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

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

Contents

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

(From JEDEC Council Ballot JCB-95-30, formulated under the cognizance of JC-15 Committee on Electrical and Thermal Characterization Techniques for Electronic Packages and Interconnects.)

1 Introduction

1.1 Puppose

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. 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.

1.2 Scope

The environmental conditions described in this document will apply only to natural convection θ_{JA} measurements. These environmental conditions are pertinent to surface-mount packages mounted on a standard test board. Further discussion of the board design is found in document LOW THERMAL CONDUCTIVITY TEST BOARD FOR LEADED SURFACE-MOUNT PACKAGES among others. 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.

1.3 Rationale

It is very important to have well-defined, well-documented test conditions to satisfy the industry requirements of accuracy and repeatability. The environmental conditions have significant impact on the test results and must be tightly controlled. Comparison of data sheets between different vendors or packages have very little meaning unless the thermal data was collected under identical conditions. For these reasons it is imperative that the environmental conditions are well defined.

1.4 References

SEMI Test Method #G38-87, Still and Forced Air Junction-To-Ambient Thermal Resistance Measurements of Integrated Circuit Packages

SEMI Test Method #42-87, Thermal Test Board Standardization for Measuring Junction-To-Ambient Thermal Resistance of Semiconductor Packages

SEMI Test Method #43-87, Junction-To-Case Thermal Resistance Measurements of Molded Plastic Packages

JEDEC JCB-95-28, Methodology for the Thermal Measurement of Component Packages (Single Semiconductor Devices)

JEDEC JCB-95-29, Integrated Circuit Thermal Measurement Method - Electrical Test Method (Single Semiconductor Devices)

JEDEC JCB-95-40, Low Thermal Conductivity Test Board for Leaded Surface Mount Packages

1.5 Definitions

Refer to the ANNEX in this document for definitions of terminology and symbols applicable to this document only. Refer to document INTEGRATED CIRCUIT THERMAL MEASUREMENT METHOD - ELECTRICAL METHOD for an additional list of terminology and symbols pertinent to this document.

2 Environmental conditions for natural convection measurements

The following conditions clearly detail all aspects necessary to construct a test fixture. Refer to figure 1 and 2.

2.1 Test enclosure assembly

The enclosure shall be a box with an inside dimension of 1 $ft.^3$ (0.0283 m^3). All seams should be thoroughly sealed to ensure no airflow through the enclosure. A list of potential construction materials is detailed in 2.6. The box material shall be a low conductance 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.

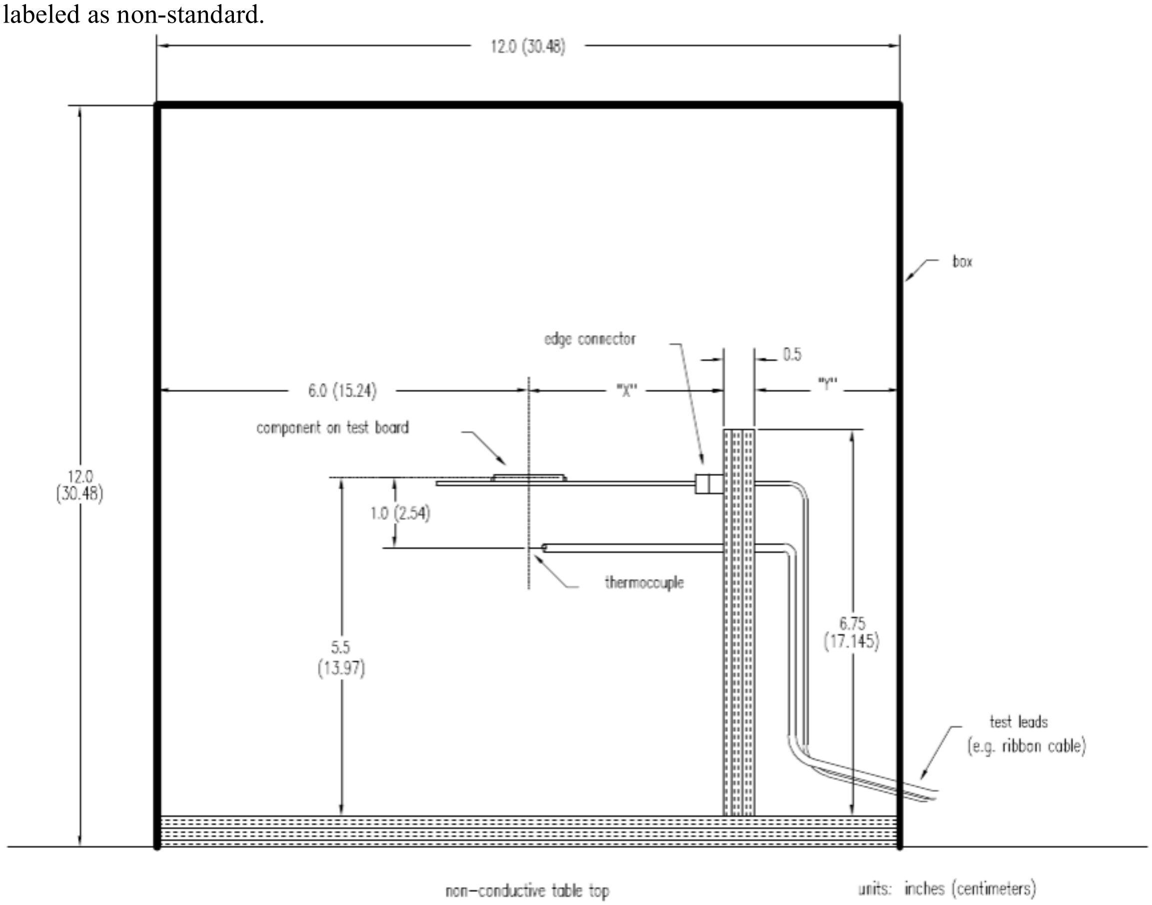

FIGURE 1, TEST FIXTURE & ENCLOSURE

2.2 Test fixture support

The support fixture shall be constructed per figure 2. The package shall be positioned in the geometric center of the chamber. The vertical support position will be determined by the board size. Therefore the "X" and "Y" dimensions in figure 1 and 2 will change according to the test board dimensions. The material used for the fixture shall be an insulating material and have a low thermal conductance.

NOTE — Any deviations from this configuration must be recorded and labeled as non-standard.

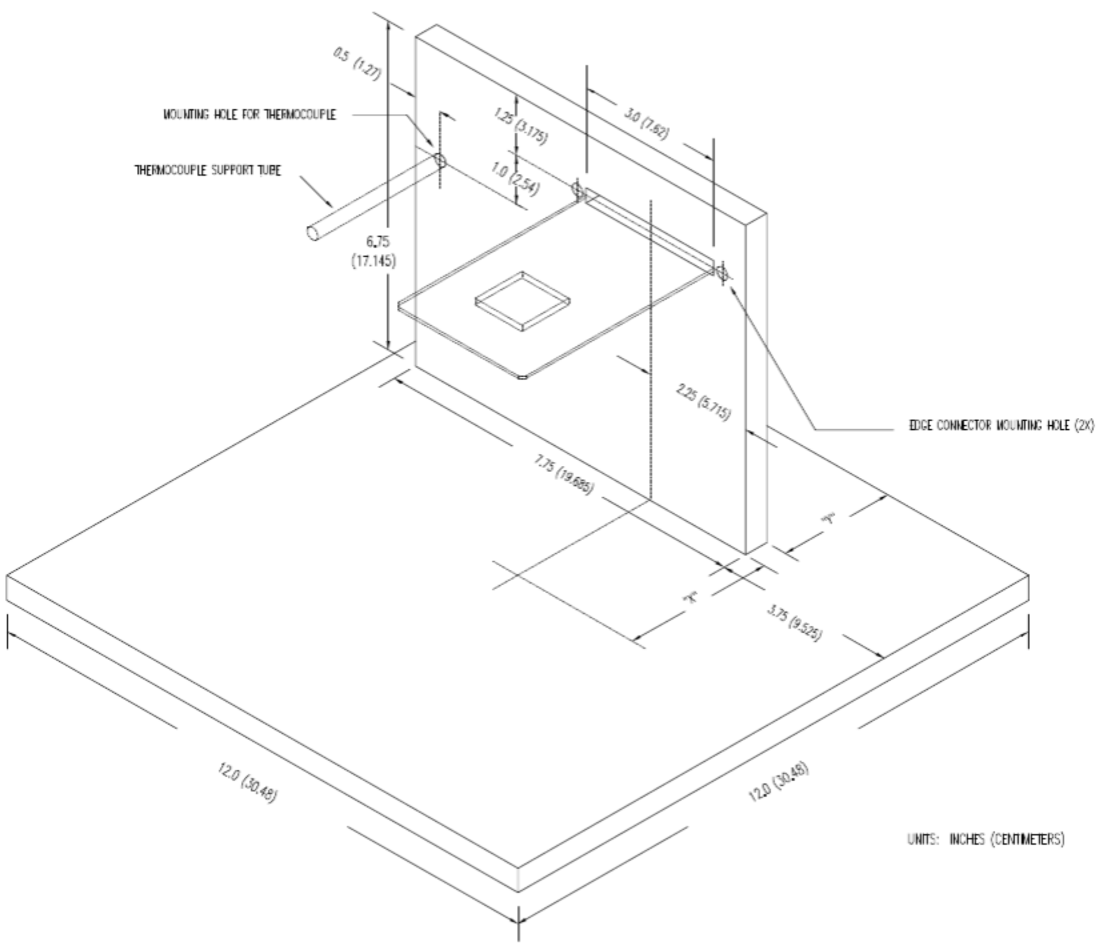

FIGURE 2, TEST FIXTURE (HORIZONTAL & VERTICAL)

2.3 Edge connector

The socket shall accommodate the printed circuit board described in the board specification, LOW THERMAL CONDUCTIVITY TEST BOARD FOR LEADED SURFACE-MOUNT PACKAGES.

2.4 Thermocouple

The wire diameter shall be no larger than AWG size 30. Placement of the thermocouple shall be 1" (2.54 cm) below the bottom plane of the test board (PCB) and 1" (2.54 cm) from the side wall. Refer to figure 2. The accuracy of the thermocouple and associated measuring system shall be 1°C or better.

2.5 Test board

See Document LOW THERMAL CONDUCTIVITY TEST BOARD FOR LEADED SURFACE-MOUNT PACKAGES.

2.6 Material

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

2.6.1 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 conductance. Minimum wall thickness of 1/8" (3.175 mm) is required.

2.6.1.1 Considerations For Changes In Room Temperature

The room ambient temperature when the tests are conducted shall be between 20°C and 30°C. If the room in which the testing occurs suffers from drastic temperature changes (>±3°C), then placement of a larger box over the test enclosure should be considered. Thicker test enclosure walls should also be considered.

2.6.2 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 conductance. Common fasteners and adhesives may be used in the construction.

3 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.

The junction-to-ambient thermal resistance is determined from equation 1:

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

where θ_{JA} = thermal resistance from junction-to-ambient (°C/W)
T_J = junction temperature when the device has achieved a steady-state after application of P_H (°C)
T_A = ambient temperature (°C)
P_H = power dissipation that produced change in junction temperature (W)

As described in the document, INTEGRATED CIRCUIT THERMAL MEASUREMENT METHOD - ELECTRICAL TEST METHOD, 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,

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

where ΔTSP = change in the TSP caused by the application of P_H
K = K factor is the ratio of junction temperature change to temperature-sensitive parameter change in the linear region of the temperature-sensitive parameter -temperature relationship, specified in units of °C/mV; usually applicable to semiconductor devices using a forward bias temperature sensitive parameter.

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

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

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.

3.1 Device mounting

Mount the device to be tested on the appropriate test board. Reference Test Board Specification, LOW THERMAL CONDUCTIVITY TEST BOARD FOR LEADED SURFACE-MOUNT PACKAGES for board design, mounting, and wiring details.

3.2 K factor calibration

Prior to making actual thermal measurement the junction or other temperature-sensitive parameters must be empirically calibrated. Reference 3.3 of document, INTEGRATED CIRCUIT THERMAL MEASUREMENT METHOD - ELECTRICAL METHOD, for the procedure to determine the K Factor value. Record the K Factor value.

3.3 Test start-up and initial equilibrium verificaton

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 then continue for an additional 5 minutes. Equilibrium of the TSP has occurred if $(\Delta TSP \times K) \leq 0.2°C$.

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

3.4 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 and 60°C, which is the normal range of use for most devices. Hence, the following guidelines are recommended:

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

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

NOTE — At higher power the convective air can become unstable.

3.5 Verification of thermal stead-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 INTEGRATED CIRCUIT THERMAL MEASUREMENT METHOD - ELECTRICAL METHOD.

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}).

4 Thermal characterization parameter - Ψ_{JT} junction -to-top center of package (Optional Procedure)

The thermal characterization parameter, Ψ_{JT}, is proportional to the temperature difference between the top center 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 or case nearest the die attachment as the case is 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, flouroptic sensor, or infrared sensor.

4.1 Thermocouple placement location

The thermocouple bead shall be attached to the package at the geometric center of the top surface. The position must be reported, in all cases, along with the measurement data.

4.2 Package thermocoupl 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:

4.2.1 The thermocouple wire and bead shall touch the surface of the package.

4.2.2 Best practice for attaching the wire and thermocouple bead is the use of a minimal amount of thermally conducting epoxy. The distance across the epoxy bead shall not exceed .1" (2.54 mm) in any direction.

4.2.3 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.

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

4.3 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 center of the package surface(°C/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 flouroptic sensor.

The relationship between the junction-to-ambient thermal resistance, θ_{JA}, and the junction-to-top center of package thermal characterization parameter, Ψ_{JT}, is described by equation 5:

$$\theta_{JA} = \Psi_{JT} + \Psi_{TA} \quad (5)$$

where Ψ_{TA} = thermal characterization parameter from top surface of the package-to-air (°C/W)

The package-to-air thermal characterization parameter, Ψ_{TA}, is based on the steady-state ambient air temperature as shown here:

$$\Psi_{TA} = (T_{Tss} - T_{Ass})/P_H \quad (6)$$

The thermal characterization parameters, Ψ_{JT} and Ψ_{TA}, have the units °C/W but are mathematical constructs rather than thermal resistances because not all of the heating power flows through the exposed case surface. It is not necessary to report Ψ_{TA} because it can be determined from the relationship between θ_{JA} and Ψ_{JT}. Also, Ψ_{TA} is very dependent on the application-specific environment.

5 Test conditions to be reported

The conditions listed in table 1, which are pertinent to the natural-convection thermal measurement, must be reported when publishing measurement results.

Measurement Area	Condition Parameter(s)	Data Parameter(s)
Electrical	V_H (V) I_H (A) t_{Hss} (s) I_M (ma) K (°C/mV)	ΔV_F (V) ΔT_J (°C) P_H (W) θ_{JA} (°C/W)
Environmental	Test Board Orientation Enclosure (box) Size T_{A0} (°C) T_{Ass} (°C)	
Package Surface Measurement (Optional Method)	T_{T0} (°C) T_{Tss} (°C) Measurement method (e.g. Thermocouple, Flouroptic sensor, Infrared sensor) Thermocouple wire gauge # (AWG) Thermocouple type (T, J, or K) Thermocouple location Attachment method	Ψ_{JT}(°C/W)

Table 1 — Thermal measurement test conditions and data parameter summary.

ANNEX A (informative)

1.A Definitions

Ψ_{JT} - The thermal characterization parameter to report the difference between junction temperature and the temperature at the top dead center of the outside surface of the component package, divided by the power applied to the component.

Ψ_{TA} - The thermal characterization parameter from the top surface of the package to surrounding natural convection (still-air) ambient.

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.

For all other DEFINITIONS not listed here refer to Annex A-1 through A-4 of document INTEGRATED CIRCUITS THERMAL MEASUREMENT METHOD - ELECTRICAL METHOD