

## Thermal Design

# $\theta_{JA}$ and $\Psi_{JT}$

$\theta_{JA}$  and  $\Psi_{JT}$  indicate how difficult it is for heat to be conducted. Although both of these are indicators of heat, there may be questions about what their differences are and how they are used in different situations. This application note explains the differences between  $\theta_{JA}$  and  $\Psi_{JT}$  and how to use them correctly.

### Definition of $\theta_{JA}$

$\theta_{JA}$  is defined in the JEDEC Standards JESD51-1 and JESD51-2A. In the definition,  $\theta_{JA}$  is described as follows: Thermal resistance from junction to ambient: Thermal resistance from the moving part of the semiconductor device to the natural convection (still air) environment surrounding the device. The symbol is  $R_{\theta JA}$  (alternative  $\theta_{JA}$ ).

For  $\theta_{JA}$ , mount the device on a PCB created to conform to the JESD51-3, JESD51-5, and JESD51-7 standards and measure the temperature under the measurement environment of JESD51-2A.

Figure 1 shows an example of a four-layer PCB for surface-mounted ICs. For details on JEDEC Standard, refer to References [1], [2], and [3] on the last page. These documents contain detailed instructions on PCB dimensions and materials, device mounting positions, copper foil thickness and size, lead wire dimensions, thermal via dimensions, and so on. For an example of the specifications, refer to Reference [4].

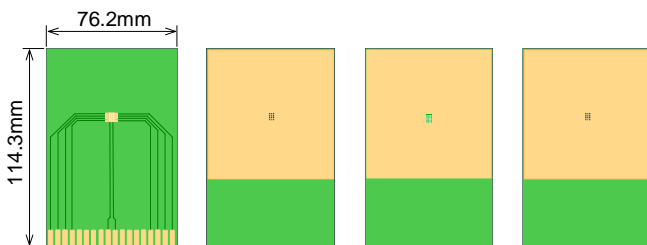


Figure 7. Example of a four-layer PCB for surface-mounted ICs created to conform to the JESD51-3, JESD51-5, and JESD51-7 standards

Implement the measurement environment and method in accordance with JESD51-1 and JESD51-2A. The description here provides an overview. Refer to Reference [5] and [6] for details.

As shown in Figure 2, the measurement environment consists of a PCB-mounted IC fixed in a predetermined position, which is placed in an enclosure (box) made of a material with low thermal conductivity and completely sealed to prevent air flow to and from the outside.

The ambient temperature is measured with a thermocouple in accordance with the specifications specified in JESD51-2A fixed in a predetermined position (i.e., a position unaffected by the heat source).

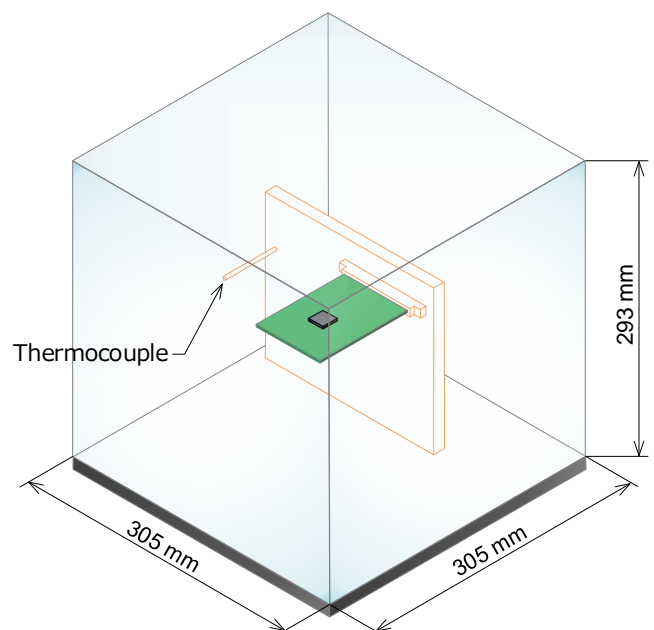


Figure 2. Schematic diagram of the test fixture and enclosure

As a preparation for the measurement, measure the forward voltage so as to use a diode in the IC as the sensing diode to determine the junction temperature. For this diode, as shown in Figure 3, use the body diode of the MOSFET, which becomes the heat source while the IC is operated. Place the IC in a thermostatic chamber and measure the forward voltage at each temperature by applying a minute current that does not cause the diode to get hot. An example of the measurement result is shown in Figure 4. Now it is possible to determine the junction temperature by measuring the forward voltage.

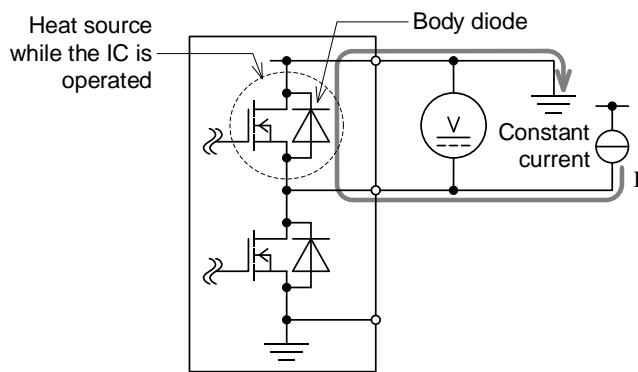


Figure 3. Using the body diode of the heat source MOSFET as the sensing diode to determine the junction temperature

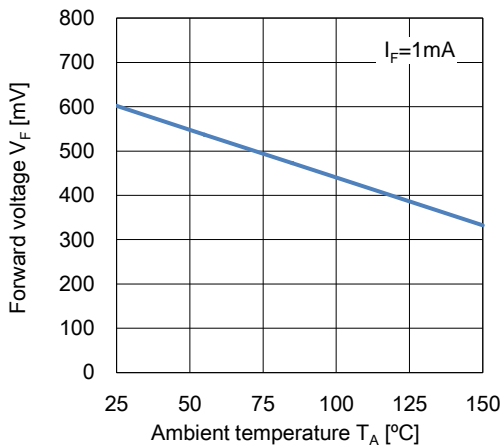


Figure 4. Example of the forward voltage temperature characteristic of the body diode

Start measuring  $\theta_{JA}$  from here. Apply a large current to the body diode in Figure 3 to heat the IC so as to raise the junction temperature by 30°C - 60°C. Then, switch to a minute current, measure the forward voltage, and convert it to the junction temperature using the graph in Figure 4. When the temperature change is stabilized, record the junction temperature and ambient temperature. Use the following equation to calculate  $\theta_{JA}$  from the measured value.

$$\theta_{JA} = \frac{T_{Jss} - T_{Ass}}{P_H} \quad [^{\circ}C/W] \quad (1)$$

$T_{Jss}$ : Junction temperature when the device reaches the steady state after Power  $P_H$  is applied [°C]

$T_{Ass}$ : Ambient temperature when the device reaches the steady state [°C]

$P_H$ : Consumption power that causes the change in the junction temperature [W]

The thermal resistance  $\theta_{JA}$  is the temperature difference between the junction temperature and the ambient temperature divided by the consumption power.

Figure 5 shows the heat radiation path when  $\theta_{JA}$  is measured. Heat is transferred from the junction through various paths. Therefore, changes in board conditions and space environment cause changes in the thermal resistance.

The purpose of measuring  $\theta_{JA}$  is only to compare the thermal performance of one package with another in a standardized environment.  $\theta_{JA}$  is neither intended nor able to predict package performance in application-specific environments.

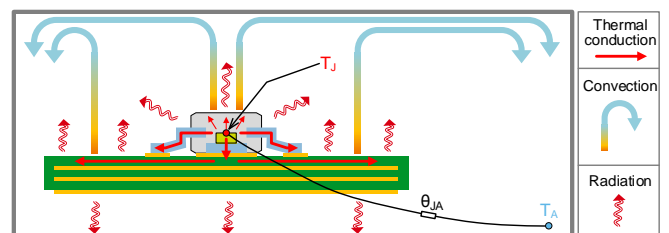


Figure 5. Heat dissipation path when  $\theta_{JA}$  is measured

## How to use $\theta_{JA}$

The following shows how to use  $\theta_{JA}$ .

Example 1:

Comparing  $\theta_{JA}$  between different products to select the one with better heat dissipation performance (lower  $\theta_{JA}$ ).

Example 2:

Comparing  $\theta_{JA}$  between different products to roughly estimate how many degrees C the junction temperature will change relative to each other.

$$\Delta T_j = (\theta_{JA2} - \theta_{JA1}) \times P_D \quad [^\circ\text{C}] \quad (2)$$

$\theta_{JA1}$ : Thermal resistance of Product 1 [ $^\circ\text{C}/\text{W}$ ]

$\theta_{JA2}$ : Thermal resistance of Product 2 [ $^\circ\text{C}/\text{W}$ ]

$P_D$ : Power loss [W]

## Misuse of $\theta_{JA}$

A common type of misuse is to use  $\theta_{JA}$  listed in the data sheet and the following equation to calculate the junction temperature.

$$T_j = \theta_{JA} \times P_D + T_A \quad [^\circ\text{C}] \quad (3)$$

$P_D$ : Power loss [W]

$T_A$ : Ambient temperature [ $^\circ\text{C}$ ]

Since  $\theta_{JA}$  listed in the data sheet is measured in an environment standardized by JEDEC, it is not possible to estimate the junction temperature in unique applications with different environments.

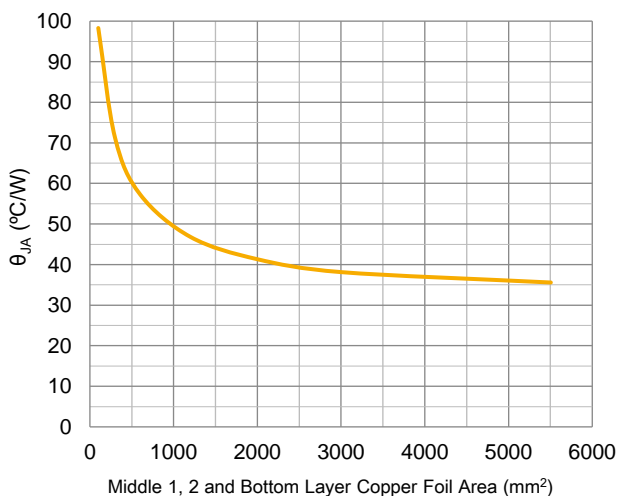


Figure 6. Change in  $\theta_{JA}$  when the copper foil area is varied (HTSOP-J8 package, JEDEC 4-layer PCB)

Figure 6 shows the change in  $\theta_{JA}$  when the copper foil area is varied, where the HTSOP-J8 package is mounted on the JEDEC 4-layer PCB.  $\theta_{JA}$  listed in the data sheet is located at the right end of the curve, which shows that only the difference in copper foil area among many environmental conditions causes such a change. In addition to this, there are many environmental conditions that should be considered, such as board thickness, number of layers, copper foil thickness, thermal via placement, and enclosure space capacity.

## Definition of $\Psi_{JT}$

$\Psi_{JT}$  is defined in JEDEC Standard JESD51-2A. In the definition,  $\Psi_{JT}$  is described as follows: 「The thermal characterization parameter to report the difference between junction temperature and the temperature at the top center of the outside surface of the component package, divided by the power applied to the component.」

Measure  $\Psi_{JT}$  in the same environment as  $\theta_{JA}$  described earlier. To measure the temperature at the center of the package surface, fix a thermocouple in the center of the package with thermally conductive epoxy adhesive as shown in Figure 7.

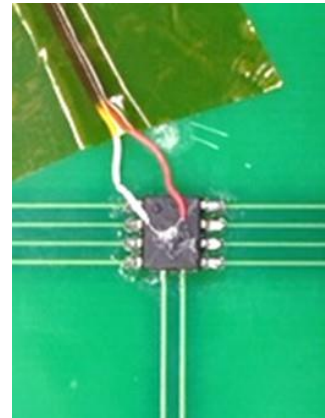


Figure 7. Fixing a thermocouple in the center of the package surface with thermally conductive epoxy adhesive

Next, apply a large current to the body diode in Figure 3 to heat the IC so as to raise the junction temperature by  $30^\circ\text{C}$  -  $60^\circ\text{C}$ . Then, switch to a minute current, measure the forward voltage, and convert it to the junction temperature using the graph in Figure 4. When the temperature change is stabilized, record the junction temperature and thermocouple temperature. Use the following equation to calculate  $\Psi_{JT}$  from the measured value.

$$\psi_{JT} = \frac{T_{Jss} - T_{Tss}}{P_H} \quad [^{\circ}C/W] \quad (4)$$

$T_{Jss}$ : Junction temperature during the steady operation [°C]

$T_{Tss}$ : Temperature at the center of the package surface during the steady operation [°C]

$P_H$ : Consumption power that causes the change in the junction temperature [W]

The thermal characteristics parameter  $\Psi_{JT}$  is the temperature difference between the package surface and the junction temperature divided by the consumption power. If the transfer rate of heat flow from the junction to the package surface is constant,  $\Psi_{JT}$  is proportional to the temperature difference between the package surface and the junction temperature. Therefore, it is possible to estimate the junction temperature by measuring the package temperature of the device in the actual environment if the temperature characteristics parameters are measured under similar conditions.

Figure 8 shows the heat dissipation path when  $\Psi_{JT}$  is measured. Heat is dissipated from the junction in the three-dimensional direction, where thermal conduction is the largest form of heat transfer. Since SMDs (Surface Mount Devices) dissipate most of their heat to the PCB, the heat flow between the junction and the package surface is very small. Therefore, it is found that the temperature difference between  $T_J$  and  $T_T$  is very small and the value of  $\Psi_{JT}$  is also small. When the value of  $\Psi_{JT}$  is small, the error in estimating the junction temperature is also small, even if there are differences between the JEDEC board and the actual equipment board.

Figure 9 shows the change in  $\Psi_{JT}$  when the copper foil area is varied, where the HTSOP-J8 package is mounted on the JEDEC 4-layer PCB.  $\Psi_{JT}$  listed in the data sheet is located at the right end of the curve, which shows that the change is very small compared with  $\theta_{JA}$  marked with a dotted line (the same curve as in Figure 6).

### How to use $\Psi_{JT}$

The following shows how to use  $\Psi_{JT}$ .

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

Use the following equation to calculate the junction temperature.

$$T_J = \Psi_{JT} \times P_D + T_T \quad [^{\circ}C] \quad (5)$$

$\Psi_{JT}$ : 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  $\Psi_{JT}$  data listed in the data sheet or the thermal resistance application note, select the PCB condition value closest to that of the actual equipment.
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 [7].

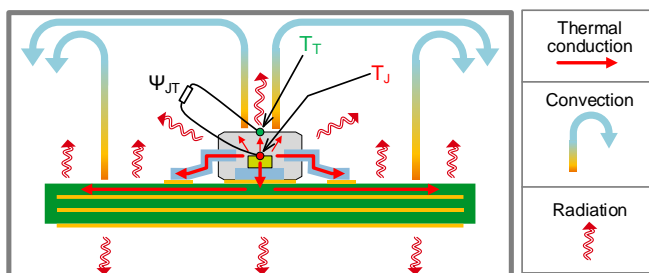


Figure 8. Heat dissipation path when  $\Psi_{JT}$  is measured

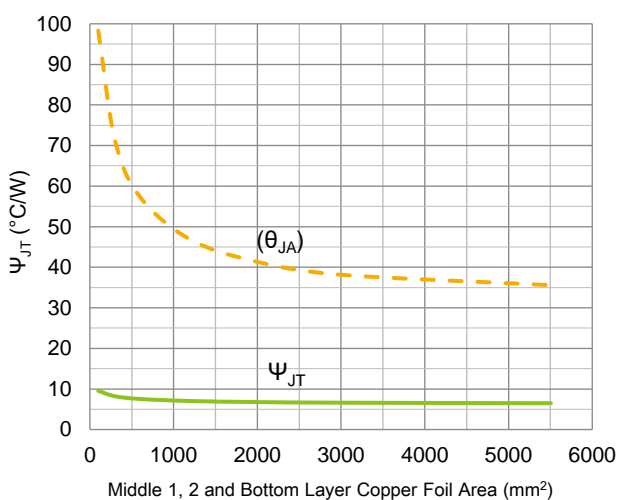


Figure 9. Change in  $\Psi_{JT}$  when the copper foil area is varied (HTSOP-J8 package, JEDEC 4-layer PCB)

### Summary

$\theta_{JA}$  is the temperature difference from the junction to the surrounding environment divided by the heat flow between the two points (power loss). Since there are multiple paths between two points as shown in Figure 10 and the heat flow for each path is different in applications other than the JEDEC measurement environment,  $\theta_{JA}$  also changes. Although it is possible to compare  $\theta_{JA}$  values measured in the JEDEC environment to each other to select a product with better heat dissipation performance and estimate how many degrees C the junction temperature will change relatively, it is impossible to estimate the junction temperature for an application that differs from the JEDEC environment.

$\Psi_{JT}$  is the temperature difference from the junction to the center of the package surface divided by the heat flow (power loss) generated by the device. Since  $\Psi_{JT}$  is measured in the same JEDEC environment as  $\theta_{JA}$ ,  $\Psi_{JT}$  changes in other applications as in the case of  $\theta_{JA}$ . However, most of the heat is dissipated toward the board in the SMD application, so the heat flow between the two points, the junction and the package surface, is very small. Therefore, since the value of  $\Psi_{JT}$  is also smaller, the error in estimating the junction temperature is small even if there are differences between the JEDEC environment and the application.

	$\theta_{JA}$	$\Psi_{JT}$
Standard	JEDEC Standard JESD51-1, 51-2A	JEDEC Standard JESD51-2A
Definition	Thermal resistance from junction to ambient: Thermal resistance from the moving part of the semiconductor device to the natural convection (still air) environment surrounding the device	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
Ambient temperature measurement method	Measured with a thermocouple in the position specified by JESD51-2A	
Package temperature measurement method		Measurement of the center of the package surface with a thermocouple
Measurement environment (Figure 10)	Thermal resistance including the board, when heat is dissipated from the junction in the three-dimensional direction with the device mounted on a board conforming to JEDEC	Thermal characteristics including the board, when heat is dissipated from the junction in the 3-dimensional direction with the device mounted on a board conforming to JEDEC
Applications	<ul style="list-style-type: none"> <li>Comparing <math>\theta_{JA}</math> between different products to select one with better heat dissipation performance</li> <li>Comparing <math>\theta_{JA}</math> between different products to roughly estimate how many degrees C the junction temperature will change relative to each other</li> </ul>	<ul style="list-style-type: none"> <li>Thermal design of SMD applications</li> <li>Measuring the temperature of the package surface and estimating the junction temperature</li> </ul>
Junction temperature estimation	Not possible	$T_J = \Psi_{JT} \times P_D + T_T$ $P_D$ : Power loss [W] $T_T$ : Temperature at the center of the package surface [°C]

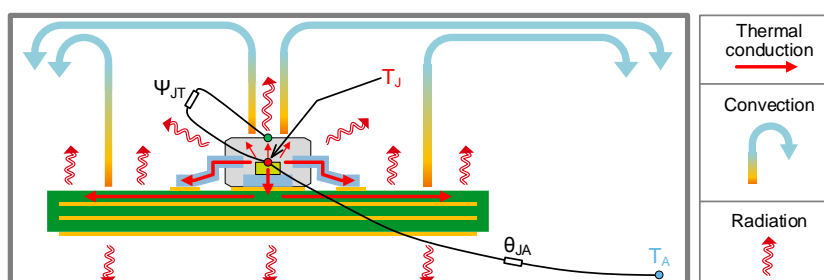


Figure 10. Schematic diagram of the measurement environment for  $\theta_{JA}$  and  $\Psi_{JT}$

## References

- [1] [JESD51-3](#), Low Effective Thermal Conductivity Test Board for Leaded Surface Mount Packages, 1996
- [2] [JESD51-5](#), Extension of Thermal Test Board Standards for Packages with Direct Thermal Attachment Mechanisms, 1999
- [3] [JESD51-7](#), High Effective Thermal Conductivity Test Board for Leaded Surface Mount Packages, 1999
- [4] Application Note "[HTSOP-J8 Package Thermal Resistance Information](#)" page 3 to 4, ROHM CO., LTD., 2022
- [5] [JESD51-1](#), Integrated Circuits Thermal Measurement Method – Electrical Test Method (Single Semiconductor Device), December 1995
- [6] [JESD51-2A](#), Integrated Circuits Thermal Test Method Environmental Conditions - Natural Convection (Still Air), January 2008
- [7] Application Note "[Notes for Temperature Measurement Using Thermocouples](#)" , ROHM CO., LTD., 2020

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