# Plastic power ICs need skillful thermal design

## Minimizing power dissipation and lowering thermal resistance with batwing lead frames and heat sinks enables 5- to 10-watt linear ICs to operate reliably

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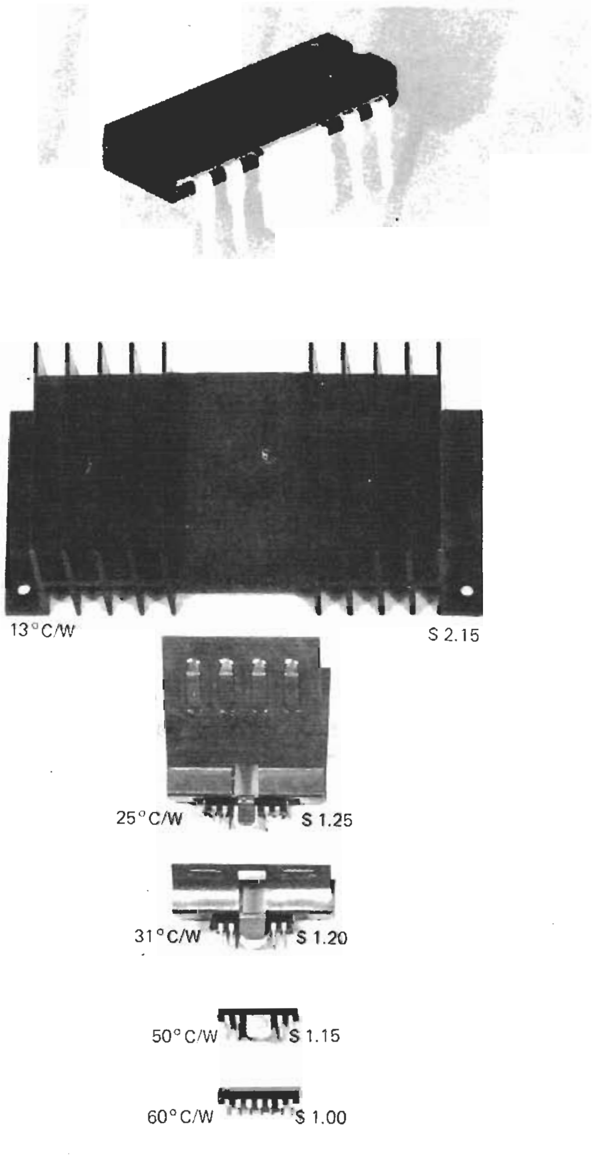


**1. Sink the heat.** Batwing power IC (top) lets heat sink be directly attached to lead-frame tabs, greatly increasing thermal dissipation capability. Larger sink geometries (middle) lower the thermal resistivity and thus increase the power capability. Such arrangements contrast sharply with the high thermal resistance (60° C/W) of the conventional 14-lead device with no heat sink (bottom).

☐ Linear power ICs in plastic packages can now deliver 5 to 10 watts of continuous power and are beginning to supplant the more expensive metal-cased transistor. However, their thermal requirements are much trickier to handle than those of the discrete power device, for there is no simple way to heat-sink them and assure them of a path of low thermal resistance. ICs are soldered to a printed wiring board or, what's worse from a thermal viewpoint, plugged into plastic sockets.

Thermal design can be an important contributor to performance. Merely adding a heat sink costing less than half a dollar to a plastic-packaged IC can raise the rated power output by a factor of eight. But from the reliability standpoint, thermal design is really crucial because failure to heed its requirements will assure the onset of a whole raft of thermally-induced ailments—increased leakage currents, material decomposition, drift, and premature device failure. It falls to the designer, then, first to select a device that satisfies not only the electrical and mechanical requirements but the thermal criteria as well, and then to protect the device from damaging temperatures.

To perform these tasks, he must understand the thermal paths within the plastic-packaged device, and familiarize himself with the roles of heat sinks (Fig. 1) and forced air cooling. With this background he is well equipped to optimize the thermal operating environment of the plastic-packaged power IC.

### Start of the trouble

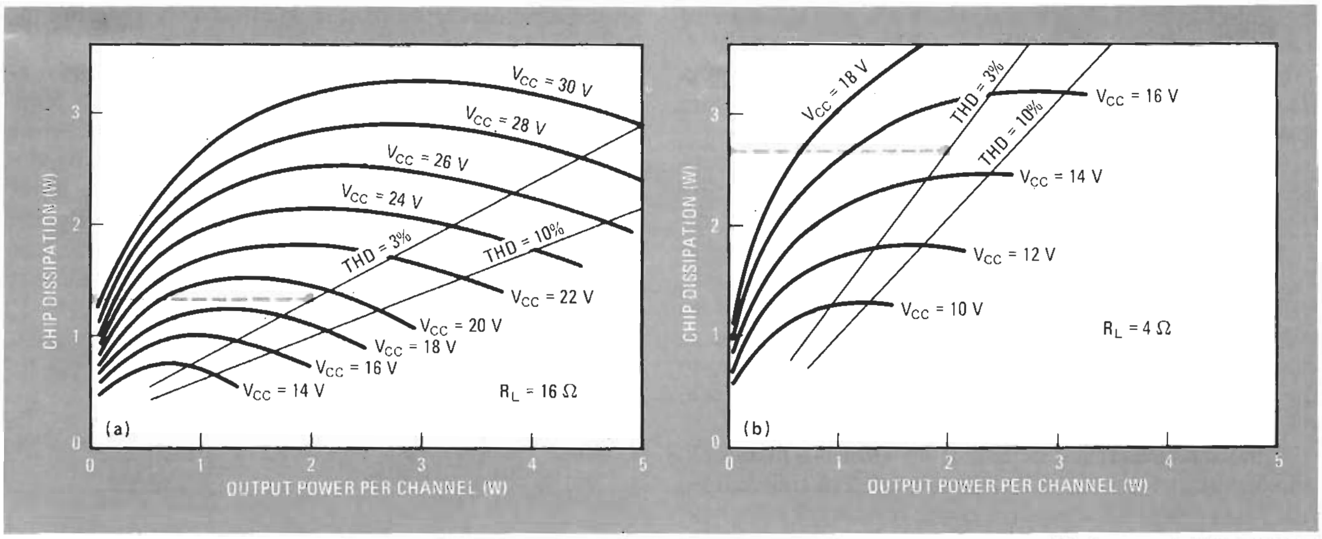
The power IC must be held below its maximum safe operating temperature. This is typically 150°C for silicon.

A second constraint is the temperature of the operating environment of the packaged device, usually termed the ambient. If the plastic package were the only consideration, the ambient could be allowed to rise to perhaps 70° or 85°C. But usually the maximum operating temperatures of nearby components will restrict the ambient to an upper limit of 50°C.

Another constraint is that a minimum temperature differential must be maintained between the ambient and the chip, to ensure that the required power can be dissipated. These relationships are apparent in the thermal equation:

$$P\theta_{J\text{-}A} = T_J - T_A$$

where P is the rate of heat flow in watts



**2. Minimize dissipation.** The curves shown here apply to a Sprague type ULN-2277 dual power IC. If the amplifier is operated into 16-ohm loads (a), rather than 4-ohm loads (b), chip dissipation is minimized. This also minimizes device temperature and enhances reliability. Dissipation values indicated are for 2 watts of delivered power and 3% total harmonic distortion (THD).

$\theta_{J\text{-}A}$ is thermal resistance from junction to ambient in °C per watt

$T_J$ is the junction temperature in °C

$T_A$ is the ambient temperature in °C

The design task then is to first minimize the dissipated power and the thermal resistances from the junction of the chip to the ambient, and then to take whatever additional steps are required to lower the ambient.

A good place to begin is to select both the circuit components and the dc supply voltage for minimal power dissipation. The chip power dissipation for various load impedances and supply voltages can be obtained from manufacturers' specifications.

A typical example is the Sprague Type ULN-2277 dual 2-watt audio amplifier IC. As shown in Fig. 2, the power dissipation is determined by the output power required, the maximum acceptable total harmonic distortion (THD), and the dc supply voltage, $V_{CC}$. If a power output of 2 W is required with a 3% maximum total harmonic distortion, then chip power dissipation is about 2.7 W at a $V_{CC}$ of 15 V with a load impedance of 4 ohms. However, power dissipation is only 1.4 W at $V_{CC} = 19$ V with a 16-ohm load. In general, the highest load impedance for a given output power is the most desirable, within the output voltage capability of the device.

Once the circuit has been optimized for minimal power dissipation, attention can be turned to the matter of thermal resistance.

### The path out

Heat removal from plastic-packaged ICs is difficult. Unlike discrete components, which often have studs and thus fairly low junction-to-ambient thermal resistances, ICs are usually soldered into printed-circuit boards or plugged into plastic sockets, and chip-to-ambient thermal resistance without a heat sink are relatively high.

There are two paths from the chip to the ambient. One is the path from the junction through the plastic case (denoted by the upward pointing arrow in Fig. 3) and has a thermal resistance of between 50°C/W and 100°C/W. The second path (indicated by the downward pointing arrow in Fig. 3) is the sum of the thermal resistances of the silicon chip, the die bond, and the lead frame, and has a much lower thermal resistance. So the designer's best course is to make sure that the thermal resistance of this path is as low as possible.

Device manufacturers frequently employ Kovar, an iron-nickel-cobalt alloy, for lead frames because it has a coefficient of thermal expansion which is quite close to silicon. In this way they minimize the mechanical stress that develops between the lead frame and the chip when the device is subjected to temperature variations. However, Kovar's thermal resistance is about 30 times that of copper, so in high-power circuits a copper or copper-alloy lead frame is preferable.

### Batwings help

Manufacturers are further enhancing the thermal path by altering the conventional 14- and 16-lead designs. One such design is the "batwing" IC package (shown with and without heat sinks attached in Fig. 1). It is becoming an industry standard. Size is the same as a conventional 14-lead IC package, but the central lead-frame sections are formed as tabs that measure ¼ inch square. These tabs may be soldered, welded or bolted to a heat sink or inserted directly into some sockets. This geometry achieves a worst-case thermal resistance of about 11°C/W, junction to case, whereas an IC with a conventional 14-pin copper lead frame exhibits a thermal resistance of 19°C/W.

Sometimes even a package that boasts as good a thermal design as the batwing configuration will require a heat sink. The manufacturer's data on a given device will enable the designer to make this decision. The data, which sometimes is presented in the form of curves, takes into account the maximum chip temperature that can be tolerated and the thermal resistance of the IC package.

Actual thermal performance in any design, however, also depends on many other factors, like interference in the air flow by nearby components, heat radiated or convected by other components, atmospheric pressures, and humidity. So, in selecting the thermal resistance of a heat sink, it is wise to allow a generous safety factor.

Heat sinks for plastic ICs can be procured from a number of vendors in a variety of styles. A few are shown in Fig. 1.

As an alternative, sinks can be fabricated from copper sheet. This material is quite effective in reducing thermal resistance from the case to ambient, and dimensions for a range of thermal resistances are given in Fig. 4. These values are for square sinks, 0.015 in. thick, with a dull or painted finish. They are intended to be mounted vertically on either side of the lead frame as shown in the figure. They should be soldered directly to the lead frame. Soldering adds on an interface thermal resistance of the order of 0.3°C/w.

Although unfinished copper is an effective heat sink, it lacks the eye appeal of finished metal. For this reason, and also to prevent corrosion of the raw metal part, heat sinks are often painted or anodized.

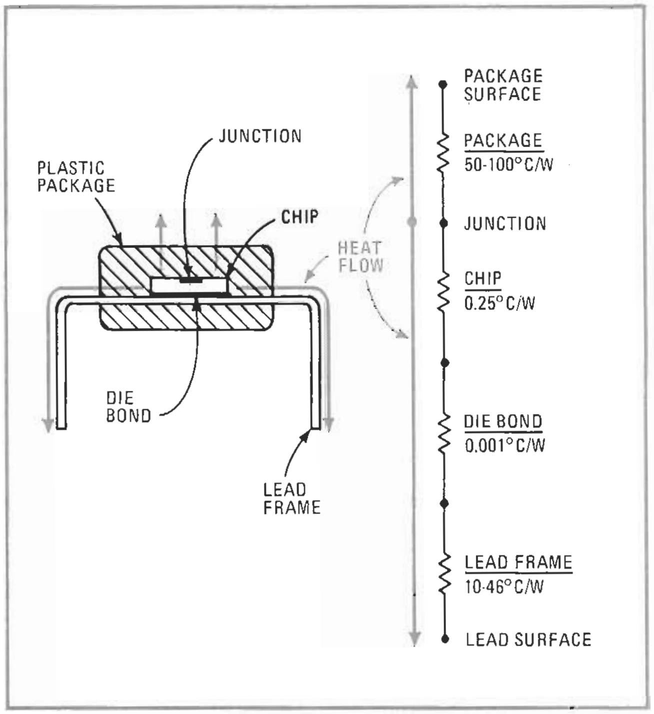
The most common finish is black anodizing. Besides being economical and attractive to look at, it enhances thermal performance by as much as 25% because the dull black is the most efficient surface for thermal radiation. On the other hand, an anodized surface is a poor thermal conductor, so those surfaces which mate with the IC must be free of anodization to ensure optimum thermal conductivity.

Iridite and chromic acid are other popular metal finishes because they offer low electrical and thermal resistivities. But like anodization, they also result in poor thermal radiators.

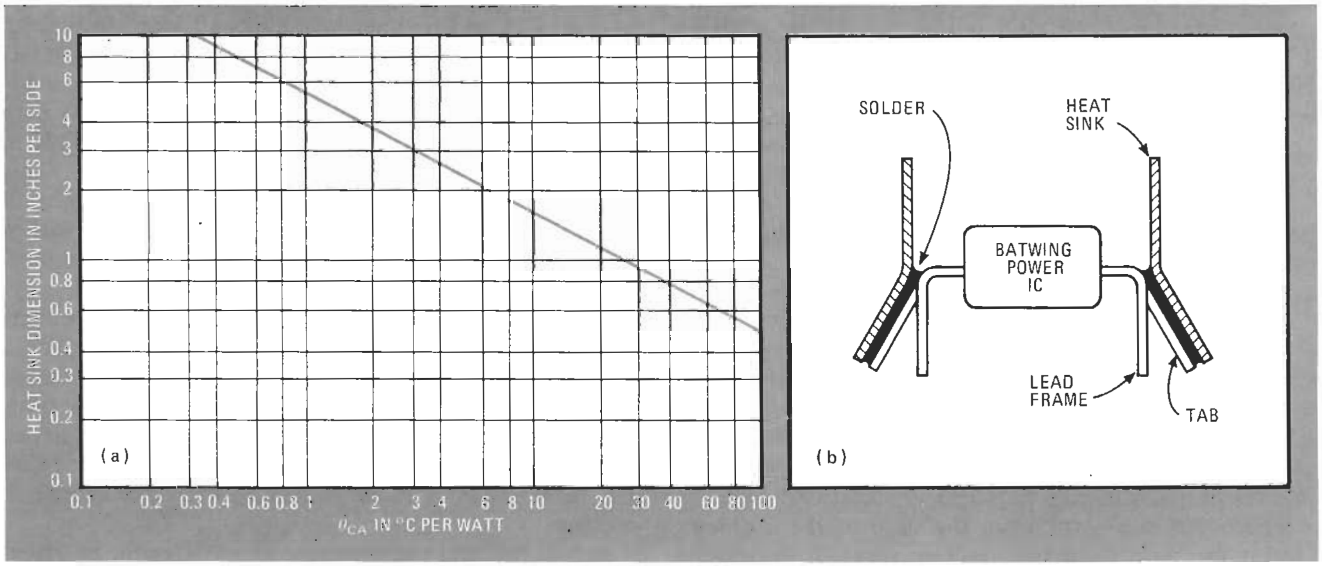
## Convective cooling

Convection as well as radiation is at work removing heat from the sink. If the power dissipated is low, then the air is essentially stagnant, and the effective thermal resistance of the sink-to-air interface will be quite high. However, as the power dissipation rises, the air adjacent to the sink heats up and begins to rise. This induced air flow is known as a natural convection, and it sweeps the heated air clear of the heat sink, effectively lowering the sink-to-air thermal resistance.

Forced air cooling can improve heat sink performance by as much as 100%. A rule of thumb is that semiconductor failure rate is halved for each 10°C reduction in junction operating temperature. Even where space is at a premium, the cost of a small, compact fan or blowers can often be justified. Often an air-moving device, intended primarily to flush air from an enclosure, can be so located that it will force a high air flow directly across a plastic power IC. ☐



**3. Two paths.** Thermal resistivity is lower—on the order of 10° -46° C/W—through the lead frame than through the package—over 50° C/W. Device designers can optimize the thermal resistance through the leads by selecting a material with low thermal resistivity.



**4. Design a sink.** Once the required case-to-ambient thermal resistance is determined, the dimensions for pairs of square, 0.015-inch-thick copper plates can be selected (a). Plates are mounted to lead-frame tabs (b). Soldering holds interface thermal resistance to about 0.3° C/W. A dull black finish will enhance the radiating properties of the sinks.