# PACKAGE INFORMATION

## *THERMAL DESIGN FOR PLASTIC INTEGRATED CIRCUITS*

Proper thermal design is essential for reliable operation of many electronic circuits. Under severe thermal stress, leakage currents increase, materials decompose, and components drift in value or fail. Present-day linear integrated circuits are capable of delivering 5 to 10 watts of continuous power. Previously, such power levels came only with discrete metal can power transistors. It was relatively easy to determine the thermal resistance of these devices and attach a massive heat sink. However, in many markets, economic factors now dictate the use of molded dual in-line plastic packaged monolithic circuits. The guidelines to be discussed will provide the circuit design engineer with information on maintaining junction temperature below a safe limit under worst case conditions.

### DESIGN CONSIDERATIONS

Four factors must be considered before the required heat-sinking can be determined. These are:

**1.** Maximum ambient temperature

**2.** Maximum allowable chip temperature

**3.** Junction-to-ambient thermal resistance

**4.** Continuous chip power dissipation

Maximum ambient temperature for the integrated circuit is normally between +70°C and +85°C and is usually dependent on the case material. In most applications, however, the limiting factor is the associated discrete components and a limit of about +50°C is specified. The maximum allowable chip temperature is usually +150°C for silicon.

Thermal resistance is the all-important design factor. It is composed of several individual elements, some of which are determined by the integrated circuits manufacturer, and some by the user.

### CHIP POWER DISSIPATION

The chip power dissipation should be obtainable from the manufacturer's specifications. In most applications it is a variable and determined by the user when he specifies the circuit variables.

### HEAT DISSIPATION

In any circuit involving power, a major design objective is to reduce the temperature of the components in order to improve reliability, reduce cost, or improve operation. The logical place to start is with the heat-producing component itself. First, keep the amount of heat generated to a minimum. Second, get rid of the heat that must be generated.

Heat generation can be minimized through proper circuit design. Heat dissipation is a function of thermal resistance.

With the typical discrete component, heat dissipation can be accomplished by fastening it directly to the chassis. Dual in-line plastic packaged integrated circuits, however, are quite a bit different. Their shape is not conducive to fastening directly to the chassis, they are normally installed in a plastic socket or on a printed wiring board, and the heat producing chip is not readily accessible.

Some users specify unusual packages so as to get the heat sink as close as possible to the chip and/or provide an attachment point for an external heat sink. A common factor in many of these special designs is that the lead frame is an integral part of the heat sink.

Because the plastic package may have a thermal resistance of between 50 and 100°C/W and the lead frame a thermal resistance of only 10 to 20°C/W, this would seem like the best route to go.

## STANDARD PACKAGES

The most common lead frame material has been Kovar (an iron-nickel-cobalt alloy). Its coefficient of expansion is close to that of silicon thereby minimizing mechanical stresses. However, Kovar has a relatively high thermal resistance and consequently is not suitable for standard lead frames in high power dissipation circuits. For these applications, copper or copper-alloy lead frames should be used. Additionally, some type of added heat sinking may be necessary. Thus lead frame configurations are being altered from the standard 14-pin or 16-pin designs.

Rapidly becoming an industry standard is the “bat-wing” package. This package is the same size as a dual in-line package, but the center portion of the frame is left as tabs. These tabs can be soldered to a heat sink or inserted directly into a socket. The worst case thermal resistance of various lead frames ($R_{\theta JC}$) is given below.

| Lead Frame | Thermal Resistance |
|---|---|
| 14-pin Kovar | 47°C/W |
| 14-pin copper | 38°C/W |
| “Bat-wing” | 13°C/W |

## WHICH HEAT SINK?

If the integrated circuit manufacturer has done his job well, the chip-to-ambient thermal resistance wil be minimized for maximum chip power dissipation. It would appear that even the Kovar lead frame would be adequate for most applications. However, the total thermal resistance ($R_{\theta JA}$) is also dependent on a stagnant layer of air at the lead frame-ambient interface that will suport a temperature gradient. The total thermal resistance of a non-heat sinked dual in-line plastic package is therefore much higher. Because air is a natural thermal insulator, maximum heat transfer is through convection and the total thermal resistance will decrease some at high power levels.

| Lead Frame | Total Thermal Resistance | Max. Power Diss. (W) at 50°C $T_A$, 150°C $T_J$ |
|---|---|---|
| 14-Pin Kovar | 120°C/W | 0.83 |
| 14-Pin Copper | 60°C/W | 1.67 |
| “Bat-Wing” | 45°C/W | 2.22 |

Ignoring any safety margin and device performance, even the “bat-wing” is now only barely adequate for many power driver applications. The obvious solution is the use of an external heat sink.

Actual performance in a specific situation depends on factors such as the proximity of objects interfering with air flow, heat radiated or convected from other components, atmospheric pressure, and humidity. A good safety factor is therefore in order.

Heat sinks for plastic dual in-line packages can be of almost unlimited variety in design, material, and finish. Economics will normally play a very important role in the selection of any heat sink.

The least expensive and easiest to fabricate heat sink is the plain copper sheet. It is also very effective in reducing the total thermal resistance. The necessary dimensions can be obtained from Figure 1. These heat sinks are square in geometry, 0.015 inches thick, mounted vertically on each side of the lead frame, and with a dull or painted surface (Figure 2). The heat sinks should be soldered directly to the lead frame (approximately 0.3°C/W interface thermal resistance)

The plain copper sheet heat sink is also available commercially and may be less expensive than in-house manufacture. Two standard types are the Staver V7 and V8.


115 Northeast Cutoff, Box 15036
Worcester, Massachusetts 01615-0036 (508) 853-5000

*THERMAL DESIGN*
*FOR PLASTIC ICs*

## HEAT SINK FINISHES

The most common finish is probably black anodizing. It is economical and offers a good appearance. The black finish will also increase the performance of the heat sink, due to radiation, by as much as 25%. However, since anodizing is an electrical and thermal insulator, the heat sink should have an area free of anodize where the heat-generating device is attached.

Other popular finishes for heat sinks are irridite and chromic acid dips. They are economical and have negligible thermal and electrical resistances. These finishes, however, do not enjoy the 25% increase in performance that a dull black finish has.

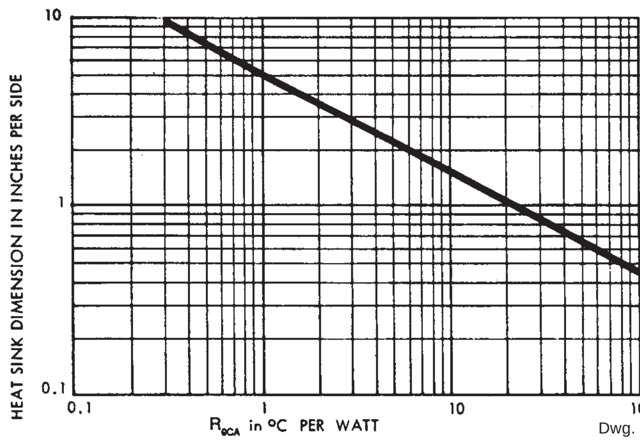
## FORCED AIR COOLING

The performance of many heat sinks can be increased by as much as 100% by forcing air over the fins. Where space is a problem, the cost of a small fan can often be justified. If a fan is required for other purposes, it is advantageous to place the semiconductor heat source in the air flow. A rule-of-thumb is that semiconductor failure rate is halved for each 10°C reduction in junction operating temperature.

## CHIP DESIGN

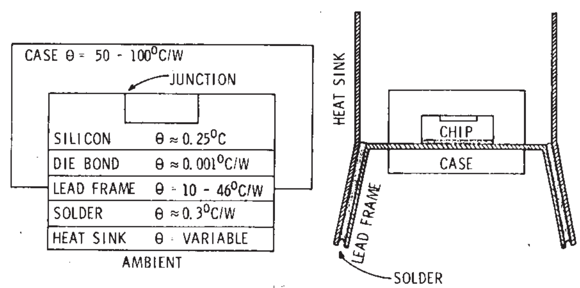
Proper thermal design by the integrated circuit user can reduce the operating temperature of the semiconductor junction. However, the minimum chip temperature at any power level is determined solely by the device manufacturer. For this reason, care must be taken in choosing the manufacturer. “Exact equivalent” integrated circuits are not necessarily identical. Electrically and mechanically they may be the same, but thermal differences can mean that “identical” audio power amplifiers will not put out the same power without exceeding the rated junction temperature.

The circuit manufacturer must optimize his chip design so that component drift is minimized and/or equalized so that rated



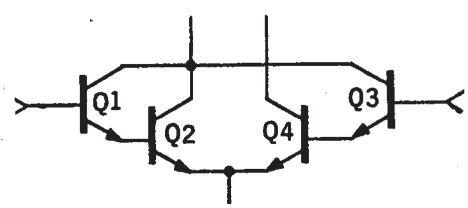

Dwg. No. A-11,434

FIGURE 1




Dwg. No. A-11,435

FIGURE 2




Dwg. No. A-11,436

FIGURE 3

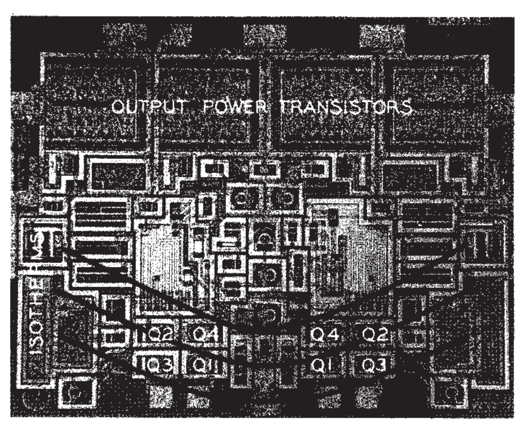
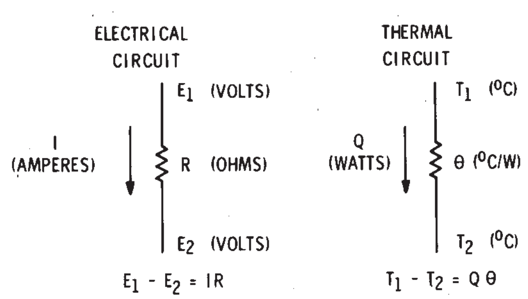


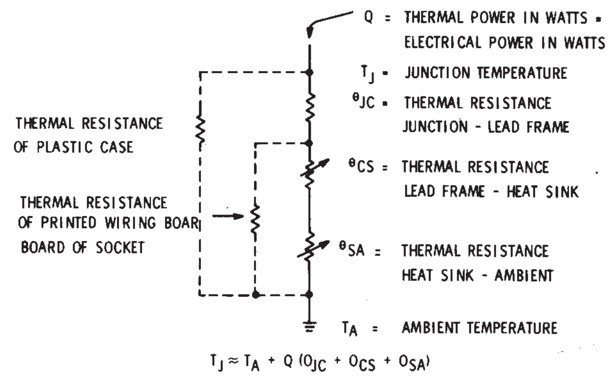

FIGURE 4

# *THERMAL DESIGN FOR PLASTIC ICs*




Dwg. No. A-11,437

**FIGURE 5**




Dwg. No. A-11,438

**FIGURE 6**

| Material | Relative Thermal Resistance |
|---|---|
| Silver | 0.09 |
| Copper, Annealed | 0.10 |
| Gold | 0.12 |
| Beryllia Ceramic | 0.20 |
| Aluminum | 0.20 |
| Brass (66 Cu, 34 Zn) | 0.40 |
| Silicon | 0.50 |
| Germanium | 0.70 |
| Steel, SAE 1045 | 0.80 |
| Solder (60 Sn, 40 Pb) | 1.5 |
| Alumina Ceramic | 2.0 |
| Kovar (54 Fe, 29 Ni, 17 Co) | 3.0 |
| Glass | 40 |
| Epoxy | 40 |
| Mica | 50 |
| Teflon PTFE | 200 |
| Air | 2000 |

performance can actually be obtained under maximum thermal stress.

Note in Figures 3 and 4 that the Darlington-input differential pairs are cross-connected so as to minimize differences in gain as a function of output transistor power dissipation. Transistor $Q_4$, being closest to the output power transistors, is naturally the hottest; $Q_3$ is a degree or two cooler; $Q_1$ and $Q_2$ are about equal and midway between $Q_3$ and $Q_4$. The gain of the $Q_1$-$Q_2$ Darlington pair is about equal to the gain of $Q_3$-$Q_4$ at all output power levels because of careful thermal design.

In certain specialized applications, thermal coupling can be used to a distinct advantage. Experimentally, thermal coupling has been used to provide a low-pass feedback network which otherwise could be obtained only with very large values of capacitance.

The foregoing discussion has covered the average thermal characteristics of dual in-line plastic integrated circuits. The specific devices will vary with the different packages and bonding techniques employed, but the concepts will remain the same.

## APPENDIX

The following is intended to review terminology and compare thermal circuits with the more familiar electrical quantities.

The first law of thermodynamics states that energy cannot be created or destroyed but can be converted from one form to another. The second law of thermodynamics states that energy transfer will occur only in the direction of lower energy. In the semiconductor junction, the electrical energy is converted to thermal energy. Because no heat will be stored at the junction, the heat will flow to a lower temperature medium, air. The rate of heat flow is dependent on the resistance to that flow and the temperature difference between the source and the sink.

This thermal electrical analogy is convenient only for conduction problems where heat flow and temperature obey linear equations. The analogy becomes much more complex for situations involving heat flow by convection and radiation. Where these two modes are not negligible, they can be approximated by an equivalent thermal resistance. If ignored, the error introduced will only improve the device reliability.


Allegro® MicroSystems, Inc.
115 Northeast Cutoff, Box 15036
Worcester, Massachusetts 01615-0036 (508) 853-5000