Thermal Design

How to Use the Thermal Resistance and Thermal Characteristics Parameters

The thermal resistances $θ_{JA}$ or $θ_{JC}$ and the thermal characteristics parameters $Ψ_{JT}$ of a package are listed in the data sheet. This application note explains how to use these values for thermal design.

How to use thermal resistance $θ_{JA}$

$θ_{JA}$ is the thermal resistance from the junction of the device to the ambient temperature. It is also represented by other symbols including R_{thJA}, $R_{θJA}$, and Theta-JA. $θ_{JA}$ is shown in Figure 1. It is also shown in Equation (1) where the difference between the junction temperature and the ambient temperature is divided by the power loss (heat flow).

The values of $θ_{JA}$ listed in the data sheet are measured in the environment defined in JEDEC Standard JESD51-2A. These values are used for comparing heat dissipation performance with that of other products and competing products measured in the same environment.

Values of $θ_{JA}$ in a specific application are different from those described above because the environment of this application is not the same as that of JEDEC. Therefore, the junction temperature cannot be estimated in a specific application by rearranging Equation 1 into an equation for calculating T_J with $θ_{JA}$ listed in the data sheet.

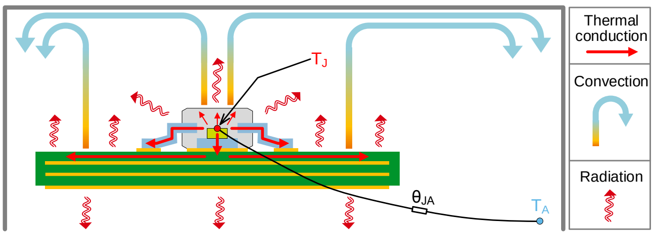

Figure 1. Definition of $θ_{JA}$

$$\theta_{JA} = \frac{T_J - T_A}{P_D} \quad [°C/W] \qquad (1)$$

T_J: Junction temperature [°C]

T_A: Ambient temperature [°C]

P_D: Power loss [W]

Usage examples of $θ_{JA}$

Example 1:

Comparing $θ_{JA}$ between different products to select a product that has better heat dissipation performance (low $θ_{JA}$).

Product	$θ_{JA}$	Conditions
A	40.5 °C/W	JEDEC 4-layer board
B	33.1 °C/W	JEDEC 4-layer board
C	157.2 °C/W	JEDEC 1-layer board

In this example, Products A and B can be compared because the conditions of their boards are the same while Product C, whose conditions are not the same as them, cannot be compared. Data under the same conditions must be obtained.

Example 2:

Comparing $θ_{JA}$ between different products to estimate how many degrees C the junction temperature will change relative to each other when the junction temperature in the current application is found in advance. Though this is a relative comparison, use the result of this only as a rough guide because $θ_{JA}$ of JEDEC is different from $θ_{JA}$ in the application.

$$\Delta T_J = (\theta_{JA2} - \theta_{JA1}) \times P_D \quad [°C] \qquad (2)$$

θ_{JA1}: Thermal resistance of Product 1 [°C/W]

θ_{JA2}: Thermal resistance of Product 2 [°C/W]

P_D: Power loss [W]

The junction temperature of the current application where Product A is used is 155°C. Then, estimate the junction temperature by switching to Product B. Calculate it with a power loss of 2 W.

Product	$θ_{JA}$	Conditions
A	40.5 °C/W	JEDEC 4-layer board
B	33.1 °C/W	JEDEC 4-layer board

$$\Delta T_J = (33.1 - 40.5) \times 2 = -14.8 \ \ [°C]$$
$$T_J = 155 - 14.8 = 140.2 \ \ [°C]$$

Example 3:

Since through-hole components such as TO packages have a low heat dissipation influence on PCBs, θ_{JA} of an IC alone is listed in the data sheet. The junction temperature can be estimated with Equation 3 if no heat sinks are used in an application. The ambient temperature of the application must be supposed to be increased by self-heating and the heat generation of other components.

$$T_J = \theta_{JA} \times P_D + T_A \quad [°C] \tag{3}$$

P_D: Power loss [W]

T_A: Ambient temperature [°C]

The junction temperature can be estimated as the following equation when θ_{JA} of the IC alone is 70°C/W, the power loss is 1 W, and the maximum ambient temperature in the chassis is 65°C.

$$T_J = 70 \times 1 + 65 = 135 \ \ [°C]$$

Example 4:

In the section "How to use θ_{JA}," we described that "the junction temperature cannot be estimated in a specific application by rearranging Equation 1 into an equation for calculating T_J with θ_{JA} listed in the data sheet"; however, θ_{JA} can be used for the estimation of the junction temperature in the circuit design phase where no boards are present if the variation of θ_{JA} according to different PCBs is understood. In this way, rough estimations are carried out for SMDs (Surface Mount Devices).

T_J is estimated by using Equation 3, where it is important to determine which value of θ_{JA} is used. Use a value of θ_{JA} listed in the data sheet, but the junction temperature more likely exceeds the absolute maximum rating because a margin is negative when θ_{JA} in the data sheet is lower than θ_{JA} of a PCB to be completed later.

To prevent this, use a value of θ_{JA} so that the thermal resistance is higher than that of a PCB to be designed. When a PCB to be designed is a 4-layer board, for example, use a value of θ_{JA} for a 1-layer PCB listed in the data sheet.

JEDEC PCB	θ_{JA} (°C/W)
1 layer (1s)	139.0
4 layers (2s2p)	35.6

Figure 2. θ_{JA} of HTSOP-J8 package

Since 1-layer and 4-layer PCBs have largely different copper foil areas, their values of θ_{JA} are also largely different (Figure 3). When the junction temperature apparently goes over due to an excessive margin, obtain θ_{JA} for various copper foil areas to select θ_{JA} with an adequate margin (Figure 4).

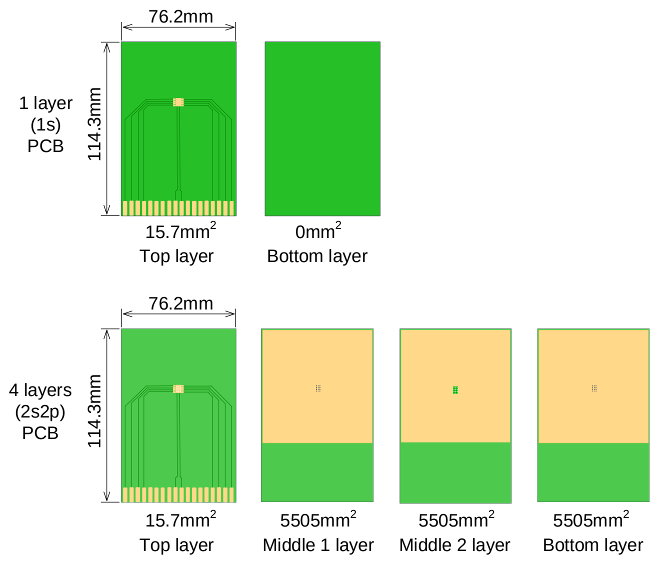

Figure 3. Difference of copper foil areas between 1-layer and 4-layer PCBs

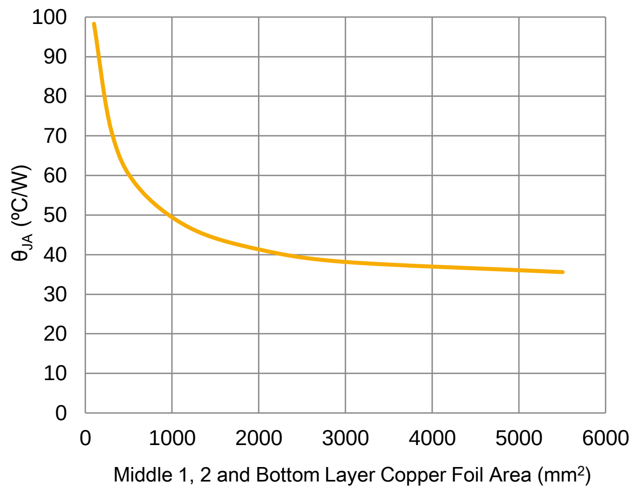

Figure 4. Change in θ_{JA} for various copper foil areas

How to use thermal resistance θ_{JC}

θ_{JC} is the thermal resistance from the junction to the case surface of the device. It is also represented by other symbols including R_{thJC}, $R_{\theta JC}$, and Theta-JC. The values of θ_{JC} listed in the data sheet are measured by applying the Transient Dual Interface (TDI) test method defined in JEDEC Standard JESD 51-14.

θ_{JC} is shown in Figure 5. Since θ_{JC} is measured in an environment where the package surface is in contact with the heat sink and furthermore other surfaces are insulated, it is assumed that the device is used in a very good cooling environment where all the heat generated at the junction is transferred. Thus, these values can be used for the thermal design of power semiconductor applications using a heat sink. The case surface temperature T_C is the temperature at the boundary between the package and the TIM (Thermal Interface Material), where there is no physical measurement point. The junction temperature thus cannot be estimated with Equation 4 by measuring T_C with a thermocouple.

$$T_J = \theta_{JC} \times P_D + T_C \quad [°C] \qquad (4)$$

P_D: Power loss [W]

T_C: Case surface temperature [°C]

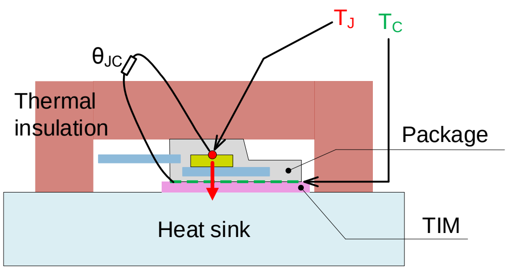

Figure 5. Definition of θ_{JC}

T_C indicates the temperature at the boundary between the package surface and the TIM.

Usage examples of θ_{JC}

Example 1:

Comparing θ_{JC} between different products to estimate how many degrees C the junction temperature will change relative to each other when the junction temperature in the current application is found in advance. Though this is a relative comparison, use the result of this only as a rough guide because θ_{JC} of JEDEC is different from θ_{JC} in the specific application (actual equipment).

$$\Delta T_J = \left(\theta_{JC2} - \theta_{JC1}\right) \times P_D \quad [°C] \qquad (5)$$

θ_{JC1}: Thermal resistance of Product 1 [°C/W]

θ_{JC2}: Thermal resistance of Product 2 [°C/W]

P_D: Power loss [W]

The junction temperature of the current application where Product A is used is 150°C. Then, estimate the junction temperature by switching to Product B. Calculate it with a power loss of 5 W.

Product	θ_{JC}	Conditions
A	2.6 °C/W	JESD51-14
B	1.3 °C/W	JESD51-14

$$\Delta T_J = (1.3 - 2.6) \times 5 = -6.5 \ [°C]$$

$$T_J = 150 - 6.5 = 143.5 \ [°C]$$

Example 2:

Performing thermal design with a heat sink. As shown in Equation 6, the junction temperature is calculated by multiplying the thermal resistance from the junction to the ambient temperature by the power loss of the device, and then adding the ambient temperature to the product. As shown in Figure 6, the thermal resistance from the junction to the ambient temperature consists of the thermal resistance θ_{JC} from the junction to the case, the contact thermal resistance θ_{CH} from the case including the TIM to the heat sink, and the thermal resistance θ_{HA} from the heat sink to the ambient temperature. The ambient temperature of the application must be supposed to be increased by self-heating and the heat generation of other components.

$$T_J = (\theta_{JC} + \theta_{CH} + \theta_{HA}) \times P_D + T_A \quad [°C] \qquad (6)$$

θ_{JC}: Thermal resistance from the junction to the case [°C/W]

θ_{CH}: Thermal resistance from the case to the heat sink [°C/W]

θ_{HA}: Thermal resistance from the heat sink to the ambient temperature [°C/W]

P_D: Power loss [W]

T_A: Ambient temperature [°C]

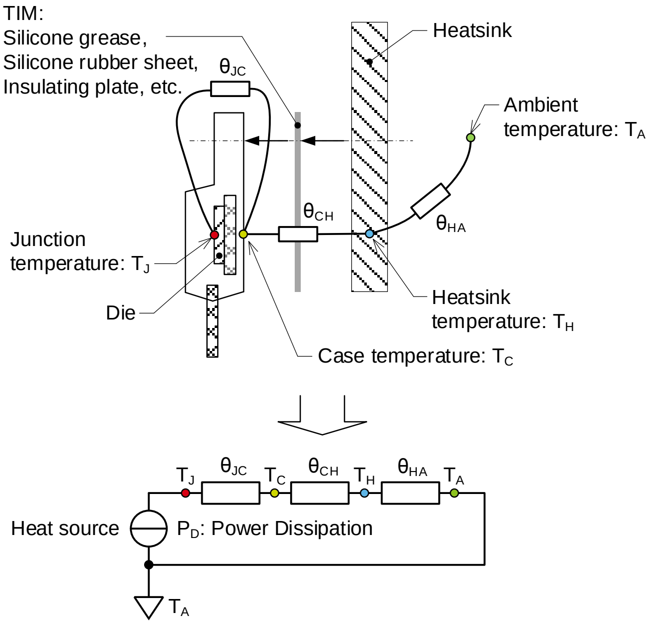

Figure 6. Heat dissipation equivalent circuit from the heat source to the ambient environment

Calculate T_J of a TO-220FM package as an example. θ_{JC} is 2.6°C/W according to the data sheet. To determine θ_{CH}, read the thermal conductivity from the data sheet of the TIM and convert it into thermal resistance with Equation 7. A heat sink is assumed to be used so that θ_{HA} is 10.9°C/W. P_D is 3.5 W. Then, carry out a calculation for the case where the maximum ambient temperature in the chassis is 60°C.

First, convert the heat conductivity of the TIM into thermal resistance with Equation 7.

$$\theta_{CH} = \frac{t}{K \times L \times W} \quad [°C/W] \qquad (7)$$

t : Thickness of silicone grease [m]

K : Thermal conductivity [W/m·K]

L : Length of case contact surface [m]

W : Width of case contact surface [m]

Conditions of TIM (Pay attention to units)

Thickness of silicone grease $t = 0.1\ [mm]$

Thermal conductivity $K = 1\ [W/m \cdot K]$

Length of TO-220FM contact surface $L = 14.8\ [mm]$

Width of TO-220FM contact surface $W = 9.9\ [mm]$

$$\theta_{CH} = \frac{t}{K \times L \times W} = \frac{\frac{0.1}{1000}}{1 \times \frac{14.8}{1000} \times \frac{9.9}{1000}} = 0.68\ [°C/W]$$

Next, calculate T_J by substituting the parameters for Equation 6.

$$T_J = (2.6 + 0.68 + 10) \times 3.5 + 60 = 106.5\ [°C]$$

How to use thermal characteristics parameter Ψ_{JT}

Ψ_{JT} is the thermal characteristics parameter indicating the temperature difference between the junction of the device and the center of the outer surface of the package divided by the power applied to the component. It is also represented by another symbol, Psi-JT. Ψ_{JT} is shown in Figure 7. It is also shown in Equation 8 where the difference between the junction temperature T_J and the temperature T_T at the center of the package surface is divided by the power loss.

The values of Ψ_{JT} listed in the data sheet are measured in the environment defined in JEDEC Standard JESD51-2A. The junction temperature can be estimated by measuring the package temperature of the device in a specific environment if the temperature characteristics parameters are measured under similar conditions. Figure 7 shows the heat dissipation path. Since SMDs radiate most of their heat to the PCB, the heat flow between the junction and the package surface is very small. Therefore, the temperature difference between T_J and T_T is very small, and the value of Ψ_{JT} is also small. When the value of Ψ_{JT} is small, the error in estimating the junction temperature is also small, even if there are differences between the JEDEC environment and the specific application environment.

After being estimated theoretically by using θ_{JA} or θ_{JC} in the circuit design phase, the junction temperature is recommended to be checked actually with a trial PCB by using Ψ_{JT} when the PCB is completed.

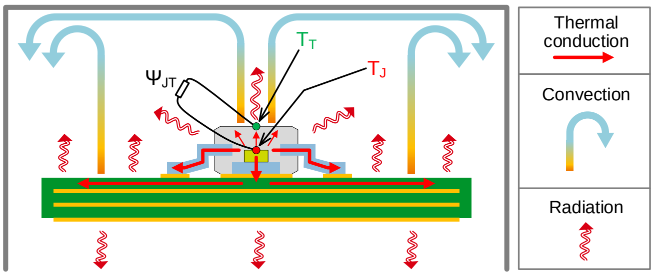

Figure 7. Definition of Ψ_{JT}

$$\psi_{JT} = \frac{T_J - T_T}{P_D} \quad [°C/W] \tag{8}$$

T_J: Junction temperature [°C]

T_T: Temperature at the center of the package surface [°C]

P_D: Power loss [W]

Usage example of Ψ_{JT}

Measure the temperature of the package surface and estimate the junction temperature using Ψ_{JT} that is listed in the data sheet.

Use the following equation to calculate the junction temperature.

$$T_J = \Psi_{JT} \times P_D + T_T \quad [°C] \tag{9}$$

Ψ_{JT}: Thermal characteristics parameter from the junction to the package surface [°C/W]

P_D: Power loss [W]

T_T: Temperature at the center of the package surface [°C]

Prepare the parameter values required for the calculation.

1. From among the Ψ_{JT} data listed in the data sheet or the thermal resistance application note, select the PCB condition value closest to that of the actual equipment. When the junction temperature must be estimated more accurately, measure Ψ_{JT} with the actual PCB.

2. P_D is the power loss while the applicable device is operated. Determine this by actual measurement or by calculation.

3. Measure T_T by fixing a thermocouple in the center of the package surface with thermally conductive epoxy adhesive. For precautions for the measurement, refer to Reference [3].

Summary

The thermal resistance θ_{JA} or θ_{JC} is used to estimate the junction temperature in the circuit design phase. Either θ_{JA} or θ_{JC} is selected properly according to the package to be used and the presence of a heat sink. See the table below for more details.

Check the junction temperature by using the thermal characteristics parameter Ψ_{JT} when a trial PCB is completed. Use the values of Ψ_{JT} listed in the data sheet. However, when the junction temperature must be estimated more accurately, measure Ψ_{JT} with the actual PCB to check the junction temperature.

	θ_{JA}	θ_{JC}	Ψ_{JT}
Standard	JEDEC Standard JESD51-2A	JEDEC Standard JESD51-14	JEDEC Standard JESD51-2A
Definition	Thermal resistance from the junction of the device to the ambient temperature	Thermal resistance from the junction to the case surface of the device, where the surface must be properly provided with a heat sink to minimize the temperature change across the entire surface	Thermal characteristics parameter indicating the difference between the junction temperature and the temperature at the center of the outer surface of the component package divided by the power applied to the component
Usage phase	Theoretical calculation in the circuit design phase	Theoretical calculation in the circuit design phase	Actual equipment measurement on trial
Applications	1. Comparing θ_{JA} between different products to select a product that has better heat dissipation performance (lower θ_{JA}). 2. Comparing θ_{JA} between different products to estimate how many degrees C the junction temperature will change relative to each other. 3. Estimating the junction temperature if no heat sinks are used on through-hole components such as TO packages. 4. Estimating the junction temperature for SMDs (conditionally)[*1]	1. Comparing θ_{JC} between different products to estimate how many degrees C the junction temperature will change relative to each other. 2. Estimating the junction temperature in applications such as TO packages where a heat sink is used.	1. Measuring the temperature of the package surface of an SMD and estimating the junction temperature of it. 2. Checking the junction temperature with the actual equipment for proper thermal design (theoretical calculation).
Junction temperature estimation	Applicable devices: 1. Applications for through-hole components, where no heat sinks are used, such as TO packages. 2. SMDs, conditionally[*1] $T_J = \theta_{JA} \times P_D + T_A$ P_D: Power loss [W] T_A: Ambient temperature [°C]	Applicable devices: Applications, where a heat sink is used, such as TO packages. $T_J = (\theta_{JC} + \theta_{CH} + \theta_{HA}) \times P_D + T_A$ θ_{CH} : Contact thermal resistance [°C/W] θ_{HA} : Thermal resistance of the heatsink [°C/W] P_D: Power loss [W] T_A : Ambient temperature [°C]	Applicable devices: SMD $T_J = \Psi_{JT} \times P_D + T_T$ P_D: Power loss [W] T_T: Temperature at the center of the package surface [°C]

TO: Transistor Outline

SMD: Surface Mount Device

*1: Can be used if the change in θ_{JA} according to different PCBs is understood. Select θ_{JA} with an adequate margin.

References

[1] JESD51-2A, Integrated Circuits Thermal Test Method Environmental Conditions - Natural Convection (Still Air), January 2008

[2] JESD51-14, Transient Dual Interface Test Method for the Measurement of the Thermal Resistance Junction to Case of Semiconductor Devices with Heat Flow Through a Single Path, November 2010

[3] Application Note "Notes for Temperature Measurement Using Thermocouples" , ROHM CO., LTD., 2020

Notes

1) The information contained herein is subject to change without notice.

2) Before you use our Products, please contact our sales representative and verify the latest specifications :

3) Although ROHM is continuously working to improve product reliability and quality, semiconductors can break down and malfunction due to various factors.
Therefore, in order to prevent personal injury or fire arising from failure, please take safety measures such as complying with the derating characteristics, implementing redundant and fire prevention designs, and utilizing backups and fail-safe procedures. ROHM shall have no responsibility for any damages arising out of the use of our Poducts beyond the rating specified by ROHM.

4) Examples of application circuits, circuit constants and any other information contained herein are provided only to illustrate the standard usage and operations of the Products. The peripheral conditions must be taken into account when designing circuits for mass production.

5) The technical information specified herein is intended only to show the typical functions of and examples of application circuits for the Products. ROHM does not grant you, explicitly or implicitly, any license to use or exercise intellectual property or other rights held by ROHM or any other parties. ROHM shall have no responsibility whatsoever for any dispute arising out of the use of such technical information.

6) The Products specified in this document are not designed to be radiation tolerant.

7) For use of our Products in applications requiring a high degree of reliability (as exemplified below), please contact and consult with a ROHM representative : transportation equipment (i.e. cars, ships, trains), primary communication equipment, traffic lights, fire/crime prevention, safety equipment, medical systems, servers, solar cells, and power transmission systems.

8) Do not use our Products in applications requiring extremely high reliability, such as aerospace equipment, nuclear power control systems, and submarine repeaters.

9) ROHM shall have no responsibility for any damages or injury arising from non-compliance with the recommended usage conditions and specifications contained herein.

10) ROHM has used reasonable care to ensure the accuracy of the information contained in this document. However, ROHM does not warrants that such information is error-free, and ROHM shall have no responsibility for any damages arising from any inaccuracy or misprint of such information.

11) Please use the Products in accordance with any applicable environmental laws and regulations, such as the RoHS Directive. For more details, including RoHS compatibility, please contact a ROHM sales office. ROHM shall have no responsibility for any damages or losses resulting non-compliance with any applicable laws or regulations.

12) When providing our Products and technologies contained in this document to other countries, you must abide by the procedures and provisions stipulated in all applicable export laws and regulations, including without limitation the US Export Administration Regulations and the Foreign Exchange and Foreign Trade Act.

13) This document, in part or in whole, may not be reprinted or reproduced without prior consent of ROHM.

Thank you for your accessing to ROHM product informations.
More detail product informations and catalogs are available, please contact us.

ROHM Customer Support System

http://www.rohm.com/contact/