

JEDEC STANDARD

Integrated Circuits Thermal Test Method Environmental Conditions - Natural Convection (Still Air)

JESD51-2A

(Revision of JESD51-2, December 1995)

JANUARY 2008

JEDEC SOLID STATE TECHNOLOGY ASSOCIATION



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INTEGRATED CIRCUITS THERMAL TEST METHOD ENVIRONMENTAL CONDITIONS - NATURAL CONVECTION (STILL AIR)

Foreword

This document is in the JESD51 series of specifications that specify the methods to determine and report the thermal performance of integrated circuit packages. The specification was formulated under the cognizance of the JC-15.1 Committee on Thermal Characterization Techniques for Electronic Packages and Interconnects.

Introduction

The purpose of this document is to outline the environmental conditions necessary to ensure accuracy and repeatability for a standard junction-to-ambient (θ_{JA}) thermal resistance measurement in natural convection. Without the standardized control of the environment, the test results from different vendors or from different packages will not be consistent and cannot be used to judge relative performance. The intent of θ_{JA} measurements is solely for a thermal performance comparison of one package to another in a standardized environment. This methodology is not meant to and will not predict the performance of a package in an application-specific environment.

NOTE: “Still air” (in the title) signifies natural convection in an enclosure as opposed to a natural convection measurement made in a wind tunnel with the blower off.

INTEGRATED CIRCUITS THERMAL TEST METHOD ENVIRONMENTAL CONDITIONS - NATURAL CONVECTION (STILL AIR)

(From JEDEC Board Ballot JCB-07-111, formulated under the cognizance of the JC-15.1 Committee on Thermal Characterization Techniques for Electronic Packages and Interconnects.)

1 Scope

The environmental conditions described in this document will apply only to natural convection, θ_{JA} , measurements for packages mounted on standard test boards. The board will be placed in a horizontal (package up) position in an enclosure that prevents extraneous air currents and allows only natural convection generated by the package under test.

2 Normative reference

The following normative documents contain provisions that, through reference in this text, constitute provisions of this standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies.

- [1] JESD51, *Methodology for the Thermal Measurement of Component Packages (Single Semiconductor Devices)*. This is the overview document for this series of specifications.
- [2] JESD51-1, *Integrated Circuit Thermal Measurement Method - Electrical Test Method*
- [3] JESD51-3, *Low Effective Thermal Conductivity Test Board for Leaded Surface Mount Packages*
- [4] JESD51-4, *Thermal Test Chip Guideline (Wire Bond Type Chip)*
- [5] JESD51-5, *Extension of Thermal Test Board Standards for Packages with Direct Thermal Attachment Mechanisms*
- [6] JESD51-6, *Integrated Circuit Thermal Test Method Environmental Conditions – Forced Convection (Moving Air)*
- [7] JESD51-7, *High Effective Thermal Conductivity Test Board for Leaded Surface Mount Packages*
- [8] JESD51-8, *Integrated Circuit Thermal Test Method Environmental Conditions – Junction-to-Board*
- [9] JESD51-9, *Test Boards for Area Array Surface Mount Package Thermal Measurements*
- [10] JESD51-10, *Test Boards for Through-Hole Perimeter Leaded Package Thermal Measurements*
- [11] JESD51-11, *Test Boards for Through-Hole Area Array Leaded Package Thermal Measurements*
- [12] JESD51-12, *Guidelines for Reporting and Using Electronic Package Thermal Information*
- [13] JESD30D, *Descriptive Designation System for Semiconductor-device Packages*

3 Terms and definitions

For the purposes of this standard, the terms and definitions given in JESD51-1, *Integrated Circuit Thermal Measurement Method - Electrical Test Method* and the following apply:

T_A - Ambient air temperature.

T_{A0} - Initial ambient air temperature before heating power is applied.

T_{Ass} - Final ambient air temperature after heating power is applied and steady-state has been reached.

T_{T0} - Initial package (top surface) temperature before heating power is applied.

T_{Tss} - Final package (top surface) temperature after heating power is applied and steady-state has been reached.

Ψ_{JB} - Thermal characterization parameter to report the difference between junction temperature and the temperature of the board measured at the top surface of the board as described in section 7. This measurement must be done on boards with two internal planes such as specified in JESD51-7 or JESD51-9.

Ψ_{JT} - 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. When Greek letters are not available, Ψ_{JT} is written Psi-JT.

4 Environmental conditions for natural convection measurements

4.1 Test enclosure assembly

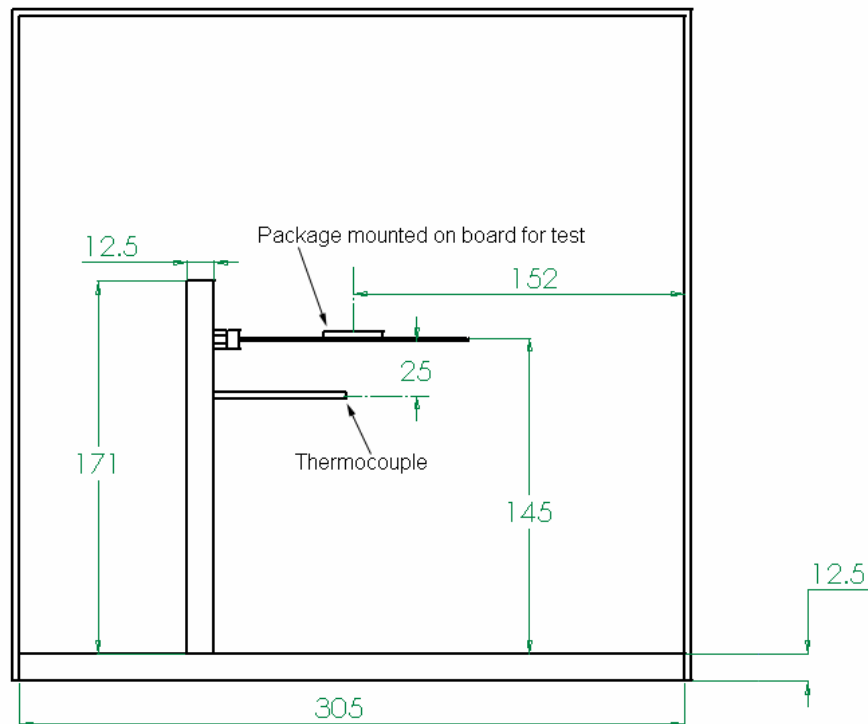
The enclosure shall be a box with a nominal inside dimension of 305 mm x 305 mm x 305 mm as shown in Figures 1 and 2. This is approximately 1 foot x 1 foot x 1 foot in keeping with previous specification. All seams should be thoroughly sealed to ensure no airflow through the enclosure. A list of potential construction materials is detailed in 4.6. The box material shall be a low conductivity material (less than 0.5 W/m K). The box should sit on a table or shelf constructed of low conductivity material.

NOTE For high power devices, dissipating >3 watts, increasing the size of the box should be considered if the ambient temperature rise above the initial ambient temperature is 10% or more of the rise in junction temperature during the test (ΔT_J). Any dimensional changes in the box size must be reported in the data and labeled as non-standard if the deviation of the dimension from the nominal is more than 10% of the nominal dimension.

4 Environmental conditions for natural convection measurements (cont'd)

4.2 Test fixture support

The support fixture shall be constructed per Figures 1, 2, and 3. The package shall be positioned in the geometric center of the chamber by adjusting the position of the support structure as necessary. The material used for the fixture shall be a low thermal conductivity material as detailed in 4.6.2. There shall be no structures above the package and board being tested to avoid disturbing the convection plume unless it can be proved that the deviation causes less than a 2% change in the measured thermal resistances. Alternate structures for mounting the connector and board are acceptable if it can be demonstrated that the measured thermal resistances are within 2% of the values measured with this reference design.



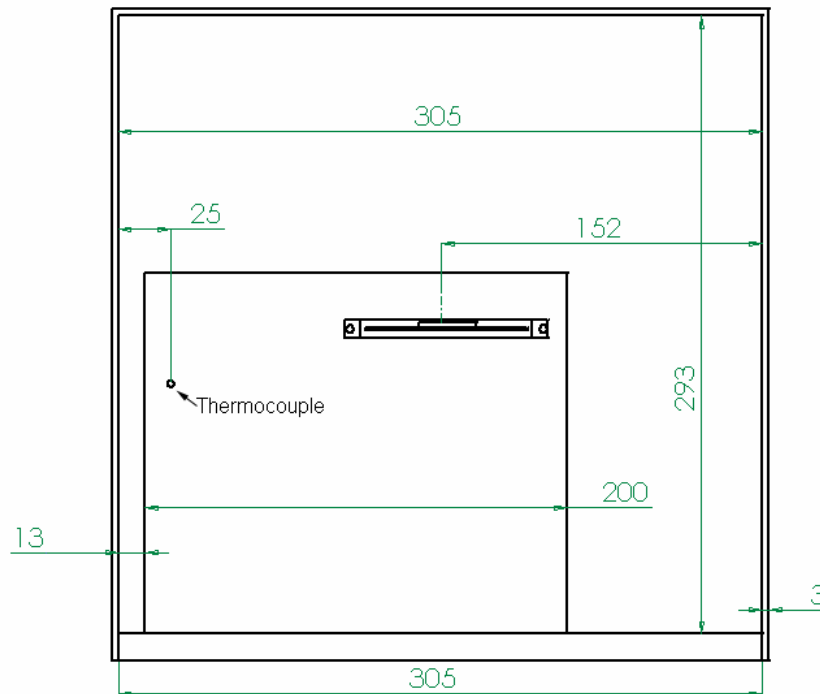
NOTE 1 Dimensions in mm.

NOTE 2 Wiring not shown, but will be placed to avoid interfering with the convection air flow.

Figure 1 — Side view of the test fixture and enclosure

4 Environmental conditions for natural convection measurements (cont'd)

4.2 Test fixture support (cont'd)



NOTE 1 Dimensions in mm.

Figure 2 — End view of test fixture and enclosure

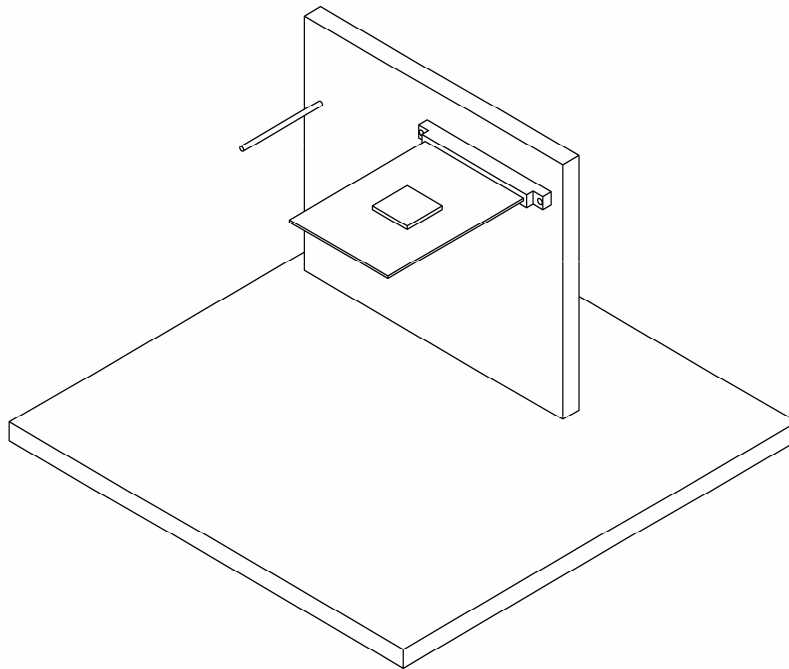


Figure 3 — Isometric view of the test board and fixture without the enclosure

4 Environmental conditions for natural convection measurements (cont'd)

4.3 Edge connector and printed circuit board support

The socket shall accommodate the printed circuit board.

The board must be horizontal within +/- 5 degrees. If the edge connector and socket do not provide adequate support, it may be necessary to provide additional support such as a rod with diameter less than 3.5 mm to support the end of the board. The rod must be made of a low-thermal-conductivity material (less than 0.5 W/m K) or must be thermally insulated from the board.

4.4 Ambient temperature thermocouple

The wire diameter shall be no larger than AWG size 30 (or no larger than 0.26 mm diameter). Placement of the thermocouple shall be 25 +/- 5 mm below the bottom plane of the printed circuit test board and 25 +/- 5 mm from the side wall. Refer to Figures 1, 2, and 3. The accuracy of the thermocouple and associated measuring system shall be 1°C or better.

4.5 Test board

The test board defined by the JESD51 series of specifications shall be used for the thermal measurement. The board used shall be referenced when the thermal performance is specified by both the JEDEC specification and the short reference. Table 1 lists the packages, appropriate JEDEC board specification and the suggested short reference name that would be used when reporting data.

Table 1 — Thermal test boards

Package	Specification	Short Reference
Leaded Surface Mount, Peripheral Leads (e.g. QFP)	JESD51-3	1s Board
	JESD51-7	2s2p Board
Leaded Surface Mount Peripheral Leads with direct thermal attach (e.g. exposed pad QFP)	JESD51-3 plus JESD51-5	1s Board
	JESD51-7 plus JESD51-5	2s2p Board
Leadframe based perimeter array with direct thermal attach (e.g. QFN)	JESD51-3 plus JESD51-5	1s Board
	JESD51-7 plus JESD51-5	2s2p Board
Array surface mount (e.g. BGA, or LGA)	JESD51-9	1s Board
	JESD51-9	2s2p Board
Through Hole Perimeter Array (e.g. DIP)	JESD51-10	1s Board
	JESD51-10	2s2p Board
Through Hole Array (e.g. PGA)	JESD51-11	1s Board
	JESD51-11	2s2p Board

Table 1 lists the thermal test boards standardized under the JESD51 series of specifications at the time that this specification was updated. Refer to the JESD51 overview document for a current list of standardized boards.

4 Environmental conditions for natural convection measurements (cont'd)

4.6 Material

The suggested construction materials listed in this document are intended as a guideline and are not all-inclusive.

4.6.1 Enclosure (box)

The following materials, or their thermal equivalent, have been and may be used for construction of the enclosure: cardboard, polycarbonate, polypropylene, wood, and plywood. Each of these materials has a low thermal conductivity (less than 0.5 W/m K) and high infrared emissivity. Minimum wall thickness of 3 mm is required.

4.6.1.1 Considerations for changes in room temperature

The room ambient temperature when the tests are conducted shall be between 15°C and 30°C. If the room in which the testing occurs suffers from drastic temperature changes ($>\pm 3^\circ\text{C}$), then placement of a larger box over the test enclosure should be considered. Thicker test enclosure walls should also be considered.

4.6.2 Test fixture

The following materials, or their thermal equivalent, may be used for construction of the support structure: plywood, wood, polycarbonate, or polypropylene. Each of these materials has a low thermal conductivity. Common fasteners and adhesives may be used in the construction.

5 Thermal measurement procedure and methodology

This section details the steps necessary to perform a thermal resistance measurement in a natural convection (still air) environment. The following equations describe the measured and calculated parameters required for making a thermal measurement for a single chip (die) package with one heat source

5.1 Methodology

The junction-to-ambient thermal resistance ($R_{\theta_{JA}}$ or θ_{JA} or Theta-JA) is determined from equation 1:

$$\theta_{JA} = (T_J - T_A) / P_H \quad (1)$$

where θ_{JA} = thermal resistance from junction-to-ambient ($^\circ\text{C}/\text{W}$)

T_J = junction temperature when the device has achieved a steady-state after application of P_H ($^\circ\text{C}$)

T_A = ambient temperature ($^\circ\text{C}$)

P_H = power dissipation that produced change in junction temperature (W)

5 Thermal measurement procedure and methodology (cont'd)

5.1 Methodology (cont'd)

As described in the JESD51-1, a temperature-sensitive parameter (TSP) is used to sense the change in temperature of the junction operating area due to the application of electrical power to the device. In equation terms,

$$\Delta T_J = (\Delta TSP \times K) \quad (2)$$

where ΔTSP = change in the TSP caused by the application of P_H
 K = K factor, which is the ratio of junction temperature change to temperature-sensitive parameter change in the linear region of the temperature-sensitive parameter - temperature relationship.

The junction-to-ambient thermal resistance can then be described by equation 3:

$$\theta_{JA} = ((T_{A0} + \Delta TSP \times K) - T_{Ass}) / P_H \quad (3)$$

where T_{A0} = Initial ambient air temperature before heating power is applied.
 T_{Ass} = Final ambient air temperature when steady-state has been reached.

Applying the change in the ambient temperature to the equation will provide data correction to achieve an absolute θ_{JA} value.

5.2 Device mounting

Mount the device to be tested on the appropriate test board as listed in Table 1.

5.3 K factor calibration

Prior to making actual thermal measurement, the junction or other temperature-sensitive parameters must be empirically calibrated. Reference 3.3 of JESD51-1, for the procedure to determine the K Factor value. Record the K Factor value.

5.4 Test start-up and initial equilibrium verification

Place the test device in the natural convection chamber and apply measurement current for the temperature-sensitive device, (e.g., diode, metal resistor, etc.). Prior to recording the initial conditions at the beginning of the thermal test, verify that the enclosure environment has reached a state of equilibrium.

To verify that stabilization has occurred, wait an initial 5 minutes minimum, then record the TSP, wait an additional 5 minutes and record a 2nd TSP. If ΔT_J as determined by the TSP measurement is less than or equal to 0.2 °C, then equilibrium has occurred. If equilibrium has not occurred, continue measuring the TSP at 5 minute intervals until $(\Delta TSP \times K) \leq 0.2$ °C where ΔTSP is the change in the TSP measurement in the most recent five minute interval.

After equilibrium has been reached record the values for TSP and the initial ambient temperature T_{A0} .

5 Thermal measurement procedure and methodology (cont'd)

5.5 Power level selection and applying power

The power levels at which devices are tested should be governed by actual use conditions. The minimum recommended junction temperature rise for testing is 20 °C. The typical junction temperature rise during testing is between 30 °C and 60 °C, which is the normal range of use for most devices. Hence, the following guidelines are recommended:

Table 2 — Recommended Power Levels

Power	θ_{JA} Range
0.5 watt	$\theta_{JA} > 100^{\circ}\text{C/W}$
0.75 watt	$60 < \theta_{JA} < 100^{\circ}\text{C/W}$
1 watt	$30 < \theta_{JA} < 60^{\circ}\text{C/W}$
2 watt	$20 < \theta_{JA} < 30^{\circ}\text{C/W}$
3 watt	$15 < \theta_{JA} < 20^{\circ}\text{C/W}$
etc	

After selecting the appropriate power level, apply the heating voltage (V_H) and the heating current (I_H) to the device.

NOTE Air flow in natural convection is naturally unstable; it is more unstable at higher surface temperatures and power levels.

5.6 Verification of thermal steady-state and test completion

For the test measurement to be completed, verification that thermal steady-state has been reached shall be done before the final reading can be taken. For a discussion on determining steady-state conditions, refer to 3.6 of JESD51-1.

After a steady-state has been reached, record the values for the TSP, the heater voltage (V_H), the heater current (I_H), the time required to reach equilibrium (t_{Hss}), and the final ambient temperature at the end of the test (T_{Ass}).

The junction-to-ambient thermal resistance is then calculated using equation 3.

6 Thermal characterization parameter - Ψ_{JT} , Junction-to-Top of Package (Optional Procedure)

6.1 Purpose and limitations of the thermal characterization parameter

The thermal characterization parameter, Ψ_{JT} , is proportional to the temperature difference between the top of the package and the junction temperature. Hence, it is a useful value for an engineer verifying device temperatures in an actual environment. By measuring the package temperature of the device, the junction temperature can be estimated if the thermal characterization parameter has been measured under similar conditions.

The use of Ψ_{JT} should not be confused with θ_{JC} which is the thermal resistance from the device junction to the external surface of the package held at a constant temperature. The use and reporting of the case temperature during the junction to ambient thermal resistance test is optional.

The measurement may be made using a temperature transducer such as a thermocouple, fluoroptic sensor, or infrared sensor.

6.2 Thermocouple placement location

For single chip (die) packages, the thermocouple junction shall be attached to the package at the geometric center of the top surface.

The measurement may also be made using a temperature transducer such as a thermistors, fluoroptic sensor, or infrared sensor.

6.3 Package thermocouple application

CAUTION: Usefulness of this measurement is dependent on the procedure.

Application of the thermocouple is critical to ensure proper thermal contact to the package and to ensure that the θ_{JA} measurement is not disturbed. Determination of the package surface temperature, of a low conductance package body, requires that the following factors be considered:

6.3.1 Attachment technique

The thermocouple wire and thermocouple bead shall touch the surface of the package. Best practice for attaching the wire and thermocouple junction is the use of a minimal amount of thermally conducting epoxy. The distance across the epoxy bead shall not exceed 2.5 mm in any direction.

6.3.2 Wire routing

The thermocouple wire shall be routed next to the package body down to the board and along the board. This reduces cooling of the thermocouple junction by heat flowing along the wire.

6.3 Package thermocouple application (cont'd)

6.3.3 Thermocouple wire size

Thermocouple wire size shall be small such that heat loss along the wire does not cause anomalous low readings. Recommended maximum thermocouple size is 36 gauge. For type T thermocouples, 40 gauge is required.

6.4 Procedure

The junction temperature and package temperatures are determined at the steady-state condition in the θ_{JA} measurement as specified above. The junction-to-top center of package thermal characterization parameter, Ψ_{JT} , is calculated using the following equation:

$$\Psi_{JT} = (T_{Jss} - T_{Tss})/P_H \quad (4)$$

where Ψ_{JT} = thermal characterization parameter from device junction to the top of the package surface ($^{\circ}\text{C}/\text{W}$)

T_{Jss} = the junction temperature at steady-state.

T_{Tss} = the package (top surface) temperature, at steady-state, measured by the thermocouple, infrared sensor, or fluoroptic sensor.

The thermal characterization parameter, Ψ_{JT} , has the units $^{\circ}\text{C}/\text{W}$ but is a mathematical construct rather than thermal resistance because not all of the heating power flows through the exposed case surface.

7 Thermal characterization parameter - Ψ_{JB} , Junction-to-Board (Optional Procedure)

It is occasionally useful to determine a junction-to-board thermal characterization parameter, Ψ_{JB} , in a natural convection environment. It must be remembered that the junction-to-board thermal characterization parameter, Ψ_{JB} , is not determined under the same conditions as the junction-to-board thermal resistance and hence will not be the same value. This method is useful only for packages which have sufficient symmetry that a single representative board temperature is useful.

7.1 Board temperature

The board temperature is measured using the location and attachment method defined in JESD51-8 on the top surface of the board. The board temperature for this measurement shall be determined by a 40 gauge thermocouple that is soldered in place. Since type T thermocouples are easily soldered, type T is preferred. Type J or K can also be used. Contact to the board trace or package lead foot is verified by a resistance measurement. A small amount of thermally conductive epoxy is placed over the thermocouple junction and about one mm of wire extending from the thermocouple junction. The epoxy dot shall be no larger than 2 mm in diameter. The thermocouple meter must electrically float the thermocouple to avoid electrical interactions with any voltages applied to the package during test.

For a leaded package, the thermocouple is attached to the foot of a package lead halfway along the side of the package. For a rectangular package, the lead is on one of the longer sides. The thermocouple is attached to the lead foot where the lead is joined to the test board as illustrated in Figure 4.

7 Thermal characterization parameter - Ψ_{JB} , Junction-to-Board (Optional Procedure) (cont'd)

7.1 Board temperature (cont'd)

For an area array surface mount package, the thermocouple is attached to a test board trace halfway along one side of the package. The location is illustrated in Figure 4. The solder mask should be removed to allow attaching the thermocouple directly to the trace. The trace should be a trace to which the package is soldered. The thermocouple junction must be within 1 mm of the package body.

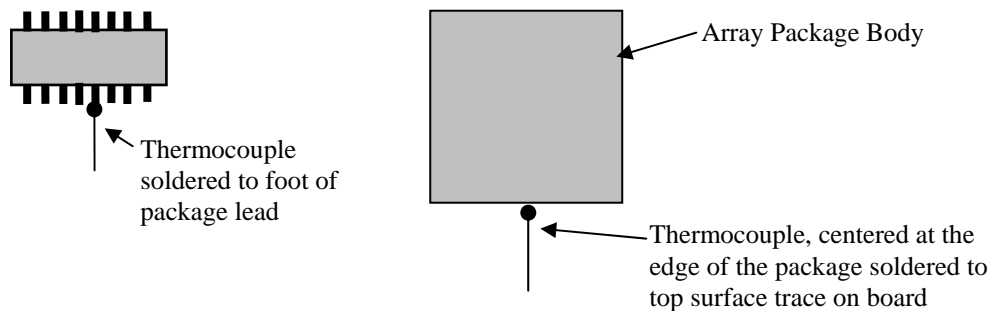


Figure 4 — Board thermocouple location (top view)

7.2 Calculation of junction-to-board thermal characterization parameter

The junction-to-board thermal characterization parameter, Ψ_{JB} , is calculated using the following equation

$$\Psi_{JB} = (T_{Jss} - T_{Bss})/P_H \quad (5)$$

where

T_{Jss} is the junction temperature at steady state condition

T_{Bss} is the board temperature at steady state condition.

Normally the junction to board thermal characterization parameter is measured only on the 2s2p test boards because the 2s2p test boards provide a more uniform temperature in the vicinity of the package

8 Test conditions to be documented

Junction-to-ambient thermal resistance determined per this specification should be reported with the following information along with the statement that the **measurement conforms to JESD51-2 with any deviations from the specification reported**. As an example, if the package is tested on a non-standard board, that deviation must be reported in the footnotes to the results. It has been found that complete package identification helps with interpretation of the data. For instance, a package might be identified as a 100 lead 14 mm x 14 mm x 1.4 mm LQFP with a flag size of 7.5 mm x 7.5 mm.

Units of thermal resistance in °C/W are numerically equivalent to thermal resistance values in K/W.

8 Test conditions to be documented (cont'd)

Table 3 — Test Conditions and Data Parameter Summary

Measurement Area	Condition Parameters	Data and Example Results
Identification		Device Identification
		Date
		Package Identification
Environmental	Test Board	1s or 2s2p
		Applicable Specification
		Test Board Drawing Number
	Test Board Orientation	Horizontal
	Enclosure (box) Size	mm x mm x mm
Measurement Results for single chip packages	Junction-to-Ambient thermal Resistance	$R_{\theta JA}$ or θ_{JA} °C/W or K/W
	Thermal Characterization Parameter junction-to-package-top	Ψ_{JT} °C/W or K/W
	Thermal Characterization Parameter junction-to-board	Ψ_{JB} °C/W or K/W
Measurement (Raw Data)	Power	P_H watts
	Ambient Temperature	T_{A0}
		T_{Ass}
	TSP - Temperature Sensitive Parameter	Kind of TSP Sensor Diode, Resistor, etc
		I_M Measurement Current (ma)
		Calibration or K factor
		ΔTSP
Time required to reach equilibrium	t_{Hss} seconds	
Package Case Temperature details	Sensor	Thermocouple, Fluoroptic sensor, or Infrared sensor
	Sensor location	Center or x,y dimensions mm
	Thermocouple Wire gauge (AWG)	36 or 40 gauge
	Thermocouple Type	K, T, J, etc
	Attachment Method	Epoxy type
Junction-to-Board details	Thermocouple location	e.g. center trace closest to edge connector
	Thermocouple Wire gauge (AWG)	40 gauge
	Thermocouple Type	T, K, or J
	Thermocouple Attachment Method	Solder

Annex A (informative) Differences between JESD51-2A and JESD51-2

This table briefly describes most of the changes made to entries that appear in this standard, JESD51-2A, compared to its predecessor, JESD51-2 (December 1995). If the change to a concept involves any words added or deleted (excluding deletion of accidentally repeated words), it is included. Some punctuation changes are not included.

Description of change

1. Forward and Introduction changed to conform to style manual.
2. Removed requirement that only single layer boards be used.
3. Dimensions changed to metric
4. Added requirement that board be horizontal within 5 degrees. Allowed support rod if needed.
5. Added list of thermal test boards and the appropriate specifications.
6. Relaxed requirement for room temperature.
7. Specified “low conductivity” to be less than 0.5 W/m K for the fixture materials.
8. Tightened requirement that Type T thermocouples used for the Ψ_{JT} measurement be 40 gauge.
9. Added Section 7, the measurement of the junction to board characterization parameter.
10. Rearranged the data reporting list and made it more consistent with the other specifications.
11. Committee after considerable discussion decided to remove Ψ_{TA} from document.



Standard Improvement Form

JEDEC JESD51-2A

The purpose of this form is to provide the Technical Committees of JEDEC with input from the industry regarding usage of the subject standard. Individuals or companies are invited to submit comments to JEDEC. All comments will be collected and dispersed to the appropriate committee(s).

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