International
IOR Rectifier

IR Application Note AN-994

TITLE:

Maximizing the Effectiveness of Your SMD Assemblies

Notices:
(HEXFET is the trademark for International Rectifier Power MOSFETs)

Summary:

Topics Covered:

IR Application Note AN-994

(Section 1 of 11)

Title:

Maximizing the Effectiveness of Your SMD Assemblies

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I. Thermal characteristics of surface-mounted packages

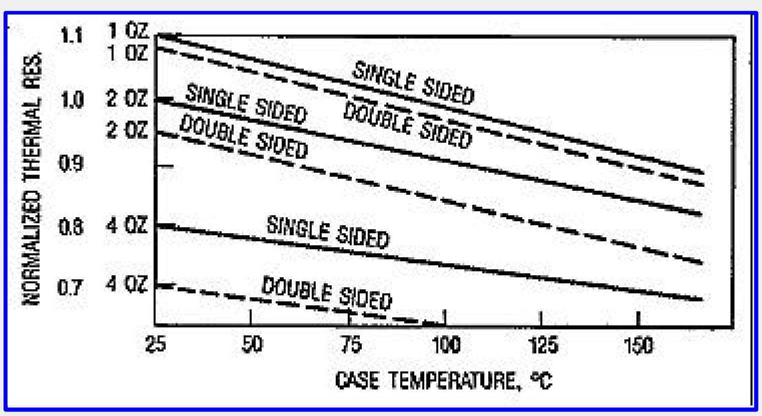
The following data (Table 1) summarizes power rating and printed circuit board mount thermal resistance figures (RJA) for IR's current family of surface mount devices. For newer devices such as the Micro3 and Micro8, International Rectifier is standardizing device rating on minimum recommended footprint which is based on the actual footprint that most closely resembles end users' applications.

TABLE 1.

Package Style		$R_{\theta JA}$ Rating (°C/W)		Max. P_d Rating @ T_c = 25°C (Watts)		Linear Derating Factor (W/°C)	
		1" Square Copper Clad Board (1)	Min. Recommended Footprint	1" Square Copper Clad Board	Min. Recommended Footprint	1" Square Copper Clad Board	Min. Recommended Footprint
SMD-220		40	+	3	•	0.025	+
D-PAK		50	+	2.5	+	0.020	+
SOT-223		60	+	2.0	+	0.016	+
SO-8	Single	80	125	1.6	1	0.013	0.008
	Dual	50(2)	190(2) (300)(3)	1.4(2)	0.66(2) (0.42)(2)	0.011(2)	0.005(2) (0.003)(3)
SOT-89		70	+	1.8	+	0.014	+
Micro8	Single	70	160	1.8	0.78	0.014	0.006
	Dual	100(2) (140)(3)	200(2) (300)(3)	1.25(2) (0.9)(3)	0.62(2) (0.42)(3)	0.010(2) (0.007)(3)	0.005(2) (0.003)(3)
Micro3		+	450	•	0.28	+	0.002
SMC		+	46	+	2.7	+	0.022
SMB		+	140	•	0.9	+	0.007
D-64		+	160	+	0.78	+	0.006
D-61		(4)	–	–	–	–	–

When using epoxy glass boards with different copper cladding thicknesses the thermal resistance values can be calculated as shown in Figure 1.

Figure 1.



Normalized Thermal Resistance vs. Case Temperature

Note: Copper Cladding Weights are Oz/sq. ft. and attachment is by 60-40 reflow solder mount.

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II. How we measure Rth JA

Total thermal resistance (RJA) for semiconductor devices consists of the sum of all thermal resistances between the junction and the ambient environment. Measurement of RJA requires a method to measure the ambient and junction temperatures as well as the power dissipation (Pd). The formula for junction to ambient thermal resistance is:

$$\boxed{R_{\theta JA} = \frac{(T_j - T_A)}{P_d}}$$

To measure the junction temperature, a temperature sensitive electrical parameter such as $R_{DS(ON)}$ is used. This parameter changes approximately 1%/deg.C, providing adequate change for an accurate temperature measurement. To measure RJA first $_{RDS(ON)}$ is calibrated at maximum junction temperature. Then the device is mounted on an industry standard one inch square copper-plated printed circuit board (the new SO-8, Micro8 and Micro3 devices are also tested on a printed circuit board using the minimum recommended footprint). Power is applied to the device and after the junction temperature is stabilized at its calibrated value, Pd and TA are measured to calculate RJA (for detailed procedure refer to design Tip DT 94.17).

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III. How we measure Rth JC

Because of the need for accurate calculation of junction temperatures International Rectifier provides RJC values for SMD packages containing a header where the die is mounted. Micro3, S0-8 and Micro8 devices that do not have a header are characterized with RJA figures.

These values are measured by clamping the device to an "infinite heat sink," in this case a copper block 10 cu. in. in volume which can be held at a known temperature. Water cooling passages are drilled in the copper block. Cold water is run through the block during the test, thus maintaining a temperature in the 20 - 25deg.C range. A small (0.040 DIA) thermo-couple is inserted into another drilled passage so that it rests against the center of the mounting surface of the SMD. This allows the actual mounting surface temperature to be accurately measured.

The actual test method involves the calibration of a temperature dependent parameter (such as a diode VF), which is performed by exposing the device to a temperature calibration cycle and measuring the VF at a known test current (usually 10mA).

When the calibration curve is obtained the device is subjected to a pulse power test where a known power level is applied (VF X IF) at a high duty cycle and then the current is reduced to 10mA for the measurement period of approximately 10mSec. Thus the junction temperatures can be measured from the calibration curve and hence RJC values (deg.C/watt) can be calculated from the expression:

TJ = (RJC x VF x IF) + TA

$$\boxed{R_{\theta JC} = \frac{J_C - T_A}{V_F x I_F} = \frac{\Delta T}{P_D} \circ C / W}$$

Thermal resistance RJC of a given package style is somewhat affected by die size but only to a second order effect in the smaller packages. The reason for this is that the dominant thermal resistance is outside the package or, put another way, a copper clad board is a poor heatsink compared with an aluminum plate or extrusion, typically more than an order of magnitude worse.

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IV. Thermal design

As with any power semiconductor device, the current carrying capability is determined by the ability of the package to dissipate heat. The peak junction temperature can be calculated as follows:

Tj = Ta + Pt (RqJC + RqCS + RqSA)
= Ta + Pt * RqJA

where:

Tj	= junction temperature
Ta	= ambient temperature
Pt	= total power dissipation in the device (conduction losses, switching losses, leakage losses, etc.)
RJC	= thermal resistance, junction-to-case
RCS	= thermal resistance, case-to-sink
RSA	= thermal resistance, sink-to-ambient
RJA	= thermal resistance, junction-to-ambient

Conversely, fixing the peak junction temperature permits the allowable power dissipation to be calculated.

In the case of surface mounted devices, the heatsink is usually the printed circuit board or ceramic substrate to which the device is soldered. The sink-to-ambient thermal impedance will depend on the board or substrate material, the pad area available for heat spreading, the proximity of other additional thermal loads on the board, and the velocity of air flow (in the case of forced cooling). Figure 2 shows how the thermal resistance of a three-inch square printed circuit board varies with pad area and air velocity. The data given in this graph should be used with caution, since local air flow can be modified by the shadowing effect of other components. Often, only prototype testing can prove the adequacy of a particular thermal design.

The heat sinking capacity of the board or substrate depends on the thermal conductivity of the board material. The reduction in thermal resistance that can be obtained depends on the material, the thickness of the material, and on the effective area of the board, as well as the air velocity. These factors can interact in a non-linear manner.

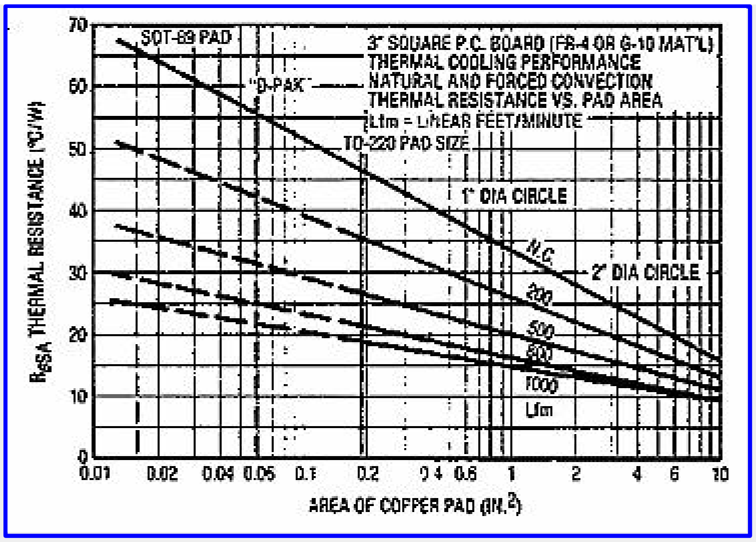

Figure 2. Thermal Resistance of 3-inch Square Printed circuit Board

All of the above data concerns the use of epoxy-glass substrates with various weights of copper cladding. SMDs are also used extensively in hybrid modules where the substrates may be alumina (Al2O3), aluminum nitride AIN, IMS (insulated metal substrate) usually aluminum with a film insulator and copper cladding up to 4 oz/sq. ft., or occasionally beryllium oxide BeO for some military or hi-rel hybrids. All of these substrate materials are superior to epoxy-glass substrates. Figure 3 shows their relative thermal resistances compared with FR-4 epoxy-glass.

Note that BeO is a toxic substance and is rapidly being phased out in military and hi-rel applications.

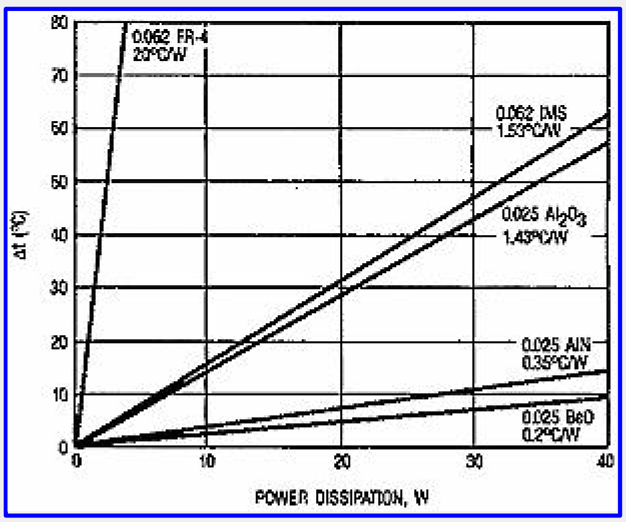

Figure 3. Thermal Resistance of 1" x 1" Substrates at 100deg.C

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V. Handling static sensitive devices

The following measures should be taken to prevent damage to the MOS-gated devices (IGBTs and MOSFETs) from electrostatic discharge (ESD):

- Always store and transport MOSFETS and IGBTs in closed conductive containers.
- Personnel who handle MOS-gated devices should wear a static dissipative outer garment and should be grounded at all times.
- Floors should have a grounded static dissipative covering or be treated with a static dissipative compound.
- Tables should have a grounded static dissipative covering.
- Avoid insulating materials of any kind while handling MOSFETs or IGBTs, since these materials may acquire a static charge, which, if discharged through them, could destroy them.
- Always use a grounded equipment for any operation related to MOS-gated transistors.
- Test HEXFETs only at a static-controlled work station.
- Use all of these protective measures simultaneously and in conjunction with trained personnel.
- More detailed information on protection against ESD is available in AN-955.

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VI. Mounting guidelines

By far the most popular mounting technique is by soldering to the substrate using low melting point solders such as Sn60, Pb40.

There are several ways of doing this which may be broken down into the following operations:

1. Fluxing the areas to be soldered.

2. Attaching the SMDs in the correct locations prior to soldering.

3. Applying heat to fuse the solder.

4. Cleaning the assembly to remove flux residues.

These operations are described in detail in the following Sections.

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VII. Attachment to board

Most designers and technicians in the electronics industry are familiar with printed circuits that are provided with holes to support leaded components during the soldering process, usually a wave solder process. Surface mount components are by definition leadless and rely on the strength of the solder joint alone for mechanical support as well as electrical connection. The problem of mechanical support can be solved by the use of adhesives that maintain the positions of SMDs on the substrate prior to soldering but are not needed and perform no function after the soldering process.

The adhesive used must provide sufficient tenacity to prevent component movement during handling and soldering but preferably provide a bond which can be broken without substrate damage in order to replace incorrect components before soldering.

It must also be capable of maintaining adhesion during the preheat cycle and it should not become a deterrent to solder flow during the reflow or wave soldering process. The ideal adhesive meeting the above criteria and providing inert residues soluble in common environmentally friendly solvents, probably does not exist. However, there are many solder pastes on the market at present which perform in a single application the functions of SMD attachment and fluxing with only the choice of heat application methods left to the user (vapor phase, infra-red, or thermal conduction).

Typical adhesives of this type are made from non-activated resins (R) which are used in forming gas atmospheres to reduce oxides and some are mildly activated resins (RMA) which can be used in normal factory environments. The activation in this case is used to reduce small amounts of oxidation of the solderable surfaces and the solder particles in the paste.

A solvent is used with RMA or R type fluxes as the vehicle to permit the deposition of these films of solder paste on the substrate when using a solder mask. After component placement on the tacky surface of the substrate, the flux is cured by evaporation of the solvent which then improves component adhesion by an order of magnitude, permitting normal handling and soldering operations to be performed.

If wave soldering is the method of choice, an RMA flux can be applied by spraying, brushing, dipping etc. over the entire assembly prior to soldering. This obviates the need for a solder mask but forms better joints if the substrate is pre-tinned before the SMDs are attached.

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VIII. Solder pastes

In today's densely populated assemblies, pin spacing of SMD components, particularly LSI chips which can have as many as 256 pins has of necessity been reduced to almost microscopic distances. In a typical 256 pin flat pack the pin spacing is only 0.4mm and solder bridging precludes the use of wave soldering systems. Even the more advanced double wave systems are really not capable of resolution this fine.

A variety of solder pastes is available today which permit reflow soldering of very high density boards but of course the registration accuracy of the solder masks and the particle size and metal content of the pastes are all critical to successful soldering of these assemblies.

The volatile component of solder pastes may be alcohol or water, either of which can be evaporated by a carefully designed preheat cycle leading up to the solder fusing cycle. In actual use, the solder paste is applied immediately prior to pick and place component placement and the solvent is then evaporated.

Resin based flux residues must be removed by spraying with a solvent such as FREON TMS which is primarily a trichlorotrifluoroethane liquid which is used below boiling point to reduce the problems of vapor loss and environmental contamination.

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IX. Heat profiles

Reflow Soldering Heat Profiles

A major problem associated with surface mounting of electronic components, especially those with mismatched internal expansion coefficients is the thermal shock of the soldering process.

To prevent mechanical failure of SMDs in the soldering process, a carefully controlled preheat and post cooling sequence is necessary.

This thermal conditioning can be applied in several ways such as infra-red heating, a belt furnace with different temperature zones or by conduction where the substrates are placed on a moving belt which passes over heating elements to vaporize flux solvents and preheat them prior to soldering.

A similar preheating and solder reflow process can be performed with vapor phase heating using a boiling fluorocarbon liquid and lowering the populated substrates into the vapor cloud above the boiling liquid at around 215 -220deg.C. This method provides much closer temperature control than infra-red heating which heats some components better than others, but the high cost of the fluorocarbon liquid, some of which escapes during the process, coupled with a relatively slow throughput makes vapor phase processing less attractive than infra-red or belt furnace techniques.

Most solder alloys are eutectic or close to it, 60Sn, 40Pb or 63Sn, 37Pb being two of the alloys most often used in reflow or wave soldering equipment. Fusing temperatures for both alloys lie in the range of 183 to 188deg.C and the actual soldering operation is usually performed below 245deg.C to minimize solder oxidation while still maintaining excellent solder meniscus and fillet formation.

When using vapor phase heating the vapor temperature is usually controlled even lower to produce superior soldering at around 215deg.C because of the more uniform temperatures obtainable. Vapor loss is reduced by cooling coils on entrance and exit ports (see Figure 7). Conveyor belt speed controls time profile.

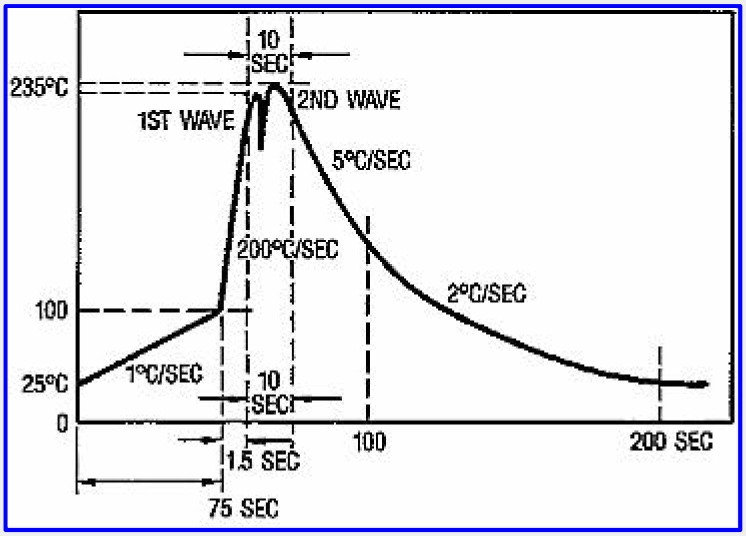

Figure 4. Double Wave Sodering Temp/Time Profile

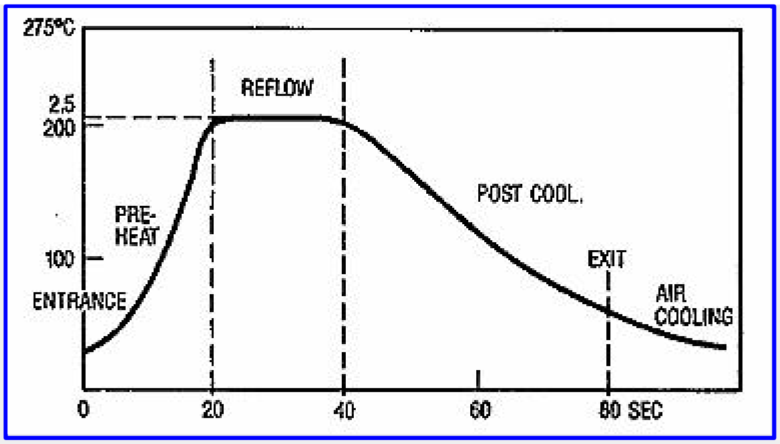

Figure 5. Infra-Red Reflow Sodering Temp/Time Profile

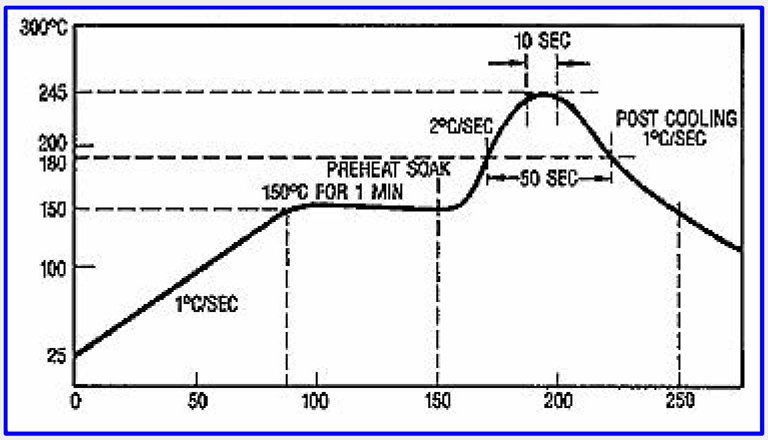

Figure 6. Vapor Phase Soldering Temp/Time Profile

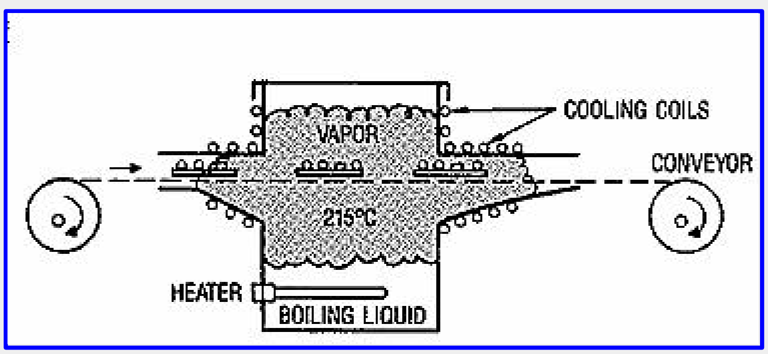

Figure 7. Vapor Phase Soldering Machine

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X. Rework

The primary problem in replacing soldered SMDs on substrates is how to apply sufficient heat to simultaneously fuse all the connections on the component to be replaced without overheating the adjacent components on the substrate itself.

Soldering irons with specially shaped tips are usually used for this purpose and because of the multiplicity of SMD package styles a corresponding variety of soldering tips is required.

These tips also must have a gripping function so that when the solder is reflowed the device can be extracted from the board assembly.

When a new device is to be mounted into an SMD assembly, the tool must perform the reverse procedure. The new part must be fluxed prior to local reflow as described.

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XI. Outlines, footprints, carriers, markings and tape and reel info

Tape and Reel

For large volume production SMDs are usually supplied on tape and reel. Dimensions and configurations for the various package styles are shown at the end of this application note.

SMD-220 (TO-263) OUTLINES	**All dimensions in mm (inches)**
D-PAK (TO-252) OUTLINES	**All dimensions in mm (inches)**
SOT-223 (TO-261) OUTLINES	**All dimensions in mm (inches)**
SO-8 OUTLINES	**All dimensions in mm (inches)**
Micro8 OUTLINES	**All dimensions in mm (inches)**
Micro3 (SOT-23) OUTLINES	**All dimensions in mm (inches)**
SOT-89(TO-243)OUTLINES	**All dimensions in mm (inches)**
SMC OUTLINES	**All dimensions in mm (inches)**
SMB OUTLINES	**All dimensions in mm (inches)**
D-64 Outlines	**All dimensions in mm (inches)**
D-61 Outlines	**All dimensions in mm (inches)**