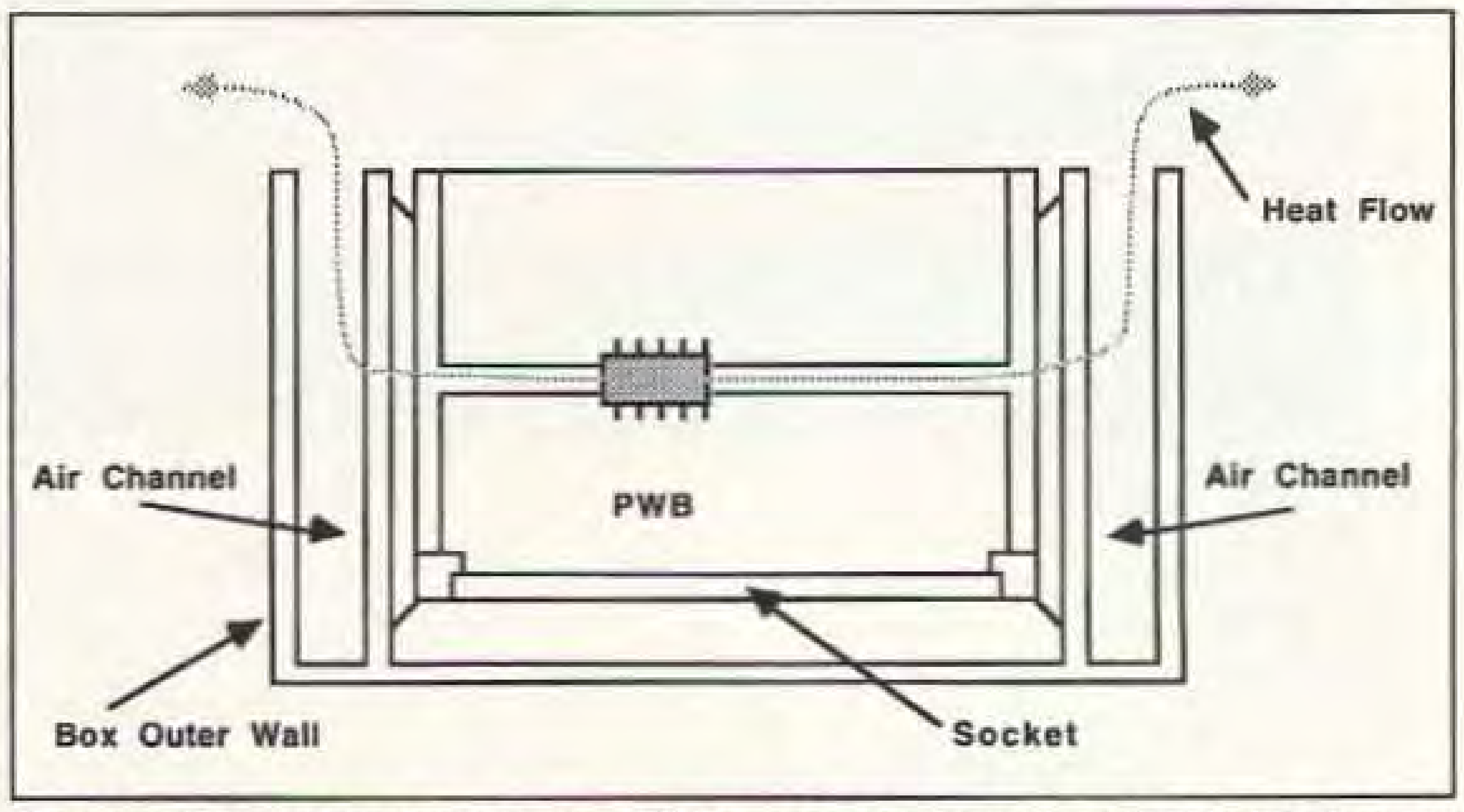

Figure 9. Closed box for mounting PWBs uses air channel and cold plate to carry away heat conducted from the printed circuit board.