JEDEC STANDARD

Zener and Voltage Regulator Diode Rating Verification and Characterization Testing

JESD211.01

(minor revision of JESD211, December 2009)

NOVEMBER 2012

JEDEC SOLID STATE TECHNOLOGY ASSOCIATION

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. Within the JEDEC organization there are procedures whereby a JEDEC standard or publication may be further processed and ultimately become an ANSI standard.

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 2012
3103 North 10th Street
Suite 240 South
Arlington, VA 22201-2107

PRICE: Please refer to www.jedec.org

ZENER AND VOLTAGE REGULATOR DIODE RATING VERIFICATION AND CHARACTERISTIC TESTING

Contents

ZENER AND VOLTAGE REGULATOR DIODE RATING VERIFICATION AND CHARACTERISTIC TESTING

Introduction

The diodes described in this document are used as voltage regulator diodes and voltage references. These devices maintain a near-constant voltage by operating in the breakdown region, where large changes in current result in relatively small fluctuations in voltage. Voltage regulator diodes are similar to Avalanche Breakdown Diode (ABD) Transient Voltage Suppressors, except that they are designed for continuous voltage regulation, rather than for short-duration overvoltage protection. They are also typically unidirectional. They may be in a single p-n junction package with two-terminals or may also have multiple p-n junctions in a single package with two-terminals as well. Other configurations beyond two-terminals may also exist depending on package and overall configuration such as with multiple p-n junctions for diode arrays.

For the purpose of achieving, specific registration formats are available to fit particular types of Zener and voltage regulator/reference diodes. These formats are subject to change as new semiconductor developments or circuit applications become practicable. At present, the following formats are available:

NUMBER	DESCRIPTION
RDF-2	Diode, Voltage Regulator Single Unit or Family
RDF-7	Diode, Voltage Reference, Single Unit

ZENER AND VOLTAGE REGULATOR DIODE RATING VERIFICATION AND CHARACTERISTIC TESTING

(From JEDEC Board Ballot JCB-09-46, formulated under the cognizance of the JC-22.2 Subcommittee on Rectifiers, Zeners and Signal Diodes.)

1 Scope

This standard is applicable to diodes that are used as voltage regulators and voltage references. It describes terms and definitions and explains methods for verifying device ratings and measuring device characteristics.

Voltage regulator diodes are sometimes used as transient voltage suppressors, but are not characterized for their clamping ability or peak pulse power rating. Terms and tests related to transient voltage suppression will not be covered in this document, but are discussed in the JEDEC document JESD210 on Avalanche Breakdown Diode (ABD) Transient Voltage Suppressors.

2 Terms and definitions

These may use terms similar to avalanche breakdown diodes, but have variations unique to Zener and voltage-regulator diodes.

2.1 Basic concepts

2.1.1 voltage-regulator diode: A semiconductor diode with a single p-n junction (or with multiple p-n junctions, none of which interact) that is normally biased in the breakdown region of its voltage-current characteristics and limits variation in voltage across its terminals over a specified current range.

NOTE 1 The breakdown region may be due to either avalanche breakdown or Zener breakdown phenomenon (also often known as tunneling or field-emission breakdown).

NOTE 2 When forward-biased, voltage-regulator diodes have voltage-current characteristics similar to rectifier diodes.

NOTE 3 In general usage, voltage-regulator diodes are often referred to as **Zener diodes**, even if their breakdown characteristics are due to avalanche breakdown. Voltage-regulator diodes are also referred to as **voltage-reference diodes** when their application is to maintain a reference voltage within a specified accuracy over a specified current and temperature range in the breakdown region of its voltage-current characteristics.

NOTE 4 Figure 1 shows the symbol for a regulator or reference diode.

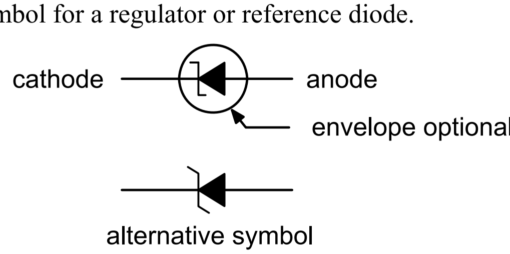


Figure 1 — Zener diode symbol

2.1 Basic concepts (cont'd)

2.1.1 voltage-regulator diode (cont'd)

NOTE 5 Figure 2 shows a typical voltage-current characteristic, which illustrates that Zener diodes operate in the third quadrant with a negative voltage applied to the anode with respect to the cathode.

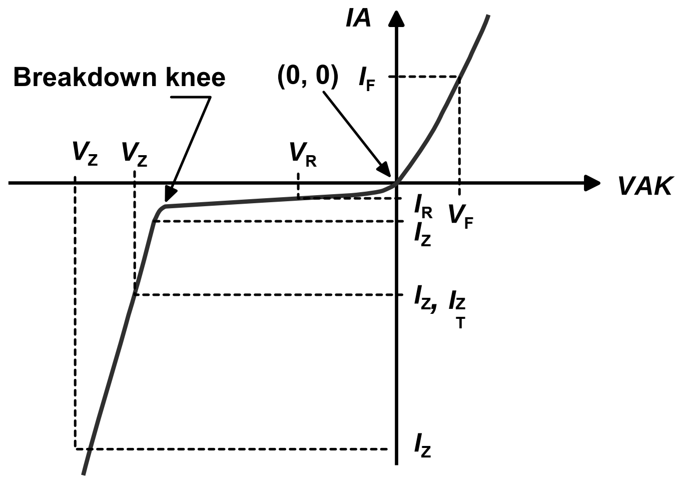


Figure 2 — Zener diode I-V characteristic

2.1.2 Zener diode: A semiconductor diode with a single p-n junction whose breakdown characteristics are due to the Zener effect.

NOTE Although true Zener breakdown occurs below approximately 6 volts, the term "Zener diode" is often used interchangeably with "voltage-regulator diode" and "voltage-reference diode" even for voltages over 6 volts, where breakdown characteristics are due to avalanche breakdown.

2.1.3 temperature-compensated voltage-reference diode: A voltage-regulator diode that is designed to have minimal changes in the regulated voltage over a broad temperature range.

NOTE A temperature-compensated voltage-reference diode is often provided with one or more forward-biased p-n junctions placed in series with a Zener p-n junction to offset or compensate the positive temperature coefficient of the Zener. This series combination may also involve more than one Zener p-n junction within the temperature-compensated voltage-reference diode, particularly for higher voltages.

2.1.4 nonconducting region: The portion of the voltage-current characteristic of a reverse-biased p-n junction that exhibits a high resistance to the passage of current.

2.1.5 breakdown region: The portion of the voltage-current characteristic beyond the initiation of breakdown where the current increases rapidly for any additional increase in reverse voltage.

NOTE In this region the voltage remains essentially constant for increases in reverse current, up to a specified current and power dissipation rating.

2.1.6 forward-conducting region: The portion of the voltage-current characteristic of a forward-biased p-n junction that exhibits a low small-signal resistance to the passage of current.

2.1 Basic concepts (cont'd)

2.1.7 anode terminal (A, a): The terminal connected to the p-type region of the p-n junction or, when two or more p-n junctions are connected in series and have the same polarity, to the extreme p-type region.

NOTE For voltage-reference diodes, any temperature-compensation diodes that may be included shall be ignored in the determination of the anode terminal.

2.1.8 cathode terminal (K, k): The terminal connected to the n-type region of the p-n junction or, when two or more p-n junctions are connected in series and have the same polarity, to the extreme n-type region.

NOTE For voltage-reference diodes, any temperature-compensation diodes that may be included shall be ignored in the determination of the anode terminal.

2.2 Voltage-regulator [voltage-reference] [Zener] diode parameters

In the parameter names and definitions below, the word "reference" may be substituted for the word "regulator" consistent with the diode-type name chosen by the manufacturer. "Zener" is often used for parameters with all three diode-type names.

2.2.1 maximum steady-state power dissipation (P_D): The maximum-rated value of continuous dc power dissipation.

NOTE The maximum steady-state power dissipation is calculated by multiplying the rated maximum regulator [Zener] current by the maximum regulator [Zener] voltage.

2.2.2 regulator [Zener] current, dc (I_Z): The dc reverse current through the diode when it is biased to operate in its breakdown region at an operating point between I_{ZK} and I_{ZM}.

2.2.3 regulator [Zener] current near breakdown knee, dc (I_{ZK}): The dc reverse current through the diode when it is biased to operate in its breakdown region at a specified current near the breakdown knee.

2.2.4 maximum regulator [Zener] current (I_{ZM}): The dc reverse current through the diode when it is biased to operate in its breakdown region at a specified current based on the maximum-rated power.

2.2.5 regulator [Zener] current at specified test point, dc (I_{ZT}): The dc reverse current through the diode when it is biased to operate in its breakdown region at a specified current between I_{ZK} and I_{ZM} for the purpose of specifying V_Z and Z_{ZT}.

2.2.6 regulator [Zener] current near breakdown knee, rms component (I_{zk}): A specified rms current for measuring regulator impedance.

NOTE According to JEDEC registration formats, this current should not exceed 10% of the simultaneously applied dc current I_{ZK}.

2.2 Voltage-regulator [voltage-reference] [Zener] diode parameters (cont'd)

2.2.7 regulator [Zener] current at specified test point, rms component (I_{zt}): A specified rms current for measuring regulator impedance.

NOTE According to JEDEC registration formats, this current should not exceed 10% of the simultaneously applied dc current I_{ZT}.

2.2.8 repetitive peak reverse surge current (I_{ZRM}): The peak reverse current in the breakdown region including all repetitive transient currents but excluding all nonrepetitive transient currents.

2.2.9 nonrepetitive peak reverse surge current (I_{ZSM}): The peak reverse current in the breakdown region including all nonrepetitive transient currents but excluding all repetitive transient currents.

2.2.10 regulator [Zener] voltage (V_Z): The voltage across the diode at a specified current I_{ZT} in the breakdown region.

2.2.11 maximum regulator [Zener] voltage (V_{ZM}): The voltage across the diode at a specified current I_{ZM} in the breakdown region.

2.2.12 reverse current (I_R): The current that flows from the external circuit into the cathode terminal at a specified reverse voltage (V_R) below the onset of breakdown.

2.2.13 reverse voltage (V_R): The positive cathode-anode voltage that is specified as a test condition for reverse current (I_R).

2.2.14 regulator [Zener] impedance (z_{zt}): The small-signal impedance of a diode when it is biased to operate in its breakdown region at I_{ZT} with a superimposed rms current of I_{zt}.

2.2.15 regulator [Zener] knee impedance (z_{zk}): The small-signal impedance of a diode when it is biased to operate in its breakdown region at I_{ZK} with a superimposed rms current of I_{zk}.

2.2.16 forward voltage (V_F): The positive anode-cathode voltage at a specified forward current, I_F.

2.2.17 capacitance (C or C_J): The capacitance between the two terminals of a diode at a specified voltage.

2.2.18 maximum operating junction temperature (T_{JM}): The maximum-rated junction temperature at which the diode may operate.

2.2.19 temperature coefficient of regulator [Zener] voltage (α_{VZ}): The change in regulator voltage divided by the change in temperature that caused it.

NOTE This quotient may be expressed as mV/°C, mV/K, %/°C, or %/K and is the average value for the total temperature change.

2.2 Voltage-regulator [voltage-reference] [Zener] diode parameters (cont'd)

2.2.20 thermal impedance ($Z_{\theta JA}$ or Z_{thJA}, $Z_{\theta JC}$ or Z_{thJC}, $Z_{\theta JL}$ or Z_{thJL}, $Z_{\theta JX}$ or Z_{thJX}): The change in temperature difference between two specified points or regions that occurs during a time interval divided by the step-function change in power dissipation that occurred at the beginning of the interval and caused the change in temperature difference.

2.2.21 thermal resistance ($R_{\theta JA}$ or R_{thJA}, $R_{\theta JC}$ or R_{thJC}, $R_{\theta JL}$ or R_{thJL}, $R_{\theta JEC}$ or R_{thJEC}): The temperature difference between two specified points or regions divided by the power dissipation under conditions of thermal equilibrium.

2.2.22 steady-state power dissipation derating curve: A graphical presentation showing how a power rating stated at a particular temperature is reduced at higher temperatures.

NOTE The steady-state power-derating curve is derived from $P_D = (T_{JM} - T_X)/ R_{\theta JX}$, where the subscript "X" can indicate L (for lead), C (for case), EC (for end cap), or A (for ambient). The usual power-derating curve is drawn with a slope of $-1/R_{\theta JX}$ from 0% at $T_X = T_{JM}$ up to 100% at a value of temperature equal to or above 25 °C, but below T_{JM}. A typical derating curve for a regulator diode is shown in Figure 3.

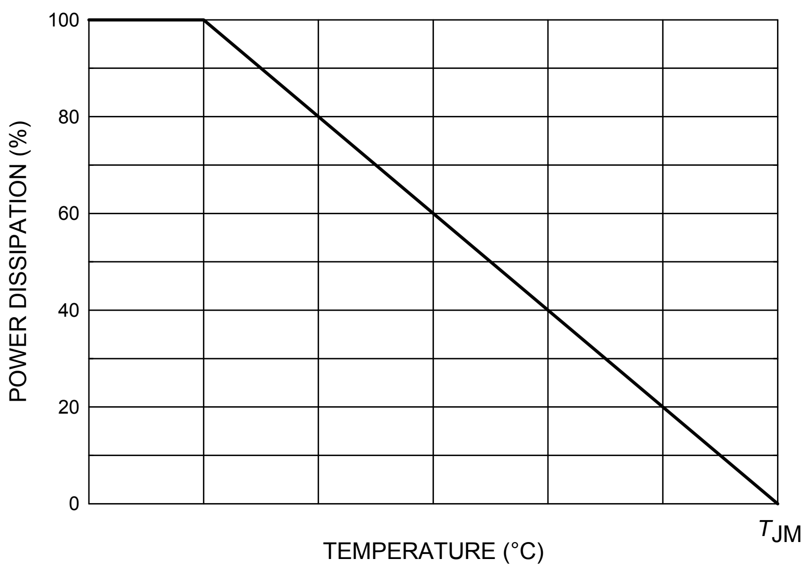


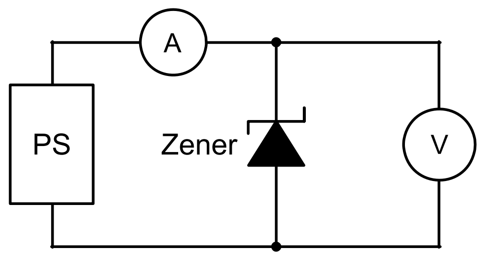
Figure 3 – Typical steady-state power derating curve

3 Rating verification tests

All tests are to be at 25 °C unless otherwise specified

3.1 Steady-state power dissipation (P_D)

The purpose of this test is to verify the steady-state power rating under a specified set of test conditions without causing failure. Verification requires the application of the rated maximum Zener current (I_{ZM}) and measuring the maximum Zener voltage (V_{ZM}) with a circuit functionally equivalent to Figure 4. Multiplication of the maximum Zener current by the maximum Zener voltage is defined as the maximum steady-state power dissipation. Multiplication of any Zener current by any Zener voltage yields a steady-state power dissipation, but maximum Zener current multiplied by the maximum Zener voltage equals maximum power. A sufficient number of devices shall be tested to obtain a statistical distribution within the desired confidence limits. A failure is defined as when the specified reverse current exceeds the maximum I_R specification at the conclusion of applied steady-state power.



PS = Power Supply A = Ammeter (mA) V = Voltmeter

Figure 4 — Steady-state power test circuit

3.1.1 Test conditions to be specified

a. Ambient (T_A), case (T_C), lead (T_L), or end cap (T_{EC}) temperature = ____ °C

NOTE If specifying T_A, the method of mounting or heatsinking must be defined.

b. Maximum Zener current (I_{ZM}) = ____ A

c. Application time of applied power = ____ s

3.1.2 Parameter to be measured

a. Maximum regulator voltage (V_{ZM}) = ____ V

b. Reverse current (I_R) at 25°C after the conclusion of applied power = ____ µA

3.1.3 Parameter to be calculated

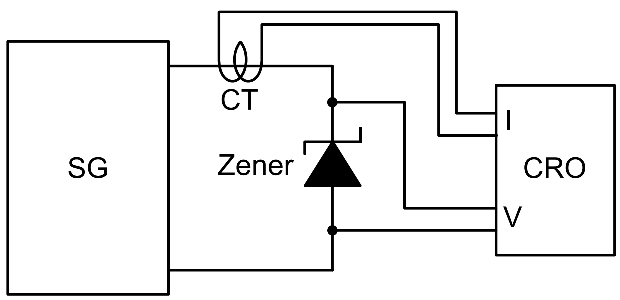
a. Steady-state power (P_D) = I_{ZM} x V_{ZM} = ____W

3.2 Maximum Zener current (I_{ZM})

The purpose of rated maximum Zener current test is to verify that the diode can withstand a continuous current of I_{ZM} without causing failure. The test circuit used shall be functionally equivalent to Figure 4. After the current is applied for a specified period of time, the reverse leakage current (I_R) shall remain within specification at 25°C (see 4.2). A statistically significant number of devices shall be tested to obtain a pass-fail ratio with the desired confidence level.

3.3 Repetitive peak reverse surge current (I_{ZRM})

This test is to verify that the diode can withstand a repetitive current, I_{ZRM}, with specified rectangular pulse width and duty factor without causing failure. The test circuit used shall be functionally equivalent to Figure 5. After the repetitive current is applied for a specified period of time, the reverse leakage current (I_R) shall be within specification at 25°C (see 4.2). The peak voltage shall also be monitored during the pulse duration to ensure the Zener voltage has not collapsed below the rated minimum voltage. A statistically significant number of devices shall be tested to obtain a pass-fail ratio with the desired confidence level.



SG = Surge (rectangular pulse) generator
CT = Current transformer or equivalent
CRO = Oscilloscope for measuring peak current and peak voltage

Figure 5 — Peak current test circuit

3.3.1 Test conditions to be specified

a. Ambient (T_A), case (T_C), lead (T_L), or end cap (T_{EC}) temperature = ____ °C

NOTE If specifying T_A, the method of mounting or heatsinking must be defined.

b. Steady-state Zener Current the surge may be superimposed on = ____ A

c. Application time of applied steady-state power (if any) = ____ s

d. Duty factor (d.f.) = ____ %

NOTE Duty factor (d.f.) = 100 t_p/t_{rep}, expressed in percent, where t_{rep} is the pulse period.

3.3 Repetitive peak reverse surge current (I_{ZRM}) (cont'd)

3.3.2 Parameter to be measured

a. Surge current (I_{ZRM}) = ____ A

a. Regulator voltage (V_Z) during surge = ____ V

b. Reverse current (I_R) at 25°C after the conclusion of the surge = ____µA

3.4 Nonrepetitive peak reverse surge current (I_{ZSM}):

The rated nonrepetitive peak reverse surge current test is to verify that the diode can withstand a number of current pulses of the same peak value without causing failure. The time between pulses should be sufficient to allow the junction temperature to return to ambient temperature. This is also known as a random recurring surge current. The test circuit used shall also be functionally equivalent to Figure 5. After the number of impulses is applied, the reverse leakage current (I_R) shall be within specification at 25 °C (see 4.2). The peak voltage shall also be monitored during the pulse duration to ensure the Zener voltage has not collapsed below the rated minimum voltage. A statistically significant number of devices shall be tested to obtain a pass-fail ratio within the desired confidence level.

3.4.1 Test conditions to be specified

a. Ambient (T_A), case (T_C), lead (T_L), or end cap (T_{EC}) temperature = ___ °C

NOTE If specifying T_A, the method of mounting or heatsinking must be defined.

b. Steady-state Zener Current the surge may be superimposed on = ____ A

c. Application time of applied steady-state power (if any) = ____ s

3.4.2 Parameter to be measured

a. Surge current (I_{ZRM}) = ____ A

b. Regulator voltage (V_Z) during surge = ____ V

c. Reverse current (I_R) at 25°C after the conclusion of the surge = ____µA

4 Characteristic Tests

4.1 Regulator voltage (V_Z)

The test generator shall be a low-current constant-current source or equivalent. A voltmeter shall be used to measure the voltage across the diode. The test circuit shall be functionally equivalent to Figure 4. Zener current, I_Z, amplitude shall be applied to the diode and the stabilized value of Zener voltage, V_Z, measured at the specified time. If very long times (20 to 90 seconds) are required for thermal equilibrium at a specified ambient temperature, then the mounting method must also be defined.

4.1.2 Test conditions to be specified

a. Ambient (T_A), case (T_C), lead (T_L), or end cap (T_{EC}) temperature = _____ °C

NOTE If specifying T_A, the method of mounting or heatsinking must be defined.

b. Zener current (I_Z) = ______ mA

c. Test time = ______ s

d. Zener current pulse width (optional) = ______ ms

4.1.3 Characteristics to be measured

a. Zener voltage (V_Z) = _____ V

4.2 Reverse current (I_R)

The purpose of this test is to determine the reverse leakage current of the diode at specified reverse voltage, V_R, and specified temperature.

4.2.1 Procedure

The reverse voltage shall be generated from a well-regulated dc power supply. The resultant dc current shall be measured with an ammeter. The voltage shall be applied for at least 10 ms to allow stabilization of the conduction. The test circuit used shall be functionally equivalent to Figure 4.

4.2.2 Test conditions to be specified

a. Ambient (T_A), case (T_C), lead (T_L), or end cap (T_{EC}) temperature = ______°C

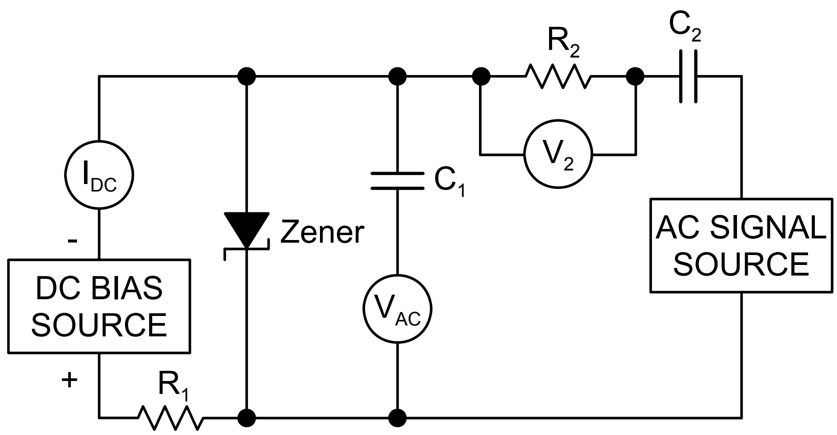
b. DC reverse voltage (V_R) = ______ V

4.2.3 Characteristics to be measured

a. Reverse current (I_R) = ______ µA

4.3 Zener Impedance (Z_{ZT} or Z_{ZK})

The purpose of this test is to measure the small-signal impedance of the diode when it is biased to operate in its breakdown region with a specified small-signal current (I_{zt} or I_{zk}) applied at a specified dc current (I_{ZT} or I_{ZK}) and frequency (typically 1 kHz). The test circuit used shall be functionally equivalent to Figure 6.



NOTE 1 The impedance of C_1 and C_2 shall be small compared to the Zener at the test frequency.
NOTE 2 Voltmeters V_{AC} and V_2 shall be high input impedance rms types.
NOTE 3 The resistance R_1 shall be large compared with the impedance being measured.
NOTE 4 A low-pass filter may be installed in series with the ac signal source.

Figure 6 — Zener Impedance test circuit

4.3.1 Procedure

The specified reverse direct current (I_{ZT} or I_{ZK}) is applied to the DUT. An ac signal (frequency typically 1 kHz) is applied to the DUT through coupling capacitor C2. The rms value of ac signal current (I_{zt} or I_{zk}) shall not exceed 10% of the simultaneously applied dc current (I_{ZT} or I_{ZK}). The rms value of the small signal voltage ($V_{AC} = V_{zt}$ or V_{zk}) shall be measured. The Zener impedance shall be calculated as follows:
$Z_{ZT} = V_{zt} / I_{zt} = V_{AC}\, R_2/V_2$ or $Z_{ZK} = V_{zk} / I_{zk} = V_{AC}\, R_2/V_2$

4.3.2 Test conditions to be specified

a. Ambient (T_A), case (T_C), lead (T_L), or end cap (T_{EC}) temperature = _____°C

b. DC current (I_{ZT} or I_{ZK}) = ______ A

c. Small-signal (rms) current (I_{zt} or I_{zk}) = ______ mA

4.3.3 Characteristics to be measured

Small-signal (rms) voltage (V_{zt} or V_{zk}) = ______ mV

4.3.4 Parameter to be calculated

Zener Impedance: $z_{zt} = V_{zt} / I_{zt}$ or $z_{zk} = V_{zk} / I_{zk}$ = ____Ω

4.4 Forward voltage (V_F)

The purpose of this test is to measure the peak forward voltage of a diode at a specified forward current (I_F). The test circuit used shall be functionally equivalent to Figure 4.

4.4.1 Procedure

A forward current (rectangular or ½ Sinewave) is applied to the diode and the resultant voltage is measured.

4.4.2 Test conditions to be specified

a. Ambient (T_A), case (T_C), lead (T_L), or end cap (T_{EC}) temperature = _____°C

b. Pulsed forward surge current (I_F) = ____ A

c. Waveshape pulse width
   1. ½ Sinewave = ______ ms
   2. Rectangular wave = ______ ms

4.4.2 Characteristics to be measured

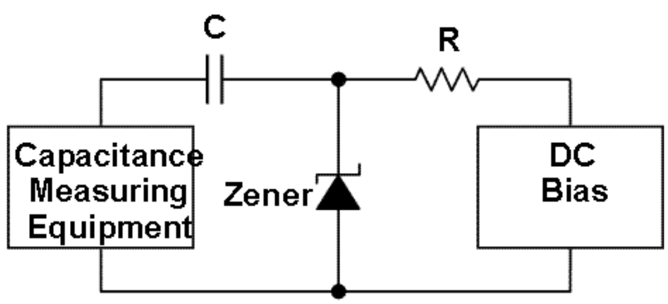
a. Forward voltage (V_F) = _____ V

4.5 Capacitance (C_J)

The purpose of this test is to determine the junction capacitance of a Zener between any two terminals at a specified sinusoidal frequency and bias voltage. For multiple terminal devices, one pair of terminals shall be measured at a time; all terminals not involved in the test shall be isolated to remove their capacitance from the measurement.

4.5.1 Procedure

The capacitance shall be measured at a dc bias voltage and ac signal voltage for a specified frequency. If the capacitance measuring equipment does not have a built in signal voltage, then use an ac rms voltage of 0.1 V between the frequencies of 100 kHz and 1 MHz. The test circuit shall be functionally equivalent to Figure 7.



NOTE Capacitance C shall be significantly greater than the capacitance of the Zener diode under test.

Figure 7 — Capacitance test circuit

4.5 Capacitance (C$_J$) (cont'd)

4.5.2 Test conditions to be specified

a. DC bias voltage	=	_____ V
b. Frequency	=	_____ Hz
c. AC rms signal voltage	=	______ V

4.5.3 Characteristics to be measured

a. Capacitance (C_J)	=	_____ pF

4.6 Temperature coefficient of regulator voltage (α_{VZ})

The purpose of this test is to determine the rate of change of regulator voltage, V_Z, between two specified temperature extremes. (See JEDEC Standard, JESD5)

4.6.1 Procedure

The regulator voltage shall be measured as described in 4.1, with a pulse of specified width, (t_W) and regulator current, (I_Z), at the specified temperature extremes. Thermal equilibrium shall be established at each measurement temperature before the regulator voltage is measured.

4.6.2 Test conditions to be specified

a. Low temperature	=	_____ °C
b. High temperature	=	_____ °C
c. Temperature reference measurement point (Ambient, case, lead, or end cap)	=	_______
d. Regulator current (I_Z)	=	______ mA
e. Regulator current pulse width (t_W) (if other than thermal equilibrium)	=	______ ms

4.6.3 Characteristics to be measured

a. Regulator voltage ($V_{Z(hi)}$)	=	_____ V
b. Regulator voltage ($V_{Z(lo)}$)	=	_____ V

4.6 Temperature coefficient of regulator voltage (α_{VZ}) (cont'd)

4.6.4 Calculation

The temperature coefficient can be expressed as either the average %/K or mV/K change over the specified temperature range.

$\alpha_{VZ} = 1000(V_{Z(hi)} - V_{Z(low)})/(T_{hi} - T_{lo})$ mV/K or mV/°C

or

$\alpha_{VZ} = 100(V_{Z(hi)} - V_{Z(low)})/((T_{hi} - T_{lo})(\mathbf{V}_Z))$ %/K or %/°C

NOTE For temperature compensated voltage reference diodes, the temperature coefficient in terms of %/ °C or mV/ °C as well as %/K or mV/K is not recommended due to the nonlinearity of the voltage variation. A voltage change over the defined temperature range is the preferred expression.

4.7 Thermal impedance ($Z_{\theta JA}$ or Z_{thJA}, $Z_{\theta JC}$ or Z_{thJC}, $Z_{\theta JL}$ or Z_{thJL}, $Z_{\theta JEC}$ or Z_{thJEC})

The purpose of this test is to determine the power capability of a diode, for a specified heating power pulse duration at a given reference temperature. The transient thermal impedance of a semiconductor device is a measure of the ability of its mechanical structure to provide for heat storage as well as heat removal from the active semiconductor element (See MIL-STD-750 method 3101).

One dimension heat flow is assumed in transient thermal impedance specifications and such specifications must always include the two points or planes between which the thermal resistance or transient thermal impedance value applies. The term virtual junction temperature is here applied to indicate the temperature of the active semiconductor element for use in the device test methods and specifications. The reference (R) temperature is usually established at one of the following:

a.) The ambient air (A).

b.) A specified point on the case (C)

c.) A specified point on a lead (L)

d.) A specified point on an end cap (EC)

4.7 Thermal impedance ($Z_{\theta JA}$ or Z_{thJA}, $Z_{\theta JC}$ or Z_{thJC}, $Z_{\theta JL}$ or Z_{thJL}, $Z_{\theta JEC}$ or Z_{thJEC}) (cont'd)

4.7.1 Equations and letter symbols

Transient thermal impedance is defined as:

$$Z_{\theta JR(t)} = (T_{J(t)} - T_R) / P_{Z(AV)}$$
$$= 1000K(V_{F(MET)1} - V_{F(MET)3}) / (V_{F(HTG)(AV)} \times I_{F(HTG)})$$

where:

$I_{F(HTG)}$ – Heating current used to produce the power dissipated in the diode.

K – Thermal Calibration Factor = $\Delta T_{(CAL)} / \Delta V_{F(MET)}$ K/mV or °C/mV

where:

$\Delta T_{(CAL)}$ – Difference between two calibration temperatures, T_{JMAX} and T_{R1}, applied to the reference point.

$\Delta V_{F(MET)}$ – Difference in $V_{F (MET)}$ when measured at two calibration temperatures, T_R and T_{JMAX}, in mV.

$V_{F(MET)}$ – Value of forward voltage at $I_{F(MET)}$, the TSP (Temperature Sensitive Parameter).

$I_{F(MET)}$ – Value of metering current, in mA.

T_{JMAX} – Maximum rated junction temperature

$P_{Z(AV)}$ – Magnitude of average heating power causing temperature difference $T_{J(t)} - T_{R1}$.

$V_{F(HTG)(AV)}$ – Average measured value of breakdown voltage for the period when $I_{F (HTG)}$ is applied.

$V_{F(MET)1}$ – Value of the TSP at the reference temperature used in the test procedure.
$V_{F(MET)3}$ – Value of the TSP immediately after the $I_{F(HTG)}$ pulse is terminated.

$T_{J(t)}$ – Measured junction temperature at time t.

T_{R1} – Measured reference (case, lead, end cap, or ambient) temperature with only metering current flowing while external heat is applied such that T_J, when T_{R1} is measured, equals T_J when T_{R2} is measured.

T_{R2} – Measured reference (case, lead, end cap, or ambient) temperature when operated with heating power.

TSP – Temperature-sensitive parameter.

NOTE In this procedure the temperature-sensitive parameter (TSP) is V_F. Zener voltage, V_Z, may also be used.

$Z_{\theta JR(t)}$ – Transient thermal impedance at a given time, junction to reference point, in K/W or °C/W.

Other letter symbols used are:

$R_{\theta JR}$ – Thermal resistance, junction to reference point, in K/W or °C/W.

NOTE This is the value of $Z_{\theta JR(t)}$ for steady state conditions.

4.7 Thermal impedance ($Z_{\theta JA}$ or Z_{thJA}, $Z_{\theta JC}$ or Z_{thJC}, $Z_{\theta JL}$ or Z_{thJL}, $Z_{\theta JEC}$ or Z_{thJEC}) (cont'd)

4.7.2 Procedure

There are two steps in the procedure: TSP calibration and measurement under power pulse conditions.

TSP (V_F) calibration uses the forward voltage (V_F) test circuit.

Calibration consists of operating the test device at a metering current $I_{F(MET)}$ that causes no significant power dissipation, so that for all practical purposes, the diode virtual junction temperature and the reference temperature will be equal.

First, the diode TSP is measured at the reference temperature, T_R, to be used for the power pulse testing. The TSP voltage is monitored while the diode is externally heated on a temperature-controlled block or in an oven to the diode maximum rated junction temperature, T_{JMAX}. When the TSP voltage has stabilized, its value is measured with $\mathbf{I_{F(MET)}}$.

In some cases, there may be significant device-to-device variation of the TSP, which could cause unacceptable $Z_{\theta JR}$ inaccuracies. Either each device shall be individually calibrated or statistical techniques shall be used to guarantee the maximum value of $Z_{\theta JR(t)}$.

The heating power pulse test circuit used shall be functionally equivalent to Figure 8. Power pulse testing applies two currents: one for TSP measurement, $I_{F(MET)}$ from PS2 with switch in position shown, and the other for heating, $I_{F(HTG)}$ from PS1 with switch operated for time t. Voltage measurements of V_F, are taken immediately prior, during, and after the heating power pulse. At the same time, I_F verification measurements are taken of $I_{F(MET)}$ and $I_{F(HTG)}$ in the diode.

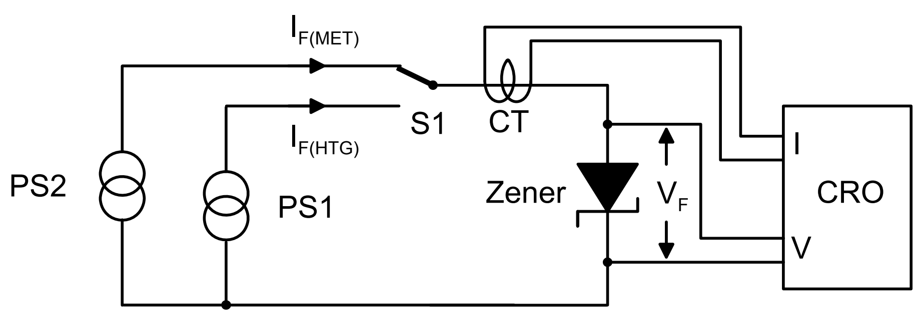


Figure 8 — Thermal impedance test circuit

The heating current is applied as a single pulse approximately rectangular in shape and of specified width, corresponding to the time value for which the transient thermal impedance is to be measured. If the heating current waveform deviates much from a truly rectangular pulse, then numeric integration of the product of the heating current and heating voltage waveforms must be employed to determine the diode power dissipation. Care must be taken, when applying heating current pulses, to avoid exceeding device random recurring surge current capabilities.

The heating current pulse should be sufficient to achieve 25 °C minimum increase in T_J. Adequate time shall be allowed between tests for the device to regain thermal equilibrium. Since the transient thermal impedance is lower for short pulse widths than for long pulse widths, a higher amplitude current pulse is required to heat the device junction when the pulse width is short.

4.7 Thermal impedance ($Z_{\theta JA}$ or Z_{thJA}, $Z_{\theta JC}$ or Z_{thJC}, $Z_{\theta JL}$ or Z_{thJL}, $Z_{\theta JEC}$ or Z_{thJEC}) (cont'd)

4.7.2 Procedure (cont'd)

For all but very short pulse widths it is generally necessary to employ an external heat dissipator to prevent appreciable device case or lead reference temperature rise during the interval when power is applied. For pulses longer than 50 ms, the reference temperature may increase and the calculated $Z_{\theta JR}$ will be higher than the true value. The $Z_{\theta JR}$ value may be corrected by using the actual reference temperature value, T_{R2}, at the end of the test.

When an approximate value for the test device transient thermal impedance is known, the $Z_{\theta JR}$ equation may be employed to calculate the approximate value of heating current required to raise the device virtual junction temperature to a maximum rated value for 25 ^{o}C minimum increase in T_J; otherwise, the required current magnitude must be arrived at by trial and error.

After the heating pulse, switching transients may prevent an accurate TSP reading until time t_3, see Figure 9. During this time the junction temperature cools and so the calculated $\boldsymbol{T_J}$ temperature will be low. This temperature error can be corrected by taking successive measurements after the heating pulse at t_3 and t_4, then linearly extrapolating the temperature decay back to the time, t_1, when the pulse ended.

4.7 Thermal impedance ($Z_{\theta JA}$ or Z_{thJA}, $Z_{\theta JC}$ or Z_{thJC}, $Z_{\theta JL}$ or Z_{thJL}, $Z_{\theta JEC}$ or Z_{thJEC}) (cont'd)

4.7.2 Procedure (cont'd)

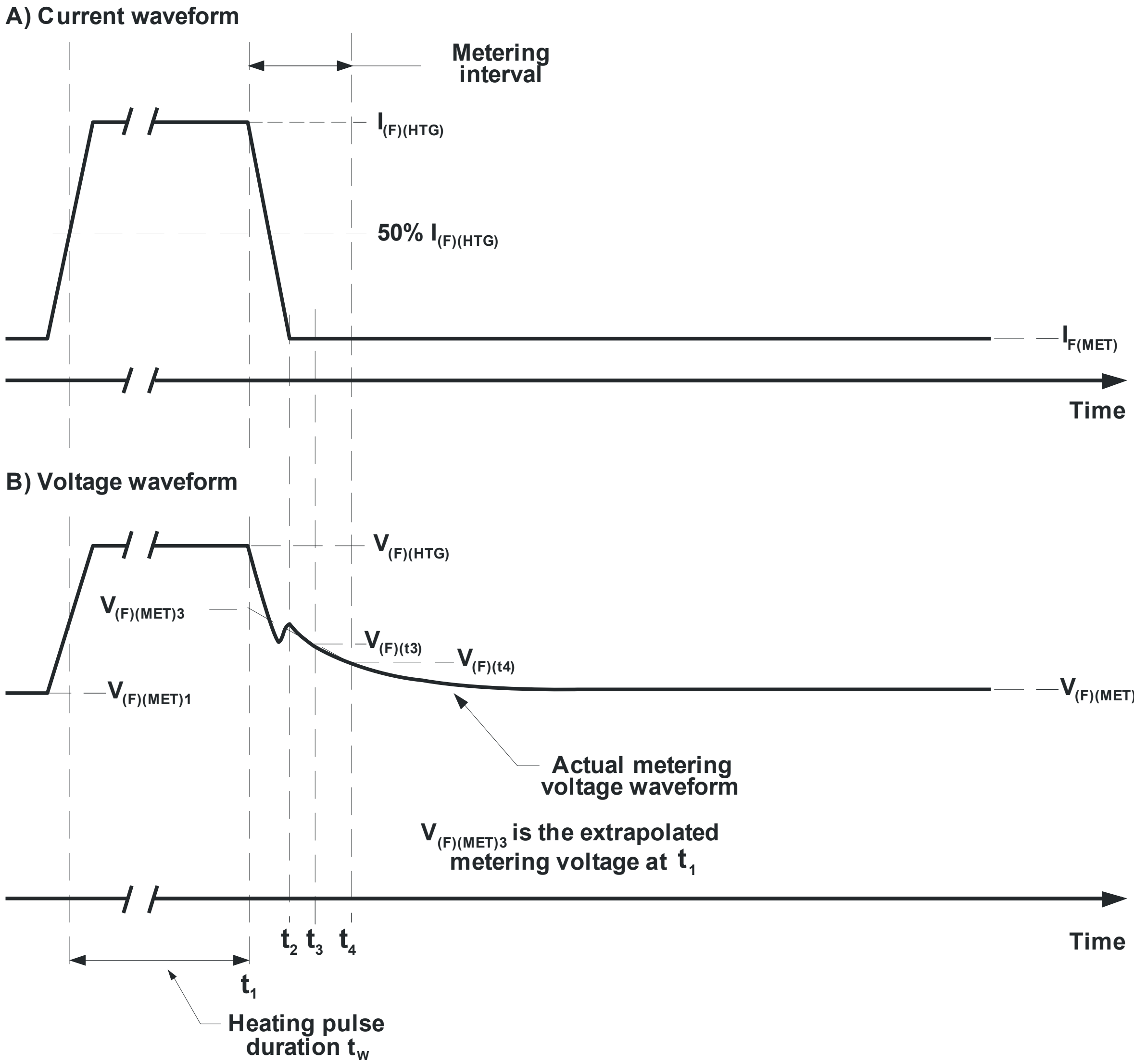


Figure 9 — Thermal impedance waveshapes

In the absence of special requirements, it is recommended that the value of $Z_{th(t)}$ be determined over a time interval of 100 µs to a time duration approximating steady state operation and expressed as a graph.

4.7 Thermal impedance ($Z_{\theta JA}$ or Z_{thJA}, $Z_{\theta JC}$ or Z_{thJC}, $Z_{\theta JL}$ or Z_{thJL}, $Z_{\theta JEC}$ or Z_{thJEC}) (cont'd)

4.7.3 Test conditions to be specified

a. Reference temperature (T_{R1}) = ______ °C

b. Maximum junction temperature (T_{JMAX}) = ______ °C

c. Temperature reference measurement point (Ambient, case, lead, or end cap) = ______ °C

d. TSP (regulator) metering current ($I_{F(MET)}$) = ______ mA

e. Diode heating current ($I_{F(HTG)}$) = ______ A

f. Heating current pulse width (t_W) = ______ ms

g. Measurement time t_3 for $V_{F(t3)}$ = ______ ms

h. Measurement time t_4 for $V_{F(t4)}$ = ______ ms

4.7.4 Characteristics to be measured

a. TSP (regulator) metering voltage ($V_{F(MET)1}$) at T_{R1} = ______ V

b. TSP (regulator) metering voltage ($V_{F(MET)2}$) at T_{JMAX} = ______ V

c. TSP (regulator) metering voltage ($V_{F(t3)}$) at t_3 = ______ V

d. TSP (regulator) metering voltage ($V_{F(t4)}$) at t_4 = ______ V

e. Diode average heating voltage ($V_{F(HTG)(AV)}$) = ______ V

f. Reference temperature (T_{R2}) at end of test = ______ °C

4.7.5 Calculation

The temperature coefficient can be expressed as either the average %/K or mV/K change over the specified temperature range.

$$K = (T_{JMAX} - T_{R1})/(V_{F(MET)2} - V_{F(MET)1}) \quad \text{K/mV}$$

$V_{F(MET)2}$ by extrapolation using $V_{F(t3)}$ at t_3 and $V_{F(t4)}$ at t_4

$$Z_{\theta JR(t)} = 1000K(V_{F(MET)1} - V_{F(MET)3}) / (V_{F(HTG)(AV)} \times I_{F(HTG)}) - (T_{R2}-T_{R1})/(V_{F(HTG)(AV)} \times I_{F(HTG)})$$

NOTE The last portion of this equation involving T_{R2} is also used for correction when the actual reference temperature at the end of the test has risen above the initial T_{R1} value. This becomes important at longer heating times such as for thermal resistance in 4.8.

4.8 Thermal resistance ($R_{\theta JA}$ or R_{thJA}, $R_{\theta JC}$ or R_{thJC}, $R_{\theta JL}$ or R_{thJL}, $R_{\theta JEC}$ or R_{thJEC})

The purpose of this test is to determine the power-handling capability of a diode, at a given reference temperature. The thermal resistance of a semiconductor device is a measure of the ability of its mechanical structure to provide for heat removal from the active semiconductor element. (See JESD531). Thermal resistance, R_{thJR}, is the limiting value of thermal impedance, Z_{thJR}, at long time duration, t. The testing is the same as for thermal impedance, with the additional requirement that thermal equilibrium must occur by the end of the heating power pulse. See thermal impedance testing in 4.7 for further details. The last portion of the equation in 4.7.5 is also important for thermal equilibrium measurements where the T_{R2} value at the end of the test cannot often be maintained at the initial T_{R1} value.

Standard Improvement Form

JEDEC JESD211.01

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 and return to:

JEDEC
Attn: Publications Department
3103 North 10th Street
Suite 240 South
Arlington, VA 22201-2107

Fax: 703.907.7583

1. I recommend changes to the following:
   - [ ] Requirement, clause number ________
   - [ ] Test method number ________ Clause number ________

   The referenced clause 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