AN-778
Application Note

MOUNTING TECHNIQUES FOR POWER SEMICONDUCTORS

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For reliable operation, semiconductors must be properly mounted. Discussed are aspects of preparing the mounting surface, using thermal compounds, insulation techniques, fastening techniques, handling of leads and pins, and evaluation methods for the thermal system.

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MOUNTING TECHNIQUES FOR POWER SEMICONDUCTORS

INTRODUCTION

Current and power ratings of semiconductors are inseparably linked to their thermal environment. Except for lead-mounted parts used at low currents, a heat exchanger is required to prevent the junction temperature from exceeding its rated limit, thereby running the risk of a high failure rate. Furthermore, semiconductor-industry field history indicates that the failure rate of most silicon semiconductors decreases approximately by one half for a decrease in junction temperature from 160°C to 135°C.*

Many failures of power semiconductors can be traced to faulty mounting procedures. With metal packaged devices, faulty mounting generally causes unnecessarily high junction temperature, resulting in reduced component lifetime, although mechanical damage has occurred on occasion from mounting securely to a warped surface. With the widespread use of various plastic-packaged semiconductors, the dimension of mechanical damage becomes very significant.

Figure 1 shows an example of doing nearly everything wrong. In this instance, the device to be victimized is in the TO-220 package. The leads are bent to fit into a socket—an operation which, if not properly done, can crack the package, break the bonding wires, or crack the die. The package is fastened with a sheet-metal screw through a 1/4"-hole containing a fiber-insulating sleeve. The force used to tighten the screw pulls the package into the hole, causing enough distortion to crack the die. Even if the die were not cracked, the contact area is small because of the area consumed by the large hole and the bowing of the package; the result is a much higher junction temperature than expected. If a rough heat sink surface and some burrs around the hole are present, many—but unfortunately not all—poor mounting practices are covered.

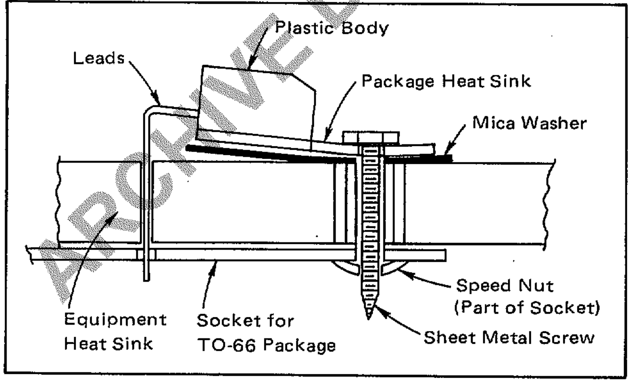

FIGURE 1 — Extreme Case of Improperly Mounting A Semiconductor (Distortion Exaggerated)

In many situations the case of the semiconductor must be isolated electrically from its mounting surface. The isolation material is, to some extent, a thermal isolator as well, which raises junction operating temperatures. In addition, the possibility of arc-over problems is introduced if high voltages are being handled. Electrical isolation thus places additional demands upon the mounting procedure.

Proper mounting procedures necessitate attention to the following areas:

1. Mounting surface preparation,
2. Application of thermal compounds,
3. Installation of the insulator,
4. Fastening of the assembly, and
5. Lead bending and soldering.

In this note, the procedures are discussed in general terms. Specific details for each class of packages are given in the figures and in Table 1. Appendix A contains a brief review of thermal resistance concepts, and Appendix B lists sources of supply for accessories. Motorola supplies hardware for all power packages. It is detailed on separate data sheets for each package type.

MOUNTING SURFACE PREPARATION

In general, the heat-sink mounting surface should have a flatness and finish comparable to that of the semiconductor package. In lower power applications, the heat-sink surface is satisfactory if it appears flat against a straight edge and is free from deep scratches. In high-power applications, a more detailed examination of the surface is required.

Surface Flatness

Surface flatness is determined by comparing the variance in height (Δh) of the test specimen to that of a reference standard as indicated in Figure 2. Flatness is normally specified as a fraction of the Total Indicator Reading (TIR). The mounting surface flatness, i.e., $\Delta h/\mathrm{TIR}$, is satisfactory in most cases if less than 4 mils per inch, which is normal for extruded aluminum—although disc type devices usually require 1 mil per inch.

Surface Finish

Surface finish is the average of the deviations both above and below the mean value of surface height. For minimum interface resistance, a finish in the range of 50 to 60 microinches is satisfactory;* a finer finish is costly to achieve and does not significantly lower contact resistance. Most commercially available cast or extruded

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*See MIL—Handbook—217B, Section 2.2

*Tests run by Thermalloy (Catalog #74-INS-3, page 14) using a copper TO-3 package with a typical 32-microinch finish, showed that finishes between 16 and 64 μ-in caused less than ±2.5% difference in interface thermal resistance.

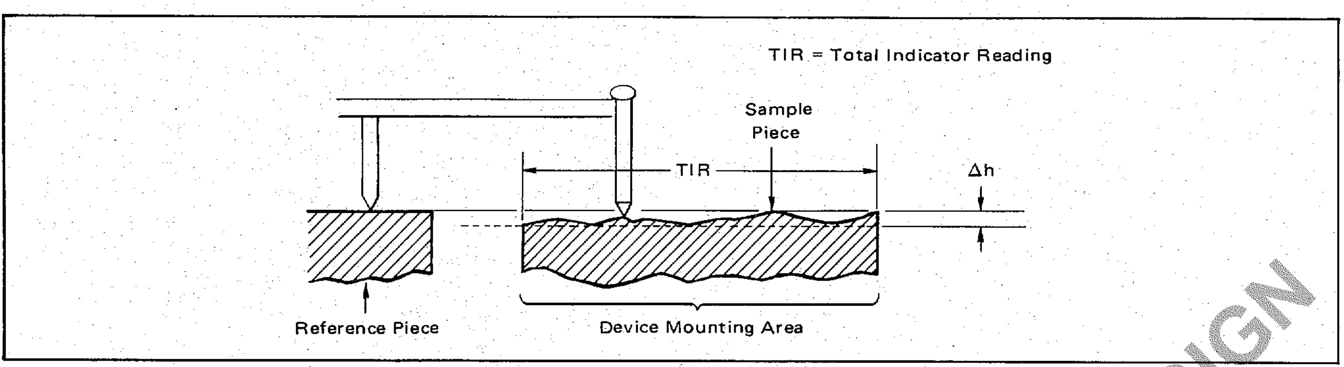


FIGURE 2 – Surface Flatness

heat sinks will require spotfacing when used in high-power applications. In general, milled or machined surfaces are satisfactory if prepared with tools in good working condition.

Mounting holes generally should only be large enough to allow clearance of the fastener. The larger packages having mounting holes removed from the semiconductor die location, such as a TO-3, may successfully be used with larger holes to accommodate an insulating bushing, but Thermopad plastic packages are intolerant of this condition. For these packages, a smaller screw size must be used such that the hole for the bushing does not exceed the hole in the package.

Punched mounting holes have been a source of trouble because if not properly done, the area around a punched hole is depressed in the process. This "crater" in the heat sink around the mounting hole can cause two problems. The device can be damaged by distortion of the package as the mounting pressure attempts to conform it to the shape of the heat-sink indentation, or the device may only bridge the crater and leave a significant percentage of its heat-dissipating surface out of contact with the heat sink. The first effect may often be detected immediately by visual cracks in the package (if plastic), but usually an unnatural stress is imposed, which results in an early-life failure. The second effect results in hotter operation and is not manifested until much later.

Although punched holes are seldom acceptable in the relatively thick material used for extruded aluminum heat sinks, several manufacturers are capable of properly utilizing the capabilities inherent in both fine-edge blanking or sheared-through holes when applied to sheet metal as commonly used for stamped heat sinks. The holes are pierced using Class A progressive dies mounted on four-post die sets equipped with proper pressure pads and holding fixtures.

When mounting holes are drilled, a general practice with extruded aluminum, surface cleanup is important. Chamfers must be avoided because they reduce heat transfer surface and increase mounting stress. The edges should be broken to remove burrs which cause poor contact between device and heat sink and may puncture isolation material.

Many aluminum heat sinks are black-anodized to improve radiation ability and prevent corrosion. Anodizing results in significant electrical but negligible thermal insulation. It need only be removed from the mounting area when electrical contact is required. Another treated aluminum finish is iridite, or chromate-acid dip, which offers low resistance because of its thin surface, yet has good electrical properties because it resists oxidation. It need only be cleaned of the oils and films that collect in the manufacture and storage of the sinks, a practice which should be applied to all heat sinks. For economy, paint is sometimes used for sinks; removal of the paint where the semiconductor is attached is usually required because of paint's high thermal resistance. However, when it is necessary to insulate the semiconductor package from the heat sink, anodized or painted surfaces may be more effective than other insulating materials which tend to creep (i.e., they flow), thereby reducing contact pressure.

It is also necessary that the surface be free from all foreign material, film, and oxide (freshly bared aluminum forms an oxide layer in a few seconds). Unless used immediately after machining, it is a good practice to polish the mounting area with No. 000 steel wool, followed by an acetone or alcohol rinse. Thermal grease should be immediately applied thereafter and the semiconductor attached as the grease readily collects dust and metal particles.

THERMAL COMPOUNDS

To improve contacts, thermal joint compounds or greases are used to fill air voids between all mating surfaces. Values of thermal resistivity vary from 0.10 degrees Celsius-inches per watt for copper film to 1200°C-in/W for air, whereas satisfactory joint compounds will have a resistivity of approximately 60°C-in/W. Therefore, the voids, scratches, and imperfections which are filled with a joint compound, will have a thermal resistance of about 1/20th of the original value which makes a significant reduction in the overall interface thermal resistance.

Joint compounds are a formulation of fine zinc particles in a silicon oil which maintains a grease-like consistency with time and temperature. Since some of these compounds do not spread well, they should be evenly applied in a very thin layer using a spatula or lintless brush, and wiped lightly to remove excess material. Some cyclic rotation of the package will help the compound spread evenly over the entire contact area. Experience will indicate whether the quantity is sufficient, as excess will appear around the edges of the contact area. To prevent accumulation of airborne particulate matter, excess compound should be wiped away using a cloth moistened with acetone or alcohol. These solvents should not contact plastic-encapsulated devices, as they may enter the package and cause a leakage path or carry in substances which might attack the assembly.

Data showing the effect of compounds on several package types under different mounting conditions is shown in Table I. The rougher the surface, the more valuable the grease becomes in lowering contact resistance; therefore, when mica insulating washers are used, use of grease is generally mandatory. The joint compound also improves the breakdown rating of the insulator and is therefore highly desirable despite the handling problems created by its affinity for foreign matter. Some sources of supply for joint compounds are shown in Appendix B.

Some users and heat-sink manufacturers prefer not to use compounds. This necessitates use of a heat sink with lower thermal resistance which imposes additional cost, but which may be inconsequential when low power is being handled. Others design on the basis of not using grease, but apply it as an added safety factor, so that if improperly applied, operating temperatures will not exceed the design values.

TABLE 1

Approximate Values for Interface Thermal Resistance and Other Package Data

(See Table II for Case Number to JEDEC Outline Cross-Reference)

Dry interface values are subject to wide variation because of extreme dependence upon surface conditions. Unless otherwise noted the case temperature is monitored by a thermocouple located directly under the die reached through a hole in the heat sink. (See Note 4.)

Package Type and Data					Interface Thermal Resistance (^{o}C/W)					
JEDEC Outline	Description	Recommended Mounting Hole and Drill Size	Machine Screw Size^{2}	Torque In-Lb	Metal-to-Metal		With Insulator			See Note
					Dry	Lubed	Dry	Lubed	Type	
Case 152*	Uniwatt	0.113, #33	4-40	6	5.0	3.8	7.4	5.4	2 mil Mica	3
DO-4	10-32 Stud 7/16" Hex	0.188, #12	10-32	20	0.3	0.2	1.6	0.8	3 mil Mica	
DO-5	1/4-28 Stud 11/16" Hex	0.250, #1	1/4-28	25	0.2	0.1	0.8	0.6	5 mil Mica	
DO-21	Pressfit, 1/2"	See Figure 8	—	—	0.15	0.10	—	—	—	
TO-3	Diamond Flange	0.140, #28	6-32	6	0.5	0.1	1.3	0.36	3 mil Mica	1
TO-66	Diamond Flange	0.140, #28	6-32	6	1.5	0.5	2.3	0.9	2 mil Mica	
TO-83 TO-94	1/2" 20 Stud 1-1/16" Hex	0.5, 0.5 —	1/2-20	130	—	0.1	—	—	—	
TO-126	Thermopad 1/4" x 3/8"	0.113, #33	4-40	6	2.0	1.3	4.3	3.3	2 mil Mica	
TO-127	Thermopad 1/2" x 5/8"	0.140, #28	6-32	8	1.6	0.8	2.6	1.8	2 mil Mica	
TO-202AC	Duowatt	0.140, #28	6-32	8	1.3	0.9	4.8	2.0	2 mil Mica	3
TO-220AB	Thermowatt	0.140, #28	6-32	8	1.2	1.0	3.4	1.6	2 mil Mica	1, 2

*Motorola Case Number

NOTE 1. See Figures 3 and 4 for additional data on TO-3 and TO-220 packages.

NOTE 2. Screw not insulated.

NOTE 3. Case thermocouple soldered to top of tab.

NOTE 4. **Measurement of Interface Thermal Resistance.** Measuring the interface thermal resistance $R_{\theta CS}$ appears deceptively simple. All that's apparently needed is a thermocouple on the semi, a thermocouple on the heat sink, and a means of applying and measuring DC power. However, $R_{\theta CS}$ is proportional to the amount of contact area between the surfaces and consequently is affected by surface flatness and finish and the amount of pressure on the surfaces. In addition, placement of the thermocouples can have a significant influence upon the results. Consequently, values for interface thermal resistance presented by different manufacturers are in poor agreement.

Consider the TO-220 package shown in the accompanying figure. The mounting pressure at one end causes the other end—where the die is located— to lift off the mounting surface slightly. To improve contact, Motorola TO-220 packages are slightly concave and use of a spreader bar under the screw lessens the lifting, but some is inevitable with a single-ended package.

The thermocouple locations are shown:

a. The Motorola location is directly under the die reached through a hole in the heat sink. The thermocouple is held in place by a spring which forces the thermocouple into intimate contact with the bottom of the semi's case.

b. The EIA location is close to the die on the top surface of the package base reached through a blind hole drilled through the molded body. The thermocouple is swaged in place.

c. The Thermalloy location is on the top portion of the tab between the molded body and the mounting screw. The thermocouple is soldered into position.

Temperatures at the three locations are generally not the same. Consider the situation depicted in the figure. Because the only area of direct contact is around the mounting screw, nearly all the heat travels horizontally along the tab from the die to the contact area. Consequently, the temperature at the EIA location is hotter than at the Thermalloy location and the Motorola location is even hotter. Since junction-to-sink thermal resistance is constant for a given setup, junction-to-case values decrease and case-to-sink values increase as the case thermocouple readings become warmer.

There are examples where the relationship between the thermocouple temperatures are different from the previous situation. If a mica washer with grease is installed between the semi package and the heat sink, tightening the screw will not bow the package;

Table 1, Note 5 (continued)

instead, the mica will be deformed. The primary heat conduction path is from the die through the mica to the heat sink. In this case, a small temperature drop will exist across the vertical dimension of the package mounting base so that the thermocouple at the EIA location will be the hottest. The thermocouple temperature at the Thermalloy location could be close to the temperature at the EIA location as the lateral heat flow is generally small.

The EIA location is chosen to obtain the highest temperature on the case. It is of significance because power ratings are supposed to be based on this reference point. Unfortunately, the placement of the thermocouple is tedious and leaves the semiconductor in a condition unfit for sale.

The Motorola location is chosen to obtain the highest temperature of the case at a point where, hopefully, the semi is making contact to the heat sink, since heat sinks are measured from the point of semi contact to the ambient. Once the special heat sink to accommodate the thermocouple has been fabricated, this method lends itself to production testing and does not mark the device. However, this location is not easily accessible to the user.

The Thermalloy location is convenient and is often chosen by equipment manufacturers. However, it also blemishes the case and may yield results differing up to 1°C/W for a TO-220 package mounted to a heat sink without thermal grease and no insulator. This error is small when compared to the heat dissipators often used with this package, since power dissipation is usually a few watts. When compared to the specified junction-to-case values of some of the higher power semiconductors becoming available, however, the difference becomes significant, and it is important that the semiconductor manufacturer and equipment manufacturer use the same reference point.

Another method of establishing reference temperatures utilizes a soft copper washer (thermal grease is used) between the semiconductor package and the heat sink. The washer is flat to within 1 mil/inch, has a finish better than 63 μ-inch, and has an imbedded thermocouple near its center. This reference includes the interface resistance under nearly ideal conditions and is therefore application-oriented. It is also easy to use and yields reproducible results. At this printing, however, sufficient data to compare results to other methods is not available.

The only way to get accurate measurements of the interface resistance is to also test for junction-to-case thermal resistance at the same time. If the junction-to-case values remain relatively constant as insulators are changed, torque varied, etc., then the case reference point is satisfactory.

JEDEC TO-220 Package mounted to heat sink showing various thermocouple locations and lifting caused by pressure at one end.

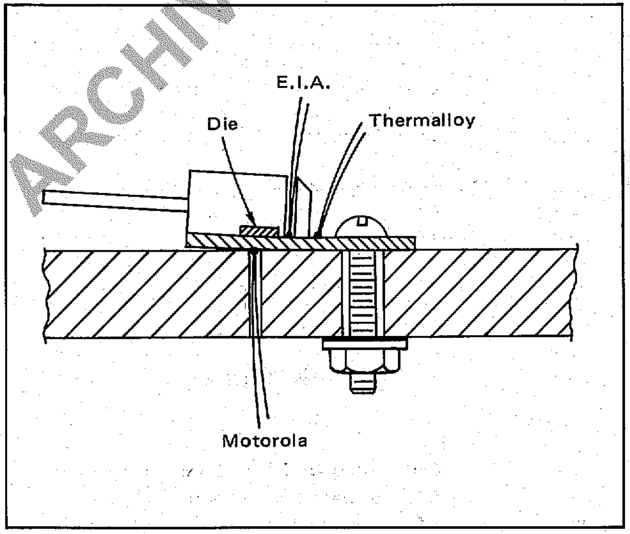


TABLE 2

Cross Reference Chart

Motorola Case Number to JEDEC Outline Number and Table 1 Reference

Motorola Number	JEDEC Number	Reference in Table 1
1	TO-3	TO-3
3	TO-3^{2}	TO-3
9	TO-61	DO-5
11	TO-3	TO-3
11A	TO-3^{2}	TO-3
12	TO-3^{2}	TO-3
36	TO-60	DO-4
42A	DO-5	DO-5
44	DO-4	DO-4
54	TO-3^{2}	TO-3
56	DO-4	DO-4
58	DO-5^{2}	DO-5
77	TO-126	TO-126
80	TO-66	TO-66
86	TO-208^{1}	DO-4
86L	TO-298^{1}	DO-4
90	TO-127	TO-127
145C	TO-232^{1}	DO-4
152	TO-202^{1}	Case 152
160-03	TO-59	DO-4
167	DO-203^{1} –1.25″ hex	DO-4
157	DO-203^{1}	DO-5
197	TO-3^{2}	TO-3
199	TO-225^{1}	TO-127
219	TO-94	TO-83
221	TO-220AB	TO-220AB
221A	TO-220AB	TO-220AB
235	TO-208^{1}	DO-5
238	TO-208^{1}	DO-5
239	TO-208	–
245	DO-4	DO-4
246	TO-83	TO-83
257-01	DO-5	DO-5
263	TO-208^{1}	DO-5
283	DO-4	DO-4
285	TO-209^{1}	TO-83
288	TO-208^{1}	TO-83
289	TO-209^{1}	DO-5
291	TO-94	TO-83
306	TO-202AC	TO-202AC

NOTE 1. Would fit within this family outline if registered with JEDEC.

NOTE 2. Not within all JEDEC outline dimensions. The data in Table 1 and suggested mounting hardware and procedures generally apply.

INSULATION CONSIDERATIONS

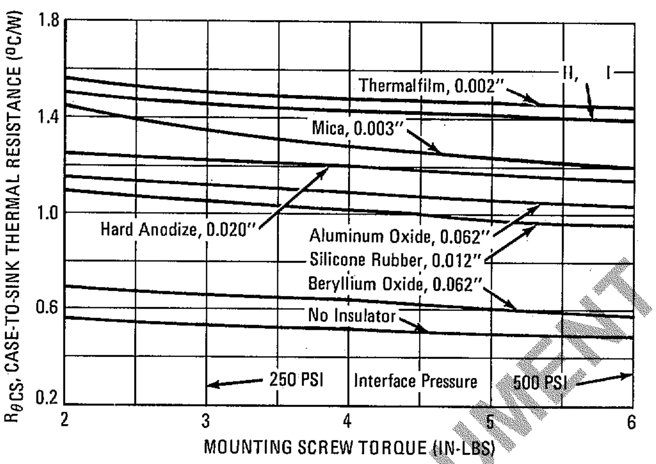
Since it is most expedient to manufacture power semiconductors with collectors or anodes electrically common to the case, the problem of isolating this terminal from ground is a common one. For lowest overall thermal resistance, it is best to isolate the entire heat sink/semiconductor structure from ground, rather than to use an insulator between the semiconductor and the heat sink. Where heat sink isolation is not possible, because of safety reasons or in instances where a chassis serves as a heat sink or where a heat sink is common to several devices, insulators are used to isolate the individual components from the heat sink.

When an insulator is used, thermal grease assumes greater importance than with a metal-to-metal contact, because two interfaces exist instead of one and some materials, such as mica, have a markedly uneven surface. Reduction of interface thermal resistance of between 2 to 1 and 3 to 1 are typical when grease is used.

Data obtained by Thermalloy, showing interface resistance for different insulators and torque applied to TO-3 and TO-220 packages, are shown in Figure 3 for bare surfaces and Figure 4 for greased surfaces. It is obvious that with some arrangements, the interface thermal resistance exceeds that of the semiconductor (junction to case). When high power is handled, beryllium oxide is unquestionably the best choice. Thermafilm is Thermalloy's tradename for a polyimide material which is also commonly known as Kapton*; this material is fairly popular for low power applications because it is low cost, withstands high temperatures and is easily handled, in contrast to mica which chips and flakes easily.

When using insulators, care must be taken to keep the mating surfaces clean. Small particles of foreign matter can puncture the insulation, rendering it useless or seriously lowering its dielectric strength. In addition, particularly when voltages higher than 300 V are encountered, problems with creepage may occur. Dust and other foreign material can shorten creepage distances significantly so that having a clean assembly area is important. Surface roughness and humidity also lower insulation resistance. Use of thermal grease usually raises the breakdown voltage of the insulation system. Because of these factors, which are not amenable to analysis, hi-pot testing should be done on prototypes and a large margin of safety employed. In some situations, it may be necessary to substitute "empty" packages for the semiconductors to avoid shorting them or to prevent the semiconductors from limiting the voltage applied during the hi-pot test.

(a) TO-3



(b) TO-220AB

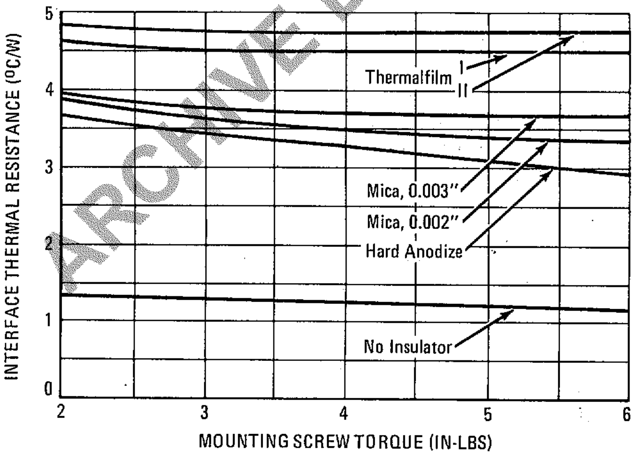
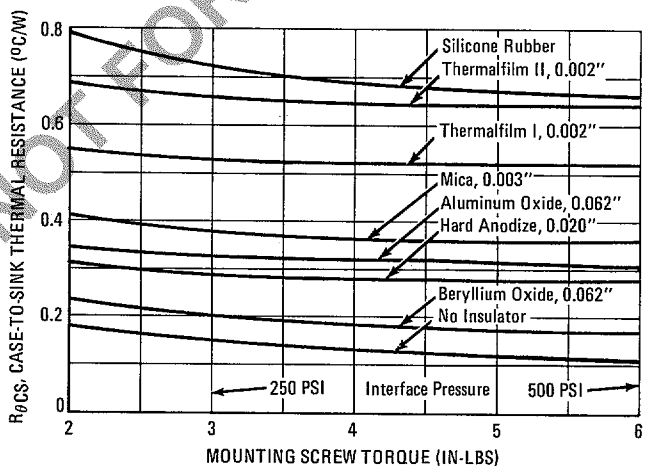


FIGURE 3 — Interface Thermal Resistance Without Thermal Grease as a Function of Mounting Screw Torque Using Various Insulating Materials

(a) TO-3



(b) TO-220AB

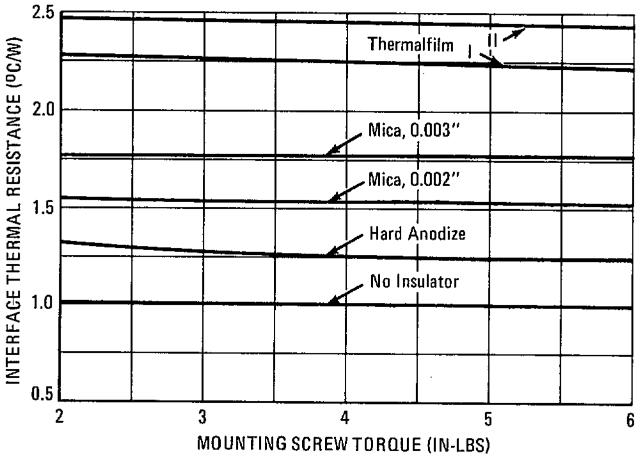


FIGURE 4 — Interface Thermal Resistance Using Thermal Grease as a Function of Mounting Screw Torque Using Various Insulating Materials

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FASTENER AND HARDWARE CHARACTERISTICS

Characteristics of fasteners, associated hardware, and the tools to secure them determine their suitability for use in mounting the various packages. Since many problems have arisen because of improper choices, the basic characteristics of several types of hardware are discussed next.

Compression Washers

A very useful piece of hardware is the bell-type compression washer. As shown in Figure 5, it has the ability to maintain a fairly constant pressure over a wide range of physical deflection–generally 20% to 80%–thereby maintaining an optimum force on the package. When installing, the assembler applies torque until the washer depresses to half its original height. (Tests should be run prior to setting up the assembly line to determine the proper torque for the fastener used to achieve 50% deflection.) The washer will absorb any cyclic expansion of the package or insulating washer caused by temperature changes. Bell type washers are the key to successful mounting of devices requiring strict control of the mounting force or when plastic hardware is used in the mounting scheme.

Motorola washers designed for use with the Thermopad package maintain the proper force when properly secured. They are used with the large face contacting the packages.

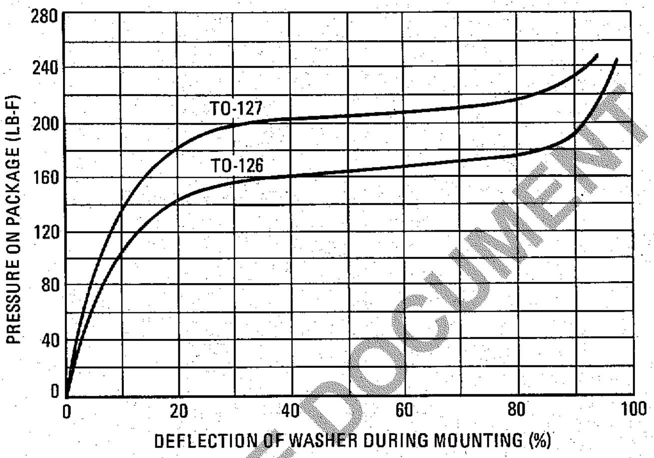

FIGURE 5 – Characteristics of the Bell Compression Washers Designed for Use with Thermopad Semiconductors

Machine Screws

Machine screws and nuts form a trouble-free fastener system for all types of packages which have mounting holes. Torque ratings apply when dry; therefore, care must be exercised when using thermal grease to prevent it from getting on the threads as inconsistent torque readings result. Machine screw heads should not directly contact the surface of any of the Thermopad plastic package types as the screw heads are not sufficiently flat to provide properly distributed force.

Self-Tapping Screws

Under some conditions, sheet-metal screws are acceptable. However, during the tapping process with a standard screw, a volcano-like protrusion will develop in the metal being threaded; a very unsatisfactory surface results. When used, a speed-nut must be used to secure a standard screw, or the type of screw must be used which roll-forms machine screw threads.

Eyelets

Successful mounting can also be accomplished with hollow eyelets provided an adjustable, regulated pressure press is used such that a gradually increasing pressure is used to pan the eyelet. Use of sharp blows could damage the semiconductor die.

Rivets

When a metal flange-mount package is being mounted directly to a heat sink, rivets can be used. Rivets are not a recommended fastener for any of the plastic packages except for the tab-mount type. Aluminum rivets are preferred over steel because less pressure is required to set the rivet and thermal conductivity is improved.

Insulators and Plastic Hardware

Because of its relatively low cost and low thermal resistance, mica is still widely used to insulate semiconductor packages from heat sinks despite its tendency to chip and flake. It has a further advantage in that it does not creep or flow so that the mounting pressure will not reduce with time in use. Plastic materials, particularly Teflon*, will flow. When plastic materials form parts of the fastening system, a compression washer is a valuable addition which assures that the assembly will not loosen with time.

FASTENING TECHNIQUES

Each of the various types of packages in use requires different fastening techniques. Details pertaining to each type are discussed in following sections. Some general considerations follow.

To prevent galvanic action from occurring when devices are used on aluminum heat sinks in a corrosive atmosphere, many devices are nickel- or gold-plated. Consequently, precautions must be taken not to mar the finish.

Manufacturers which provide heat sinks for general use and other associated hardware are listed in Appendix B. Manufacturer's catalogs should be consulted to obtain more detailed information. Motorola also has mounting hardware available for a number of different packages. Consult the Hardware Data Sheet for dimensions of the components and part numbers.

Specific fastening techniques are discussed in the remainder of this note for the following categories of semiconductor package.

1. Stud mount: DO-4, DO-5, DO-9, DO-30, TO-59, TO-60/63, TO-83, TO-93/94, etc.
2. Flange mount: DO-43, DO-44, TO-3, TO-37, TO-41, TO-53, TO-66, etc.
3. Pressfit: DO-21, DO-24, TO-203
4. Disc: DO-200 and TO-200 Families
5. Thermopad®: TO-126/7
6. Thermowatt®: TO-220 Family
7. Tab Mount (Duowatt® and Uniwatt®): TO-202 Family
8. RF Stripline: TO-119/121, TO-128/9, TO-216

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Stud Mount

Mounting errors with stud-mounted parts are generally confined to application of excessive torque or tapping the stud into a threaded heat-sink hole. Both these practices may cause a warpage of the hex base which may crack the semiconductor die. The best fastening method is to use a nut and washer; the details are shown in Figure 6.

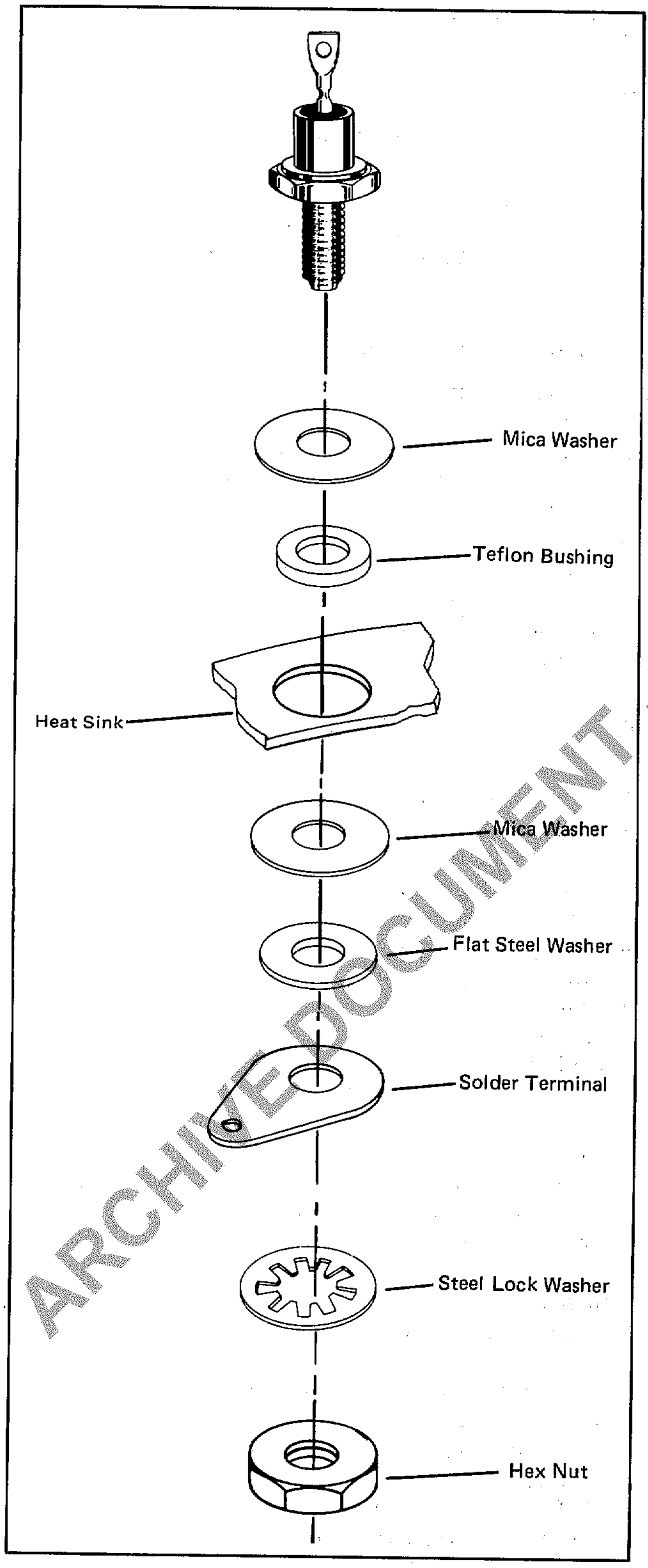


FIGURE 6 – Mounting Details For Stud-Mounted Semiconductors

Flange Mount

Few known mounting difficulties exist with this type of package. The rugged base and distance between die and mounting holes combine to make it extremely difficult to cause any warpage unless mounted on a surface which is badly bowed or unless one side is tightened excessively before the other screw is started. A typical mounting installation is shown in Figure 7. Machine screws, self-tapping screws, eyelets, or rivets may be used to secure the package.

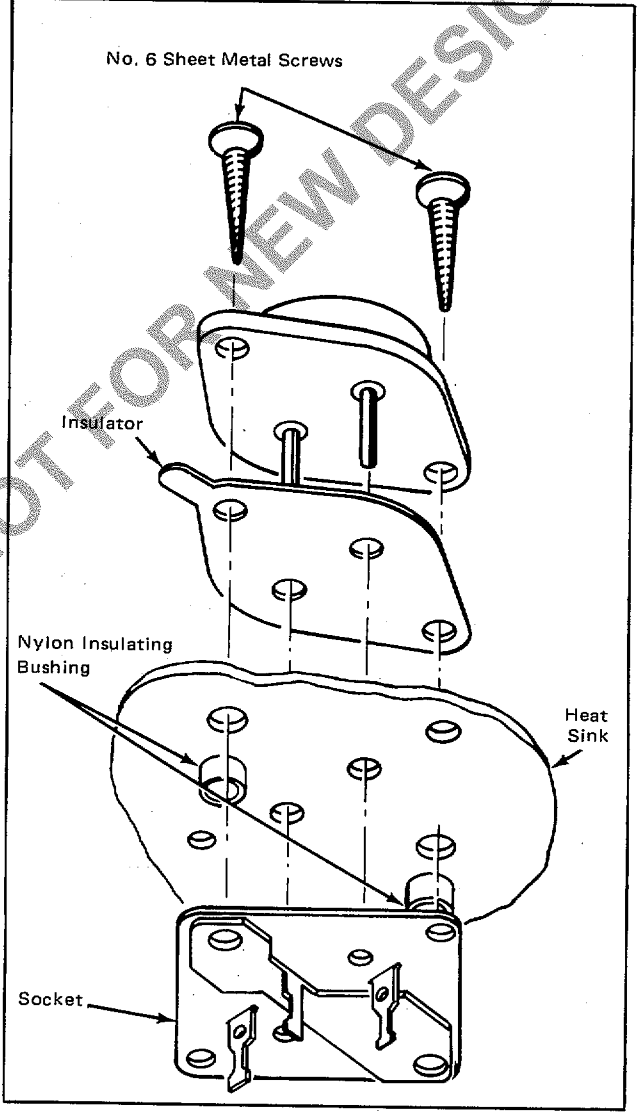


FIGURE 7 – Mounting Details for Flat-Base Mounted Semiconductors (TO-3 Shown).

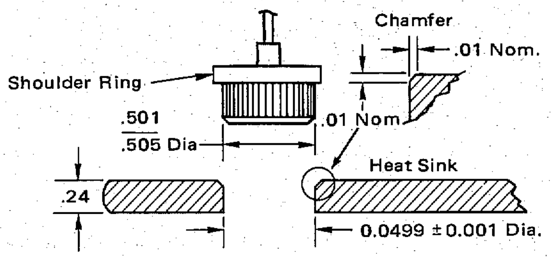
When not using a socket, machine screws tightened to their torque limits will produce lowest thermal resistance.

Press Fit

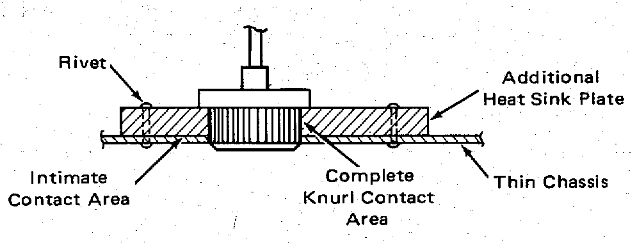
For most applications, the press-fit case should be mounted according to the instructions shown in Figure 8. A special fixture meeting the necessary requirements is a must.

Disc

Disc type devices also require special handling. The details are shown in Figure 9.



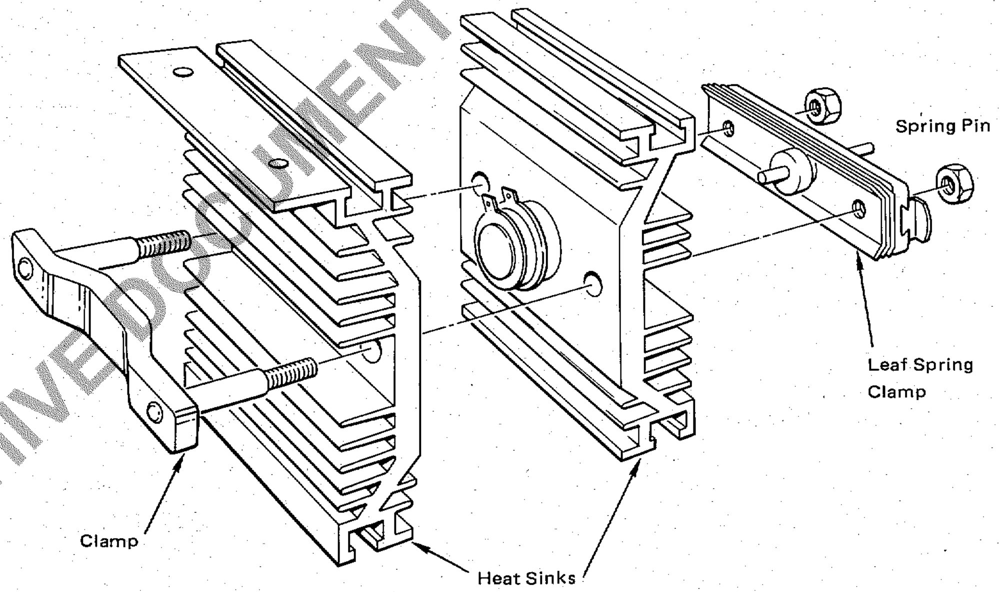
Heat Sink Mounting



Thin-Chassis Mounting

The hole edge must be chamfered as shown to prevent shearing off the knurled edge of the case during press-in. The pressing force should be applied evenly on the shoulder ring to avoid tilting or canting of the case in the hole during the pressing operation. Also, the use of a thermal joint compound will be of considerable aid. The pressing force will vary from 250 to 1000 pounds, depending upon the heat-sink material. Recommended hardnesses are: copper—less than 50 on the Rockwell F scale; aluminum—less than 65 on the Brinell scale. A heat sink as thin as 1/8" may be used, but the interface thermal resistance will increase in direct proportion to the contact area. A thin chassis requires the addition of a backup plate.

FIGURE 8 — Mounting Details for Press-Fit Semiconductors



A self-leveling type mounting clamp is recommended to assure parallelism and even distribution of pressure on each contact area. A swivel type clamp or a narrow leaf spring in contact with the heat dissipator provides acceptable performance.

The clamping force should be applied smoothly, evenly, and perpendicularly to the semiconductor package to prevent deformation of the device or the heat-dissipator mounting surfaces during installation. The spring used should provide a mounting force within the range recommended by the semiconductor manufacturer; clamping forces usually range from 800 to 2000 pounds force depending upon the type number.

Installation of an assembly of disc-type semiconductors mounted between two heat dissipators should be done in a manner to permit one heat dissipator to move with respect to the other. Movement will avoid stresses being developed due to thermal expansion, which could damage the semiconductor.

Similarly, when two or more devices are to be operated electrically in parallel, one of the heat dissipators used may be common to all devices. Individual heat dissipators must be provided against the other mounting surfaces of the semiconductors so that the mounting force applied in each case will be independently adjustable.

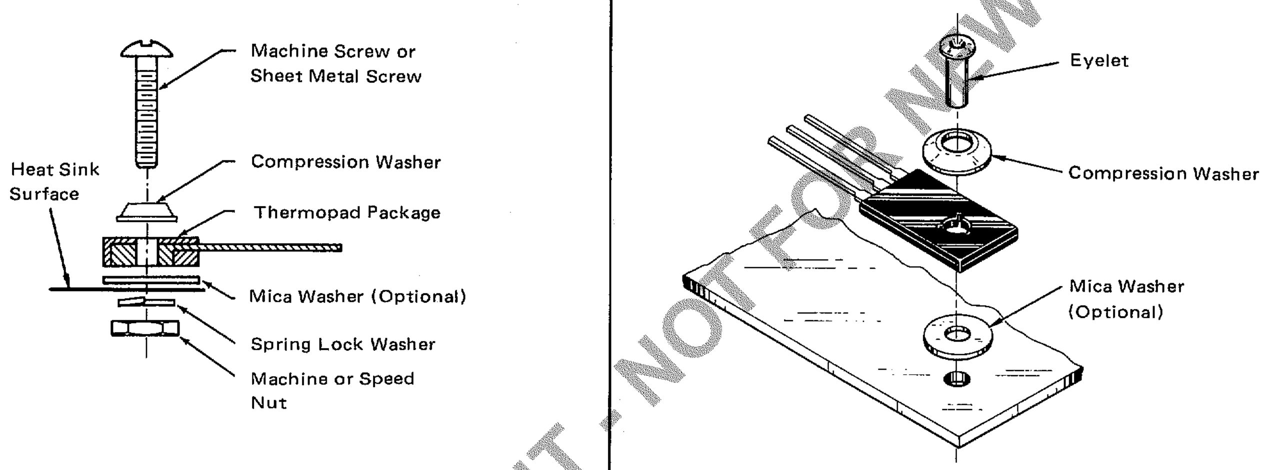
FIGURE 9 — Mounting Details for Disc-Type Semiconductors

Thermopad

The Motorola Thermopad® plastic power packages have been designed to feature minimum size with no compromise in thermal resistance. This is accomplished by die-bonding the silicon chip on one side of a thin copper sheet; the opposite side is exposed as a mounting surface. The copper sheet has a hole for mounting, i.e., plastic is molded enveloping the chip but leaving the mounting hole open. The benefits of this construction are obtained at the expense of a requirement that strict attention be paid to the mounting procedure. Success in mounting Thermopad devices depends largely upon using a compression washer which provides a controllable pressure across a large bearing surface. Having a small hole with no chamfer and a flat, burr-free, well-finished heat sink are also important requirements.

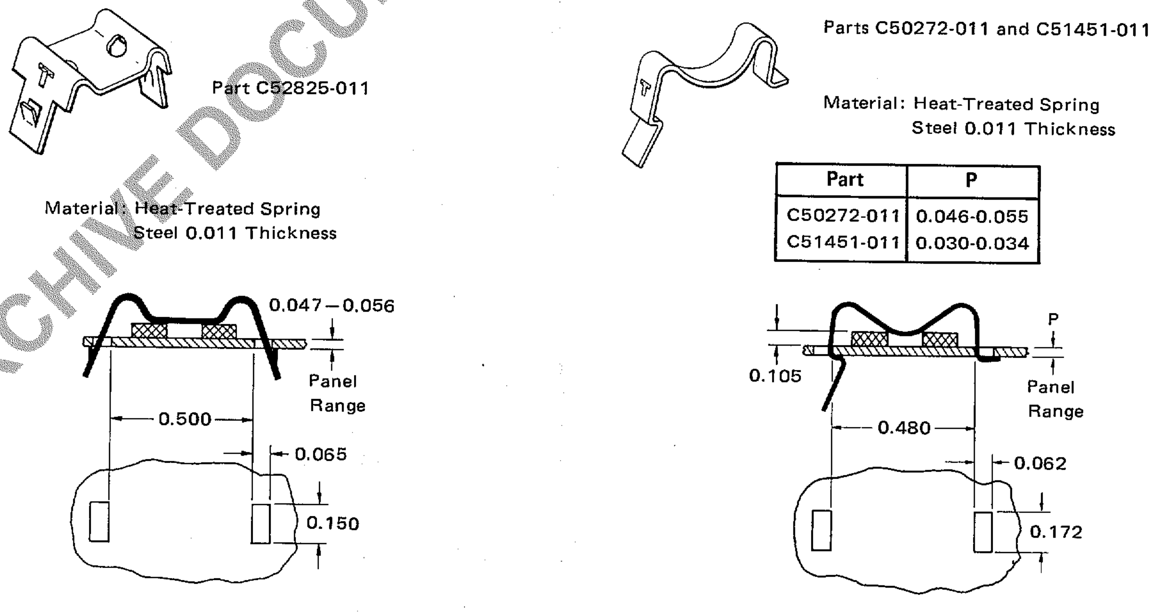
Several types of fasteners may be used to secure the Thermopad package; machine screws, eyelets, or clips are preferred. With screws or eyelets, a bell compression washer should be used which applies the proper force to the package over a fairly wide range of deflection. Screws should not be tightened with any type of air-driven torque gun or equipment which may cause high impact. Characteristics of the recommended washers are shown in Figure 5.

Figure 10 shows details of mounting TO-126 or TO-127 devices. Use of the clip requires that caution be exercised to insure that adequate mounting force is applied. When electrical isolation is required, a bushing inside the mounting hole will insure that the screw threads do not contact the metal base.



(a) Machine Screw Mounting

(b) Eyelet Mounting



Part	P
C50272-011	0.046-0.055
C51451-011	0.030-0.034

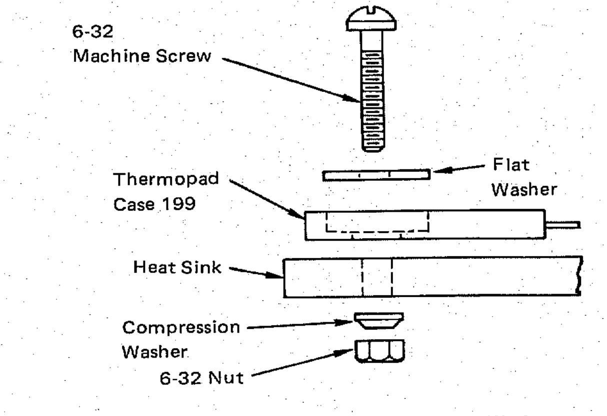
TO-127 Clip

TO-126 Clip

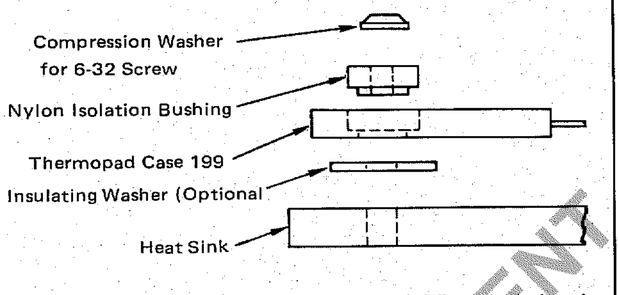
(c) Tinnerman Clips (Eaton Corp.)

FIGURE 10 — Recommended Mounting Arrangements for TO-126 and TO-127 Thermopad Packages

The case 199 Thermopad is not more tolerant of mounting conditions than Case 77 or 90 parts even though the fastener does not bear on the plastic. The screw must not contact the semiconductor base plate as screw heads are not flat enough to apply pressure evenly and may cause warpage of the base plate resulting in die fracture. Procedures for mounting the Case 199 are shown in Figure 11.



(a) Machine Screw Mounting with Compression Washer



(b) Preferred Mounting Method, Required When Isolation Is Needed. Machine Screw, Flat Washer and Nut, Sheet Metal Screw and Speed Nut, or Eyelet May Be Used for Fasteners

FIGURE 11 – Various Mounting Schemes For the Case 199 Thermopad

(a) shows direct contact with heat sink.
(b) shows technique when isolation is required.

Manual Assembly Should Be Used.

Thermowatt®

The popular TO-220 Thermowatt® package also requires attention to mounting details. Figure 12 shows suggested mounting arrangements and hardware. The rectangular washer shown in Figure 12a is used to minimize distortion of the mounting flange; excessive distortion could cause damage to the semiconductor chip. Use of the washer is only important when the size of the mounting hole exceeds 0.140 inch (6-32 clearance). Larger holes are needed to accommodate insulating bushings when the screw is electrically connected to the case; however, the holes should not be larger than necessary to provide hardware clearance and should never exceed a diameter of 0.250 inch. Flange distortion is also possible if excessive torque is used during mounting. A maximum torque of 8 inch-pounds is suggested when using a 6-32 screw.

Care should be exercised to assure that the tool used to drive the mounting screw never comes in contact with the plastic body during the driving operation. Such contact can result in damage to the plastic body and internal device connections. To minimize this problem, Motorola TO-220 packages have a chamfer on one end. TO-220 packages of other manufacturers may need a spacer or combination spacer and isolation bushing to raise the screw head above the top surface of the plastic.

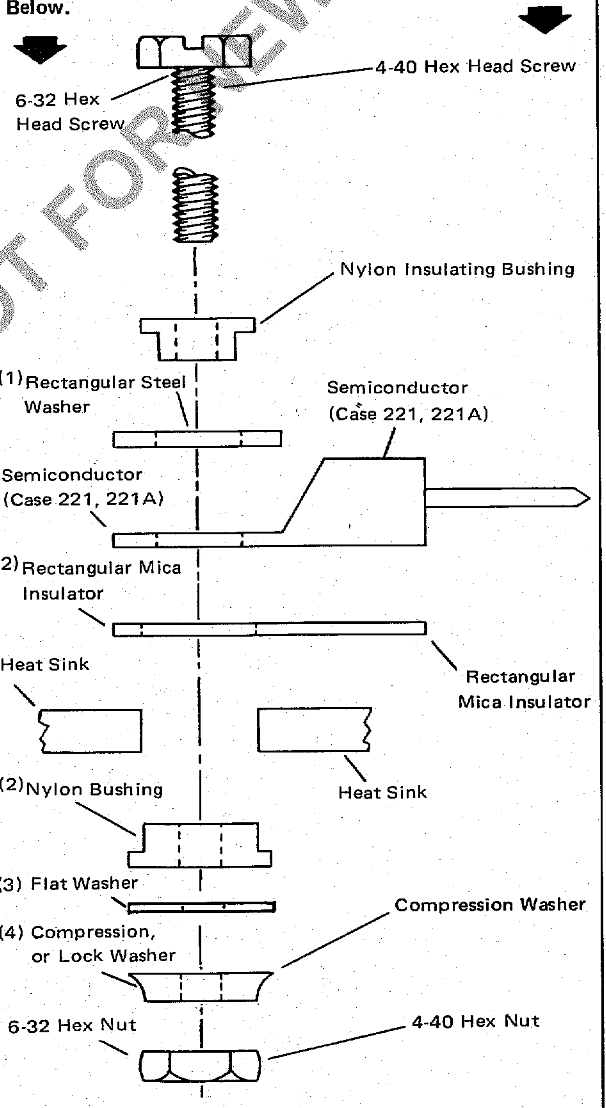
In situations where the Thermowatt package is making direct contact with the heat sink, an eyelet may be used, provided sharp blows or impact shock is avoided.

a) Preferred Arrangement for Isolated or Non-isolated Mounting. Screw is at Semiconductor Case Potential. 6-32 Hardware is Used.

Choose from Parts Listed Below.

b) Alternate Arrangement for Isolated Mounting when Screw must be at Heat-Sink Potential. 4-40 Hardware is Used.

Use Parts Listed Below.



(1) Used with thin chassis and/or large hole.
(2) Used when isolation is required.
(3) Required when nylon bushing and lock washer are used.
(4) Compression washer preferred when plastic insulating material is used.

TORQUE REQUIREMENTS

Insulated 0.68 N-M (6 in-lbs) max
Noninsulated 0.9 N-M (8 in-lbs) max

FIGURE 12 – Mounting Arrangements for Thermowatt Packages

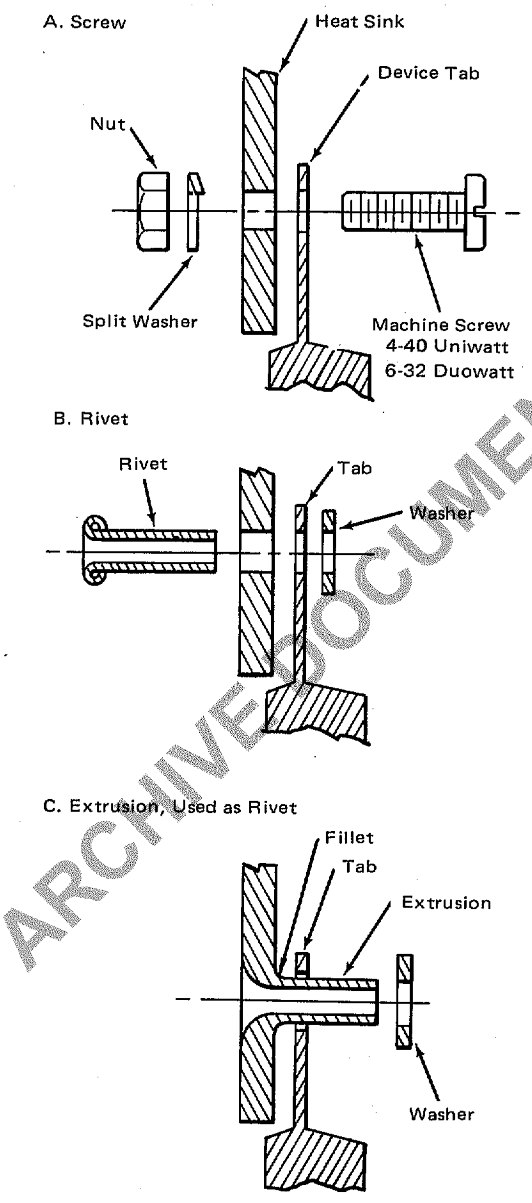
Tab Mount

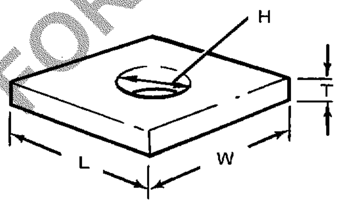
Although the Duowatt® and Uniwatt® packages are designed primarily for use in low-power applications where heat sinks are not required, they can be used to dissipate up to 10 watts if properly mounted to a heat sink. These packages are relatively rugged, since the mounting hole is not close to the die; mounting stresses, therefore, are not easily transmitted to the die.

Figure 13 shows some possible mounting arrangements. An axial load of 300 lbs-force produces minimum contact thermal resistance. This is achieved at 6 in-lbs when a 4-40 machine screw is used. A sheet-metal screw and speed-nut can be substituted for the machine screw and nut, but torque readings are uncertain. The riveting technique should produce 300 lbs-force, using a gradually increasing pressure such as provided by an arbor press.

The extrusion requires a punch press to manufacture; however, it is potentially the least expensive technique. Note that the radius of the fillet must be small enough to allow the tab to lie flat on the heat sink. To utilize an existing chassis and board arrangement on heat sinking, it may be necessary to have the device lie flat on the chassis. In this case, the chassis mounting blocks shown in Figure 13d might be utilized. A possible application is shown in Figure 13e, where a complementary transistor pair is used. Insulated screws and mica insulating washers under the blocks must be used to prevent shorting of the collector circuits of the two transistors. Alternately, an insulated bushing and a #3 screw could be used to secure the packages.

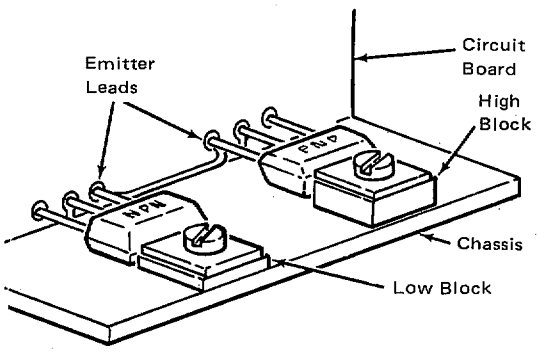
To avoid the use of mounting blocks, a tab-forming option is available. Alternately, some equipment manufacturers have constructed heat sinks with a flat, raised island to permit the package to be flat. Users should not attempt to bend the tab as a cracked die is the probable result.





D. Chassis Mounting Block Details

	Block Dimensions				
	H	W	L	T	
				Low Block	High Block
Duowatt	0.140	0.4	0.5	0.07	0.12
Uniwatt	0.113	0.3	0.3	0.06	0.12



E. Chassis Mount Block, Mounting Details

Use Nylon Screws and Mica Insulating Washer to Prevent Shorting the Tabs to the Chassis, and Thus to Each Other.

FIGURE 13 – Methods of Mounting Duowatt and Uniwatt Transistors to a Heat Sink

R.F. Stripline

Besides the usual precautions regarding surface flatness and torque, the stripline package (see Figure 14a) requires attention to the following:

1. The device should never be mounted in such a manner as to place ceramic-to-metal joints in tension.
2. The device should never be mounted in such a manner as to apply force on the strip leads in a vertical direction towards the cap.
3. When the device is mounted in a printed circuit board with the copper stud or flange and BeO portion of the header passing through a hole in the circuit board, adequate clearance must be provided for the BeO to prevent shear forces from being applied to the leads.
4. Some clearance must be allowed between the leads and the circuit board when the device is properly secured to the heat sink.
5. The device should be properly secured into the heat sinks before the device leads are attached into the circuit.
6. The leads must not be used to prevent device rotation on stud type devices during stud torque application. A wrench flat is provided for this purpose.

Most of the considerations listed above are designed to prevent tension at the metal-ceramic interfaces on the SOE package. Improper mechanical design can lead to application of stresses to these joints resulting in device destruction. Three joints are considered: the cap to the BeO disc, the leads to the disc, and the stud or flange to the disc.

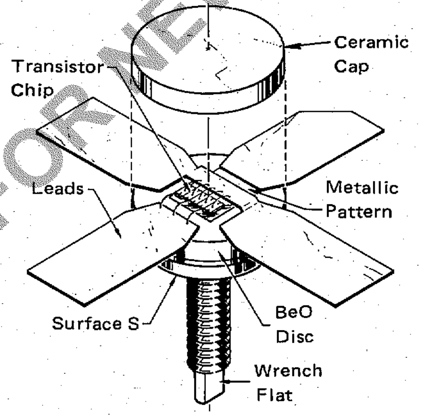
The joint between the ceramic cap and the BeO ceramic disc is composed of a material which loses strength above 175°C. While the strength of the material returns upon cooling, any force applied to the cap at high temperature may result in failure of the cap to ceramic joint.

Figure 14b shows a cross-section of a printed circuit board and heat-sink assembly for mounting a stud type stripline device. H is the distance from the top surface of the printed circuit board to the D-flat heat-sink surface. If H is less than the minimum distance from the bottom of the lead material to the mounting surface of the package, there is no possibility of tensile forces in the copper stud–BeO ceramic joint. If, however, H is greater than the package dimension, considerable force is applied to the cap to BeO joint and the BeO to stud joint. Two occurances are possible at this point. The first is a cap joint failure when the structure is heated, as might occur during the lead-soldering operation; while the second is BeO to stud failure if the force generated is high enough. Lack of contact between the device and the heat-sink surface will occur as the differences between H and the package dimension becomes larger, this may result in device failure as power is applied.

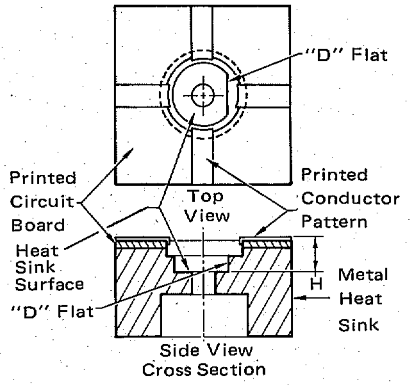
Figure 14c shows a typical mounting technique for flange-type stripline transistors. Again, H is defined as the distance from the top of the printed circuit board to the heat-sink surface. If distance H is less than the minimum distance from the bottom of transistor lead to the bottom surface of the flange, tensile forces at the various joints in the package are avoided. However, if distance H exceeds the package dimension, problems similar to those discussed for the stud type devices can occur. Because of the ability of the copper flange to bend under the types of loads encountered when the mounting screws are tightened, permanent deformation of the flange may result. Corrective action after the flange has been bent will not necessarily insure proper thermal contact with the heat sink.

The flange surface as supplied with Motorola transistors is either flat or slightly convex. It is important that the mating heat-sink surface also be flat or slightly convex to provide the best contact when the device is properly secured.

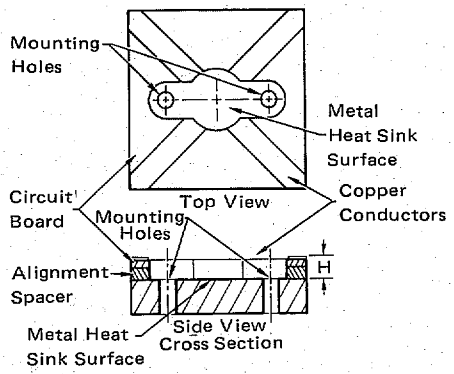
Since the flange may be permanently deformed during mounting, the device should not be dismounted and remounted in another position, without checking the flatness. The flange may be resurfaced using emery cloth mounted on a large, flat block. While this removes the gold- or nickel-plating, the thin layer of copper oxide which rapidly forms causes an insignificant increase in thermal resistance, although corrosion may occur.



(a) Component Parts of a Stud Mount Stripline Package. Flange Mounted Packages Are Similarly Constructed



(b) Typical Study Type SOE Transistor Mounting Methods



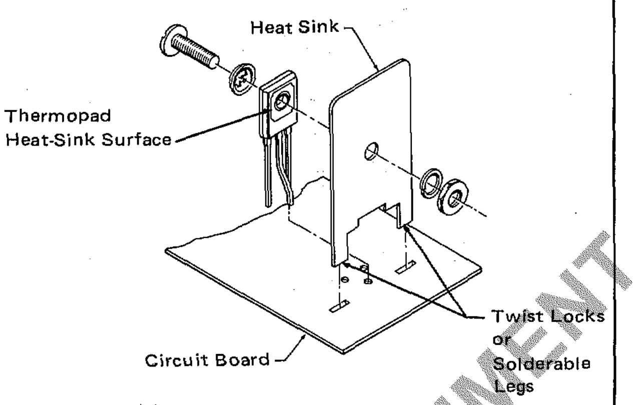
(c) Flange Type SOA Transistor Mounting Method

FIGURE 14 – Mounting Details for SOE Transistors

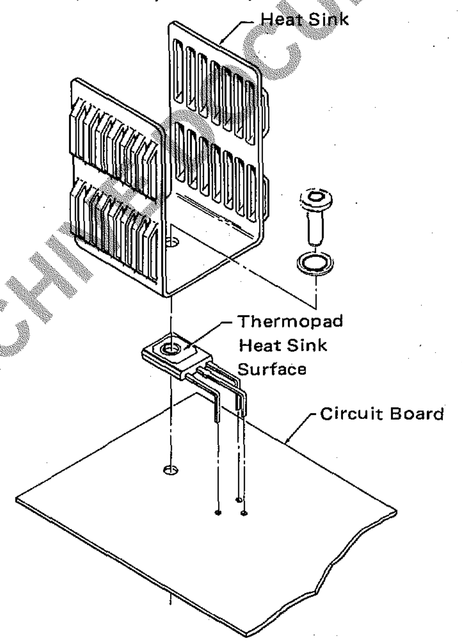
FREE AIR AND SOCKET MOUNTING

In applications where average power dissipation is of the order of a watt or so, power semiconductors may be mounted with little or no heat-sinking. The leads of the various metal power packages are not designed to support the packages; their cases must be firmly supported to avoid the possibility of cracked glass-to-metal seals around the leads. The plastic packages may be supported by their leads in applications where high shock and vibration stresses are not encountered and where no heat sink is used. The leads should be as short as possible to increase vibration resistance and reduce thermal resistance.

In many situations, because its leads are fairly heavy, the TO-127 package has supported a small heat sink; however, no definitive data is available. When using a small heat sink, it is good practice to have the sink rigidly mounted such that the sink or the board is providing total support for the semiconductor. Two possible arrangements are shown in Figure 15. The arrangement of part (a) could be used with any plastic package, but the scheme of part (b) is more practical with Case 77 or Case 90 Thermopad devices. With the other package types, mounting the transistor on top of the heat sink is more practical.



(a) Simple Plate, Vertically Mounted



(b) Commercial Sink, Horizontally Mounted

FIGURE 15 – Methods of Using Small Heat Sinks With Plastic Semiconductor Packages

In certain situations, in particular where semiconductor testing is required, sockets are desirable. Manufacturers have provided sockets for all the packages available from Motorola. The user is urged to consult manufacturers' catalogs for specific details.

HANDLING PINS, LEADS, AND TABS

The pins and lugs of metal-packaged devices are not designed for any bending or stress. If abused, the glass-to-metal seals could crack. Wires may be attached using sockets, crimp connectors, or solder, provided the data-sheet ratings are observed.

The leads and tabs of the plastic packages are more flexible and can be reshaped, although this is not a recommended procedure for users to do. In some cases, a heat sink can be chosen which makes lead-bending unnecessary. Numerous lead- and tab-forming options are available from Motorola. Preformed leads remove the risk of device damage caused by bending from the users.

If, however, lead-bending is done by the user, several basic considerations should be observed. When bending the lead, support must be placed between the point of bending and the package. For forming small quantitites of units, a pair of pliers may be used to clamp the leads at the case, while bending with the fingers or another pair of pliers. For production quantities, a suitable fixture should be made.

The following rules should be observed to avoid damage to the package.

1. A lead-bend radius greater than 1/16 inch is advisable for TO-126, 1/10 inch for TO-127 and Case 199, and 1/32 inch for TO-220.
2. No twisting of leads should be done at the case.
3. No axial motion of the lead should be allowed with respect to the case.

The leads of plastic packages are not designed to withstand excessive axial pull. Force in this direction greater than 4 pounds may result in permanent damage to the device. If the mounting arrangement imposes axial stress on the leads, a condition which may be caused by thermal cycling, some method of strain relief should be devised. An acceptable lead-forming method that provides this relief is to incorporate an S-bend into the lead. Wire-wrapping of the leads is permissible, provided that the lead is restrained between the plastic case and the point of the wrapping. The leads may be soldered; the maximum soldering temperature, however, must not exceed 275°C and must be applied for not more than 5 seconds at a distance greater than 1/8 inch from the plastic case. When wires are used for connections, care should be exercised to assure that movement of the wire does not cause movement of the lead at the lead-to-plastic junctions.

CLEANING CIRCUIT BOARDS

It is important that any solvents or cleaning chemicals used in the process of degreasing or flux removal do not affect the reliability of the devices.

Alcohol and unchlorinated Freon solvents are generally satisfactory for use with plastic devices, since they do not damage the package. Hydrocarbons such as gasoline may cause the encapsulant to swell, possibly damaging the transistor die. Likewise, chlorinated Freon solvents are unsuitable, since they may cause the outer package to dissolve and swell.

When using an ultrasonic cleaner for cleaning circuit boards, care should be taken with regard to ultrasonic energy and time of application. This is particularly true if the packages are free-standing without support.

THERMAL SYSTEM EVALUATION

Assuming that a suitable method of mounting the semiconductor without incurring damage has been achieved, it is important to ascertain whether the junction temperature is within bounds.

In applications where the power dissipated in the semiconductor consists of pulses at a low duty cycle, the instantaneous or peak junction temperature, not average temperature, may be the limiting condition. In this case, use must be made of transient thermal resistance data. For a full explanation of its use, see Motorola Application Note, AN-569.

Other applications, notably RF power amplifiers or switches driving highly reactive loads, may create severe current crowding conditions which render the traditional concepts of thermal resistance or transient thermal impedance invalid. In this case, transistor safe operating area or thyristor di/dt limits, as applicable, must be observed.

Fortunately, in many applications, a calculation of the average junction temperature is sufficient. It is based on the concept of thermal resistance between the junction and a temperature reference point on the case. (See Appendix A.) A fine wire thermocouple should be used, such as #32AWG, to determine case temperature. Average operating junction temperature can be computed from the following equation:

$$T_J = T_C + R_{\theta JC} \times P_D$$

where T_J = junction temperature (°C)
T_C = case temperature (°C)
$R_{\theta JC}$ = thermal resistance junction-to-case as specified on the data sheet (°C/W)
P_D = power dissipiated in the device (W).

The difficulty in applying the equation often lies in determining the power dissipation. Two commonly used empirical methods are graphical integration and substitution.

Graphical Integration

Graphical integration may be performed by taking oscilloscope pictures of a complete cycle of the voltage and current waveforms, using a limit device. The pictures should be taken with the temperature stabilized. Corresponding points are then read from each photo at a suitable number of time increments. Each pair of voltage and current values are multiplied together to give instantaneous values of power. The results are plotted on linear graph paper, the number of squares within the curve counted, and the total divided by the number of squares along the time axis. The quotient is the average power dissipation.

Substitution

This method is based upon substituting an easily measurable, smooth dc source for a complex waveform. A switching arrangement is provided which allows operating the load with the device under test, until it stabilizes in temperature. Case temperature is monitored. By throwing the switch to the "test" position, the device under test is connected to a dc power supply, while another pole of the switch supplies the normal power to the load to keep it operating at full power level. The dc supply is adjusted so that the semiconductor case temperature remains approximately constant when the switch is thrown to each position for about 10 seconds. The dc voltage and current values are multiplied together to obtain average power. It is generally necessary that a Kelvin connection be used for the device voltage measurement.

APPENDIX A

THERMAL RESISTANCE CONCEPTS

The basic equation for heat transfer under steady-state conditions is generally written as:

$$q = hA\Delta T \tag{1}$$

where q = rate of heat transfer or power dissipation (P_D),
h = heat transfer cofficient,
A = area involved in heat transfer,
ΔT = temperature difference between regions of heat transfer.

However, electrical engineers generally find it easier to work in terms of thermal resistance, defined as the ratio of temperature to power. From Equation 1, thermal resistance, R_θ, is

$$R_\theta = \Delta T/q = 1/hA \tag{2}$$

The coefficient (h) depends upon the heat transfer mechanism used and various factors involved in that particular mechanism.

An analogy between Equation (2) and Ohm's Law is often made to form models of heat flow. Note that ΔT could be thought of as a voltage; thermal resistance corresponds to electrical resistance (R); and, power (q) is analogous to current (I). This gives rise to a basic thermal resistance model for a semiconductor as indicated by Figure A1.

The equivalent electrical circuit may be analyzed by using Kirchoff's Law and the following equation results:

$$T_J = P_D(R_{\theta JC} + R_{\theta CS} + R_{\theta SA}) + T_A \tag{3}$$

where T_J = junction temperature,
P_D = power dissipation,
$R_{\theta JC}$ = semiconductor thermal resistance (junction to case),
$R_{\theta CS}$ = interface thermal resistance (case to heat sink),
$R_{\theta SA}$ = heat sink thermal resistance (heat sink to ambient),
T_A = ambient temperature.

The thermal resistance junction to ambient is the sum of the individual components. Each component must be minimized if the lowest junction temperature is to result.

The value for the interface thermal resistance, $R_{\theta CS}$, is affected by the mounting procedure and may be significant compared to the other thermal-resistance terms.

The thermal resistance of the heat sink is not constant; it decreases as ambient temperature increases and is affected by orientation of the sink. The thermal resistance of the semiconductor is also variable; it is a function of biasing and temperature. In some applications such as in RF power amplifiers and short-pulse applications, the concept may be invalid because of localized heating in the semiconductor chip.

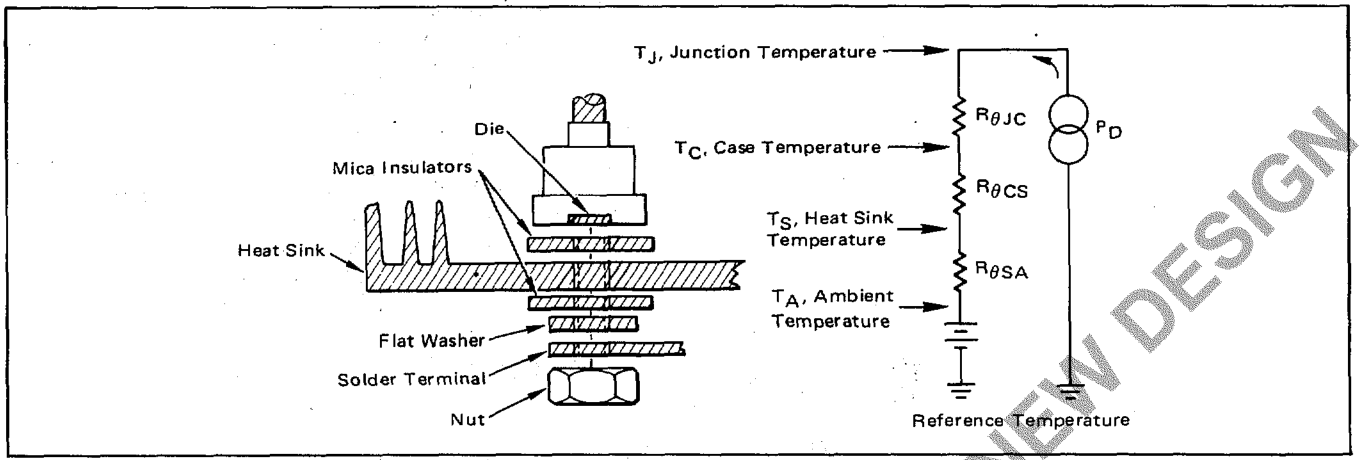


FIGURE A1 – Basic Thermal Resistance Model Showing Thermal to Electrical Analogy for a Semiconductor

APPENDIX B

SOURCES OF ACCESSORIES

		Insulators						Heat Sinks					
Manufacturer	Joint Compound	BeO	AlO_2	Anodize	Mica	Plastic Film	Silicone Rubber	Stud	Flange	Disc	Thermowatt	Uni/Duo Watt	RF Stripline
Aavid Eng.	Ther-o-link 1000	–	–	–	–	–	–	X	X	–	X	–	–
AHAM	–	–	–	–	–	–	–	X	X	–	X	–	–
Astrodyne	#829	–	–	–	–	–	–	X	X	X	X	X	–
Delbert Blinn	–	X	–	X	X	X	X	X	X	–	–	–	–
IERC	Thermate	–	–	–	–	–	–	X	X	–	X	X	X
Staver	–	–	–	–	–	–	–	X	X	–	X	X	X
Thermalloy	Thermacote	X	X	X	–	X	–	X	X	X	X	X	X
Tor	TJC	X	–	X	X	X	–	X	X	–	X	–	–
Tran-tec	XL500	X	–	–	–	X	X	X	X	X	X	X	X
Wakefield Eng.	Type 120	X	–	X	–	–	–	X	X	X	X	X	–
Wei Corp.	–	–	–	–	–	–	–	X	X	–	–	–	–

Other sources for Joint Compounds: Dow Corning, Type 340
Emerson & Cuming, Eccoshield – SO (Electrically Conducting)
Emerson & Cuming, Eccotherm – TC-4 (Electrically Insulating)

APPENDIX B
SUPPLIERS ADDRESSES

Aavid Engineering, Inc., 30 Cook Court, Laconia, New Hampshire 03246 (603) 524-4443

AHAM Heat Sinks, 27901 Front Street, Rancho, California 92390 (714) 676-4151

Astrodyne, Inc., 353 Middlesex Avenue, Wilmington, Massachusetts 01887 (617) 272-3850

Delbert Blinn Company, P.O. Box 2007, Pomona, California 91766 (714) 623-1257

Dow Corning, Savage Road Building, Midland, Michigan 48640 (517) 636-8000

Eaton Corporation, Engineered Fasteners Division, Tinnerman Plant, P.O. Box 6688, Cleveland, Ohio 44101 (216) 523-5327

Emerson & Cuming, Inc., Dielectric Materials Division, 869 Washington Street, Canton, Massachusetts 02021 (617) 828-3300

International Electronics Research Corporation, 135 West Magnolia Boulevard, Burbank, California 91502 (213) 849-2481

The Staver Company, Inc., 41-51 North Saxon Avenue, Bay Shore, Long Island, New York 11706 (516) 666-8000

Thermalloy, Inc., P.O. Box 34829, 2021 West Valley View Lane, Dallas, Texas 75234 (214) 243-4321

Tor Corporation, 14715 Arminta Street, Van Nuys, California 91402 (213) 786-6524

Tran-tec Corporation, P.O. Box 1044, Columbus, Nebraska 68601 (402) 564-2748

Wakefield Engineering, Inc., Wakefield, Massachusetts 01880 (617) 245-5900

Wei Corporation, 1405 South Village Way, Santa Ana, California 92705 (614) 834-9333

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