



APPLICATION BULLETIN

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MOUNTING CONSIDERATIONS FOR TO-3 PACKAGES

By Hubert Biagi (602) 746-7422

Proper mounting of TO-3 packages is required to assure rated performance and reliability. Although the procedures are simple, ignoring them can result in poor performance and catastrophic failure of the device.

PACKAGE HANDLING

The TO-3 package is a rugged hermetic package, but it can be damaged with improper handling. Excessive bending or twisting of the package pins can crack the glass seal around the pin and result in loss of hermeticity. If pin straightening is required, clamp the pin against the package base using needle-nose pliers. This will strain-relieve the pin during the straightening operation.

Another potential problem is cracking the internal circuit substrate from bending of the package base. This can be caused by mounting the package onto a non-flat surface, improper use of a compressible thermal pad, or over-tightening the mounting fasteners.

TO-3 SOCKET

The Burr-Brown 0804MC TO-3 socket is designed to meet the requirements of high current, high power products such as the OPA512, OPA541, and OPA2541. The socket has a rugged contact design which assures positive and reliable

contact even when using thermal grease and pre-tinned pins. The closed-ended contacts will accept the full pin length of the TO-3 and guard against solder and flux contamination. The socket body has a center hole which allows for direct measurement of TO-3 case temperature.

FASTENERS

The fastener hardware used to mount the TO-3 package is very important. Table I describes the proper hardware combination. Sources for fastener hardware are listed at the end of this bulletin. The preferred fastener material is stainless steel. Plated steel is a good alternative. Brass or plastic fasteners are not recommended.

The mounting holes of the TO-3 package are designed to accept 6-32 machine screws; no other size should be used (see exploded views in Figure 1A and 1B). The pan-head is the best head style. It has a low profile and large bearing face to properly cover the mounting hole, but its not so large as to ride up onto the lip of the welded cover.

In order to maintain proper mounting pressure, the Belleville spring washer (also known as a conical compression washer), is recommended. Split ring and star lock washers are not recommended. They typically bottom out at less than 50 pounds, whereas 150-300 pounds of pressure is needed to

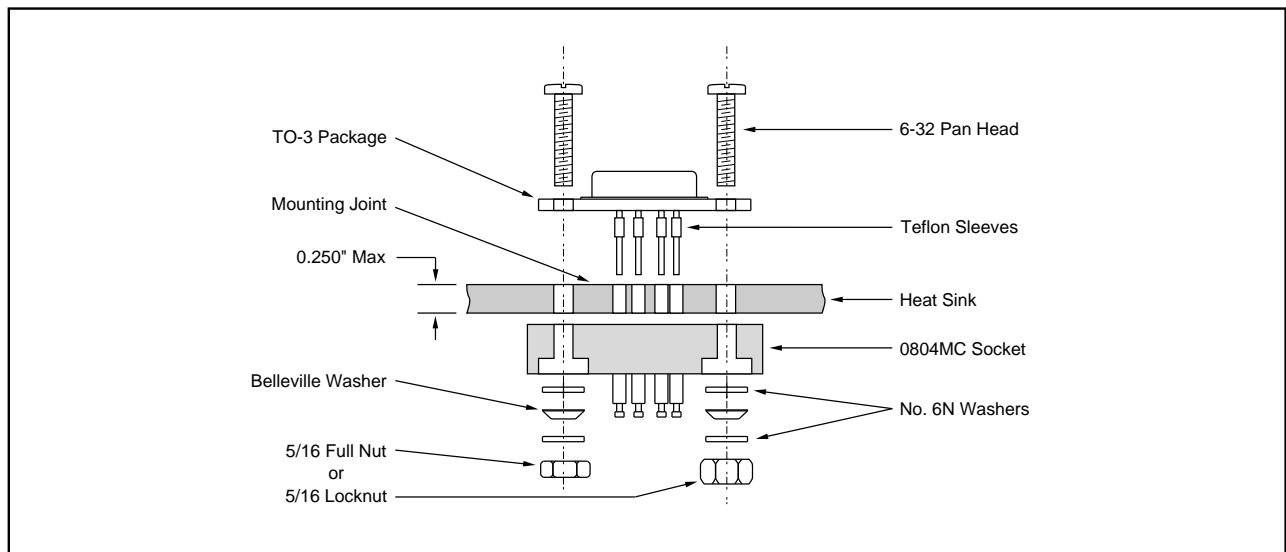


FIGURE 1A. High Power Application Using 0804MC Socket.

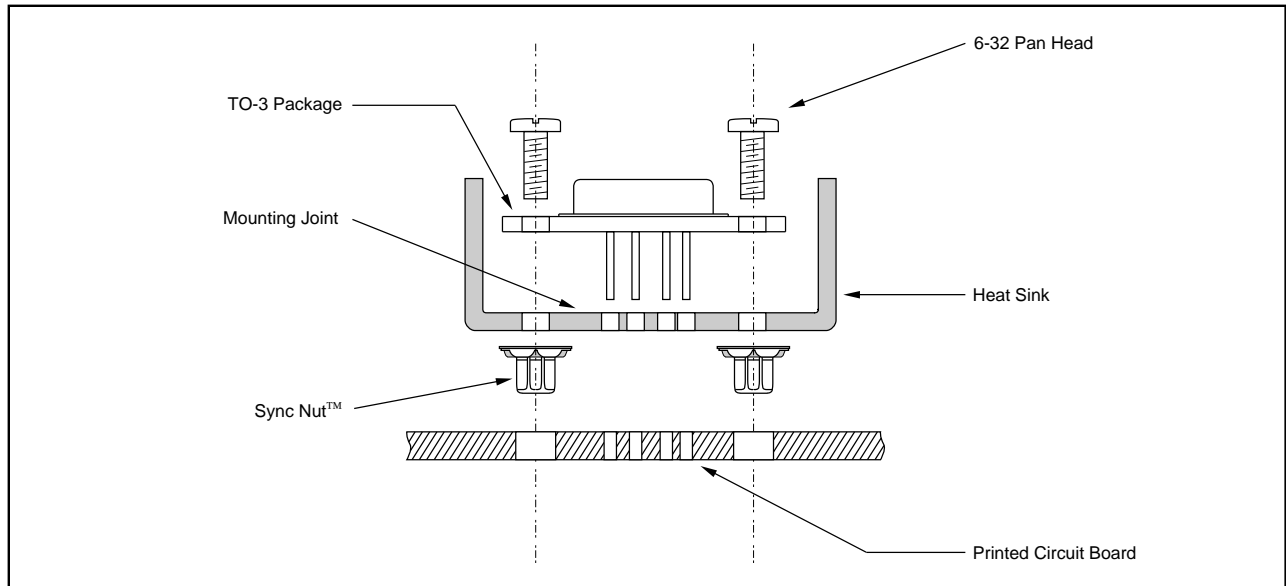


FIGURE 1B. Low Power Application Using Printed Circuit Board.

achieve low thermal resistance⁽¹⁾. The Belleville washer does not bottom out and therefore can absorb the thermal expansion of the package⁽²⁾ or any slight compression of the socket material that may occur over time. An excellent variation of the conical washer is called the Sync Nut™ and is available from EG&G Wakefield. It includes a spring washer as part of the nut.

The Belleville washer should be installed on the board or heat sink side of the fastener, *not* on top of the package flange. Install the large face of the Belleville washer toward the mounting surface. When tightening against a board or 0804MC socket, install an additional No.6N (narrow) flat washer against the relatively soft material to insure that the Belleville washer functions correctly. Tighten the fasteners slowly, and alternate between them until both are tighten to the specification.

The recommended tightening torque is 6 inch-lbs., with an acceptable range of 4 - 7 inch-lbs. (0.45 - 0.79 N-m).

Avoid contaminating the fastener threads with thermal grease since it can change the torque readings. Over-tightening the fasteners can damage the package or internal substrate, under-tightening can lead to poor thermal performance. Re-torquing may be required after environmental screening operations such as burn-in. For permanent installation, an all-metal locknut is preferred. Don't use locknuts with plastic inserts.

TO-3 HOLE PATTERN

A good mounting joint between the TO-3 package and the heat sink requires a properly machined mounting hole pattern. Never drill out a single (large diameter) clearance hole for the package pins. Drill individual holes for each pin. Follow the TO-3 hole pattern illustrated in Figure 2. For best thermal performance, use a minimum hole size of 0.073 inch (#49 drill). Smaller holes could interfere with the glass seal around each pin.

| | BEST | ACCEPTABLE | NOT RECOMMENDED |
|---|---|------------------------------|---|
| Material | Stainless Steel | Plated Steel | Brass, Plastic |
| Fastener Head | Pan | Round, Hex | Binding, Flat, Oval, Truss, Fillister, Socket, Hex Washer |
| Washers | No.6 Belleville ⁽¹⁾ + No.6N Flat | No.6N Flat | |
| Nut | 5/16" Full, Sync Nut™ | 1/4" Hex Threaded, 1/4" Full | |
| Locking Device | 5/16" Locknut ⁽²⁾ | Split Ring ⁽³⁾ | Star Washer |
| NOTES: (1) Recommended No.6 Belleville washer is available from ASMCO (part number 24087; diameter 0.312"; rated 78lbs initial force). (2) For high power use all metal type, elastic inserts not recommended. (3) Not recommended for high power or temp cycling conditions. | | | |

TABLE I. 6-32 Fastener Hardware.

To avoid shorting the pins to the heat sink, use #18 Teflon tubing to sleeve all pins. Make sure the sleeve length is slightly less than the thickness of the heat sink. Most pre-drilled heat sinks use larger 3/32 (0.094") holes for the pins, and sleeving is not required so long as a socket or PC board pattern is used. You may still want to sleeve at least two opposite pins to help center the package. When wiring directly to the pins, all pins should be sleeved, regardless of the hole size used.

A word of caution concerning anodized heat sinks. Unless you know what type of anodizing was used, do not trust the anodizing to provide electrical insulation. Refer to the section called "Heat Sink Surface Treatment" for more information.

MOUNTING SURFACE PREPARATIONS

In general, the heat sink mounting area should have a flatness and finish comparable to that of the TO-3 package. When

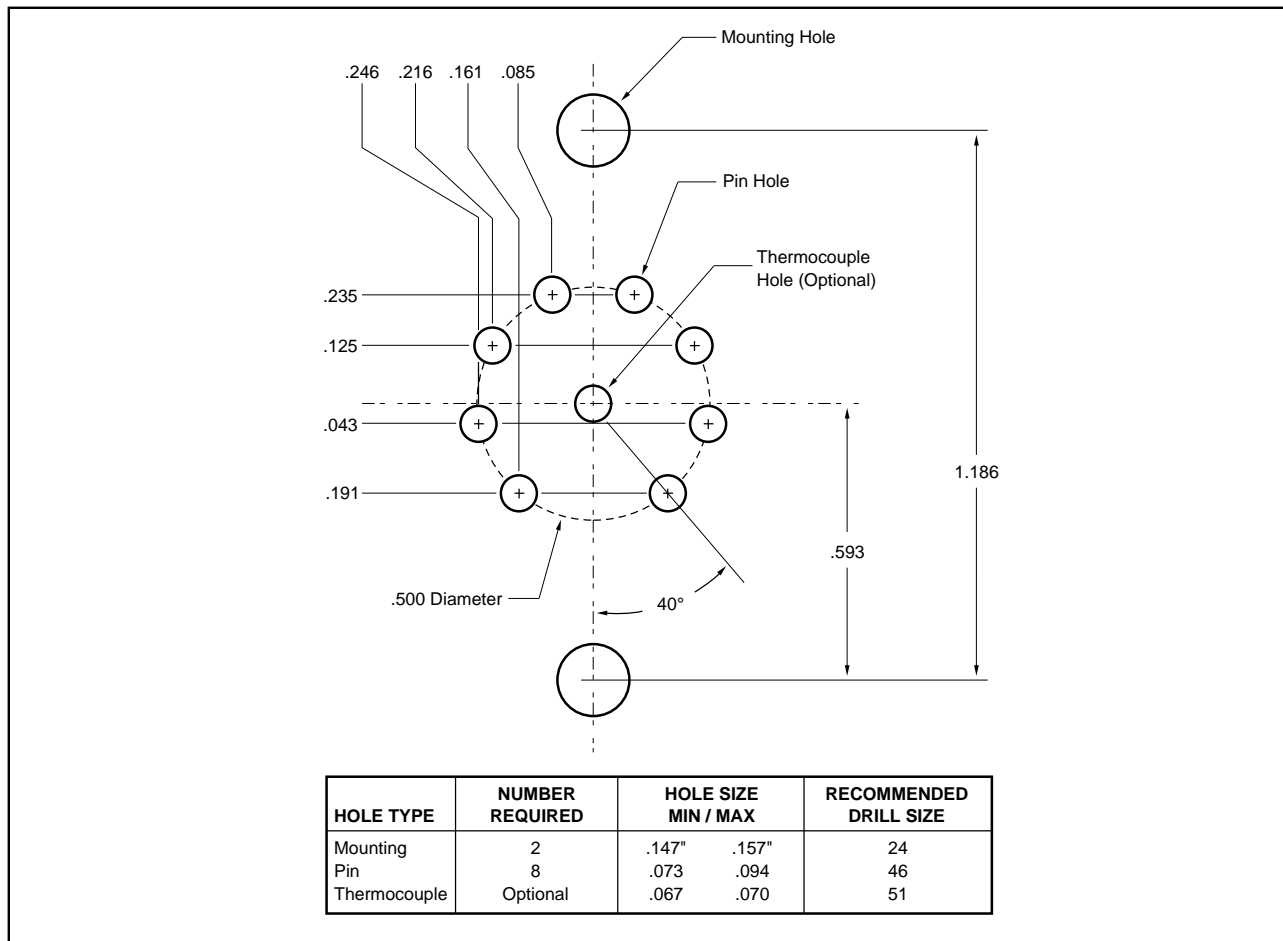


FIGURE 2. TO-3 Hole Pattern.

using thinner, low power heat sinks, it is sufficient that the mounting area appears flat against a straight edge. When mounting on thicker material, surface flatness is important not only for thermal performance, but to avoid distorting and stressing the package base when it is tightened down.

HEAT SINK SURFACE FLATNESS AND FINISH

JEDEC recommends a surface flatness of 0.004 inch/inch max. The standard flatness tolerance for most extruded heat sinks is 0.004 inch/inch, maximum, which results in typical values closer to 0.002 inch/inch. Surface finish is normally specified around 60 micro-inches (rms). Testing has shown that this is acceptable for most high power applications⁽³⁾. It is a good practice to polish the mounting area with No. 000 steel wool, followed by an acetone or alcohol rinse, immediately prior to assembly.

For best thermal performance, the mounting area of the heat sink can be spot faced. This removes oxidation or anodization and improves the surface flatness and finish. When using thermal pads instead of thermal grease, a surface flatness of 0.001 inch/inch is recommended. When mounting the TO-3 package to panels, brackets, or other structural members of the system, spot facing may be required to insure the proper flatness and finish.

HEAT SINK SURFACE TREATMENT

The typical surface treatment for aluminum heat sinks is black anodized⁽⁴⁾ per MIL-A-8625, Type II. This surface treatment prevents corrosion and maximizes thermal performance. Do not trust this surface treatment to provide electrical insulation. For electrical insulation, always specify hard anodized, 0.001 inch thick, per MIL-A-8625, Type III. This *file hard* surface treatment resists scratches and punctures, and is typically rated for 200VDC electrical insulation for a 0.001 inch thick treatment.

HEAT SINK THRU-HOLES

Be wary of heat sinks with punched, rather than drilled, thru-holes. If not properly done, the area around each punched hole can be depressed into a crater with a raised lip or mound on the opposite side. This irregular surface can significantly degrade thermal performance.

For high power, extruded heat sinks, the general practice is to drill the hole pattern. All holes should be de-burred. The holes for the TO-3 pins should not be chamfered too deeply, as this will reduce the contact area of the mounting joint. Unless special precautions are taken, threading the TO-3 mounting holes is not recommended. The threading process can also leave a raised mound around each hole. Threading the mount-

ing holes also eliminates the possibility of using Belleville washers and locknuts for proper control of mounting pressure.

MOUNTING THERMAL RESISTANCE

Even if all of the proper mounting preparations are followed, the thermal resistance at the mounting joint will consist largely of small air gaps. Only a small percentage of the mounting area will actually have metal-to-metal contact. To minimize the thermal resistance, these gaps must be filled with a stable, thermally conductive material. Table II describes the common thermal fillers available and the performance that can be expected. Note that the tightening torque of the mounting fasteners also affects thermal performance⁽⁵⁾.

| DESCRIPTION | θ_{CH} (°C/W) | APPLICATION | HEAT SINK FLATNESS REQUIREMENTS |
|---|----------------------|-----------------------|--|
| Bare Joint | 0.5 - 1.0 | Low power only | Very sensitive to variations in flatness and finish |
| Thermal Grease | 0.1 - 0.2 | High Power | Not sensitive, standard .004 inch/inch (max) ok |
| Aluminum Foil ⁽¹⁾ (pre-coated with alumina filled silicone) | 0.2 - 0.4 | High Power | For lowest θ_{CH} , .001inch/inch (typ) recommended |
| Aluminum Foil ⁽²⁾ (pre-coated with thermal grease) | 0.2 - 0.4 | High Power | For lowest θ_{CH} , .001inch/inch (typ) recommended |
| Kapton ⁽³⁾ (pre-coated with thermal grease) | 0.3 - 0.5 | Electrical Insulation | For lowest θ_{CH} , .001inch/inch (typ) recommended |
| Silicon Rubber (compressible) | 0.4 - 1.0 | Electrical Insulation | See Text |
| Mica (bare) | 1.0 - 1.5 | Electrical Insulation | Not recommended Mica is brittle and prone to crack |
| Mica (with thermal grease) | 0.3 - 0.4 | | |

NOTE: (1) Available from BERGQUIST, part number QI-88 (with .094 inch holes). (2) Available from Power Devices, part number AL-155-10C. (3) Available from Crayotherm, part number TO-3-8 CR2-MT. See Appendix for manufacturers listings.

TABLE II. Thermal Interface Options For TO-3 Packages.

Understanding the thermal model of the system will enable you to make the best mounting compromises. Consider the simplified thermal model in Figure 3. The mounting thermal resistance is represented as θ_{CH} (case-to-heat sink). The overall thermal resistance is represented by θ_{JA} (junction-to-ambient). For low power applications, θ_{JA} can be as high 30°C/W. In this case, the mounting thermal resistance is not a significant portion of the overall thermal resistance. For high power applications, θ_{JA} can be as low as 1°C/W. Then it is critical to obtain a low θ_{CH} . For example, at a power dissipation of 50W, an additional 0.5°C/W mounting thermal resistance will increase the junction temperature by 25°C.

BARE MOUNTING

For no-load or low power applications, you can mount the TO-3 package bare against the heat sink. For high power applications, this is not recommended, even if the extra thermal resistance is acceptable. This is because the thermal resistance of a bare joint can vary greatly depending on the surface flatness and finish of the heat sink.

THERMAL GREASE

For the lowest θ_{CH} , thermal grease should be used in conjunction with a properly machined and finished mounting surface. This combination will result in a θ_{CH} of about 0.1°C/W. Using the proper fastener hardware is critical for maintaining this low thermal resistance over time and temperature.

There are many suppliers of thermal grease (also known as heat sink compound). Thermal grease is a formulation of fine zinc oxide or other thermally conductive, electrically insulating, particles in a silicone oil or other synthetic based fluid. The shelf life for most thermal greases is indefinite when kept sealed in its container, but over time, the oil may separate out. Mixing the components back together before use will restore the thermal properties.

Thermal grease should not be applied in excess, the objective is to fill the air gaps, not decrease the amount of metal-to-metal contact. Slight rotation of the TO-3 package against the heat sink will promote even spreading. With the correct amount applied and the fasteners properly torqued, a very small bead of thermal grease should appear around the perimeter of the TO-3 package. Although the grease may dry up over time, this does not degrade the thermal resistance provided the mounting joint remains tight.

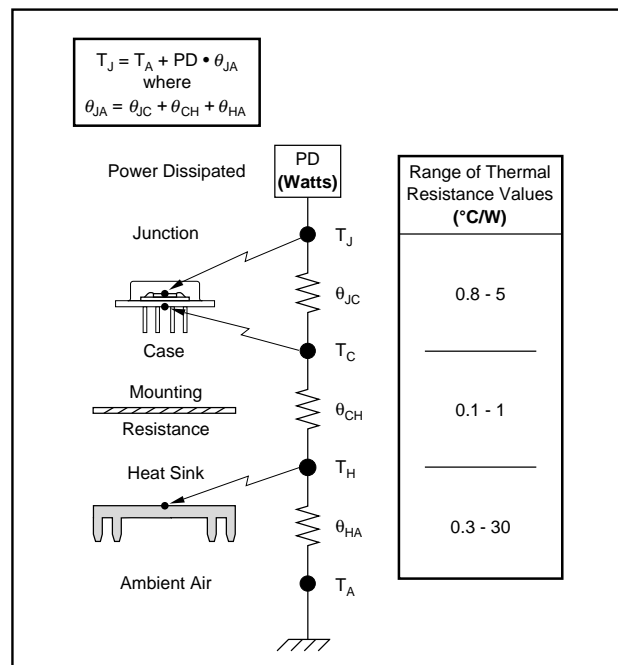


FIGURE 3. Simplified Thermal Model.

THERMAL PADS

Thermally conductive pads offer a cleaner, simpler method for improving the thermal interface. The lowest θ_{CH} attainable using a thermal pad is about $0.2^{\circ}\text{C}/\text{W}$, which is almost as good as thermal grease. However, one should approach with caution the multitude of different materials, designs, and applications for thermal pads.

Basically there are two types of thermal pads, electrically insulating and electrically conductive. Electrically insulating pads are designed to be used with discrete transistor TO-3s, which do not have an electrically isolated package. In general, they do not provide a low enough θ_{CH} for high power use because a dielectric layer must be sandwiched into the pad. Hybrid TO-3s with isolated headers do not require electrically isolated pads. They can use electrically conductive pads. Without the need for a dielectric layer, a very low θ_{CH} can be achieved, almost as good as thermal grease.

While they do a good job of filling small air gaps, all thermal pads suffer the same problem when used against heat sinks with standard flatness tolerances of 0.004 inch/inch. They do not flow to conform with the surfaces as does thermal grease. Therefore, it is recommended that whenever thermal pads are to be used, the mounting area should be spot faced to a typical surface flatness of 0.001 inch/inch. Silicon rubber pads are also sensitive to surface flatness⁽⁶⁾. Approach these with caution. Most do not improve thermal performance over a bare joint. The compressibility of these rubber pads can cause the package header to flex and possibly crack the internal substrate. They can also settle over time and temperature, resulting in loose fasteners and low mounting pressure.

SUGGESTED MOUNTING SCHEMES

The mounting schemes presented here address the more common operating conditions for TO-3 power products (see Figure 4). These conditions include high power operation, low power operation, and functional testing under unloaded, quiescent conditions. The options are for the 0804MC socket, individual cage jacks, and direct PC board soldering. Table III describes the recommended cage jacks.

| MANUFACTURER | PART NUMBER | DRILL SIZE INCHES (NUM) | COMMENTS |
|----------------|-------------------------|-------------------------|--|
| Cambion | 450-3716-01-03 | .076 48 | Knock-out bottom permits wave soldering. |
| Concord | 09-9047-1-03 | .104 37 | Heavy duty, open ended. |
| SPC Technology | MC76 | .089 43 | PC board press fit. |
| Mil-Max | 0325-0-15-01-34-27-10-0 | .089 43 | Closed end, accepts full pin length. |

(See Appendix for manufacturers listings)

TABLE III. Recommended Cage Jacks.

FUNCTIONAL TESTING AND NO-LOAD CHARACTERIZATION

For functional testing and no-load characterization at room temperature, heat sinking may not be required. These mounting schemes are the least critical and easiest to fabricate. When using the 0804MC socket, the socket can be mounted directly to the test box or PC board by drilling a single clearance hole for all eight socket contacts. The hole should be (0.63 - 0.75) inches in diameter. Be careful not to short the copper cladding or metal box to any of the contacts. The socket body should be mounted using flat head machine screws. For electrical insulation, nylon flat head machine screws may be used instead. When using cage jacks, follow the TO-3 hole pattern illustrated in Figure 2. Use close ended cage jacks whenever possible to avoid solder contamination.

LOW POWER OPERATION

The mounting schemes for low power applications are an extension of those used for functional testing and no-load characterization. The difference is that a small heat sink is must be attached to the TO-3 package. The overall thermal resistance (θ_{JA}) for low power applications can be relatively high, from 5 - $30^{\circ}\text{C}/\text{W}$. Therefore, θ_{CH} is not as critical as for high power operation. In most instances, the TO-3 package can be mounted bare.

Low power heat sinks are usually stamped rather than extruded, and some even press fit around the TO-3 cover. They are called "low power" or "standard" heat sinks (versus "high power" or "extruded" heat sinks used for high power operation). The thermal resistance of these types of heat sink range from 3 - $20^{\circ}\text{C}/\text{W}$, depending on their size, weight, and design.

Low power mounting schemes are commonly used on PC board applications. For these applications, heat sink manufacturers have developed many custom accessories such as wave solderable fasteners and thermally conductive pads. These must be approached with caution. It is important to follow the specific recommendations of this bulletin. Thermal pads are discussed in the section called "Thermal Mounting Resistance".

The recommended fastener for PC board applications is the Sync Nut™. This fastener allows the TO-3/heat sink combination to be wave soldered directly to the board. Re-torquing should be performed after any wave solder. For low power applications that do not involve temperature cycling, split ring lock washers may be safely used.

HIGH POWER OPERATION

Mounting schemes for high power operation involve the use of larger, heavier heat sinks, that are machined rather than stamped. Their size and weight usually requires that they be integrated into the system layout, rather than simply attached to the TO-3 package. In general, they are cut to length from extruded sections, thus are often called "extruded" heat sinks.

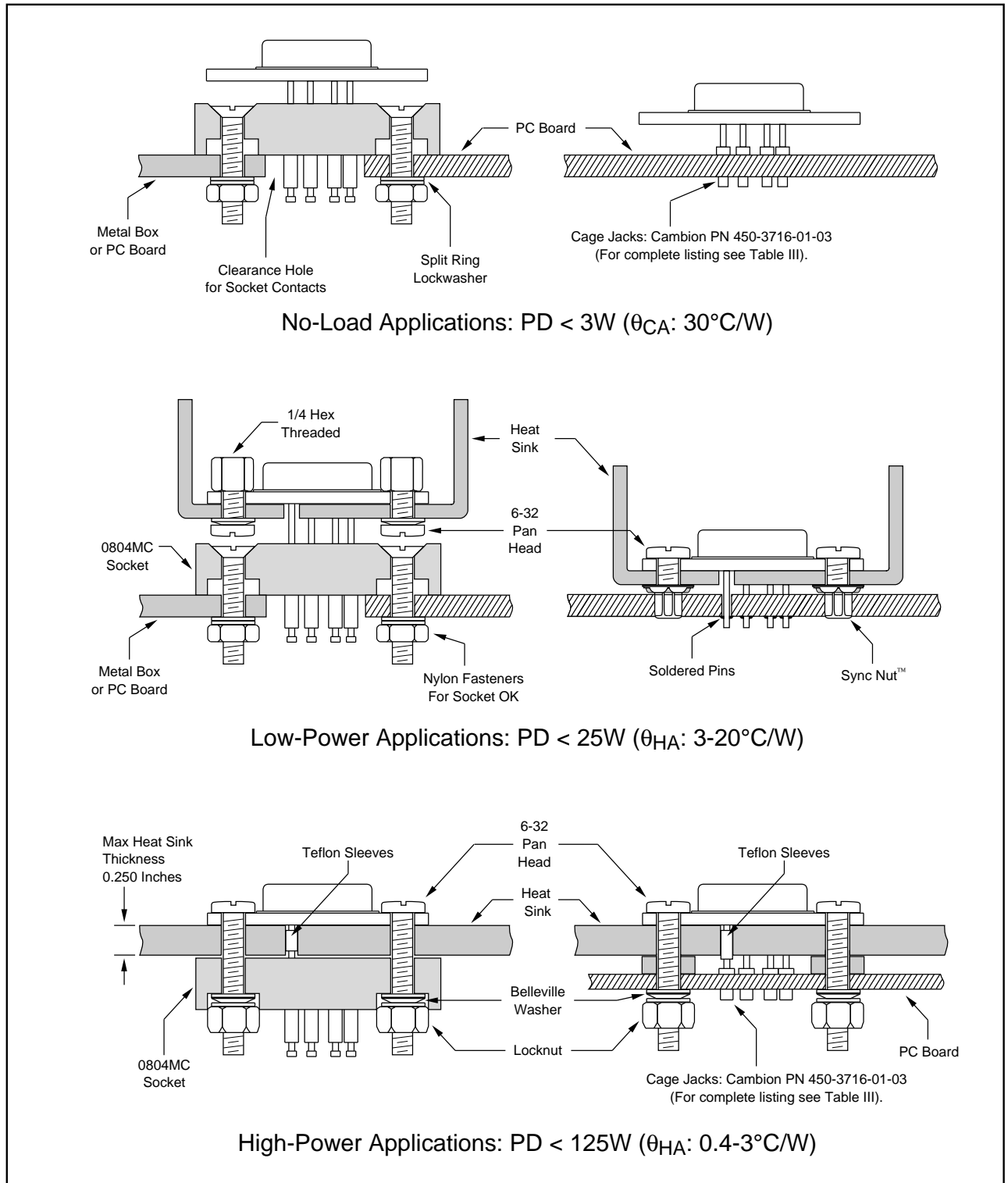


FIGURE 4. TO-3 Mounting Examples.

The thermal resistance of these types of heat sink range from 0.4 - 3°C/W for operation in still air. With forced air, θ_{HA} can be reduced by one-half to two-thirds.

For high power applications, the overall thermal resistance (θ_{JA}) can be as low as 1°C/W. Under these conditions, obtaining a low θ_{CH} is critical. To insure a good mounting joint, use the recommended fastener hardware and surface preparations as described in the previous sections of this application bulletin.

THERMAL MEASUREMENT AND EVALUATION

It is always a good idea to check the TO-3 mounting scheme by measuring the package case temperature (T_C) under actual operating conditions. The semiconductor junction temperature (T_J) can then be calculated from the case temperature, as indicated in Figure 3 :

$$T_J = T_C + PD \cdot \theta_{JC}$$

where PD is the total power dissipation (including quiescent power) and θ_{JC} is the junction-to-case thermal resistance (given in the product data sheet). The calculated junction temperature should be less than the maximum allowable temperature indicated by the product data sheet (typically 150°C).

The true case temperature is located directly below the substrate and centered within the package pins (see Figure 5). This location, called the case backside, will also give the most repeatable measurements. To directly access the case backside, drill the heat sink with the optional thermocouple hole⁽⁷⁾ as illustrated in Figure 2. The recommended thermocouple is

an Omega fast-response probe (part no. SDX-SET-RT-K-SMP). Allow enough time for the system to reach thermal equilibrium. A touch of thermal grease on the probe tip will ensure good thermal contact.

The package case temperature can also be estimated by fitting a spade-lug type thermocouple under the head of the mounting fastener. This will give the temperature at the mounting flange of the package rather than the case backside. The case backside will actually be hotter than the mounting flange. The difference can be as large as 10°C, depending on the power dissipation, mounting thermal resistance, etc. For high power applications, it is recommended that the case backside temperature be measured directly, at least for the prototype setup.

References:

- (1) Thermalloy catalog #90-HS-11 (page 13), Figures 6 and 8.
- (2) EG&G Wakefield catalog, printed 4/90 (page 103), "115, 116, 117, & 118 Series SyncNut".
- (3) Thermalloy catalog #90-HS-11 (page 12), "Test Results".
- (4) Thermalloy catalog #90-HS-11 (page 9), "Available Finishes".
- (5) Thermalloy catalog #90-HS-11 (page 13), Figures 6 and 8.
- (6) Thermalloy catalog #90-HS-11 (page 106), "Test Method Comparison — TO-3 Silicon Rubber Insulators".
- (7) The optional thermocouple hole will not increase the mounting thermal resistance significantly. The difference cannot be measured experimentally. Computer simulations indicate an increase of less than 0.02°C/W.

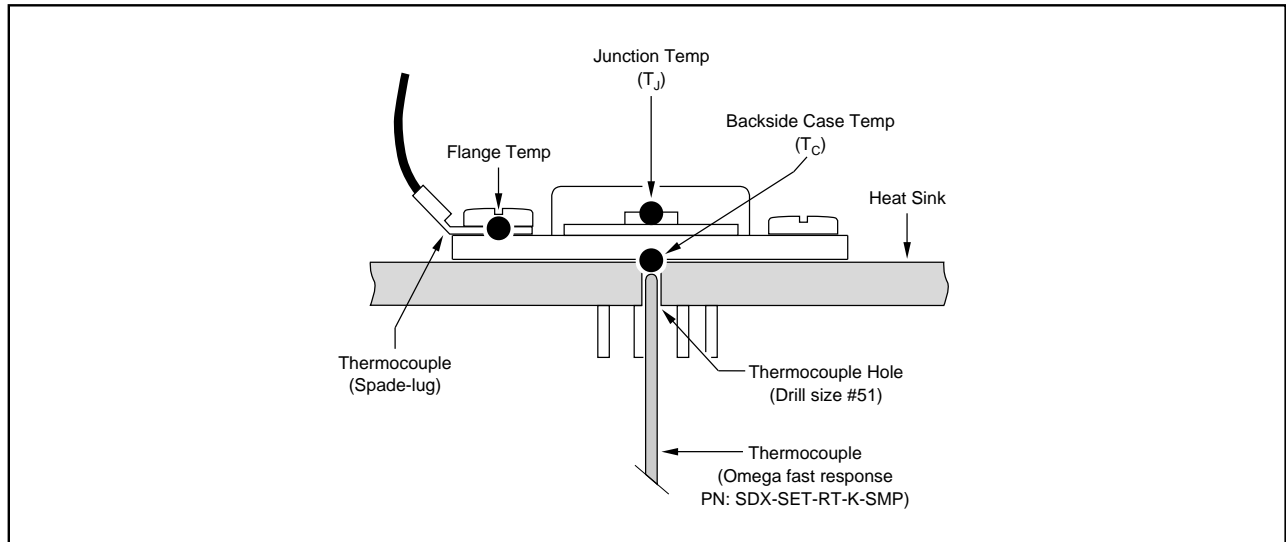


FIGURE 5. Package Case Thermal Measurement.

APPENDIX

| MANUFACTURER | TO-3 SOCKET | GAGE JACKS | THERMAL GREASE | THERMAL PADS | HEAT SINKS | TEFLON TUBING | FASTENER HARDWARE | TEMP MEAS | ASM TOOLS |
|-------------------|-------------|------------|----------------|--------------|------------|---------------|-------------------|-----------|-----------|
| BURR-BROWN | 0804MC | | | | | | | | |
| CTI | X | | | | | | | | |
| CONCORD | | X | | | | | | | |
| Cambion | | X | | | | | | | |
| Mill-Max | | X | | | | | | | |
| NEWARK | | X | | | X | | X | | |
| Thermalloy | | | X | | X | | | | |
| AAVID Engineering | | | X | | X | | | | |
| EG&G Wakefield | | | X | | X | | X | | |
| BERGQUIST | | | | X | | | | | |
| Power Devices | | | | X | | | | | |
| Crayotherm | | | | X | | | | | |
| Alpha Wire | | | | | | X | | | |
| SPC Technology | | | | | | X | | | |
| McMASTER-CARR | | | | | | | X | | X |
| ASMCO | | | | | | | X | | |
| OMEGA | | | | | | | | X | |

TABLE IV. Sources of TO-3 Mounting Hardware.

Alpha Wire Corp.
711 Lidgerwood Ave.
Elizabeth, NJ 07207-0711
(908) 925-8000

CONCORD
30 Great Jones St.
New York, NY 10012
(212) 777-6571

NEWARK Electronics
4801 N. Ravenswood Ave.
Chicago, IL 60640-4496
(312) 784-5100

ASMCO
19 Baltimore St.
Nutley, NJ 07110
(201) 661-2600

Crayotherm Corp.
1185 N. Van Home Way
Anaheim, CA 92806
(714) 630-2696

OMEGA
One Omega Drive
P.O. Box 4047
Stamford, CT 06907
(203) 359-1660

AAVID Engineering, Inc.
One Kool Path
P.O. Box 4000
Laconia, NH 03247
(603) 528-3400

CTI Technologies, Inc.
7855 E. Evans Road, Suite A
Scottsdale, AZ 85260-3411
(602) 998-1484

Power Devices
27071 Cabot Road, Bldg. 114
Laguna Hills CA 92653
(714) 582-6712

BERGQUIST
5300 Edina Industrial Blvd.
Minneapolis, MN 55435
(612) 835-2322

EG&G Wakefield
60 Audubon Road
Wakefield, MA 01880
(617) 245-5900

SPC Technology
4801 N. Ravenswood Ave.
Chicago, IL 60640
(312) 907-5181

Cambion Division
MIDLAND ROSS
One Alewife Place
Cambridge, MA 02140
617) 491-5400

McMASTER-CARR
P.O. Box 54960
Los Angeles, CA 90054-0960
(213) 692-5911

Thermalloy, Inc.
2021 W. Valley View Lane
P.O. Box 810839
Dallas, TX 75381-0839
(214) 243-4321

Mill-Max Mfg. Corp.
P.O. Box 300
190 Pine Hollow Road
Oyster Bay, NY 11771-0300
(516) 922-6000

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