EIA/JEDEC STANDARD

Integrated Circuit Thermal Test Method Environmental Conditions - Forced Convection (Moving Air)

JESD51-6

MARCH 1999

ELECTRONIC INDUSTRIES ALLIANCE

JEDEC Solid State Technology Association

Electronic Industries Alliance

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INTEGRATED CIRCUIT THERMAL TEST METHOD
ENVIRONMENTAL CONDITIONS - FORCED CONVECTION (MOVING AIR)

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(From JEDEC Board Ballot JCB-98-103, under the cognizance of the JC-15.1 Committee on Thermal Characterization.)

1 Scope

This standard specifies the environmental conditions for determining thermal performance of an integrated circuit device in a forced convection environment when mounted on a standard test board. The thermal resistance measured using this document is $R_{\theta JMA}$ or θ_{JMA}. This methodology is not meant to and will not predict the performance of a device in an application-specific environment.

2 Normative references

The following standards contain provisions that, through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below.

JESD51, "Methodology for the Thermal Measurement of Component Packages (Single Semiconductor Devices)". This is the overview document for this series of specifications.

JESD51-1, "Integrated Circuit Thermal Measurement Method - Electrical Test Method".

JESD51-2, "Integrated Circuit Thermal Test Method Environmental Conditions - Natural Convection (Still Air).

JESD51-3, "Low Effective Thermal Conductivity Test Board for Leaded Surface Mount Packages".

JESD51-4, "Thermal Test Chip Guideline (Wire Bond Type Chip)"

JESD51-7, "High Effective Thermal Conductivity Test Board for Leaded Surface Mount Packages"

3 Definitions, symbols, and abbreviations

Refer to the documents JESD51, JESD51-1 and JESD51-2 for a general list of terminology.

4 Specification of environmental conditions

4.1 Wind tunnel specifications

A low velocity wind tunnel is shown in figure 1 as an example only. The package and test fixtures are not shown in this example. In most electronic applications, the wind tunnels are normally used at velocities less than 10 m/s. The minimum specifications for acceptable wind tunnels are detailed in the following paragraphs. Normally the manufacturer of the wind tunnel will characterize the wind tunnel to certify performance to these specifications. The wind tunnel is characterized without the test board and package.

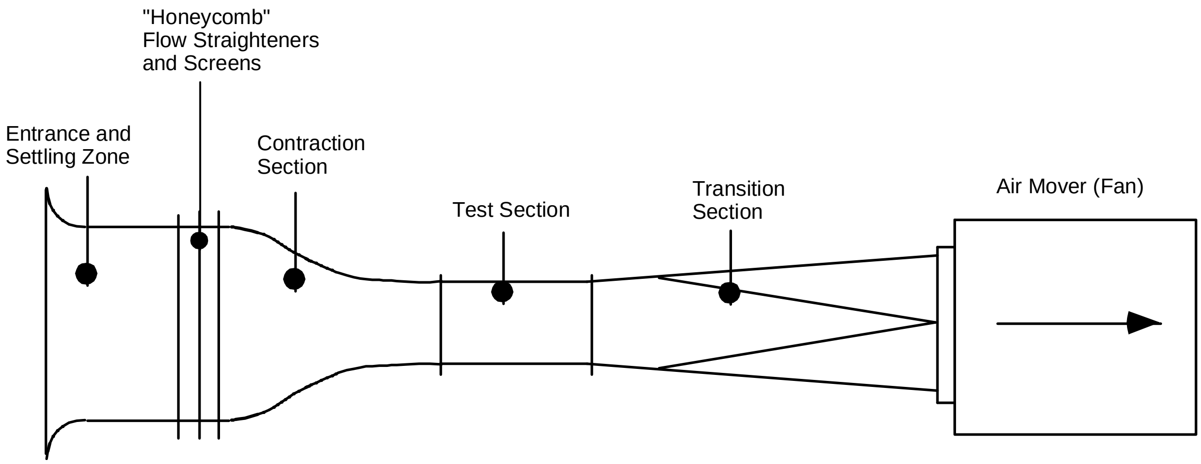

Figure 1 — Open circuit wind tunnel

This type of tunnel (Eiffel type, fan at downstream end of system) is also commonly called a suction or indraft style. A radiused inlet prevents separation of the flow from the settling length walls. The flow management components include a honeycomb, which reduces lateral velocity differences, and screens which, owing to their higher pressure drop in the flow direction, promote a more uniform axial velocity. The combined effect of these elements is the reduction of turbulence intensity and production of a flat velocity profile. A contraction duct is employed to accelerate the flow while maintaining flow quality. The diffuser/transformation conveys the flow from the test section to the circular fan inlet. Proper selection of diffuser angles helps to prevent flow separation which would create unsteadiness. A flow-through tunnel (Wenham type) incorporates similar design features.

4.1.1 Flow uniformity

The flow velocity shall be uniform to +/-5% of the mean velocity across the central 90% of the test chamber cross-section, and constant within +/-5% along the length of the test section.

4.1.2 Swirl

The cross stream component (swirl) of the mean flow shall be less than 5% of the mean flow velocity. The cross stream component of the mean flow is measured with a three axis or cross wire anemometer capable of measuring flow in a minimum of two directions.

4.1 Wind tunnel specifications (cont'd)

4.1.3 Turbulence

The turbulence shall be less than 2%. The turbulence is measured with a hot wire anemometer with a frequency response of 10 kHz or higher.

4.1.4 Unsteadiness

The unsteadiness (change in mean flow velocity) shall be less than 5% over the time period of a typical measurement.

4.1.5 Chamber size

The test section shall be large enough that the frontal area of the test sample (package, board, support fixture, and optional heat sink) shall be less than 5% of the wind tunnel cross sectional area. Adequate "bypass" of the air is allowed around the test specimen to avoid the channel flow (or "ducted") regime. The minimum clearance on each side of the part is specified in figure 2. Wall effects are avoided if the wind tunnel test section dimension perpendicular to the plane of the test board is at least twice the flow length along the test board and the test board is mounted in the center of the wind tunnel. These dimensions are illustrated in figure 3. Minimum distances to the wall in both directions are reported in table 2. Using this specification, the measured thermal resistance will be largely independent of wind tunnel cross section dimensions.

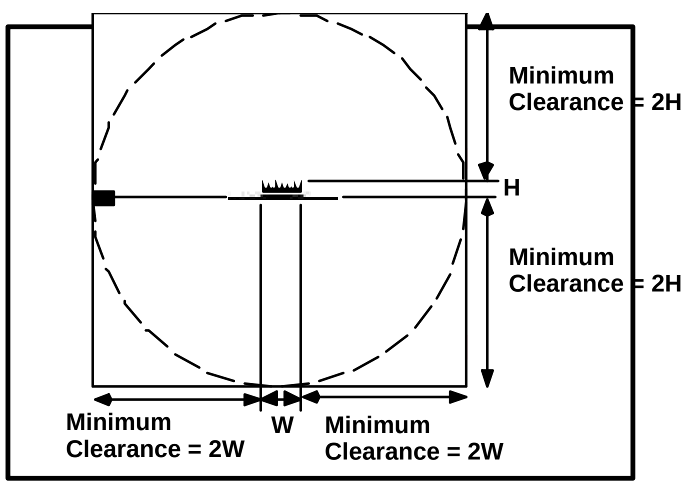

Figure 2 — Minimum clearance

The minimum clearance around a package or around a package and heat sink is twice the width of the heat sink (or package whichever is larger) or twice the height of the heat sink plus package and board. In addition, the frontal area of the package, heat sink, test board, and fixture must be less than 5% of the cross section of the test section of the wind tunnel. The same rules apply for a wind tunnel with round section as illustrated with the dashed lines.

4.1 Wind tunnel specifications (cont'd)

4.1.5 Chamber size (cont'd)

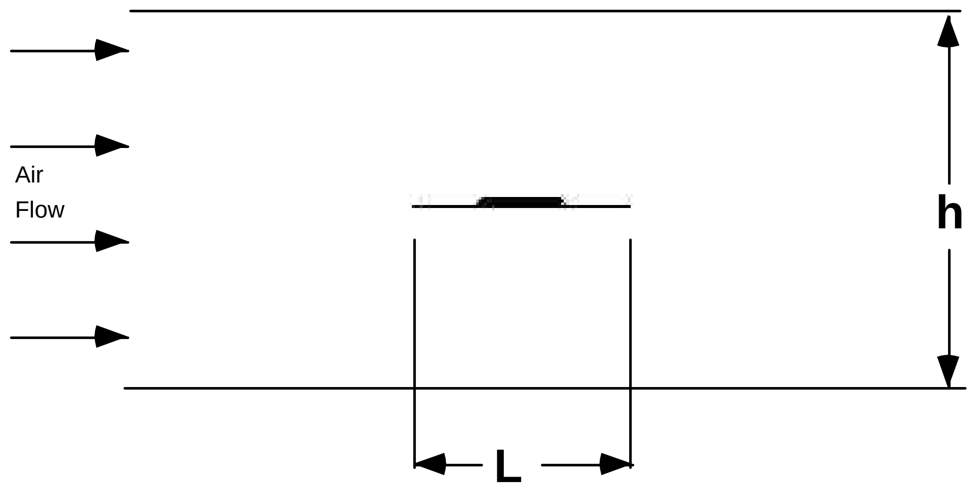

Figure 3 — Test section

It is recommended that the test section perpendicular distance be twice the flow length of the test board (h > 2L).

4.1.6 Temperature uniformity

The air temperature in an empty test section shall be uniform to +/- 1 °C.

4.1.7 Performance verification

The performance of the wind tunnel to the above characteristics must be periodically checked. Typical causes of degradation in performance are sagging screens, dust in screens and honeycomb section, dust on the contraction duct, and fan damage such as bent blades or wobble in the fan bearings. Careful inspection of the wind tunnel on a yearly basis will normally be sufficient.

4.2 Test board

The test board specified in JESD51-3, and JESD51-7, which are appropriate for the device being tested, shall be used. It is essential that any reported data must specify the test board used if the data was not obtained using the appropriate 1s test board

4.3 Placement in the test section

The device that is mounted on the test board will be placed in the test section of the wind tunnel as described in figures 4, 5, or 6.

4 Specification of environmental conditions (cont'd)

4.3 Placement in the test section (cont'd)

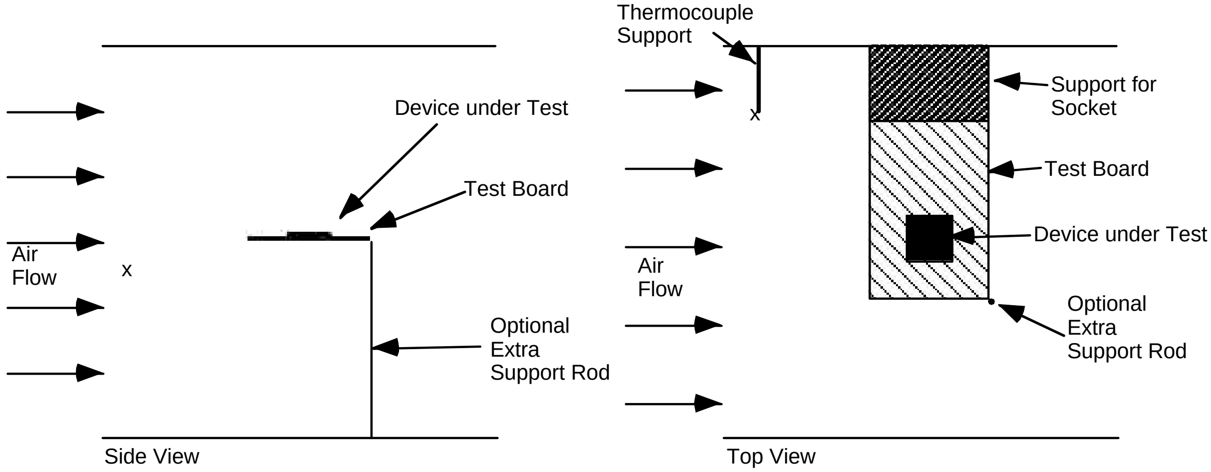

Figure 4 — Horizontal air flow, horizontal board (Package up)

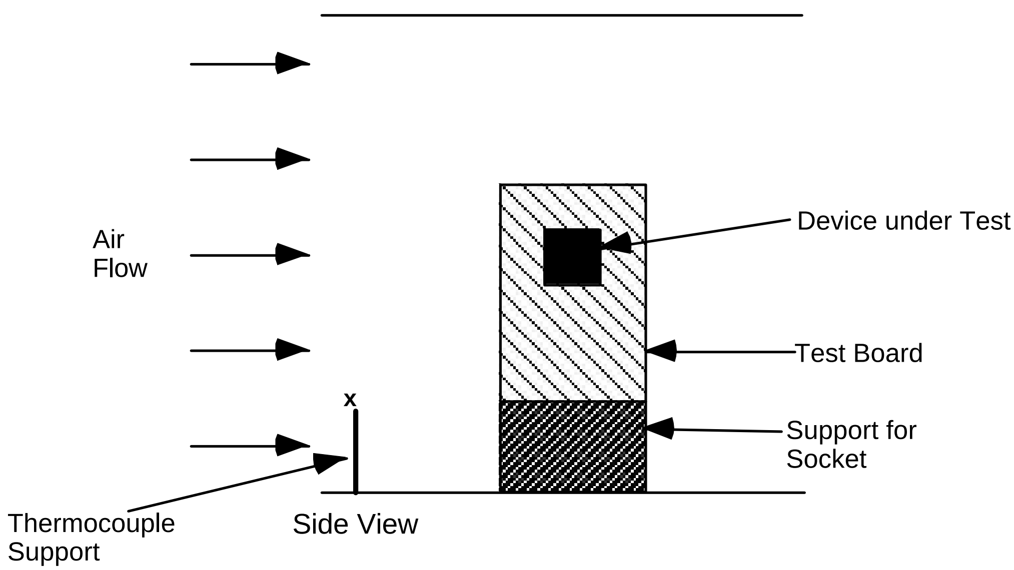

Figure 5 — Horizontal air flow, vertical board orientation

4 Specification of environmental conditions (cont'd)

4.3 Placement in the test section (cont'd)

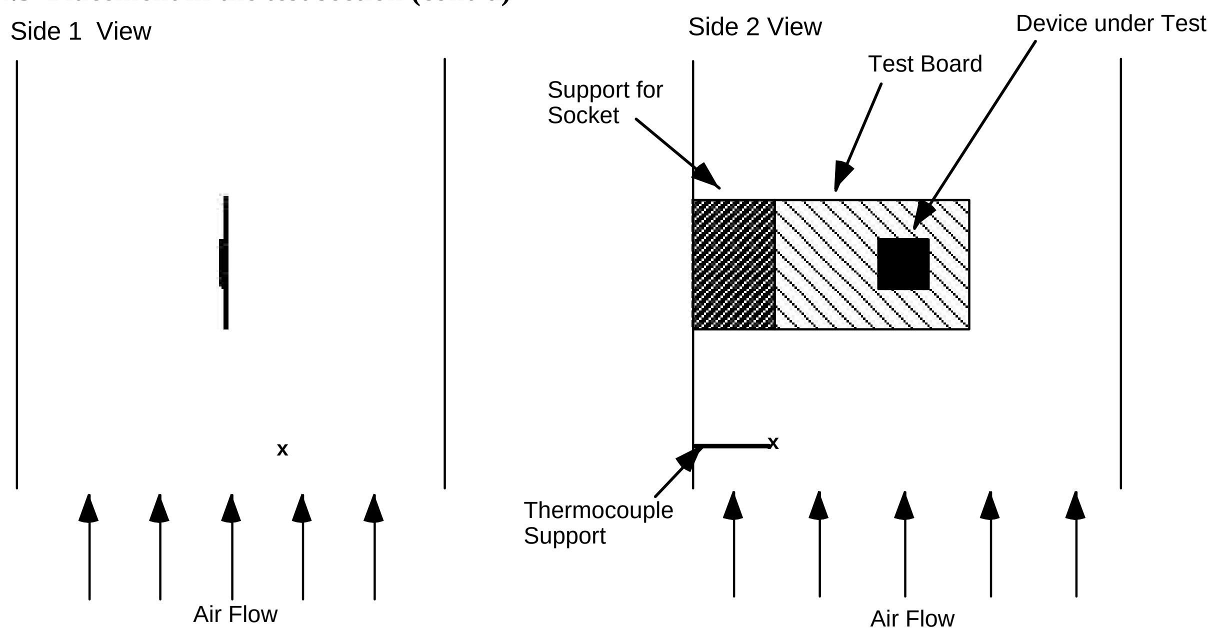

Figure 6 — Vertical air flow, vertical board

4.3.1 Orientation

The orientation of the printed circuit board and the flow direction of the wind tunnel must be specified when test data is reported. The printed circuit board is specified as horizontal or vertical orientation with the flow of air in the wind tunnel either horizontal or vertically upward. If the printed circuit board is horizontal, the package being tested shall be on the upward-facing side of the board.

4.3.2 Measurement

The measurement of thermal resistance in a horizontal wind tunnel with a horizontal orientation of the test board in a mixed convection mode will yield thermal resistance measurements that will approach the values obtained using reference [3] as the mean flow velocity in the tunnel approaches zero. Testing in the vertical orientation will yield slightly lower thermal resistance values. Typically, at mean flow velocities above 2 m/s (about 400 ft/min), there will be no difference between the different orientations when the devices are at the surface temperatures produced by the power ranges specified in this document.

4.3.3 Simultaneous testing

Simultaneous testing of more than one single-device board in the wind tunnel is possible if the devices are arranged such that the resulting thermal resistance measurement is within +/- 3% of the average value obtained when single devices are tested in the uniform velocity portion of the cross section. This qualification of the test methodology for a given lab must be done with a statistically significant number of samples. It should be tested on both the smallest device with highest thermal resistance and the highest power device with lowest thermal resistance being tested.

4 Specification of environmental conditions (cont'd)

4.4 Test fixture support

The printed circuit board and device being tested must be supported with minimal obstruction to the air flow. The recommended support should lie in the plane of the board and be no thicker than the socket and not more than 20 mm longer than the socket. To minimize turbulence, leading and trailing edges of the support should not have square edges. Because the support structure can act as an airfoil, it must be aligned with the air flow.

> **CAUTION** — The geometrical angle of attack of the printed circuit board with the air flow may cause significant differences in the measured thermal resistance. Normally a level is used to align the test section; then the angle of attack is determined using measurements of the distance from the leading and trailing edges to the test section wall. The board shall be aligned with the test section wall within +/- 2 degrees.

Although the board is normally supported only by the edge connector, it may be necessary to provide additional support such as a rod with diameter less than 3.5 mm to stabilize the end of the board as shown in figure 4. The rod must be thermally insulated from the board.

4.5 Environmental conditions and measurements

4.5.1 Flow velocity measurement

The mean flow velocity shall be measured upstream from the device being tested with an anemometer (air velocity transducer). The velocity reported shall be the velocity as if the air were at the standard air conditions with a density of 1.2 kg/m^3. This air density is equivalent to dry air at 101.325 kPa (760 mmHg) at 21 °C or moist air at 50% humidity at the same pressure and 20 °C. A thermal anemometer that is temperature compensated and calibrated to give the equivalent mass flow velocity is normally used. If the air velocity measurement equipment does not automatically correct to those conditions, the appropriate corrections shall be applied as described in Annex A. Placement of the anemometer shall be such that the anemometer reads the same as it would in the location where a device is normally tested. The placement of the anemometer shall be in a location where it does not cause turbulence in the air reaching the device being tested. The anemometer shall be calibrated with traceability to NIST or other recognized standards organization at the vendors' recommended intervals. Calibration at more frequent intervals is required if dust collects on the sensor or if the sensor drifts out of calibration during the normal calibration interval. Minimum accuracy of the anemometer shall be +/- 4% of reading and +/- 0.05 m/s.

4.5.2 Ambient temperature measurement

Ambient temperature of the air in the wind tunnel shall be measured with a calibrated thermocouple with wire diameter no larger than 0.5 mm. Accuracy of the thermocouple and associated measuring system shall be +/- 1 °C or better. The thermocouple shall be located such that it measures the air temperature approaching the device. The location shall be 100 mm to 150 mm upstream of the device being tested, 25 mm "below or behind" the plane of a board and the same distance from the test section side wall as the connector or a minimum of 25 mm from the wall. The suggested location is shown with an "x" on figures 4 through 6. The thermocouple should be supported from the nearest wall. The thermocouple and support structure shall be less than 2 mm in diameter.

4.5 Environmental conditions and measurements (cont'd)

4.5.2 Ambient temperature measurement (cont'd)

The air temperature shall be between 20 °C and 30 °C. The temperature inside the wind tunnel must not change more than 2 °C per hour to allow achieving an adequate steady state thermal performance measurement.

For an open circuit wind tunnel, adequate clearance must exist at the entrance and exit of the tunnel as specified by the wind tunnel designer for the wind tunnel to meet its specified performance. Traffic or air conditioning flows in those areas must be restricted to prevent unsteady airflow within the wind tunnel. The temperature control in the room must be sufficient to achieve the specified temperature uniformity in the tunnel.

5 Thermal measurement procedure and methodology

This section details the steps necessary to perform a thermal resistance measurement in moving air. The following equations describe the measured and calculated parameters required for making the measurement.

The junction-to-moving-air thermal resistance is determined from equation (1):

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

where

θ_{JMA} is thermal resistance (°C/W) from junction to ambient as described by this specification

T_J is the junction temperature (°C) when the device has achieved a steady-state after application of P_H and the forced convection condition

T_A is the ambient temperature (°C) when steady state occurs

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

In conjunction with the measured thermal resistance, the moving air environment must be specified in units of feet per minute or meters per second.

5 Thermal measurement procedure and methodology (cont'd)

As described in 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,

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

where

ΔTSP = change in the TSP caused by the application of P_H

K factor is the quotient of the junction temperature change to the temperature sensitive parameter change in the linear region of the temperature-sensitive parameter temperature relationship, typically specified in units of °C/mV; usually applicable to semiconductor devices using a forward bias temperature sensitive parameter.

The junction to moving air ambient thermal resistance can then be determined by equation (3):

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

where

T_{A0} is the initial ambient air temperature (°C) before heating power is applied

T_{ASS} is final ambient air temperature (°C) when steady state has been reached.

The junction temperature can also be calculated directly from a calibration curve (reference 2).

5.1 K factor calibration

Prior to making actual thermal measurements, the junction or other temperature-sensitive parameters must be empirically calibrated using the procedure in JESD51-1, subclause 3.3, K factor calibration.

5.2 Test start-up and initial equilibrium verification

Place the device to be tested in the wind tunnel and apply measurement current to the temperature-sensitive device. Prior to recording the initial conditions at the beginning of the thermal test, verify that the device has reached a state of equilibrium with the ambient temperature.

To verify that stabilization has occurred, wait an initial 5 minutes minimum, then record the TSP, wait an additional 5 minutes and record a second TSP. If change in junction temperature as determined by the TSP measurement is less than or equal to a 0.2 °C, then equilibrium has been achieved. If equilibrium has not occurred, then continue for additional 5 minute intervals. The recommended practice is for the equilibrium to be established with an air speed of 1 to 2 m/s.

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)

5.3 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 during testing is 20 °C. For low air speeds below 1 m/s (200 ft/min), the guidelines in table 1 are recommended.

Table 1 — Recommended power levels

Power	θ_{JMA} Range
0.5 watt	θ_{JMA} > 100 °C/watt
0.75 watt	60 < θ_{JMA} <100 °C/watt
1 watt	30 < θ_{JMA} < 60 °C/watt
2 watts	20 < θ_{JMA} < 30 °C/watt
3 watts	15 < θ_{JMA} < 20 °C/watt

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

5.4 Verification of thermal steady-state and test completion

For a test measurement to be completed, verification that thermal steady state has been reached shall be done using the method documented in JESD51-1, subclause 3.6, Thermal steady-state determination.

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 steady state (t_{Hss}), the final ambient temperature at the end of the test (T_{ASS}), and the air speed measured with the anemometer.

If tests at additional air speeds are desired, the air speed can be set to the new value. After steady state has occurred, the values are determined as described above.

5.5 Verification of absence of interaction between applied power level and temperature-sensitive parameter (optional procedure)

Once moving air velocity is in excess of approximately 2 m/s, the relationship between applied power dissipation and junction temperature generally becomes very linear over typical temperature ranges encountered in integrated circuit packages using thermal test die. That is, if the power is doubled, the temperature rise of the junction above ambient will double. However, there are also occasions when an undesired and generally difficult-to-detect electrical interaction exists between the applied power level and the temperature sensitive parameter in the die or the effective heat generation area of the die. Also, the conductivity of silicon decreases more than 30% from 25 °C to 125 °C.

Therefore, at the conclusion of a device test at a moving air velocity greater than or equal to 2 m/s, if the power level was chosen based on the criteria established in section 5.3, table 1, a "verification" test may then be performed at 1.5 times that power level (and at the same wind speed). If the resulting value in θ_{JMA} differs by less than 2%, one may conclude that there is no significant electrical interaction between applied power and the TSP. At higher wind speeds, the test reaches thermal equilibrium quicker; therefore it is most expeditious to perform this verification test at the highest wind speed used during a particular test series.

6 Thermal characterization parameters

6.1 Ψ_{JT} Junction-to-top-center of the package (Optional procedure)

The junction-to-top-center 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 temperature of the top center of the device, the junction temperature can be estimated if the thermal characterization parameter has been measured under similar conditions. The methodology of attaching the thermocouple on the top of the package to obtain the temperature of the top of the package (T_{T0} and T_{Tss}) has been described in JESD51-2 together with the definition of Ψ_{TA}, the package-top-surface-to-air thermal characterization parameter. The thermocouple wire should be routed next to the package body to the printed circuit board in the downstream direction. The thermal characterization parameter depends on the mean flow velocity; hence, the mean flow velocity must be reported along with the measured value for Ψ_{JT}.

6.2 Ψ_{JB} Junction-to-board (Optional procedure)

The junction-to-board thermal characterization parameter, $\Psi_{JB,}$ is a useful indicator of the thermal resistance between the junction and the thermal test board. The board temperature is measured with a 40 gauge thermocouple soldered to the thermal test board trace at the edge of the package footprint at the center of one side of the package as shown in figure 7. A small amount of thermally conductive epoxy is placed over the thermocouple joint and about 1 mm of thermocouple wire leading to the joint. By thermally coupling the wire to the thermocouple joint, errors caused by temperature gradients in the vicinity of the joint are minimized. The thermocouple wire should be thermally grounded to the test board with either tape or epoxy and must lie flat on the board to minimize airflow disturbance. For square packages, the board temperature thermocouple should be placed halfway along the package edge on either the connector side of the package or the opposite side. For rectangular packages the thermocouples would be located along each of the longer sides; upwind and downwind thermocouple measurements should be averaged.

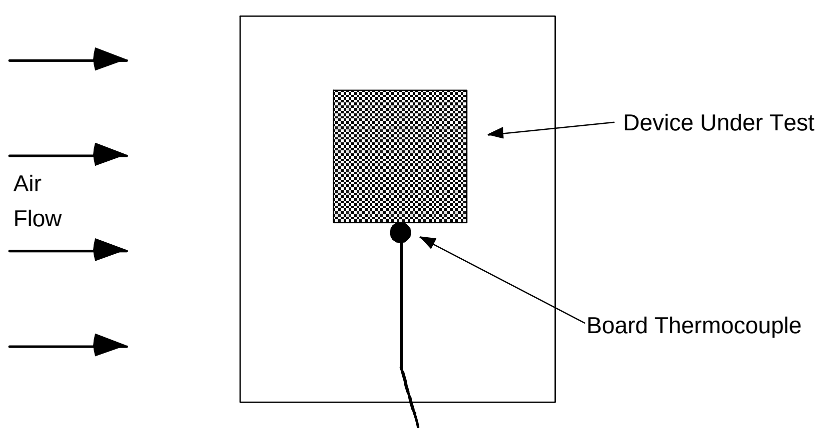

Figure 7 — Thermocouple location

The board thermocouple should be soldered to thermal test board trace as close to the package as possible. Thermocouple wire must lie flat on the board to minimize air flow disturbance.

6 Thermal characterization parameters (cont'd)

6.2 Ψ_{JB} Junction-to-board (Optional procedure) (cont'd)

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

$$\Psi_{JB} = (T_{Jss} - T_{Bss})/P_H \tag{4}$$

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.

7 Test conditions to be reported

The values listed in table 2, which are needed to describe this test and the results, must be reported.

Table 2 — Thermal measurement test conditions and data parameters.

	Condition Parameters	Data Parameters and Results
Device Identification		Device Identification Date
Environmental	Test Board Specification Wind Tunnel Type Wind Tunnel Test Section Dimensions, length Flow Orientation Test Board Orientation Minimum distances to wall Wind Tunnel Length Tunnel Contraction Ratio Optional Barometric Pressure	
For Each Mean Flow Velocity Environmental	T_{A0} (°C) T_{ASS} (°C)	(m/s or ft/min)
Electrical	V_H (V) I_H (mA) t_{Hss} (s) I_m (mA) K (°C/mV)	ΔV_f (V) ΔT_J (°C) T_{Jss} P_H (W) θ_{JMA} (°C/W)
Package Case Measurement (Optional)	T_{T0} (°C) T_{Tss} (°C)	Ψ_{JT} (°C/W)
Board Measurement (Optional)	T_{Bss} (°C)	Ψ_{JB} (°C/W)

Bibliography

[1] SEMI Test Method #G38-0996, Still and Forced Air Junction-to-Ambient Resistance Measurements of Integrated Circuit Packages

[2] SEMI Test Method #42-0996, Thermal Test Board Standardization for Measuring Junction-to-Ambient Thermal Resistance of Semiconductor Packages

Annex A — Air velocity corrections

It is normal industry practice to calibrate industrial thermal anemometers to indicate the velocity as if the air being measured were at standard air conditions (density of 1.2 kg/m^3). The velocity readings must be corrected to standard air conditions if the anemometer has been calibrated to read actual velocity by calibrating with a moving structure or by using a Laser Doppler Velocimeter or a similar instrument which measures actual velocity of particles in the air. For typical values of humidity, the following equation can be used to make the correction:

$$V_{std} = V_{act}\left[\frac{294}{273+T_a}\right]\left[\frac{P_{barometric}}{760}\right] \qquad (5)$$

where

V_{std} is the air velocity at standard air conditions

V_{act} is the actual air velocity as if measured with tracer particles in the air

T_a is the ambient temperature (°C)

$P_{barometric}$ is the atmospheric pressure (mmHg) in the room where the wind tunnel is located.

NOTE — Standard air conditions are not the same as standard atmosphere conditions.

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