Application Report
SPRAAE4A–April 2008

TMS320DM644x Thermal Considerations

Device Applications

ABSTRACT

As IC components become more integrated and more complex, the challenge of producing an end product with good thermal performance also increases. Thermal performance is a system level concern, impacted by IC packaging as well as PCB design. This application note addresses the thermal considerations for the DM644x devices.

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1 Introduction

As technology advances, the demand is rising for more highly complex ICs with faster clock rates, smaller packages, higher pin counts, and increased reliability all at a lower cost. One result from this is higher power consumption and increased thermal challenges across IC component products. Many of today's trends in IC packages increase the challenge of producing an end product which meets the thermal limitations of the components in the product. Some of these trends are listed below:

- Decreased package size
- Decreased die size
- Increased pin count
- Increased system complexity/integration
- Faster clocks
- Processes with increased leakage
- Need for lower cost
- Higher reliability/lower junction temperatures

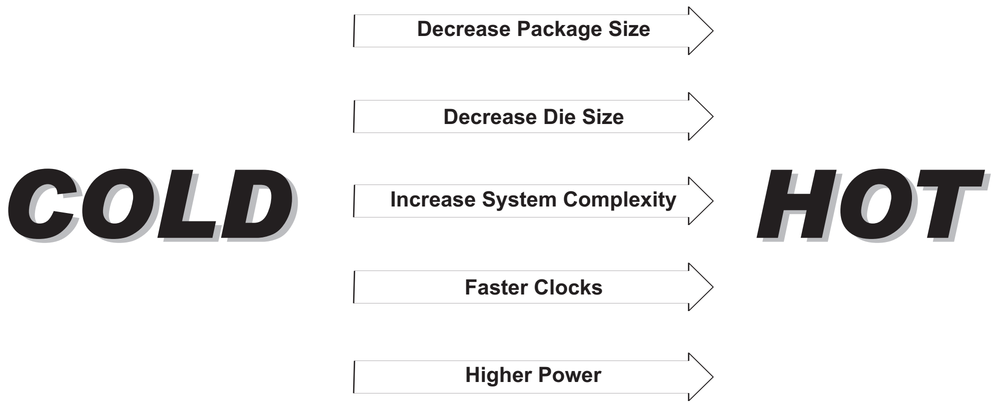


Figure 1. Thermal Trends in IC Packages

This application note discusses the thermal considerations of the DM644x devices and offers guidance on analysis of the thermal performance as well as improvements for an end system to aid in overcoming some of the existing challenges of producing a good thermal design

2 DM644x Thermal Considerations

When designing DM644x into a system, the following items must be considered:

- Potential maximum power consumption of 2W in some applications
- 85 C case temperature specification
- Typical θ_{JA} in real systems estimated to range between 20-40 C/W (without a heat sink)

The DM644x power consumption varies across applications. The potential for the DM644x to consume a maximum total power of 2W in some applications is a worst case, high activity usage condition. When calculating total power consumption, the DM644x power spreadsheet (*TMS320DM644x Power Consumption Summary* (SPRAAD6)) should be used to estimate the DM644x power consumption for a specific application.

In the DM644x data manual, TI specifies a maximum case temperature of 85 C. To ensure device reliability and proper operation, customers must not exceed 85 C case temperature. Although this case temperature specification is the only thermal requirement TI specifies for the DM644x, other system characteristics such as PCB characteristics, PCB layout, and ambient temperature must be designed to meet TI's maximum case temperature specification. This is because the DM644x is not the only contributor to the thermal performance of the system. There are several other contributors impacting the thermal performance such as PCB characteristics, PCB layout, and chassis configuration just to name a few. In fact, the most commonly used thermal parameter, θ_{JA} is not just a function of the DM644x package, but is also a function of the PCB characteristics on which it is mounted.

3 Thermal Definitions

In the next few sections, a brief summary will be given that defines as well as describes the usage of the thermal resistances discussed in the DM644x data manual.

3.1 Overview

Figure 2 below shows a simplified representation of the thermal path from the junction of the die through both the top and bottom of the package. As shown here, the thermal path can be modeled as an equivalent electrical circuit. In this approach, power in watts is equivalent to current in amps, temperature delta in degrees is equivalent to Voltage drop, and thermal resistance in C/W is equivalent to electrical resistance in Ohms. Therefore, a thermal resistance can be calculated as the temperature delta between node X and node Y, divided by the power.

$$\theta_{XY} = \frac{T_X - T_Y}{Power} \tag{1}$$

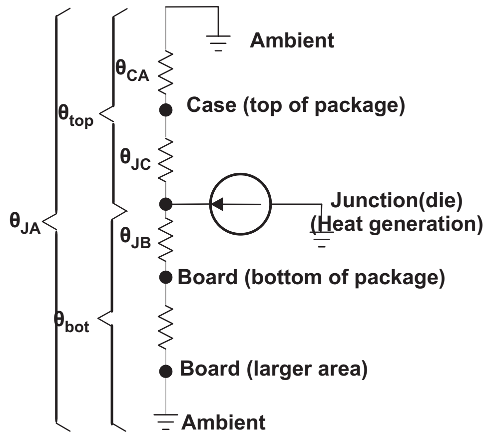


Figure 2. Thermal Path

The resistances of Figure 2 relates to the thermal resistances of the package and system as follows:

- $\theta_{JA,effective}$, : Total resistance of the whole system from die (junction) to ambient air
- Total θ through top (θ_{top}) of DM644x to environment (including heat sink if used)
- Total θ through bottom (θ_{bot}) of DM644x and PCB to environment
- θ_{CA} : Resistance from top of DM644x through air or heat sink to environment
- θ_{JC} : Resistance from die (junction) to the top of the package (case)
- θ_{JB} : Resistance from die (junction) to the board (near to DM644x), as defined by JESD 51-8

  The resistances θ_{top}, θ_{bot}, and θ_{CA} are not defined in the TI data manual but are mentioned here because they are useful in heat sink calculations.

3.2 Theta-JA (θ_{JA}) Junction to Ambient

θ_{JA} is defined as the difference in junction temperature to ambient temperature divided by the operating power. As discussed above, θ_{JA} is not constant but instead is a function of any and all factors which influence the thermal resistance between the junction of the device and the ambient environment. Some key factors which influence θ_{JA} are:

- PCB design and layout
- Chassis/box design
- Venting
- Altitude

When recorded in TI’s data manual, θ_{JA} is a measurement of the thermal performance of an IC package mounted on a specific test coupon. Texas Instruments, Inc. conducts measurements on systems defined in the following JEDEC specifications:

- JEDEC theta-JA measurement conditions defined in JESD51-2
- 1s0p or “low effective thermal conductivity” test board defined in JESD51-3
- 1s2p or “high effective thermal conductivity” test board defined in JESD51-7

The intent of θ_{JA} is to give a metric by which the relative thermal performance of a package can be compared. Thus, the thermal performance of a Texas Instruments, Inc. device such as DM644x can be compared to a device from another company. This is true when the other company follows the JEDEC conditions defined in the specifications noted above.

These θ_{JA} values are not intended to provide an accurate estimate of the temperature difference between junction and ambient in a real system. Methods for estimating this temperature difference are discussed in the next section. Instead, the θ_{JA} value as defined by JEDEC provides a means of comparing the thermal performance between packages.

3.3 *Theta-JC (θ_{JC}) Junction to Case*

θ_{JC} is defined as the difference in junction temperature to case temperature divided by the operating power in a specified environment. There is not currently a JEDEC specification for this parameter, although one is in work. θ_{JC} is measured by putting a mounted package up against a Cu block cold plate to force heat to flow from the die, through the mold compound into the Cu block.

As shown later in this application note, this parameter is useful when a heat sink is applied to a package. Without a heat sink, θ_{JC} is not a useful characteristic to predict junction temperatures. When case temperatures are measured in a system and junction temperatures are then calculated from the following equation, pessimistic junction temperatures are obtained.

$$T_{\mathbf{Junction}} = T_{\mathbf{CASE}} + \left(\mathbf{Power} \times \theta_{\mathbf{JC}}\right) \tag{2}$$

3.4 *Theta-JB (θ_{JB}) Junction to Board*

θ_{JB} is defined as the difference in the junction temperature and the PCB temperature at the PCB perimeter (closest to the die) when the PCB is clamped in a cold plate structure. θ_{JB} provides an overall thermal resistance between the die and the PCB. Theta-JB measurement conditions and board measurement location are defined in JEDEC standard JESD 51-8.

3.5 *Psi-JT (Ψ_{JT}) Junction to Top of Package*

Ψ_{JT} is defined as the difference in junction temperature to case temperature at the top center of the package divided by the operating power. Ψ_{JT} has the same measurement points and units as θ_{JC}. The only difference is Ψ_{JT} is measured when the package is mounted only on the test PCB which allows power to partition itself into any path that it wants to take. Whereas θ_{JC} is a true thermal resistance, Ψ_{JT} is measured under conditions that are closer to the real world use case.

The primary use of Ψ_{JT} is to calculate the junction temperature from a measured case temperature. The following equation may be used for this calculation.

$$T_{\mathbf{Junction}} = T_{\mathbf{Case}} + \left(\mathbf{Power} \times \Psi_{\mathbf{JT}}\right) \tag{3}$$

4 Rough Estimate of System Thermal Performance Using Theta-JA (θ_{JA})

Before finalizing system layout and PCB design, a plan needs to be in place for meeting the DM644x maximum case temperature specification in the data manual. This will require a preliminary assessment of the DM644x case temperature in context of the entire system. The most accurate method for evaluating the DM644x case temperature prior to completion of the system layout is the use of detailed thermal models of DM644x in the final system. One service provider that TI is aware of who can assist with system thermal modeling and analysis is Applied Thermal Technologies, see www.thermalcooling.com.

Although thermal models are the most accurate method for predicting the case temperature of the DM644x in a specific application, a less accurate ball park estimate can be made by comparing to Texas Instruments Inc. JEDEC θ_{JA} data. Texas Instruments Inc. measures θ_{JA} on two JEDEC defined test boards.

- θ_{JA}(no airflow) = 29.75 C/W. On high effective thermal conductivity test board defined in JESD51-7.
- θ_{JA}(no airflow) = 48.75 C/W. On low effective thermal conductivity test board defined in JESD51-3.

As noted above, since θ_{JA} is not just a function of the DM644x package alone, but also a function of other factors in the system and will vary between application scenarios. Therefore, the temperature rises above ambient, as measured under JEDEC test conditions, will be different from the temperature that rises above ambient in a real application. To differentiate the use of the term θ_{JA} as measured in JEDEC conditions vs. that estimated or measured in a real application, Texas Instruments, Inc. introduces and this application note uses the term $\theta_{JA,effective}$ to mean the θ_{JA} in a real application.

The window defined by the θ_{JA} values provided under the JEDEC defined test conditions can be used as a very rough estimate of $\theta_{JA,effective}$ for a specific application. Applications could fall anywhere in that window and even outside that window. Ultimately, $\theta_{JA,effective}$ is best gathered from system thermal modeling or actual measurements.

Once $\theta_{JA,effective}$ has been estimated, the following equation may be used:

$$T_{Case} \approx T_{Junction} = T_{Ambient} + \left(Power \times \theta_{JA,effective}\right) \tag{4}$$

Note: To be consistent with JEDEC measurement techniques, TI recommends measuring the final system ambient temperature (outside the enclosure), rather than inside the enclosure which may be influenced by heating from other parts.

In this rough estimate, case temperature can be assumed to roughly equal the junction temperature because without a heat sink the difference will be less than 1C (based on Ψ_{JT}= 0.11 C/W).

The power included in Equation 4 should be estimated for a specific application using the *TMS320DM644x Power Consumption Summary* (SPRAAD6) application note.

5 Case Temperature Measurement

Once the system has been finalized and manufactured, a case temperature measurement may be performed to ensure that the maximum case temperature specification of the DM644x has not been exceeded.

5.1 Case Temperature Measurement without a Heat Sink

Case temperature is defined as the hottest temperature on the top of the device and should be measured at the center of the top/lid of the device. The case temperature measurement can be performed with (in order of accuracy) an IR camera, a fluoroptic probe, a thermocouple, or IR gun (maximum field view of 4mm diameter) just to name a few techniques. When a thermocouple is chosen as the technique to perform the measurement, a fine gauge wire (36 to 40 gauge, J or K wire) should be used to minimize the local cooling from the thermocouple.

If using a thermocouple, it should be attached to the center of the package surface (+/- 1mm) with a bead of thermally conductive epoxy no larger than 2x2mm on a side. Taping the thermocouple to the package surface is not recommended. To minimize the heat sinking nature of the thermocouple, the wire should be dressed along the diagonal of the package, down to the PCB surface, and over a minimum distanced of 25mm before lifting from the PCB. The thermocouple wire can be tacked to the PCB for this routing purpose by using a tape. Use of improper thermocouple wire gauge can create errors in the measurements of 5-50%.

When using either a IR camera or IR gun, be sure to correct the reading for the emissivity of the surface being investigated. See your instrument's documentation for details.

5.2 Case Temperature Measurement with a Heat Sink

Measuring case temperatures with heat sinks applied represents special challenges since the heat sink covers the surface to be measured. If the user wishes to measure the case temperature with a heat sink applied, the following procedure is recommended.

1. Drill a hole with a diameter of 1mm or less in heat sink such that the hole will be at the center of the package when the heat sink is attached. Be sure to drill the hole through the heat sink before attaching the heat sink to the package. If a pressure sensitive adhesive is used to attach the heat sink, drill through this adhesive. Be sure there are no burrs or other material which would interfere with the mating surfaces.
2. Attach the heat sink to the package. If an epoxy will be used for the heat sink attach, fill the hole drilled in step 1 with a wax, foam, or other material which will insure the hole is not filled by the epoxy. Be careful not to contaminate the heat sink attach surface with this material.
3. Fill the hole with thermal grease. If the hole was plugged to avoid epoxy filling, be sure to unplug the hole.
4. Thread a fine gauge thermocouple of the type described above into the hole and secure with a drop of epoxy or tape.

5.3 Case Temperature Measurement: Accounting for Leakage Variations

As noted above, the resulting case temperature of the DM644x that is measured in the finalized system is dependent on the power consumption of the DM644x in this specific application. To determine the maximum case temperature measurement, the worst case power consumption of the DM644x for the finalized product must be accounted for.

The power consumption of the DM644x can be broken down into the sum of two components, active power and static (also called leakage) power. The active power component is essentially dependent upon application activity and voltage. For a given application and constant voltage, it can be assumed that active power remains the same. Static power varies across voltage, temperature and manufacturing process. The DM644x power consumption summary spreadsheet takes into account the static power consumption from the strong units (representative of maximum end of static power consumption on production units). The spreadsheet may be used to estimate the worst case static power consumption for a given case temperature. The obtained value may then be used to calculate the final worst case total power consumption.

The following method describes the procedure to account for worst case static power in the case temperature measurement.

1. Measure the case temperature using the method described above.
2. Measure ambient temperature (outside of the enclosure).
3. Measure total power consumption of the DM644x in the finalized application.
4. Measure the static power consumption of the DM644x at the case temperature measured in step 1.
5. Calculate the active power consumption of the DM644x in the finalized application.

$$\textbf{Active power} = \textbf{Total power} - \textbf{Static power} \tag{5}$$

6. Calculate $\theta_{JA,effective}$ of the finalized system using the following equation.

$$\theta_{\textbf{JA,effective}} \approx \frac{\mathbf{T_C - T_A}}{\textbf{Total Power}} \tag{6}$$

7. Use the power application spreadsheet to estimate the maximum static power consumption at the case temperature measured in step 1.
8. Recalculate the maximum total power consumption of the DM644x.

$$\textbf{Max Total Power} = \textbf{Active Power (step 5)} + \textbf{Max Static power (step 7)} \tag{7}$$

9. Recalculate the case temperature, accounting for maximum total power consumption.

$$T_C \approx T_A\,(\text{step}\,2) + \left(\text{Total power}\,(\text{step}\,8) \times \theta_{JA,\text{effective}}\,(\text{step}\,6)\right) \quad (8)$$

Note: The max case temperature measurement should account for worst case ambient conditions for the specific application.

6 System Thermal Improvements

As stated throughout this application note, the thermal performance of a system is impacted by both the DM644x and the PCB layout. The following bullets list several items that can improve a system's ability to dissipate heat. This is not an exhaustive list and each item should be evaluated to see if it is a good fit for each application.

- Maximize thermal vias in PCB under DM644x (connected to GND BGA balls and GND plane in PCB)
- Spread out parts on the PCB (including power supplies, etc) which are dissipating >500mW or so
- Insure the power and ground planes which connect to the DM644x are relatively continuous for a 25-50mm radius around the package
- Add venting to chassis, especially near DM644x
- Add screws from PCB to chassis near DM644x
- Use thermal gap filler material between top of DM644x and chassis (especially if chassis is metal). The gap between the PCB and chassis should be less than 3mm for this cooling scheme to be effective. The gap filler works by conducting heat from the PCB to the system chassis where it can be more effectively rejected from the system. Thermal gap fillers can be obtained from many sources with thermal conductivities ranging from 0.5 W/m-C to 3 W/m-C. One company supplying a variety of gap fillers is The Berquist company. The following link references one of their products, the Gap-Pad.
- Use metal clip between top of DM644x and chassis
- Add heat sink to DM644x (optimize heat sink type based on airflow)

7 Thermal Improvements via a System Heat Sink

Heat sinks are one of the most commonly considered thermal improvement methods. In the context of this application note the usage of the term heat sink includes an off the shelf heat sink purchased from a vendor as well as a direct connection between the top of the DM644x and the chassis (if the chassis is metal or another good thermal conductor), in which case the chassis becomes a heat sink for DM644x. . When applied to the top of a package, heat sinks increase the effective surface area of the package face which increases convection and radiation off of the top surface of the package.

Typically, without a heat sink, 80-90% of the heat generated by the device will be dissipated through the PCB. Attaching a heat sink will improve the heat flow through the top of the device. A good heat sink could potentially increase the percentage of heat flowing through the top of device from 10-20% up to 30-80%. This increase in heat flow through the top of the device would result in the following improvements:

- Estimated reduction in $\theta_{JA,\text{effective}}$ of 20-80%
- Estimated T_{Junction} reduction of 10-30 C

Detailed analysis needs to be performed to determine the exact impact of a certain heat sink in a certain system.

7.1 Thermal Heat Dissipation Example

This section describes a numerical approach that estimates the thermal impact of adding an off the shelf heat sink purchased from a vendor. This method requires ambient temperature, case temperature, and DM644x power to be either measured or estimated without a heat sink in the real system. To be consistent with JEDEC measurement techniques, TI recommends measuring the final system ambient temperature (outside the enclosure), rather than inside the enclosure which may be influenced by heating from other parts.

Numbers for an actual application will need to be calculated. Suppose from system analysis you determine:

- Ambient Temperature: T_A = 45 C
- Case Temperature: T_C = 85 C
- Device Power = 1.5W

Note: This is a reasonable example, but customer specific info is required.

1. Calculate an estimate of $\theta_{JA,effective}$ using the following equation. Plug in values for ambient temperature, case temperature and device power from above.

$$\theta_{JA,effective} \approx \frac{T_C - T_A}{Power} = \frac{85-45}{1.5} = 26.7\,\frac{°C}{W} \qquad (9)$$

2. Estimate the percentage of heat flowing through the PCB vs. the top of the device. Based on experience with typical systems, TI estimates 80% of heat flow is through the PCB, without a heat sink attached. The thermal resistance through the top of the device and the thermal resistance through the bottom of the device are two parallel resistances that equal $\theta_{JA,effective}$ (see Figure 2). Use the following equations.

$$\frac{80\%}{20\%} = 4 \text{ therefore, } \theta_{top} = 4 \times \theta_{bot}$$

$$\theta_{JA,effective} = \frac{1}{\frac{1}{\theta_{top}} + \frac{1}{\theta_{bot}}} = \frac{1}{\frac{1}{4\theta_{bot}} + \frac{1}{\theta_{bot}}} \qquad (10)$$

$$1.25 \times \theta_{JA,effective} = \theta_{bot} = \frac{1}{4} \times \theta_{top}$$

$$5 \times \theta_{JA,effective} = \theta_{top} \qquad (11)$$

Use the following equations to calculate θ_{top} and θ_{bot}.

$$\theta_{top} = \theta_{JA,effective} \times 5 = 26.7 \times 5 = 133.5\,\frac{°C}{W}$$

$$\theta_{bot} = \theta_{JA,effective} \times 1.25 = 26.7 \times 1.25 = 33.4\,\frac{°C}{W}$$

Check by calculating the parallel resistance of θ_{top} and θ_{bot}.

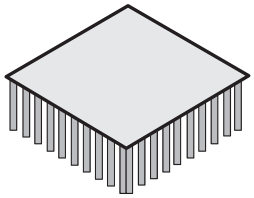
$$\theta_{JA,effective} = \frac{1}{\frac{1}{\theta_{top}} + \frac{1}{\theta_{bot}}} = \frac{1}{\frac{1}{133.5} + \frac{1}{33.4}} = 26.7\,\frac{°C}{W} \qquad (12)$$

3. For reference, estimate the thermal resistance from the top of the DM644x to the environment. This thermal resistance if called θ_{CA} (see Figure 2). Use the following equation. For DM644x, θ_{JC} =6.5 °C/W. θ_{JC} is documented in the DM644x data manual.

$$\theta_{CA} = \theta_{top}\,(\text{step 2}) - \theta_{JC} = 133.5 - 6.5 = 140\,\frac{°C}{W} \qquad (13)$$

4. Replace θ_{CA} calculated in step 3, with θ_{CA} specified from a heat sink data sheet and then recalculate heat flow through the top of the device with a heat sink added. Note that θ_{CA} and thus θ_{top} should be reduced with the addition of a heat sink.

   For this example we chose a heat sink with θ_{CA}=62.5 C/W (example heat sink).



Width	Length	Height	Fin Thickness Across Width	Fin Thickness Across Length	Base Thickness	# of Fins Across Width	# of Fins Across Length
15.20 mm	15.20 mm	6.35 mm	0.89 mm	0.89 mm	1.52 mm	8	9

Figure 3. Heat Sink Example Information

$$\theta_{top}\left({}^{W}\!/_{HS}\right) = \theta_{CA}(\text{from HS}) + \theta_{JC} = 62.5 + 6.5 = 69\,\frac{°C}{W} \quad (14)$$

5. Calculate the new $\theta_{JA,effective}$ with a heat sink as well as the improved T_C.

$$\theta_{JA,effective} = \frac{1}{\frac{1}{\theta_{top}} + \frac{1}{\theta_{bot}}} \quad (15)$$

$$\theta_{JA,effective}\left({}^{W}\!/_{HS}\right) = \frac{1}{\frac{1}{69} + \frac{1}{33.4}} = 22.5\,\frac{°C}{W} \quad (16)$$

Therefore, the Tc with heat sink can be calculated as follows:

$$T_C \approx T_A + \left(\text{Power} \times \theta_{JA,effective}\right) = 45 + (1.5 \times 22.5) = 78.8\ °C \quad (17)$$

Therefore, the heat sink in this application is estimated to improve the case temperature from a value of 85 C, that is marginal with respect to the data sheet T_C spec, to a value of 78.8 C.

Note: This example uses published data from an off the shelf heat sink. The same type of method may be used to estimate the impact of using a chasis as a heat sink, but the calculation is more difficult because this is not published data.

8 Heat Sink Recommendations

There are several general types of heat sinks available in the market for cooling BGA IC devices such as DM644x. The simplest approach is to find a standard product from a heat sink supplier. There is often room for significant optimization of the heat sink type and design based on the details of the application (geometry, usage, chassis material, design flexibility, assembly flow, etc), which can result in better thermal performance, and often a more cost-effective design as well. In this section there will be examples of simple, mid-range, and higher-performance heat sink types, as well as recommendations on heat sink selection and a list of heat sink vendors that TI is aware of.

Probably the simplest type of heat sink is simply a spreading plate which is attached to the top of the DM644x. One product that uses this concept and is thus a cheap and simple heat sink is available here: http://www.chomerics.com/products/twing.htm.

Most standard heat sinks are of the plate-fin or pin-fin type, where the heat sink has a base and then fins which extend off of the base which can be rectangular or round and can extend at different angles and profiles. There are many designs of this type available and prices can be reasonable, but the key to selecting this type of heat sink is to look at the airflow regime. For example if forced airflow is coming from one direction, a design with long rectangular fins may be optimal, but if forced airflow is mixing a lot, then round fins may be needed to ensure air effectively moves through the fins. If there is no forced airflow, it is important to consider the heat sink performance curve with natural convection (often called θn), which is often much worse than with forced airflow. An example of this type of heat sink (used for calculation in previous section) is available here:

http://www.aavidthermalloy.com/cgi-bin/bga_disp.pl?partnum=042987&attach=DEVICE&size=15.20&height=6.35&length=15.20&nc=62.50&fc=17.60&pkg=Plastic.

One higher-end heat sink is called radial type, where there is a round plate which attaches to a pedestal which presses on to the top of the part. This type advertises much lower thermal resistance values at natural convection. An example of this type of heat sink (larger body size than DM644x) is available here: http://catalog.tycoelectronics.com/TE/bin/TE.Connect?C=16819&P=92295,93176,92312&M=PPROP&LG=1&I=13&G=G&N=1&IDS=228052

Based on the industry trends of miniaturization and increased power density, many heat sink vendors are already advertising that they have geared their mode of operations to create and support custom designs with quick prototypes and flexible manufacturing.

Based on the number of heat sink types available (standard and custom) and the uniqueness of DM644x applications, TI recommends that if thermal analysis indicates that DM644x may need a heat sink in a customer's application, that the customer work closely with a heat sink vendor to find an optimal solution that meets the thermal needs as well as the other system design constraints.

9 Heat Sink Attachment Methods

When attaching a heat sink to a package surface, it is important to reduce the thermal resistance of the heat sink attachment. If a thermal insulating material is used between the heat sink and the package surface, the thermal performance can conceivably be worse than having no heat sink at all. The thermal resistance of the bond line layer can be calculated by the following equation.

$$\theta_{ca} = \frac{t}{kA} \tag{18}$$

Where:

k = thermal compound conductivity

A = package surface area

t = heat sink compound bound line thickness

Three primary materials are commonly used to attach heat sinks to the package:

- epoxy glue
- thermal grease
- thermal pads with and without self adhesive
  Other thermal interface materials include Grafoil and solders

9.1 Epoxy Glue

The most reliable material for attaching a heat sink is simply a thermally conductive epoxy compound. These materials can be purchased from heat sink vendors, and have thermal conductivities that typically range from 0.5-1.5 W/m-C. Specialty materials with metal fillers can be obtained which have much higher bulk thermal conductivities. When gluing the heat sink to the package surface with an epoxy, it is best to use pressure during cure to squeeze out excess material and thereby minimize the bond line thickness. When a heat sink is attached with an epoxy, it is important to ensure the package surface is cleaned of any greases or other contaminates which can degrade the adhesion strength. The adhesive/package combination should be tested in the intended environment to ensure reliable operation over the lifetime of the device.

Advantages of epoxies in attaching heat sink include:

- No fixturing is required to hold the heat sink in place after the epoxy has cured.
- The epoxy can fill large surface asperities.
- Little or no change in thermal properties as a function of time and temperature.
- Good shock and vibration resistance.

Disadvantages include:

- The epoxy attach is usually permanent, meaning the heat sink can not be removed from the package, if needed.
- Fixturing may be required to hold the heat sink in place with pressure during epoxy cure.
- Epoxies may not adhere strongly to certain plastic compounds such as those used in plastic molded IC packages.

9.2 Thermal Greases

Thermal greases have long been used to minimize the thermal contact resistance between a heat sink and package surface. These materials are normally formed by suffusing high viscosity silicone greases with metal oxide powders for thermal conductivity. Thermal conductivies are roughly 0.6-0.9 W/m-C.

Advantages include:

- Easy to apply.
- Allows heat sink removal.
- Good gap filler for non-planar surfaces.

Disadvantages include:

- Heat sink needs to be clamped to package with some force to minimize the bond line thickness.
- Silicone has a tendency to wet out over other surfaces, depleting the grease and making it brittle and crack prone over time which reduces the thermal conductivity.
- Can be messy to apply.

9.3 Thermal Pads

Thermal pads, with or without pressure sensitive adhesives, are often used to attach large heat sinks to packages. Thermal pads normally consist of low modulus (pliable, rubbery) polymer material that is filled with a thermally conductive material. Thermal conductivities range from 0.8-3 W/m-C. They have multiple advantages over epoxies or greases, but also some disadvantages.

Advantages include:

- Easy to handle.
- Can be cut to fit.
- Can easily remove the heat sink.
- Little performance change with time.

Disadvantages include:

- Must have method to clamp heat sink to package surface.
- Not as good as epoxy or grease at filling between warped surfaces.
- Normally, the bond line achievable with these materials is thicker than can be achieved with epoxies or thermal greases.

Many adhesives used on thermal pad materials are pressure sensitive, non-permanent adhesives. As such, they may be sensitive to change with moisture in the environment and tend to creep under loading. If the system is positioned such that there is substantial gravitational loading of the heat sink on the package, i.e., the PCBs are positioned vertically such that the heat sinks are pulling on the package, pressure sensitive adhesives alone should not be relied upon to hold the heat sink to the package.

10 Heat Sink Vendor List

Here is a list of a number of heat sink vendors that TI is aware of:

Aavid Thermalloy	http://www.aavidthermalloy.com/products/bga/index.shtml
Alpha	http://www.alphanovatech.com/
Calgreg	http://www.calgreg.com/heatsinks.html
Chomerics	http://www.chomerics.com/products/thermal.htm
Enertron	http://www.enertron-inc.com/enertron-products/index.php
Graftech	http://www.graftechaet.com/egraf/products.asp
Malico	http://www.malico.com.tw/
Radian	http://www.radianheatsinks.com/
R-Theta	http://www.r-theta.com/
ThermShield	http://www.thermshield.com/ThermshieldPages/ThermalProducts.html
Tyco Electronics	http://catalog.tycoelectronics.com/TE/bin/TE.Connect?M=FEAT&LG=1&I=13&C=16819

IMPORTANT NOTICE

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

Products		**Applications**	
Amplifiers	amplifier.ti.com	Audio	www.ti.com/audio
Data Converters	dataconverter.ti.com	Automotive	www.ti.com/automotive
DSP	dsp.ti.com	Broadband	www.ti.com/broadband
Clocks and Timers	www.ti.com/clocks	Digital Control	www.ti.com/digitalcontrol
Interface	interface.ti.com	Medical	www.ti.com/medical
Logic	logic.ti.com	Military	www.ti.com/military
Power Mgmt	power.ti.com	Optical Networking	www.ti.com/opticalnetwork
Microcontrollers	microcontroller.ti.com	Security	www.ti.com/security
RFID	www.ti-rfid.com	Telephony	www.ti.com/telephony
RF/IF and ZigBee® Solutions	www.ti.com/lprf	Video & Imaging	www.ti.com/video
		Wireless	www.ti.com/wireless

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