JEDEC STANDARD

Thermal Resistance Test Method for Signal and Regulator Diodes (Forward Voltage, Switching Method)

JESD531

(Reaffirmation of ANSI/EIA-531-1986, previously published as IS-13)

JULY 1986
(Reaffirmed: APRIL 1999, APRIL 2002)

JEDEC SOLID STATE TECHNOLOGY ASSOCIATION

JEDEC

EIA
Electronic Industries Alliance

NOTICE

JEDEC standards and publications contain material that has been prepared, reviewed, and approved through the JEDEC Board of Directors level and subsequently reviewed and approved by the JEDEC legal counsel.

JEDEC standards and publications are designed to serve the public interest through eliminating misunderstandings between manufacturers and purchasers, facilitating interchangeability and improvement of products, and assisting the purchaser in selecting and obtaining with minimum delay the proper product for use by those other than JEDEC members, whether the standard is to be used either domestically or internationally.

JEDEC standards and publications are adopted without regard to whether or not their adoption may involve patents or articles, materials, or processes. By such action JEDEC does not assume any liability to any patent owner, nor does it assume any obligation whatever to parties adopting the JEDEC standards or publications.

The information included in JEDEC standards and publications represents a sound approach to product specification and application, principally from the solid state device manufacturer viewpoint.

No claims to be in conformance with this standard may be made unless all requirements stated in the standard are met.

Inquiries, comments, and suggestions relative to the content of this JEDEC standard or publication should be addressed to JEDEC at the address below, or call (703) 907-7559 or www.jedec.org

Published by
©JEDEC Solid State Technology Association 2002
2500 Wilson Boulevard
Arlington, VA 22201-3834

PRICE: Please refer to the current
Catalog of JEDEC Engineering Standards and Publications or call Global Engineering Documents, USA and Canada 1-800-854-7179, International (303) 397-7956

THERMAL RESISTANCE TEST METHOD
FOR
SIGNAL AND REGULATOR DIODES

(FORWARD VOLTAGE, SWITCHING METHOD)

TABLE OF CONTENTS

3.0 TERMS AND DEFINITIONS

(a) $R_{\theta JR}$ - Thermal resistance, junction-to-reference point, in degrees celsius/watt.

(b) T_J - Junction temperature in degrees celsius.

(c) T_R - Lead- or case-temperature in degrees celsius. Equivalent to T_L for lead-mounted diodes and T_C for case-mounted diodes when measured at the reference point.

(d) P_H - Magnitude of heating power in watts applied to the diode causing temperature difference $T_J - T_R$.

(e) P_C - Magnitude in watts applied to the diode during measuring and calibration.

(f) I_M - Measuring current in milliamperes (mA).

(g) V_{MH} - Value at temperature-sensitive parameter in millivolts, measured at I_M, and corresponding to the temperature of the junction heated by P_H.

(h) T_{MC} - Calibration temperature in degrees celsius, measured at the reference point on lead or case.

(i) V_{MC} - Value of temperature-sensitive parameter in millivolts, measured at I_M and the specified value of T_{MC}.

(j) T_{RO} - Lead- or case-temperature in degrees celsius, measured at the reference point prior to application of heating power P_H.

(k) V_{MO} - Value of temperature-sensitive parameter in millivolts, measured at I_M, prior to the application of heating power P_H.

(l) T_{RH} - Lead- or case-temperature in degrees celsius, measured at the reference point after the junction has been heated by P_H.

(m) D - Heating power duty factor.

3.1 Characteristics to be Measured

Thermal resistance, junction to specified reference point ($R_{\theta JR}$). Two of the most common thermal resistance specifications are:

(a) $R_{\theta JL}$ Thermal resistance from junction to lead.

(b) $R_{\theta JC}$ Thermal resistance from junction to case.

4.Ø APPARATUS

The apparatus required for this test shall include the following as applicable to the specified test procedure.

4.1 The thermocouple material shall be copper-constantan (Type T) or equivalent, for the temperature range -183°C to +371°C. The wire size shall not exceed AWG size 3Ø. The junction of the thermocouple shall be welded to form a bead rather than having the wires soldered or twisted together. The accuracy of the thermocouple and associated measuring system shall be ± Ø.5°C.

4.2 The controlled temperature chamber or heat sink shall be capable of maintaining the specified reference point temperature to within ± Ø.5°C of the preset (measured) value. See Figures 2 or 3 for mounting arrangement.

4.3 Suitable electrical equipment as required to provide controlled levels of conditioning shall be available to make the specified measurements. The instrument used to electrically measure the temperature-sensitive parameter shall be capable of resolving a voltage change of 2 mV. An appropriate sample-and-hold unit or cathode ray oscilloscope with a differential amplifier shall be used for this purpose.

5.Ø PROCEDURE

In measuring the thermal resistance, the forward voltage is used as the temperature-sensitive parameter to indicate the junction temperature.

5.1 Power Application Test

The power application test shall be performed in two parts. For both portions of the test, the reference point temperature shall be held constant at the specified value. The value of the temperature-sensitive parameter V_{MO} shall be measured with a measuring current (I_M) that will produce negligible internal heating. The diode under test* shall be operated with heating power (P_H) intermittently applied at a duty factor of 98% or greater.

---

*Diode under test = (DUT)

5.1 Power Application Test (continued)

The temperature-sensitive parameter V_{MH} shall be measured during the interval between heating pulses ($\leq$ 300 μs) with constant measuring current (I_M) applied as shown in Figure 1 and Section 5.4 Test Circuit.

To obtain the most accurate measure of the junction temperature, the V_{MH} should be measured at the instant that the heating power is discontinued. However, it is not possible to do this because a finite time is required for the diode current to decay from the heating value to the measuring value. In addition, transients in the measuring voltage waveform are present for some time after the measuring current value has been reached which delays further the time when a measurement of the V_{MH} can be made. The transients are primarily due to charge storage effects in the diode under test. Also, devices with magnetic leads will illustrate their own nonthermal switching transients due to the skin effect. The time before the V_{MH} can be measured in most diodes is in the range from 10 to 100 μs.

Because some cooling occurs between the time that the heating power is removed and the time that the V_{MH} is measured, the junction temperature value determined from the V_{MH} will be in error, leading to the calculation of a deceptively low thermal-resistance. It may be necessary to extrapolate the measured junction temperature back to the time when the heating power was terminated, based on the shape of the cooling waveform beyond the measuring point. This is particularly true on devices with relatively low thermal resistance ($R_{\Theta JR}$ < 50°C/watt). The extrapolated value should then be used in the calculation of thermal resistance. The procedure for performing this extrapolation is described in Appendix A.

If it is not possible to maintain the lead- or case-temperature constant during the power application test, the difference in the lead- or case-temperature at which V_{MH} and V_{MO} are measured shall be recorded. This lead- or case-temperature difference (T_{RH} - T_{RO}) divided by the average heating power (DP_H) shall be subtracted from the calculated thermal resistance to correct for this error. The heating power (P_H) shall be chosen such that the calculated junction-to-reference point temperature difference as measured at V_{MH} is $\geq$ 50°C.

5.2 Measurement of the Temperature Coefficient of the Temperature-Sensitive Parameter (Calibration)

The temperature coefficient of the temperature-sensitive parameter shall be measured utilizing the chosen measuring current (I_M) used during the "Power Application Test", see paragraph 5.1. The device under test shall be externally heated in an oven or on a temperature controlled heat sink. The measuring current shall be selected such that the temperature-sensitive parameter varies linearly with temperature over the range of interest and that negligible internal heating ($P_C \approx 0$) occurs during the calibration procedure, i.e. $T_R \approx T_J$. The reference point temperature range used during calibration shall encompass the temperature range encountered in the "Power Application Test", see paragraph 5.1. The value of the temperature-sensitive parameter temperature coefficient $[\Delta V_{MC}/\Delta T_{MC}]$ shall be calculated from the calibration curve (V_{MC} vs T_{MC}).

It can generally be assumed, that for devices of a given design and construction, the temperature coefficient of the temperature-sensitive parameter is constant. The temperature coefficient shall be measured on 10 devices to validate this assumption. If the relative sample standard deviation of these measurements is less $\leq \pm 3\%$, then the average of the measured temperature coefficients can be used in the calculation of thermal resistance for all other devices of that design and construction.

5.3 Calculation of Thermal Resistance

For axial lead diodes, the reference point for calculations of the junction-to-lead thermal resistance ($R_{\Theta JL}$) shall be at a point on the lead 0.375 inch (9.53 mm) from the body of the diode under test, unless otherwise specified. For thermally unsymmetrical devices or for devices with two or more internal p-n junction elements in series, the specified lead temperature shall be the average of the two lead temperatures measured with both leads terminated thermally in the same manner.

For case-mounted diodes, the reference point for calculation of the junction-to-case thermal resistance ($R_{\Theta JC}$) shall be a point on the major heat conducting element located on an exterior region close to, but not contacting, the heat sink.

5.3 Calculation of Thermal Resistance (continued)

For example, on a hex stud base the measurement shall be at a point in the center of the flat hex face, see Figure 3. For further measurement of case temperature, refer to Appendix B. The following equation is used to calculate the junction-to-reference point thermal resistance:

$$R_{\theta JR} = \frac{T_J - T_R}{DP_H} = \frac{V_{MH} - V_{MO}}{DP_H} \left[\frac{\Delta V_{MC}}{\Delta T_{MC}}\right]^{-1}_{\text{Calibration}} - \frac{T_{RH} - T_{RO}}{DP_H}$$

where $[T_{RH} - T_{RO}]$ corrects for variations in the reference temperature during the "Power Application Test" as outlined in paragraph 5.1.

Measurements of T_R are made by means of a thermocouple attached to the reference point. The power dissipation in the device under test is calculated from the equation

$$P_H = I_F V_F.$$

If the power dissipation during measuring and calibration is not negligible, then P_C should be subtracted from P_H when calculating the thermal resistance.

The junction temperature shall be considered stabilized when halving the time between the initial application of power and the taking of the reading causes no error in the indicated results within the required accuracy of the measurement.

5.4 Test Circuit

The test circuit is controlled by a clock pulse with a pulse width $\leq$ 300 μs and repetition rate $\leq$ 66.7 Hz. When the voltage level of the clock pulse is zero, the transistor Q1 is OFF and the forward current through the device under test is the sum of the constant heating current and the constant measuring current. Biasing transistor Q1 ON shunts the heating current to ground and effectively reverse biases the diode D1. The sample-and-hold unit (S & H) or [cathode ray] is triggered when the heating current is removed and is used to monitor the forward voltage of the diode under test. During calibration, switch S1 is open.

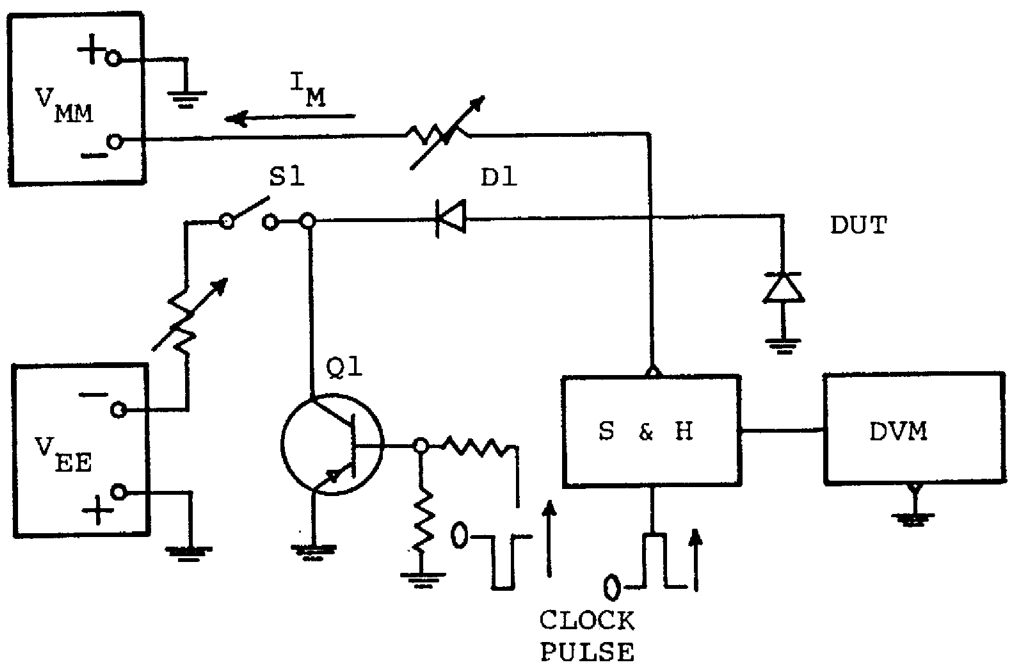

FIGURE 1

TEST CIRCUIT

6.0 TEST CONDITIONS TO BE SPECIFIED

6.1 Lead- or case-temperature range during calibration (range of T_{MC}).

6.2 Measuring or calibration current (I_M).

6.3 Heating power magnitude (P_N).

6.4 Heating power duty factor (D).

6.5 Heating power repetition rate.

6.6 Delay time before measurement of V_{MH} (t_2 and t_1).

6.7 Total heating time duration.

6.8 Reference temperature measuring point (T_R).

6.9 Reference point temperature for heating power measurements (T_{RH}).

6.10 Mounting torque (when applicable).

6.11 Mounting arrangement. See Figures 2 and 3 for recommended method.

6.12 Accept or reject criteria.

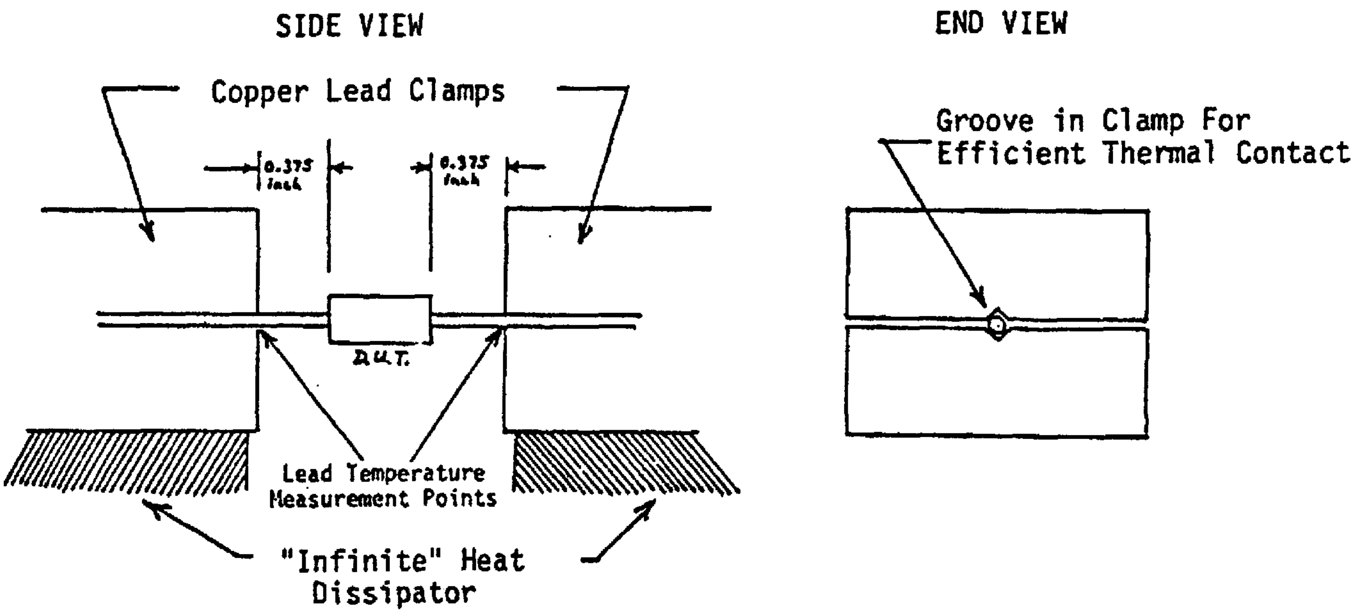

FIGURE 2

MOUNTING ARRANGEMENT
FOR
AXIAL LEADED DEVICES

(Also refer to Appendix C)

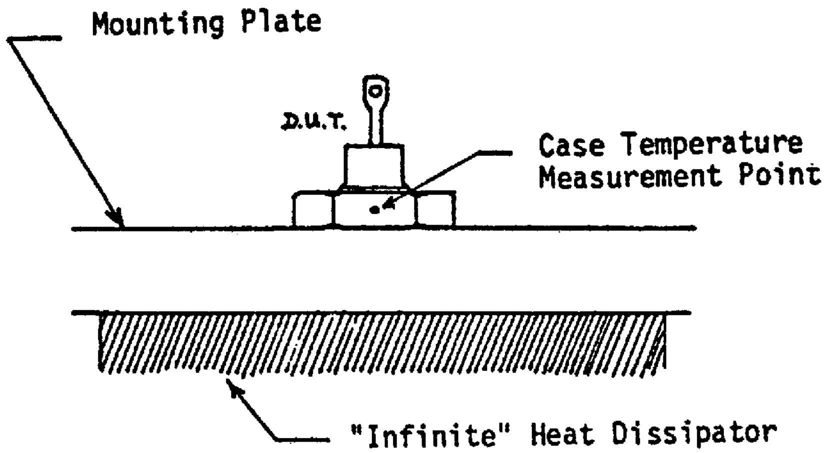

FIGURE 3

MOUNTING ARRANGEMENT
FOR
CASE-MOUNTED DEVICES

(Also refer to Appendix B)

APPENDIX A

EXTRAPOLATION PROCEDURE

The extrapolation procedure is based on the assumption that the thickness of the heat source is small compared to that of the chip, and that for approximately the first 200 or 250 μs of cooling, the heat flow is essentially one dimensional. Therefore, the junction temperature, $T_{J(cooling)}$, during the first 200 or 250μs of cooling can be represented by:

$$T_{J(cooling)}(t) = T_{J(S\ S)} - Kt^{1/2} \qquad (1)$$

where K is approximately constant and $T_{J(S\ S)}$ is the steady-state junction temperature at $t = 0$.

If $T_{J(cooling)}(t)$ vs $t^{1/2}$ is plotted on linear graph paper, then the generated curve will be a straight line with $T_{J(S\ S)}$ at the temperature axis intercepts. Plotting this curve for an actual device also provides a means for determining when nonthermal switching transients are significant because the curve, as plotted, will be nonlinear under this condition.

To calculate the extrapolated value $T_{J(S\ S)}$ $(t = 0)$, the following expression, developed from equation (1) can be used with two measurements of T_J during junction cooling:

$$T_{J(S\ S)}(t - 0) - T_{J1} + \frac{T_{J2} - T_{J1}}{t_1^{1/2} - t_2^{1/2}} \bullet t_1^{1/2}$$

where

$T_{J(S\ S)}$ $(t = 0)$ = junction temperature, extrapolated to the time at which the heating power is terminated (^{o}C)

t = delay time after heating power is terminated (μs)

T_{J1} = junction temperature at time $t = t_1$ (^{o}C)

T_{J2} = junction temperature at time $t = t_2 < t_1$ (^{o}C).

NOTE: Times t_2 and t_1 shall be greater than the duration of the nonthermal switching transients to assure they are located on the linear portion of the generated curve of $T_{J(cooling)}(t)$ vs $t^{1/2}$. This is typically greater than 10 to 100μs for most diodes.

APPENDIX B

CASE TEMPERATURE

The case temperature, T_C, of a stud-mounted, hexagonal-base diode is measured at the center of any of 6 flats at the base rim as shown in Figure 3. The case temperature of other base-mounted diodes is measured at a point specified by the manufacturer. The recommended case temperature test method employs the use of a thermocouple with characteristics given below. The method and location of the attachment to the case is also provided.

An accuracy of $\pm$ 0.5°C should be expected of the thermocouple and associated measuring system. Under diode load conditions, slight variations in the temperature of different points on the case may reduce this to $\pm$ 1.0°C for free air convection cooling and $\pm$ 2.0°C for forced air cooling.

I. TYPE OF THERMOCOUPLE

The thermocouple material shall be copper-constantan (Type T). Its useful temperature range for standard temperature measurements is from -183°C to +371°C. The wire size shall be no larger than AWG Size 30. The junction of the thermocouple shall be formed by welding together the wires to form a bead rather than having the wires soldered or twisted together. For additional information see 1974 Annual Book of ASTM Standards "Part 30, Method E220 for Calibration of Thermocouples by Comparison Techniques" for information on construction and use of thermocouples.

II. MOUNTING METHOD

A small hole, just large enough to insert the thermocouple, shall be drilled approximately 0.03 inch (0.76 mm) deep in the base plate of the semiconductor device at the point specified by the manufacturer. The edge of the hole should be peened with a small center punch to form a rigid mechanical contact with the welded bead of the thermocouple. In the event that drilling into the base plate of the device becomes impractical, because of case material or case dimensions, the thermocouple wire may be welded directly to a specified point on the case. Other methods of mounting thermocouples, with the possible exception of the thermocouple welded or soldered directly to the case, usually result in temperature readings lower than the actual temperature. Such deviations result from inadequate contact with the case when using cemented thermocouples and from the external heat dissipator in contact with the thermocouple when using pressure contacts.

APPENDIX C

LEAD TEMPERATURE

The lead temperature, T_L, of a lead-mounted diode is measured at Ø.375 inch (9.53 mm) lead length unless otherwise specified at lead length L. The lead zero point shall be considered the point where the diode body terminates and the lead begins. This point is defined as that point at which the lead diameter first becomes controlled. The lead length L shall be the length of the diode's lead measured from the lead zero point.

An accuracy of $\pm$ Ø.5°C should be expected of the thermocouple and associated measuring system.

I. TYPE OF THERMOCOUPLE

The thermocouple material shall be copper constantan (Type T). Its useful temperature range for standard temperature measurements is from -183°C to +371°C. The wire size shall be no larger than AWG size 3Ø. The junction of the thermocouple shall be formed by welding together the wires to form a bead rather than having the wires soldered or twisted together. (See 1974 Annual Book of ASTM Standards - "Part 3Ø, Method E22Ø, for Calibration of Thermocouples by Comparison Techniques" for information on construction and use of thermocouples.

The lead temperature is measured by placing the thermocouple in good contact with the lead at length L. This length will correspond to the entry point of the lead into the heat sink as shown in Figure 2.

Thermal contact from heat sink to lead should be maximized by providing a "V" shaped groove for the lead to be clamped within as shown in Figure 2. Also, a thermal grease applied only between lead and heat sink should be used to minimize thermal contact resistance between the two tightly clamped portions of the heat sink.

Standard Improvement Form — JEDEC JESD531

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).

If you can provide input, please complete this form (it can be edited in Acrobat Exchange) and return to:

JEDEC
Attn: Publications Department
2500 Wilson Blvd. Suite 220
Arlington, VA 22201-3834
Fax: 703.907.7583

---

1. I recommend changes to the following:

☐ Requirement, paragraph number __________

☐ Test method number __________ Paragraph number __________

The referenced paragraph number has proven to be:

☐ Unclear ☐ Too Rigid ☐ In Error

☐ Other ______________________________

---

2. Recommendations for correction:

____

____

____

____

---

3. Other suggestions for document improvement:

____

____

____

____

Submitted by

Name: ____________________ Phone: ____________________

Company: ____________________ E-mail: ____________________

Address: ____________________

City/State/Zip: ____________________ Date: ____________________

JEDEC