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SILICON RECTIFIER DIODES

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SILICON RECTIFIER DIODES

(From JEDEC Board Ballot JCB-98-75A, formulated under the cognizance of JC-22.2 Subcommittee on Rectifier Diodes)

1 Scope

This document is a comprehensive users' guide for silicon rectifier diode applications. It sets forth the nomenclature associated with silicon rectified diodes. This document further describes the established procedures that are followed in the registration of semiconductor devices and the assignment of type designations. For the purpose of preserving standardization, guidelines for filling in the rectifier diode registration information required in registration formats are provided. Standard ratings and test methods to be used in establishing and verifying the maximum ratings for rectifier diodes given in the JC-22 series of registration formats for rectifier diodes are provided. Accepted test methods and general guidelines of techniques and instrumentation for performing rectifier diode characteristics tests are set forth. Diode ratings and characteristics are presented with consideration to actual diode applications.

2 Definitions and Symbols

2.1 Physical Structure Nomenclature

anode: The p-type region from which the forward current flows within a semiconductor diode.

NOTE In Schottky diodes, usually the barrier metal replaces the p-type semiconductor region and the remaining semiconductor region is n-type; however, some Schottky diodes have been made with the barrier metal replacing the n-type semiconductor region, in which case the remaining semiconductor region is p-type.

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 with the same polarity, to the extreme p-type region.

NOTE See note to “anode”.

cathode: The n-type region to which the forward current flows within a semiconductor diode.

NOTE See note to “anode”.

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 with the same polarity, to the extreme n-type region.

NOTE See note to “anode”.

electrode (of a semiconductor device): An element that performs one or more functions of emitting or collecting electrons or holes, or of controlling their movements by an electric field.

2.1 Physical Structure Nomenclature (cont'd)

junction (in a semiconductor device) (general term)**:** A transition region between semiconductor regions of different electrical properties, or a physical region between a semiconductor region and a region of a different type; it is characterized by a potential barrier that impedes the movement of charge carriers from the region of higher concentration to the region with lower concentration.

rectifier stack: An integral assembly of two or more rectifier diodes, including its associated housing, and any integral mounting and cooling attachments. (See Figure 3.)

rectifying junction: A junction in a semiconductor device that exhibits asymmetrical conductance.

semiconductor device (general term)**:** A device whose essential characteristics are due to the flow of charge carriers within a semiconductor material.

NOTE The definition includes devices whose essential characteristics are only in part due to the flow of charge carriers in a semiconductor but that are considered as semiconductor devices for the purposes of specification.

semiconductor rectifier diode: A semiconductor diode intended to be used for current and voltage rectification. (See Figure 1 and Figure 2. For graphical symbol, see Figure 4.)

NOTE 1 The term "semiconductor rectifier diode" includes the associated housing and any integral mounting and cooling attachments.

NOTE 2 The term "rectifier cell" is sometimes used as a synonym for "rectifier diode" when the diode is an element of a rectifier stack.

terminal: An externally available point of connection.

2.2 Semiconductor Rectifier Diode Characteristic and Rating Terms

average current: The value of a periodic current averaged over a full cycle unless otherwise specified.

average rectified output current (50 Hz or 60 Hz sinewave input, 180º conduction angle) (I_O): The output current averaged over a full cycle from a rectifier with a 50 Hz or 60 Hz sinewave input and a 180º conduction angle.

average voltage: The value of a periodic voltage averaged over a full cycle unless otherwise specified.

blocking: A term describing the state of a semiconductor device or junction that imposes high resistance to the passage of current.

breakdown: The phenomenon, occurring in a reverse-biased semiconductor junction, whose initiation is observed as a transition from a region of high small-signal resistance to a region of substantially lower small-signal resistance for an increasing magnitude of reverse current.

breakdown current: A current in the breakdown region.

breakdown region: The portion of the voltage-current characteristic beyond the initiation of breakdown for an increasing magnitude of reverse current.

2.2 Semiconductor Rectifier Diode Characteristic and Rating Terms (cont'd)

breakdown voltage (For symbol, see Table 1)**:** The voltage measured at a specified current in a breakdown region.

fall time charge (Q_{rrf}): That part of the recovered charge that is recovered from the diode during the reverse recovery fall time.

NOTE The time intervals t_{rrf} and t_{rrr} are defined so that their sum is equal to the reverse recovery time t_{rr}, whereas the recovered charge Q_{rr} is defined for an integration time t_i. As a consequence, the sum of the partial charges Q_{rrf} and Q_{rrr} will differ from Q_{rr} unless t_{rr} equals t_i.

forward current (in a semiconductor diode) (For symbol, see Table 1)**:** The current flowing from the external circuit into the anode terminal.

forward direction: The direction of a (positive) forward current

forward power dissipation (For symbol, see Table 1)**:** The power dissipation resulting from forward current.

forward recovery time (t_{fr}): The time interval between the instant when the forward voltage rises through a specified first value, usually 10% of its final value, and the instant when it falls from its peak value, V_{FRM}, to a specified low second value, V_{FR}, upon the application of a step current following a zero-voltage or a specified reverse-voltage condition.

forward voltage (across a semiconductor diode) (For symbol, see Table 1)**:** A positive anode-cathode voltage.

non-repetitive peak reverse voltage (V_{RSM}): The peak reverse voltage including all non-repetitive transient voltages but excluding all repetitive voltages. (See Figure 6.)

overload forward current ($I_{FM(OV)}$): A current whose continuous application would cause the maximum-rated virtual junction temperature to be exceeded, but that is limited in duration such that this temperature is not exceeded.

NOTE Devices may be subjected to overload currents as frequently as called for by the application while being subjected to normal operating voltages. (Ref. IEC 747-2.)

peak forward current (I_{FM}): The peak instantaneous value of the forward current. **peak reverse current (I_{RM}):** The peak instantaneous value of the reverse current. **peak reverse voltage (V_{RM}):** The peak instantaneous value of the reverse voltage.

recovered charge (Q_{rr}): The total amount of charge recovered from a diode, including the capacitive component of charge, when the diode is switched from a specified conductive condition to 1) a specified nonconductive condition, or 2) an unspecified nonconductive condition with the measurement ending after a specified integration time, t_i, with other circuit conditions as specified.

repetitive peak forward current (I_{FRM}): The peak forward current including all repetitive transient currents but excluding all non-repetitive transient currents.

2.2 Semiconductor Rectifier Diode Characteristic and Rating Terms (cont'd)

repetitive peak reverse current (I_{RRM}): The peak reverse current including all repetitive transient currents but excluding all non-repetitive transient currents.

repetitive peak reverse voltage (V_{RRM}): The peak reverse voltage including all repetitive transient voltages but excluding all non-repetitive transient voltages. (See Figure 6.)

reverse current (in a semiconductor diode) (For symbol see Table 1-1)**:** The current flowing from the external circuit into the cathode terminal

reverse direction: The direction of a (positive) reverse current.

reverse power dissipation (For symbol, see Table 1)**:** The power dissipation resulting from reverse current.

reverse recovery current (For symbol, see Table 1)**:** The transient reverse current associated with a change from forward current to a reverse condition. (See clause 6.6.9.)

reverse recovery current fall time (t_{rrf}, t_b): The portion of the reverse recovery time interval after the reverse recovery current has reached its maximum (peak) value. (See Figure 7.)

reverse recovery current rise time (t_{rrr}, t_a): The portion of the reverse recovery time interval prior to the instant when the reverse recovery current reaches its maximum (peak) value. (See Figure 7.)

reverse recovery softness factor (RRSF): The absolute value of the ratio of (1) di_{RR}/dt (the rate of rise of the reverse recovery current) when the current is passing through zero at the beginning of the reverse recovery time, to (2) di_{RF}/dt (the maximum value of the rate of fall of the reverse recovery current) after the current has passed through its peak value, I_{RM}. (See Figure 9.)

NOTE The ratio of reverse recovery current fall time (t_b) to the reverse recovery current rise time (t_a) has been called "recovery softness factor" (RSF); however, RRSF is a more useful measure of the diode softness characteristic.

reverse recovery time (t_{rr}): The time interval between the instant when the current passes through zero when changing from the forward direction to the reverse direction and, after reverse current reaches its peak value $I_{RM(REC)}$, the instant when

a. the reverse current first intersects the zero-current axis as shown in Figure 7(a), or
b. the extrapolated reverse current reaches zero, as shown in Figure 7(b), or
c. the reverse current reaches a specified low value $i_{R(REC)}$, as shown in Figure 7(c).

NOTE In b., the extrapolation is carried out with respect to specified points "A" and "B", as shown in generalized form in Figure 7(b). Point "A" may be specified at other than $I_{RM(REC)}$.

reverse voltage (across a semiconductor diode) (For symbol, see Table 1): A positive cathode-anode voltage.

rise time charge (Q_{rrr}): That part of the recovered charge that is recovered from the diode during the reverse recovery rise time.

NOTE See note to "fall time charge".

2.2 Semiconductor Rectifier Diode Characteristic and Rating Terms (cont'd)

stored charge (Q_s): The total amount of charge recovered from a diode minus the capacitive component of charge when the diode is switched from a specified conductive condition to a specified nonconductive condition with other circuit conditions specified.

surge peak forward current (I_{FSM}): The peak forward current including all non-repetitive transient currents but excluding all repetitive transient currents.

thermal resistance (R_{th}, $R_{\square}$): The temperature difference between two specified points or regions divided by the power dissipation under conditions of thermal equilibrium.

total power dissipation (For symbol, see Table 1)**:** The sum of the forward and reverse power dissipations.

transient thermal impedance (Z_{th}, $Z_{\square}$): 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.

virtual junction temperature (T_J): A temperature representing the temperature of the junction calculated on the basis of a simplified model of the thermal and electrical behavior of the semiconductor diode.

working peak reverse voltage (V_{RWM}): The peak reverse voltage excluding all transient voltages. (See Figure 6.)

2.3 Terms Used in Describing Rectifier Diode Circuits

blocking period (of a rectifier circuit element): The part of an alternating-voltage cycle during which the current flows in the reverse direction.

NOTE The blocking period is not necessarily the same as the reverse period because of the effect of circuit parameters and semiconductor rectifier diode characteristics.

bridge rectifier circuit: See "double-way rectifier circuit".

commutation: The transfer of unidirectional current between rectifier circuit elements that conduct in succession.

conducting [conduction] period (of a rectifier circuit element): The part of an alternating-voltage cycle during which the current flows in the forward direction.

NOTE The forward period is not necessarily the same as the conducting period because of circuit parameters and semiconductor rectifier diode characteristics

double-way rectifier circuit: A circuit in which the current flows in both directions from each terminal of the alternating-voltage circuit to the rectifier circuit elements connected to each terminal.

2.3 Terms Used in Describing Rectifier Diode Circuits (cont'd)

NOTE The terms "single-way" and "double-way" provide a means for describing the effect of the rectifier circuit on current in the transformer windings connected to rectifier circuits. Most rectifier circuits may be classified into these two general types. Many double-way circuits are also referred to as bridge circuits. Both single-way and double- way circuits are illustrated in Figure 61 and Figure 63. The 1-1-1-H, 2-1-1-C, 3-1-1-Y, 6-1-1-Y, and 6-1-1-S types are examples of single-way circuits. The 4-1-1-B and 6-1-1-B types are examples of double-way circuits.

form factor (of a waveform): The ratio of the root-mean-square value of the wave to the average value.

forward period (of a rectifier circuit element): The part of an alternating-voltage cycle during which forward voltage appears across the rectifier circuit element.

full-wave rectifier circuit: A circuit that changes single-phase alternating current into pulsating unidirectional current utilizing both halves of each cycle.

half-wave rectifier circuit: A circuit that changes single-phase alternating current into pulsating unidirectional current utilizing only one half of each cycle.

harmonic content (of a non-sinusoidal periodic wave): The order and magnitude of the harmonic components.

(percent) ripple voltage or current: The ratio, in percent, of the effective (root-mean-square) value of the ripple voltage or current to the average value of a pulsating unidirectional voltage or current, respectively.

rectifier circuit element: One or more semiconductor rectifier diodes or rectifier stacks connected in series, in parallel, or both, to operate as a unit that is bounded by two circuit terminals and conducts current substantially in only one direction.

NOTE Graphical symbols for rectifier circuit elements are shown in Figure 4 and Figure 5.

reverse period (of a rectifier circuit element): The parts of an alternating-voltage cycle during which reverse voltage appears across the rectifier circuit element.

ripple voltage or current: The alternating component whose instantaneous values are the difference between the average and instantaneous values of a pulsating unidirectional voltage or current, respectively.

single-way rectifier circuit: A circuit in which the current flows in only one direction from each terminal of the alternating-voltage circuit to the rectifier circuit element connected to each terminal.

NOTE See NOTE under "double way rectifier circuit".

2.4 General Letter Symbols

2.4.1 Temperature Symbols

ambient temperature	T_A
case temperature	T_C
storage temperature	T_{stg}
virtual junction temperature	T_J

NOTE T_{VJ} may be substituted for T_J

2.4.2 Thermal Resistance and Impedance Symbols

thermal resistance	R_{th}
thermal resistance, case-to-ambient	R_{thCA}
thermal resistance, junction-to-ambient	R_{thJA}
thermal resistance, junction-to-case	R_{thJC}
thermal resistance, junction-to-lead	R_{thJL}
thermal resistance, junction-to-mounting	R_{thJM}

NOTE R_θ may be substituted for R_{th}, and similarly $Z_{? (t)}$ may be substituted for $Z_{th(t)}$, etc.

transient thermal impedance	Z_{th}
transient thermal impedance, junction-to-ambient	Z_{thJA}
transient thermal impedance, junction-to-case	Z_{thJC}
transient thermal impedance, junction-to-lead	Z_{thJL}
transient thermal impedance, junction-to-mounting	Z_{thJM}

NOTE R_θ may be substituted for R_{th}, and similarly $Z_{\theta (t)}$ may be substituted for $Z_{th(t)}$, etc.

2.4.3 Transient and Electrical Symbols

fall time	t_f
forward recovery time	t_{fr}
junction capacitance	C_j
pulse duration	t_p
recovered charge	Q_{rr}
stored charge	Q_S
reverse recovery time	t_{rr}
rise time	t_r
reverse recovery current rise time	t_{rrr}, t_a
reverse recovery current fall time	t_{rrf}, t_b
reverse recovery softness factor	RRSF

2.5 Letter Symbols Subscripts

The following letters are used as qualifying subscripts in rectifier diode voltage, current, and power letter symbols to denote specific descriptive terms. The use of some of them is illustrated in Table 1 and Figure 9.

2.5 Letter Symbols Subscripts (cont'd)

A, a	anode
(AV)	average value
(BR)	breakdown
K, k	cathode
F, f	forward
M, m	maximum peak value
S	non-repetitive or surge
(OV)	overload
r	reverse or as a second subscript, recovery
R	reverse or as a second subscript, repetitive
(REC)	recovery
(RMS)	total rms value
W	working

Table 1 — Letter Symbols for Rectifier Specifications

	Total rms value	RMS value of alternating component	DC value with no alternating component	DC value with alternating component	Instantaneous total value	Maximum (peak) total value
Forward current	$I_{F(RMS)}$	I_f	I_F	$I_{F(AV)}$	i_F	I_{FM}
Forward current, overload						$I_{FM(OV)}$
Forward current, repetitive peak						I_{FRM}
Forward current, surge (non-repetitive) peak						I_{FSM}
Rectified output current, average, 180° conduction angle, 50 Hz or 60 Hz, sinewave input				I_O		
Reverse current	$I_{R(RMS)}$	I_r	I_R	$I_{R(AV)}$	i_R	I_{RM}
Reverse current, repetitive peak						I_{RRM}
Reverse recovery current					$i_{R(REC)}$	$I_{RM(REC)}$
Forward power dissipation			P_F	$P_{F(AV)}$	P_F	P_{FM}
Peak power dissipation with surge current						P_{FSM}
Reverse power dissipation			P_R	$P_{R(AV)}$	P_R	P_{RM}
Total power dissipation			P_T	$P_{T(AV)}$		P_{TM}
Breakdown voltage			$V_{(BR)}$		$v_{(BR)}$	
Forward voltage	$V_{F(RMS)}$	Vt	V_F	$V_{F(AV)}$	v_F	V_{FM}
Forward surge voltage						V_{FSM}
Reverse voltage	$V_{R(RMS)}$	Vt_r	V_R	$V_{R(AV)}$	v_R	V_{RM}
Reverse voltage, working peak						V_{RWM}
Reverse voltage, repetitive peak						V_{RRM}
Reverse voltage, non-repetitive peak						V_{RSM}
Peak junction temperature with repetitive forward current flowing						T_{JRM}
Peak junction temperature with surge forward current flowing						T_{JSM}

2.5 Letter Symbols Subscripts (cont'd)

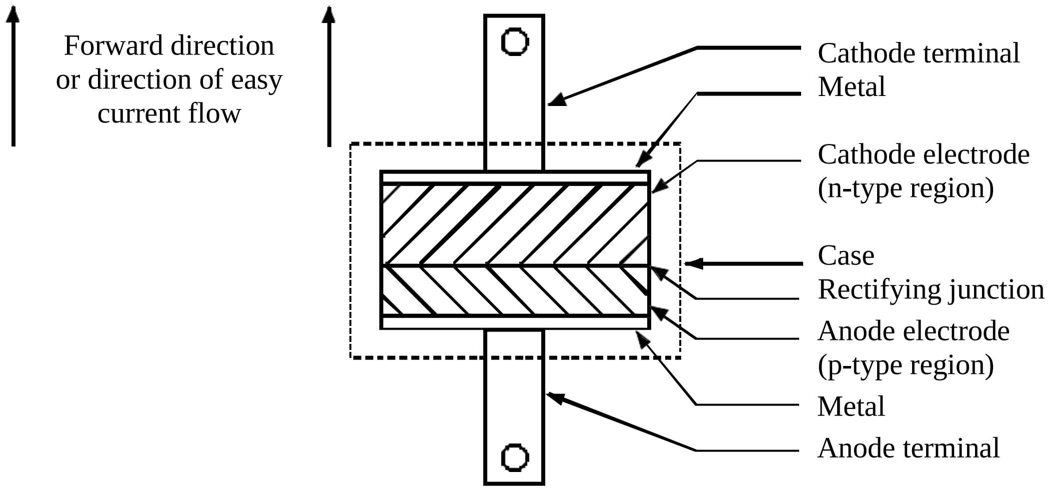


Figure 1 — Cross-Section of a Semiconductor Rectifier Diode

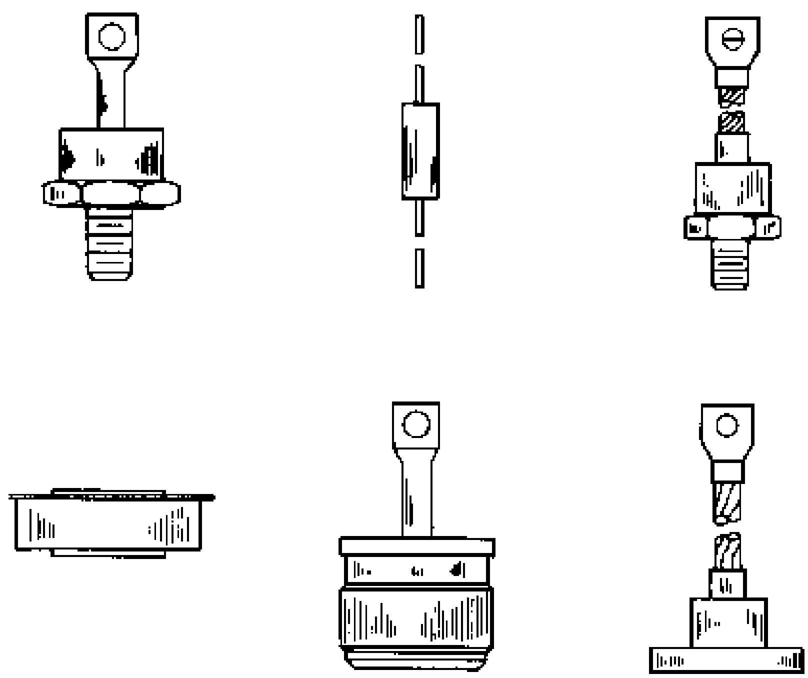


Figure 2 — Typical Semiconductor Rectifier Diode Packages

2.5 Letter Symbols Subscripts (cont'd)

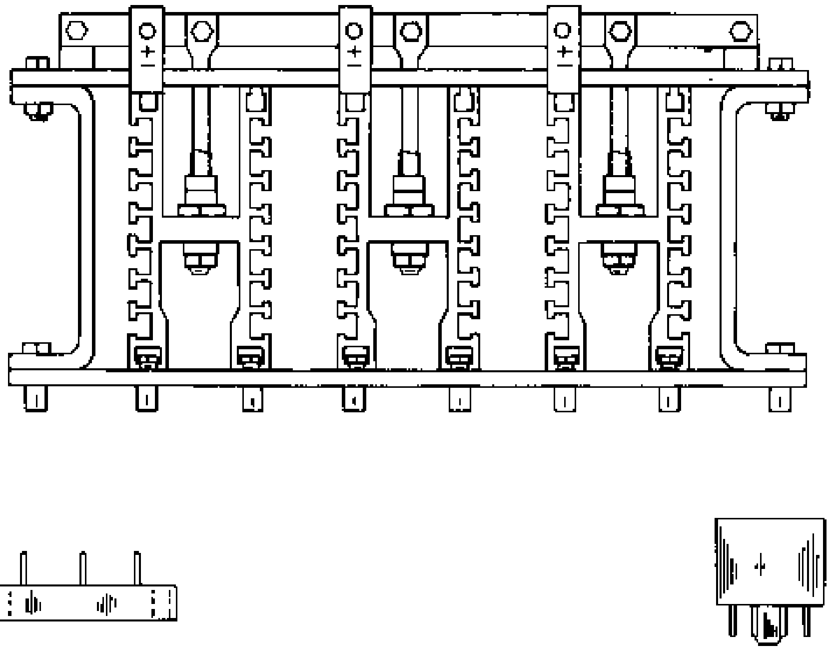


Figure 3 — Sketches of typical semiconductor rectifier stacks

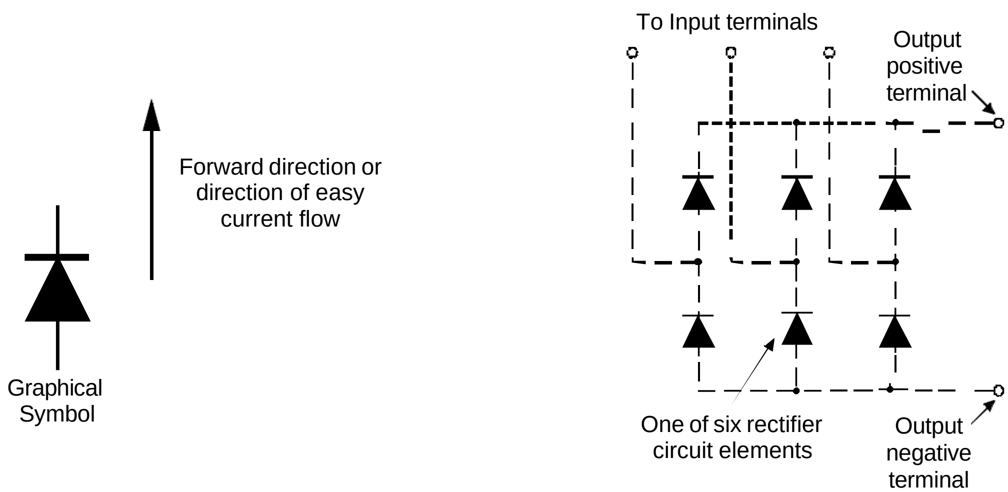


Figure 4 — Rectifier Graphical Symbol and Example Circuit

2.5 Letter Symbols Subscripts (cont'd)

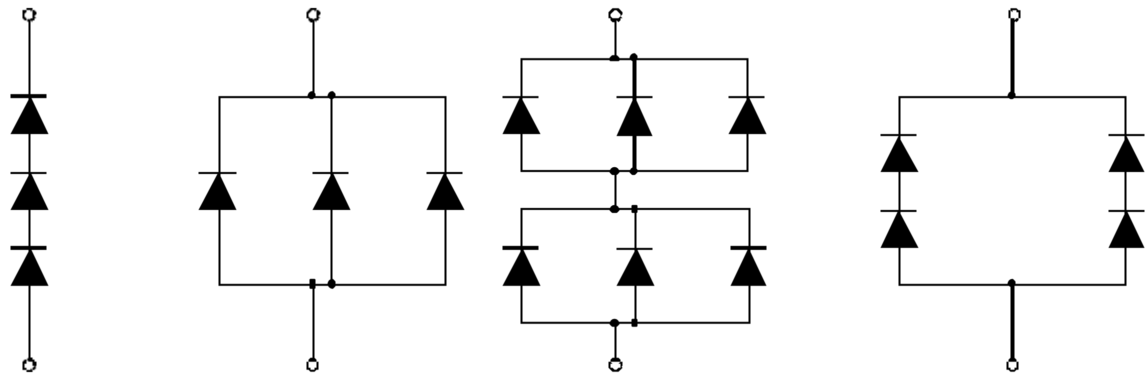


Figure 5 — Examples of Rectifier Circuit Elements

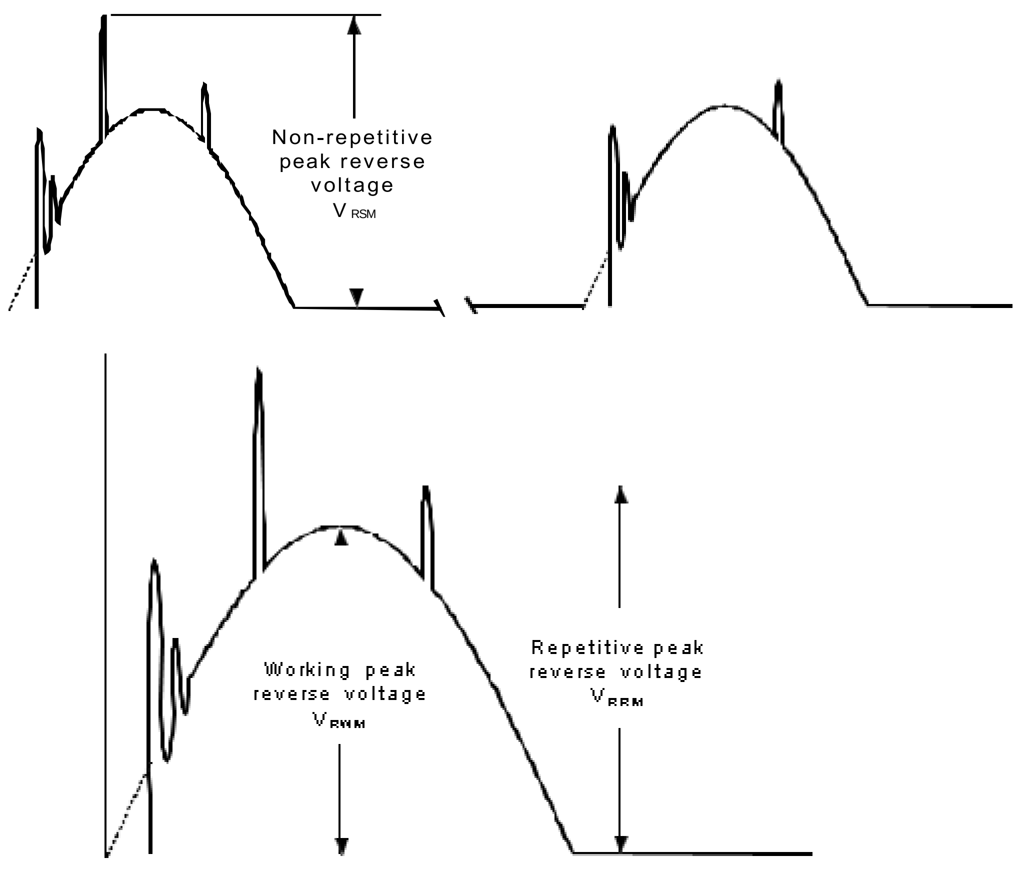


Figure 6 — Reverse Voltage Waveforms

2.5 Letter Symbols Subscripts (cont'd)

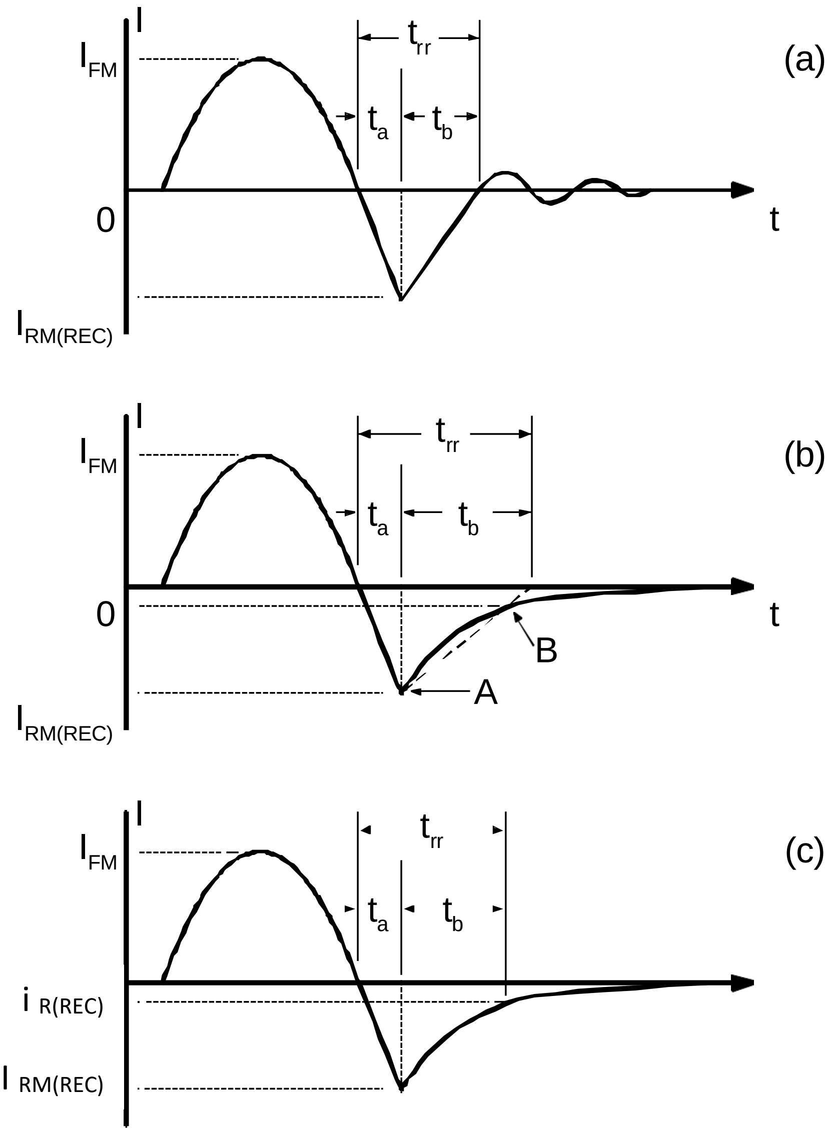
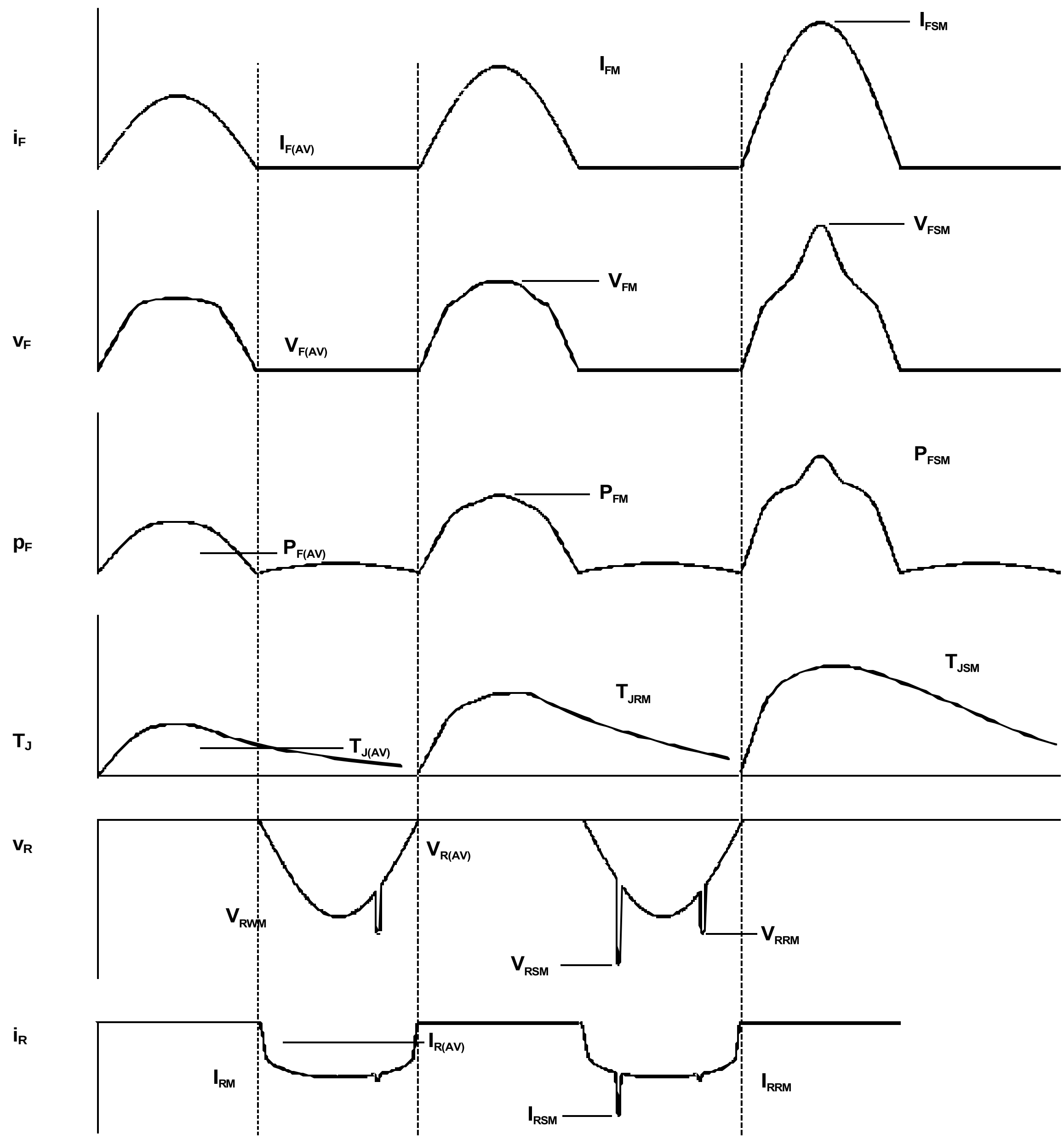


Figure 7 — Current Waveforms During Rectifier Diode Reverse Recovery

2.5 Letter Symbols Subscripts (cont'd)



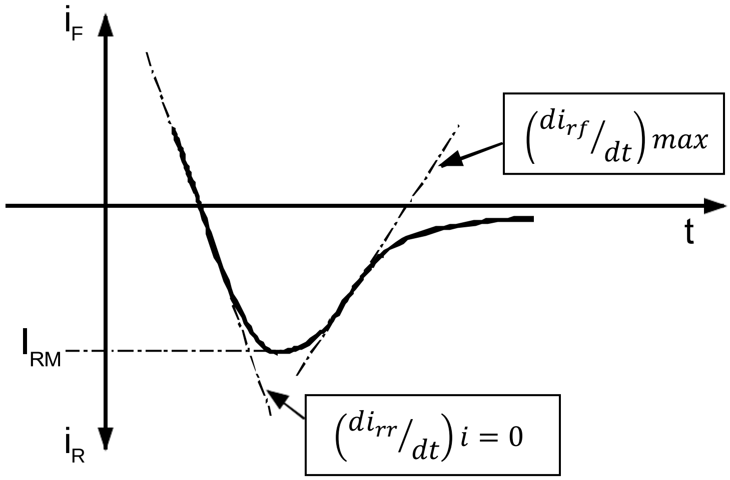
NOTE 1 Instantaneous values, such as i_F, v_F, etc. indicate a value on the waveform at a desired point in time.

NOTE 2 Io is the average rectified current of sinusoidal waveform. For other waveforms the average rectified current is designated as $I_{F(AV)}$.

NOTE 3 In the figure, vertical dashed lines are used to show concurrence of the other waveforms with the end of, and beginning of, i_F.

Figure 8 — Illustration of Symbols for Reverse and Forward Voltage and Current and Junction Temperature Excursion Resulting from the Developed Power

2.5 Letter Symbols Subscripts (cont'd)



$$RRSF = \left| \frac{\left(di_{rr}/dt\right) i = 0}{\left(di_{rf}/dt\right) max} \right|$$

Figure 9 — Reverse Recovery Softness Factor (RRSF)

3 Registration

3.1 Introduction

This chapter describes the established procedures that are followed in the registration of semiconductor devices and the assignment of type designations. These procedures are discussed from the standpoint of both administration by JEDEC and compliance by the device manufacturer. Technical standards concerning registration are not included but are discussed in clause 4.

Registration consists of the assignment of type designations to solid state devices in accordance with established rules, recording the assignment and defining data, and the full dissemination of the information to the electronics industry.

Registration procedures and rules are established by JEDEC, which is a sector of EIA (Electronic Industries Alliance). In any event, JEDEC neither assumes liability for, nor endorses the use of any products which bear its authorized registration number. JEDEC has as its primary objective the development of Recommended Standards and Registration Formats in the field of solid state devices. An effective registration procedure is considered basic to the achievement of this objective.

The material in this clause on type assignments is taken from JEDEC Publication No. 15D (February, 1981). However, the latest revision of this publication has overriding authority where any conflict may occur with the material contained herein.

The term “type designation” used here refers to the number assigned to a solid state device in accordance with EIA Recommended Standard EIA-370-B “Designation System for Discrete Semiconductor Devices” (February 1982; Reaffirmed November 1995). The term “type designation” may be applied to the original number assigned (without suffix) or to a number with a suffix letter. All procedures described here apply equally well to both the basic type designation and to the suffix letter designation unless otherwise stated (See clause 3.2.4 and clause 3.2.5).

3.2 Purpose and Intent

The purpose of the type designation and registration system is to facilitate the purchase and distribution of solid state devices by nontechnical individuals. The registration procedures are designed to ensure that devices registered with JEDEC differ from each other significantly in performance characteristics or physical dimensions.

The following is a partial list of the many ways in which the JEDEC registration system is useful to many segments of the electronics industry.

1) A single number replaces the multiple house numbers that would be used where there are two or more manufacturers of a particular device. This advantage is of particular value to the larger consumer such as the Government, because it means in most cases the procurement and supply of a single item, instead of multiple items.

2) The existence of a nationality recognized designation encourages other manufacturers to make similar devices, thereby increasing and promoting competition.

3.2 Purpose and Intent (cont'd)

3) Requires types registered under the JEDEC system to differ from each other in a significant degree in terms of performance characteristics or physical dimensions.

4) Allows types registered under the JEDEC system to be more easily compared because the defining characteristics of the specification must be based upon standard test conditions and registered according to standard formats.

5) The publication of registration information through trade channels makes it easier for consumers to obtain second sources of supply.

6) The specifications of registered devices carrying the authorized designations cannot be changed at will by the first or any subsequent manufacturer, thus promoting standardization and interchangeability.

7) In many cases it provides a means for nontechnical personnel of user stock procurement and maintenance operations to obtain equivalent replacement parts.

8) It provides a permanent record for future procurement in those cases where the original manufacturer(s) no longer exist or make the type.

9) It provides a parts identification system which is of benefit to the distributor and user of electronic parts.

10) The JEDEC system permits reduction in the required number of parts in inventory.

It is the intent of the type designation and registration system to permit the assignment of discrete semiconductor device type designations not only to single solid state devices but also to combinations of solid state devices such as more than one diode element, or diode elements and transistor or thyristor elements, within the same primary envelope. In each case, EIA Standard EIA-370-B, "Designation System for Discrete Semiconductor Devices" governs.

3.3 Brief Outline of Registration Procedures

Application: The manufacturer furnishes to the Type Administrator defining data for a device in accordance with the applicable registration format and requests assignment of a type designation. (See clause 4.1.)

Assignment: The Type Administrator assigns a type designation and notifies the manufacturer.

Release (Public Announcement): Within one hundred and twenty (120) days after the date of assignment, the Type Administrator announces the registration of the type by distributing the data to the manufacturers and users of solid state devices.

Correction Notice and Registration: Once data on a type has been released, it is possible to change the defining data for that type only by either of two methods: a correction notice or a reregistration. In those cases where an error has been discovered in the data submitted, a correction notice may be filed only by the original sponsor to the Type Administrator within sixty (60) days after release. On the other hand, any device manufacturer may, at any time, propose a reregistration to change the registered values for a device.

In order for the change to be adopted, however, there must be no opposition to the proposal from any other manufacturer of the device.

3.4 Detailed Procedures and the Rules Governing Registration of Type Designation without Letter Suffix

3.4.1 Application

Any manufacturer of solid state devices, whether or not a member of JEDEC or EIA may request a type registration from the Type Administrator for a device the manufacturer is developing or manufacturing. Foreign manufacturers may also request type registrations. All applicants for type registrations will be charged a fee for the service.

The requirement that final registration data be made available to the Type Administrator in order to obtain a type registration makes it necessary for the manufacturer to defer his application until the device is about to be marketed.

A request for registration must be made in writing by the manufacturer of the device. It must be accompanied by sufficient defining data to show that the device differs from any existing device for which a number has been assigned by the Type Administrator. The data must be submitted to Technology Association in accordance with the applicable formats developed by JEDEC Solid State. See clause 3.7, clause 3.8, and clause 3.9 for rules pertinent to development and use of formats. If an appropriate format does not exist, the information submitted must meet the minimum requirements set by the Type Administrator. In any case, the Type Administrator shall be the sole authority for determining the adequacy of data submitted. Any appeal of the Type Administrator's determination shall be made in writing within thirty (30) days, in accordance with the procedures set out in clause 3.6.

For rectifier diodes, the Type Administrator will insist that a new type number, not a suffix letter, be used, if a new device differs from an older registered device in any of the following respects:

1) Any change in forward current rating, except surge current.
2) Any change in reverse voltage rating.
3) Any change in maximum storage or operating temperature rating.
4) A new rating or characteristic not required of the older device and for which industry agreement for reregistration of the older device could not be reached.
5) A major change exceeding the greatest change permitted for suffix designations in one or more of the characteristics listed.
6) New outline dimensions.

The data submitted shall be a typed original (or equivalent quality) on unfolded 8-1/2" by 11" plain white bond paper (no letterhead). Specific instructions for data submissions appear with each registration format. The data shall be mailed with suitable protection against creasing or bending. If the material is not received in condition suitable for reproduction, the Type Administrator reserves the right to return it to the sponsor, notwithstanding delay and further costs to the sponsor.

3.4.1 Application (cont'd)

Should the Type Administrator receive more than one application for a particular device, he shall assign the designation for the type to the manufacturer having the earliest time of receipt at the office of the Type Administrator. A manufacturing wishing to establish early receipt may make use of a telegram that furnishes adequate information for assignment. The telegram must be followed within fourteen (14) days by a letter supplying the information in the standard form; otherwise the application will be canceled and the applicant so notified.

Any manufacturer filing subsequently to the first application will be furnished full information on the assignment, and the first manufacturer shall be informed of the disclosure.

3.4.2 Assignment

Upon receipt of the application for a type registration, the Type Administrator will make a search of existing type registrations to determine whether the applicant's device has sufficiently distinct characteristics to warrant the assignment of a new type designation. In determining discreteness or distinctness, the Type Administrator shall take into account major differences such as, but not limited to, different maximum ratings, new tests, different limits from those that have been applied to existing devices, physical changes, and any other characteristics that differ significantly from already registered devices.

If additional data are deemed necessary by the Type Administrator to justify an assignment of a type number, he shall so inform the applicant. If the additional information is not given to the Type Administrator within fourteen (14) days, the applicant shall be notified that the application has been rejected and given reasons therefor.

In case the submitted data closely corresponds with that of a device already assigned a designation by the Type Administrator, the Type Administrator shall reject the application in writing, giving the reasons therefor and supplying the type designation that is considered applicable. Any appeal of the Type Administrator's determination shall be made in writing within thirty (30) days in accordance with the procedures set out in clause 3.6.

Correction or changes in the data may be submitted by the original applicant in the period prior to release. Changes are permissible only to the extent that the device characterization is not changed sufficiently to warrant a change in its type designation status. All changes or corrections must be authorized by the Type Administrator prior to their publication in association with a JEDEC type number and must have prior coordination with the other applicants to whom the designations may have been disclosed under the provisions of clause 3.4.1.

In making type designation assignments, the Type Administrator shall follow current JEDEC Standards, and the technical formats and guidance rules supplied by JEDEC Solid State Technology Association. When all of this information is insufficient to cover a specific case, the Type Administrator may delay the application pending a decision from the appropriate JEDEC Committee. (In any case of rectifier diodes the Committee would be JC- 22.) The Type Administrator shall notify the applicant of the delay and the reason therefor.

3.4.3 Release (Public Announcement)

The Type Administrator shall release the registration data to the public as soon as he has been authorized to do so by the manufacturer, who in turn does so when he is ready to market the device. If earlier authorization is not received, the Type Administrator shall automatically release the data one hundred and twenty (120) days after date of assignment. A delay may be requested for legitimate causes.

3.4.3 Release (Public Announcement (cont'd)

In those cases where a manufacturer publicly discloses data on an authorized type designation before he has requested the Type Administrator to release the data, the Type Administrator shall automatically release the data without waiting for the one hundred and twenty (120) day period to end. The Type Administrator will take such action only in those cases when he has been given conclusive evidence that disclosure has been made by the manufacturer. For purposes of this clause, the term "disclosure" is meant to include the disclosure of an unreleased but authorized type designation and its data or use through advertising, general distribution of data sheets, inclusion in price lists, sampling, or other marketing steps. Disclosure as part of a government contract for the development of a device is not considered to be disclosure within the meaning of this clause.

In the case where an invitation-for-bid has been issued in connection with a government contract for a solid state type that has not been released, the Type Administrator shall use a procedure for affecting registration other than the one described in the preceding paragraph. The recipient of the invitation-for-bid shall supply details concerning the invitation and its sources. The Type Administrator will then contact the sponsor of the unreleased type designation, informing him or her of circumstances which require the immediate release of data on the type.

The registration data is distributed by the Type Administrator to all known manufacturers of solid state devices, as well as to subscription lists of equipment designers, users and other nonmanufacturers of solid state devices.

3.4.3 Correction Notice and Re-registration

After a type designation has been completely registered, one of the ways in which it is possible to change the defining data is by means of a correction notice. This can be filed only by the original sponsor or the Type Administrator and must be in the hands of the Type Administrator within sixty (60) days after the release date. Corrections to registered data after sixty (60) days from date of release must be made through the reregistration procedure.

The correction notice process may be used when it is found that the registered data contains obvious incompatibilities, typographical errors, or ambiguities. The correction notice will be circulated to the same mailing list of those persons receiving the registration information and it will clearly refer to the particular release involved.

A correction notice does not become effective until sixty (60) days after its release. During this period any manufacturer may object to the notice if he can show that the change is not truly an obvious error, incompatibility, or ambiguity. A single valid objection, if it cannot be reconciled by the Type Administrator with the proponent, will cause the correction notice to be canceled.

The second way in which the defining data for a registered type may be changed is by means of reregistration. Reregistration may be proposed only by a manufacturer or the appropriate JEDEC Committee (JC-22 in the case of rectifier diodes). In submitting data, the manufacturer should use the most current approved format. If absolutely necessary, he may use the format which was in effect at the time of registration of the device being reregistered.

3.4.3 Correction Notice and Re-registration (cont'd)

A reregistration proposal should be limited to those changes or additions which do not affect unilateral interchangeability with the original version. Any proposed reregistration, which in the opinion of the Type Administrator will affect unilateral interchangeability shall be rejected by the Type Administrator. Examples of changes which affect unilateral interchangeability are relaxed package dimensions, relaxed electrical ratings or characteristics, etc. For dimensions and characteristics, increase of maximum limit or reduction of a minimum limit constitutes a relaxation. For ratings (which imply device capability), reduction of an upper limit or increase of a lower limit constitutes a relaxation. Manufacturers who believe unilateral interchangeability will not be affected have the prerogative of appealing the Type Administrator's decision as provided in clause 3.6.

Approved reregistration requests will be processed as follows: The Type Administrator shall distribute the reregistration proposal to the device manufacturers on the mailing list to receive copies of all semiconductor registrations. The reregistration release will instruct manufacturers having valid objections to the proposal to submit their comments in writing (oral comments are not acceptable) to the Type Administrator, so that he may receive them within sixty (60) days from the date of release.

If no written adverse comments to a reregistration proposal are received within the sixty (60) day period, the reregistration proposal becomes effective, superseding the original registration, and the industry shall be so notified by the Type Administrator.

In the event that adverse comments on the proposed reregistration are received and:

1) If there is a possibility that the objections may be resolved, the Type Administrator shall issue a "HOLD IN ABEYANCE" notice at the end of the sixty (60) day period.

2) If attempts at reconciliation fail, the reregistration shall be canceled and a cancellation notice sent to all recipients of the previous information.

3) If the reconciliation results in a compromise, the previous proposal shall be canceled and the new proposal shall be submitted for a sixty day approval by the industry.

4) If the reconciliation results in the objectors, rescinding their negative comments, the Type Administrator shall issue a notice that the reregistration proposal has been accepted.

In those cases where the Type Administrator has rejected comments because he considers them to be not valid, he shall notify the objector of his action and inform the objector that he has thirty (30) days in which to file an appeal with the JEDEC office who, in turn, will notify the Type Administrator that an appeal has been filed. If no appeal is made within the specified period, the Type Administrator will proceed in accordance with the previous paragraphs.

3.5 Detailed Procedures and the Rules Governing Registration of Type Designation with Letter Suffix

All of the preceding rules are applicable to the assignment of a type designation which contains a suffix letter, except as amended in the following paragraphs.

The applicability of a suffix assignment, as opposed to a new designation, is outlined in EIA Standard EIA-370-B. In general, a suffix designation can be applied to an improved version of an existing type if the improved version is unilaterally interchangeable with the prototype and all prior suffix versions.

Exceptions exist for letters R and M. The letter R is used to indicate a reverse-polarity diode in an asymmetrical package which is mechanically and electrically identical to a forward-polarity device. When the package has a mounting base (stud, flange or case mounting) which is used as one electrical connection, the definition for polarity of a rectifier diode is as follows:

In forward-polarity devices, the mounting base shall be the cathode terminal, and in reverse-polarity devices, it shall be the anode terminal.

For the use of suffix letter M refer to EIA Recommended Standard EIA-370-B.

For rectifier diodes suffixes may be issued when there is a significant change in one or more of the characteristics or ratings listed in the table below. The change must be such that the new device is unilaterally interchangeable with the older one having the same basic number, so that the new type, which has been given the letter suffix, may be used to replace the original type device. Only changes which result in device improvement within the range shown in the table below will be allowed. If a proposed rating is between the original rating and the nearer limit of the specified range, the change is deemed not significant enough to warrant either a suffix letter or a new type number. If the proposed rating lies beyond the further limit, a new type number is required.

If the device outline is identical to that of an existing type or differs to such a slight extent that the new type may be physically substituted for the existing type, a suffix letter may be considered. If the new outline differs significantly, such as would be the case if it had a different registration (DO) number, a new type number is required, even if electrical ratings and characteristics are the same.

Table 2 — Allowed Ranges of Parameters for Use of Letter Suffix

Parameter	Allowed Range for Use of Letter Suffix
Forward Voltage (V_{FM})	0.8 - 0.9 x V_{FM} (reg)*
Reverse Current (I_{RM})	0.05 - 0.20 x I_{RM} (reg)*
Surge (Non-repetitive) Peak Forward Current (I_{FSM})	1.50 - 3.50 x I_{FSM} (reg)*
Reverse Recovery Time (t_{rr})	0.10 - 0.50 x t_{rr} (reg)*
* I_{RM} (reg) etc. represents the registered value of the particular parameter in the original type device.	

3.5 Detailed Procedures and the Rules Governing Registration of Type Designation with Letter Suffix (cont'd)

The request and the accompanying information will not be treated as confidential information but will be circulated for approval to the recipients of solid state device registration releases in the same manner as a registration proposal (See clause 3.4.4).

In submitting the data, the manufacturer should use the current format. If necessary, he may use the format which was used for registration of the last suffix letter version (or the designation without suffix letter if no letter has been previously assigned).

If adverse comments on the assignment of the suffix letter are received by the Type Administrator within the sixty (60) day period, he shall refer the entire matter to the cognizant JEDEC Committee for guidance.

When the JEDEC Committee votes on recommendations to be submitted to the Type Administrator, members whose companies are directly involved in the dispute shall be excluded from voting. The Type Administrator, preferably, or his or her designated alternate shall be present at the meeting when the JEDEC Committee discusses the matter he or she has referred to them.

The Type Administrator shall make the decision on the registration of the suffix letter designation after considering the Committee's recommendations.

The Type Administrator shall inform the cognizant JEDEC Committee and the parties involved of his decision. If no adverse comments are received within thirty (30) days, then the notice of the assignment becomes effective. If adverse comments are received, then a status notice (Hold-in-Abeyance) can be issued until all avenues of appeal are exhausted or the case dropped.

3.6 Appeal of the Type Administrator's Decision

Decisions of the Type Administrator are subject to appeal to the JEDEC Board of Directors and to an Ad Hoc Arbitration Panel as provided in JEDEC Publication No. 15D. For details the reader is referred to this Publication.

3.7 Description of the Registration Format

A format is intended to provide a uniform method for presentation of the definition and performance of a JEDEC registered device. The Type Administrator uses the completed format to assure the uniqueness of the device for type assignment purposes. The registrant manufacturer uses the format to completely define a device to the degree which the formulating Committee and JEDEC Board of Directors believe is necessary to assure device interchangeability. Other potential manufacturers use the completed format and registration data to facilitate and assure device interchangeability. Solid state device users employ the completed registration data to select, compare, and define devices to achieve intended circuit performance. The format provides for a common language of understanding between supplier and user.

Each format provides for specific values of mechanical and electrical parameters in two categories. One is for mandatory parameters, and the Type Administrator shall not accept a proposal registration unless every such parameter is provided.

3.7 Description of the Registration Format (cont'd)

The other is for additional parameters which the formulating Committee believes desirable for the further definition of a device intended for a normal application. Additional data not listed in a format are permissible if the registrant manufacturer believes it is necessary to further define the device and to assure interchangeability.

The Type Administrator must receive a properly completed registration format (See clause 3.3) in order to issue a JEDEC type number assignment. In the event an appropriate format has not been prepared by the JEDEC Committees, the Type Administrator, with advice from JEDEC Board of Directors or a Committee Chairman, will determine what shall constitute an interim substitute format.

A completed format characterizes a device by listing or referencing all mechanical outline dimensions and terminal identifications, all essential electrical performance data and maximum ratings, all necessary test methods, and all appropriate parameter symbols which are believed necessary to assure device interchangeability. Each JEDEC product Committee originates formats for every device category over which it has been assigned responsibility. Each format is approved for circulation and use by the JEDEC Board of Directors. JEDEC Committees have the responsibility for maintaining and upgrading the technical content of formats such that they reflect the advancement of the technology of both design and manufacture. Mechanical and electrical parameters are to be listed as minimum, maximum, or rated values required to assure device interchangeability.

3.8 Use of JEDEC Registered Data

The solid state device manufacturer should use the JEDEC data for a registered device as the basis for his commercial data. Since the JEDEC registration data is industry property, each manufacturer who desires to produce and market that device must comply in every respect with the registered data. Commercial data describing that device must identify by asterisks all parameters which appear on the JEDEC registration. If a manufacturer believes it desirable, he may list additional defining data, such as performance curves or quality items, provided such additions do not affect interchangeability.

JEDEC type designations should be used in the form in which they are assigned. In data presentation and in device marking, the JEDEC designation should be kept separate and distinct and not made part of other identifying numbers, if such other numbers are present.

Alternations in a JEDEC number should not be made for any purpose such as to indicate special selection, to modify characteristics, or to indicate interchangeability.

Specific examples of past practices which are considered to be in conflict with this policy are illustrated but not limited to the following:

Slash Branding:	JEDEC No./JEDEC No. JEDEC No./House No.
Unauthorized Suffixes:	1N9000Z 1N9000-2 1N9000-TO-9 1N9000/TO-9

3.8 Use of JEDEC Registered Data (cont'd)

JEDEC reserves all rights to the use of its symbols and designations. The Armed Services make use of JEDEC designations and have been permitted to modify these designations by means of prefixes to indicate conformance with military specifications.

3.9 Test and Rating Methods Applied to JEDEC Data

Defining data on a format must be supported by sufficient references or included information, to assure an understanding of the test methods used in the measurement and interpretation of data and ratings. It is the responsibility of the formulating JEDEC Committee and the Board of Directors to define as many of the following test methods, conditions and other information, as is appropriate for the device or format under consideration:

1) Standard circuits for the measurement of electrical characteristics.
2) Standard circuits for life testing of semiconductor devices.
3) Standard mechanical tests (shock, vibration, etc.).
4) Standard fixtures and gauges.
5) Standard time duration of test when applicable (hours, cycles, pulses, etc.).

There should be no question as to the intention behind, or interpretation of, any parameter or test listed on a format.

4 Use of Rectifier Diode Registration Formats

4.1 Introduction

This chapter provides the guidelines for filling in the Rectifier Diode Registration Information required in registration formats.

On a given format, every item preceded by an "M" is a mandatory item and must be completely filled in, since it represents an essential rating or characteristic required to ensure device interchangeability in broad, general rectifier diode applications. The data requested in other items are optional and should be filled in as appropriate to ensure interchangeability in those special applications in which the device is intended to serve. In any event, the data supplied should adequately define the device in terms of interchangeability in the intended application and should distinguish it from existing registered devices. (See clause 3.4 and clause 3.5).

4.1 Introduction (cont'd)

If additional data are necessary to ensure interchangeability, the data should be submitted as part of the registration. When data are submitted for which no blanks appear in the registration format, care must be taken to completely describe the conditions under which the specified performance characteristics or ratings are to be met. All data submitted for registration, whether mandatory, optional, or supplemental to the format, become a part of the formal registration.

When preparing a registration data format for submission, delete all italicized notes, all unused items and all "M's". Renumber the items in proper sequence wherever necessary to avoid gaps in the item numbers used.

Existing JEDEC standards for measurement methods (refer to clause 5 and clause 6), preferred voltage, current and temperature values (given in clause 4.4.1 and clause 4.4.2) and definitions and letter symbols (refer to chapter 2) are to be used, as applicable.

All JEDEC registered data must appear on the device manufacturer's commercial data sheets and be identified as JEDEC registration data by means of asterisks. Additional data, including performance curves, may be included in commercial data sheets provided interchangeability is not affected.

For the purpose of achieving standardization, specific registration formats are available to fit particular types of rectifier 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
JC-22, RDF-21	Lead Mounted Silicon Rectifier Diodes
JC-22, RDF-22	Stud- or Base-Mounted Silicon Rectifier Diodes
JC-22, RDF-23	Stud- or Base-Mounted Silicon Controlled Avalanche Rectifier Diodes or Transient Suppressor Rectifier Diodes
JC-22, RDF-24	Enclosed Silicon Rectifier Circuit Assemblies
JC-22, RDF-25	Unencapsulated Semiconductor Rectifier Diode Elements
JC-22, RDF-26	Diode, Stud- or Base-Mounted Rectifier Diodes having Significant Reverse loss.

The registrant is urged to contact the Type Administrator at EIA Headquarters to be abreast of the latest developments.

In the following clauses an explanation of the requirements of various parts of the formats is given.

4.2 General Description (Registration Format Part I)

This clause establishes the broad descriptive classifications pertaining to the device to be registered. For instance, the semiconductor material used, the type of mounting (lead, base, stud) and the basic electrical configuration (diode assembly, etc.) are to be given here; also the major areas of usage and similar facts.

4.3 Mechanical Data (Registration Format Part II)

The outline dimensions of the device are to be given in this clause. If possible, an outline drawing registered with JEDEC should be used. Registered outlines are found in the latest edition of JEDEC Publication No. 95 "JEDEC Registered and Standard Outlines for Semiconductor Devices". (They are assigned numbers beginning with "DO" when they are two-terminal housings.)

If such a registered outline is not applicable, an outline drawing must be furnished on a separate page attached to the format. The drawing must be prepared so as to conform with the latest edition of EIA Standard RS- 308A, "JEDEC Type Registration for Semiconductor Devices, Preparation of Outline Drawings".

The electrical function of each terminal of the device is also to be given. If the case is also an electrical terminal, its electrical function shall be given. Otherwise, a note is to be included stating "all leads insulated from case". Any terminal not performing an electrical function is to be designated "NC".

When it is required to color code rectifier diode terminals or leads, the following is recommended in the interest of standardization: Anode - Black, Cathode - Red.

For smaller rectifier diodes, a banding of the body at the cathode end is acceptable. The recommended color of the band is red but other colors are acceptable.

For assemblies, the following color code is recommended in the interest of standardization.

Terminals	**Color**
AC	Yellow
Positive or Cathode	Red
Negative or Anode	Black

Any special precautions necessary for the proper handling of the device are to be given. Likewise, any restrictions as to mounting positions which may be required in order to ensure proper operation of the device should be given here. The case or lead temperature point shall also be defined.

4.4 Maximum Ratings (Registration Format Part III)

Maximum thermal and electrical ratings assigned to the device are to be given in this clause. Maximum ratings are those which, if exceeded, may cause permanent damage, or introduce latent failure mechanisms within the device.

4.4.1 Temperature

A temperature reference point (lead or case) must be specified. For a hex base stud-mounted device, the temperature reference point shall be specified as the center of the flat surface of any one of the hex faces. For lead mounted devices, the temperature reference point is generally 3/8 inch (9.5 mm) from the body of the device or its tabulation(s). For a disc type device it shall be a point on the cylindrical surface of a designated mounting pole.

4.4.1 Temperature (cont'd)

Reference point temperatures in degrees Celsius (centigrade) are to be selected, when possible, from the table below and inserted in blanks corresponding to the symbols T_1 through T_{11} as required. A logical sequence covering the temperatures used in the formats follows:

Table 3 — Reference Point Temperatures

PREFERRED TEMPERATURE VALUES (Degrees Celsius)		
-65 *	40	115
-55 *	55	125
-40	65	150
-25 *	70	175
-10	85	200
0	90	250
	100	

* Recommended for use in new documents

If it is necessary to register values other than those given above, they should be multiples of five degrees Celsius.

Several key temperatures are specified on the formats. The following list is all-inclusive; not all temperatures are required on all formats. All temperatures defined herein must be in increments of 5 ºC.

T_1 is the minimum operating temperature and must be equal to or lower than 0 ºC.

T_2 is the minimum operating temperature with no derating and must be equal to or lower than 25 ºC.

T_3 is the maximum operating temperature with no current derating when V_R equals its rated value. T_3 is related to T_5 according to the table below.

T_4 is the temperature of a breakpoint in the maximum average forward current vs temperature relationship, which can be used to segment the derating curve, and must be greater than T_3 and also less than T_5.

T_5 is the maximum operating temperature at which point the power dissipation is derated to zero. T_6 is the minimum storage temperature and must be equal to or less than T_1.
T_7 is the maximum storage temperature and must be equal to or greater than T_5.

T_8 is the peak repetitive instantaneous junction temperature under forward current overload and must be equal to or greater than T_5.

T_9 is the maximum operating temperature, with the maximum dc reverse voltage rating applied, and must be equal to or lie between T_3 and T_5.

T_{10} is the maximum operating temperature, with the maximum working peak reverse voltage rating applied, and must lie between T_5 and T_9.

T_{11} is the maximum lead or terminal temperature for soldering purposes.

4.4.1 Temperature (cont'd)

Table 4 — Reference Point Temperature Relationships

TEMPERATURE RELATIONSHIPS		
Maximum Operating Reference Point Temperature, T_5 (ºC)	Corresponding Range of Max. Reference Point Temperature in Full Load, (T_3) (ºC)	Corresponding Preferred Maximum Reference Point Temperature at Full Load, (T_3) (ºC)
100	40 - 70	55
125	50 - 100	70
150	70 - 125	100
175	85 - 150	125
200	100 - 175	150

Once the values of T_1, etc., have been established in the section on Operating Temperatures, the same values shall be used whenever symbols T_1, etc. appear in the registration format. The actual numerical values shall be shown in parentheses following each letter symbol.

4.4.2 Electrical Ratings

The electrical ratings to be given include the maximum reverse voltage rating and the maximum forward current rating that can be continuously handled by the device over the specified operating temperature range.

For these ratings the discrete rectifier diode is operated in a single-phase, half-wave circuit with a 60 Hz sinusoidal voltage source and a resistive load. These ratings are to be applicable over a frequency range of at least 50 Hz to 400 Hz.

In the interest of standardization, it is recommended that only rectifier diodes possessing the voltage and current ratings in the following table be registered:

Table 5 — Reference Point Temperature Relationships

Preferred Voltage Ratings (V)			**Preferred Average* Current Ratings at T_3 (ºC)**				
25	100	1000	0.10	1.0	10	100	1000
50	200	1200	0.25	2.5	15	150	1200
	400	1500	0.60	6.0	25	250	1500
	600	2000			40	400	2000
	800	2500			60	600	
		3000				800	

*Full cycle average half-sine wave forward current, 50 Hz to 400 Hz.

NOTE If it is necessary to register values other than those given above, use values from the list of ANSI (rounded) 10 numbers which are: 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0 and 8.0 times any integral power of 10.

4.4.2.1 Voltage Ratings

Reverse voltage may be derated in the temperature range T_1 to T_2. This derating information is to be registered as additional information. As no blanks are provided for such derating information, it should be included in a manner consistent with the other parts of the registration, and given an appropriate paragraph number.

Where it is desired to use a single registration format to register more than one device in a series and the devices have different voltage ratings, the information required to establish the voltage ratings may be given in the form of a note at the end of the format; reference shall be made to this note in appropriate blanks in the format. This note may consist of a table giving the various voltages which apply to the different devices in the series.

Several reverse voltage ratings are required (often two or more of these have the same value):

V_{RWM}: Maximum peak value of the 60 Hz half-sine wave reverse voltage that can be withstood on a repetitive basis over the operating temperature range of T_2 to $T_{10.}$

V_{RRM}: Maximum peak value of 100 Fs pulses at a 60 Hz rate that can be withstood on a repetitive basis over the operating temperature range of T_2 to T_{10}.

V_{RSM}: Maximum peak value of non-repetitive 60 Hz half-wave reverse voltage pulses that can be withstood over the operating temperature of T_2 to T_{10} (for avalanche devices, an energy limit is required).

V_R: Maximum dc reverse voltage that can be withstood on a repetitive basis over the operating temperature range of T_2 to T_9.

4.4.2.2 Current Ratings

The current rating of a rectifier diode(s) is to be registered as an average value (averaged over a full cycle of 60 Hz sinusoidal input voltage) as this is of more significance than an rms value with respect to the major applications of rectifier diodes. Spaces are given to register the current rating over the normal (no derating) temperature range T_2 to T_3 and also for stud and base mounted devices at a value (temperature T_4) which is above the normal temperature range. By definition, the current rating at T_5 or T_{10} is zero so a complete current rating curve is to be registered.

This curve may be approximated with three straight line segments. The current at T_4 should be approximately 1/3, 1/2, or 2/3 of the rated current over the normal operating temperature range. For lead mounted devices, the current rating curve may be approximated with two straight line segments. (T_4 therefore is not required.)

The numbers registered may be rounded to whole numbers and to ± 5 ºC. Current ratings for rectifier diodes are based on 60 Hz sinusoidal waveforms into resistive loads and a conduction angle of 180º " 5º; however, the ratings are to apply from 50 Hz to 400 Hz. Additional information for establishing current ratings is found in chapter 7.

4.4.2.2 Current Ratings (cont'd)

The surge current rating is the peak value of a specified half-sinewave of current. This surge may be repeated after thermal equilibrium has been re-established with the device operating at its repetitive current rating. The device is to be capable of withstanding a minimum of 100 such surges without failure. For the 60 Hz half-sinewave surge rating, the current surge is to be preceded by and followed by the normal operating conditions consisting of maximum rated 60 Hz half-sinewave current, device reference point temperature equal to T_3 and rated repetitive 60 Hz, peak reverse blocking voltage, if applicable. In addition, the half cycle of reverse blocking voltage following the half-sinewave surge current is to be the registered non-repetitive 60 Hz peak reverse blocking voltage, if such exists. Otherwise, rated working peak reverse voltage shall be applied.

4.5 Electrical Characteristics (Registration Format Part IV)

4.5.1 Reverse Blocking Current

The reverse current characteristic generally can be registered as either $I_{R(AV)}$ or I_{RRM}; the latter is preferred. When registering $I_{R(AV)}$, the device shall be operated at its current and voltage ratings $I_{F(AV)}$ and V_{RRM}, and at T_3. When registering I_{RRM}, the device shall be operated at its voltage rating, V_{RRM}, at T_5. The dc reverse current, I_R, is registered at its dc reverse voltage rating V_R, and at T_9. For transient suppressor and controlled avalanche diodes, the minimum and maximum breakdown voltages are to be registered. In addition, the reverse currents at which these voltages are measured are to be specified in each case.

In the part of the format under reverse blocking current, where more than one device is being registered on a single format and the reverse current(s) is (are) not the same for all the devices being registered, the current value(s) may be given in the same note which lists the voltage ratings; reference shall be made to this note in the appropriate blank.

4.5.2 Forward Voltage

The peak forward voltage, V_{FM}, can be registered at either maximum continuous rated load conditions or at the peak value of rated full load half-sinewave current ($I_{R(AV)}$) using a short pulse at $T_C = 25$ ºC. The latter method is preferred because of the ease of measurement. In order to avoid significant heating of the junction during the test for forward voltage, the width of the current pulse used to make the measurement shall not exceed 2 milliseconds and the repetition rate of the pulses shall be low enough to impose a duty cycle of no more than 2%.

4.5.3 Reverse Recovery

The nature of the reverse recovery characteristics of a rectifier diode affects interchangeability with other rectifier diodes in some applications. Therefore, recovery characteristics are to be registered as follows:

When method C or D is specified (See clause 6.6.9), the maximum recovery time, t_{rr}, of the rectifier diode is to be registered in two parts, i.e., t_{rrr} and t_{rrf}. The first part, t_{rrr}, is measured from the instant of current reversal to the instant current reaches its peak reverse value, and t_{rrf} is measured from this peak value to the specified point given in chapter 6 of this document. Maximum peak recovery current, $I_{RM(REC)}$, is also to be registered.

4.5.3 Reverse Recovery (cont'd)

Rectifier diodes can possess different degrees of recovery characteristics. After peak recovery current, the current may immediately, or a short time later, decrease very abruptly (abrupt recovery) or it may decrease slowly and smoothly to its steady-state reverse blocking value (soft recovery); refer to Figure 9 and Figure 44. Recovered charge Q_{rr}, is to be registered and is defined as the area under the reverse current vs. time curve. The starting point is the instant of current reversal and the ending point is when the reverse current first crosses the zero axis after it has passed through $I_{RM(REC)}$ or where a straight line extrapolation of the reverse current after $I_{RM(REC)}$ crosses the zero axis. Another definition for the end of the reverse recover period is when some specified reverse current point, $I_{R(REC)}$, is reached.

Test conditions for registered recovery characteristic values are also registered. Fixed conditions, unless otherwise specified are T_C = 25 ºC, test repetition rate equals 60 pulses per second, and *di/dt* is equal to 25A/µs . The peak forward current, I_{FM}, is to be registered and must be greater than or equal to three times the rated average dc forward current I_o. Its pulse duration, t_p, shall also be registered.

4.6 Thermal Characteristics (Registration Format Part V)

The maximum steady-state thermal resistance between the junction and the temperature reference point specified in the beginning of the format is to be registered. When required, the maximum transient thermal impedance characteristics shall be supplied in tabular form or as a curve.

Also to be registered is the maximum allowable thermal resistance between the temperature reference point and the ambient in order to prevent thermal runaway when registered voltage is applied over the registered operating temperature range (forward current, $I_{F(AV)}$, being zero).

5 Rating Establishment and Verification Tests

5.1 Introduction and Reference Table of Ratings and Tests

This clause describes standard test methods to be used in establishing and verifying the maximum ratings for rectifier diodes given in the JC-22 series of registration formats for rectifier diodes.

NOTE The word "diode(s)" will be used throughout this chapter to indicate rectifier diodes. The term "rating" is a value that establishes either limiting condition (maxima or minima) for the diode. It is determined for specified values of environmental and operating conditions and may be stated in any suitable terms. Operation beyond a rating may result in device degradation or damage, temporary or permanent, immediate or latent.

5.1 Introduction and Reference Table of Ratings and Tests (cont'd)

The following table cross references maximum ratings, the test method(s) used to establish each rating, and the clause number of this chapter that describes the test method.

Table 6 — Reference Table of Ratings and Test Methods

Maximum Rating	Title	Reference No.
Operating Temperature	Repetitive Rating Tests	4.2.1
Storage Temperature	Storage Life Test	4.3.1
Lead or Terminal Temperature for Soldering	Lead or Terminal Temperature Test	4.3.2
Working Peak Reverse Voltage, Half Sine Wave	Steady State Operating Life Test Working Peak Reverse Voltage Life Test	4.2.1.1 or 4.2.1.2
Non-repetitive Peak Reverse Voltage, Half Sine Wave	60 Hz Sinewave Surge Current and Non-repetitive Peak Reverse Voltage Test	4.2.2.2, 4.2.2.3, or 4.2.2.4
DC Reverse Voltage	DC Reverse Voltage Life Test	4.2.1.3
Repetitive Peak Reverse Voltage	Repetitive Peak Reverse Voltage Test	4.2.1.5
Average Forward Current, Half Sine Wave	Steady State Operating Life Test	4.2.1.1
Surge (Non-repetitive) Forward Current (60 Hz 1/2 Sinewave)	60 Hz Sinewave Surge Current Test and Non-repetitive Peak Reverse Voltage Test with Average Forward Current	4.2.2.2
Surge (Non-repetitive) Forward Current (60 Hz 1/2 Sinewave)	60 Hz Sinewave Surge Current Test and Non-repetitive Peak Reverse Voltage Test without Average Forward Current	4.2.2.3
Surge (Non-repetitive) Forward Current, 1.5 Millisecond Duration	Surge (Non-repetitive) Forward Current, 1.5 Millisecond Duration, Test	4.2.2.5
Thermal Fatigue	Thermal Fatigue Life Test	4.2.1.4
Surge (Non-repetitive) Reverse Power, 40 Microseconds Duration	Triangular Pulse Non-repetitive Reverse Power Test	4.2.2.6
Surge (Non-repetitive) Reverse Power	Rectangular Pulse Non-repetitive Power Test	4.2.2.8
Reverse (Non-repetitive) Surges for Schottky Barrier Diodes	Non-repetitive Reverse Energy, Power and Current Rating Test for Schottky Barrier Diodes	4.2.2.1
Peak Destructive Current and Fault Clearing Time	Destructive Current (Rupture) Rating Test for Disc Type and Stud- and Base-Mounted Rectifier Diodes	4.2.2.7

NOTE 1 Operating Temperature Ratings cannot be established except in conjunction with other ratings. Operating Temperature Ratings are established by performing the tests in clause 5.2.1 Repetitive Ratings Tests, which are applicable to the device type.

NOTE 2 These tests are presented for information and use where applicable. It is not to be inferred that all diode(s) are required to meet all of the above tests.

NOTE 3 50 Hz may be substituted for 60 Hz where required.

5.2 Electrical Tests

5.2.1 Repetitive Ratings Tests

5.2.1.1 Steady State Operating Life test for Diodes

This test method is used to establish the maximum temperature, maximum voltage, and maximum current ratings for diodes.

Operating conditions:

1) Power sources shall be 60 Hz sinusoidal waveform sources.
2) The test device shall be made to conduct rated average current registered at T_3.
3) The conduction angle of the test current shall be 150º to 180º.
4) The test temperature shall be T_3.
5) Rated half sine wave working peak reverse voltage shall be applied during alternate non-conducting half cycles starting no later than 5º after conduction has ceased.
6) The conduction angle of the reverse voltage waveform shall be 175º ± 5º.
7) A suggestion test circuit is shown in Figure 10

Duration of the life test: 1,000 hours.

Post-test measurements: All of the characteristics given in clause 5.4 that are indicated as being applicable to the device type shall be measured to establish the rating.

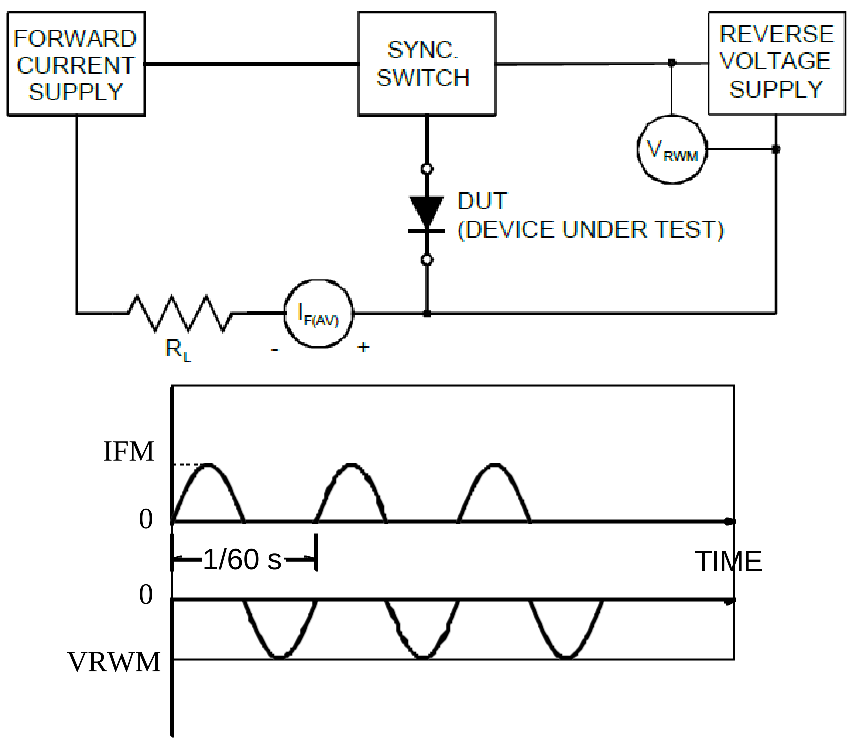


Figure 10 — Diode Operating Life Test Circuit and Waveforms

5.2.1.2 Working Peak Reverse Voltage Life Test

This test method is used to establish the half-sinewave working peak reverse voltage rating for a diode.

Operating Conditions:

1) The power source shall be a 60 Hz sinusoidal waveform source.
2) The test temperature shall be T_5.
3) The test voltage shall be rated half-sinewave working peak reverse voltage.
4) Maximum thermal resistance from case to ambient shall be specified. (This requirement is to ensure thermal stability.)
5) A suggested test circuit is shown in Figure 11.

Duration of the life test: 1,000 hours.

Post-test measurements: All of the characteristics given in clause 4.4 that are indicated as being applicable to the device type shall be measured to establish the rating.

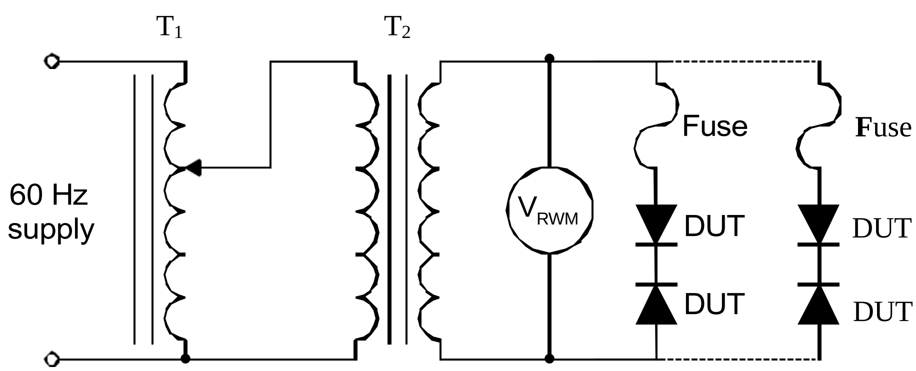


Figure 11 — Working Peak Reverse Voltage Life Test

5.2.1.3 DC Reverse Voltage Life Test

This test method is used to establish the reverse voltage rating for a diode.

Operating Conditions:

1) The power source shall be dc with 1% maximum ripple.
2) The test temperature shall be T_5.
3) The test voltage shall be the rated dc value.
4) Maximum thermal resistance from case to ambient shall be specified. (This requirement is to ensure thermal stability.)
5) A suggested test circuit is shown in Figure 12.

Duration of the life test: 1,000 hours.

Post-test measurements: All of the characteristics given in clause 5.4 that are indicated as being applicable to the device type shall be measured to establish the rating.

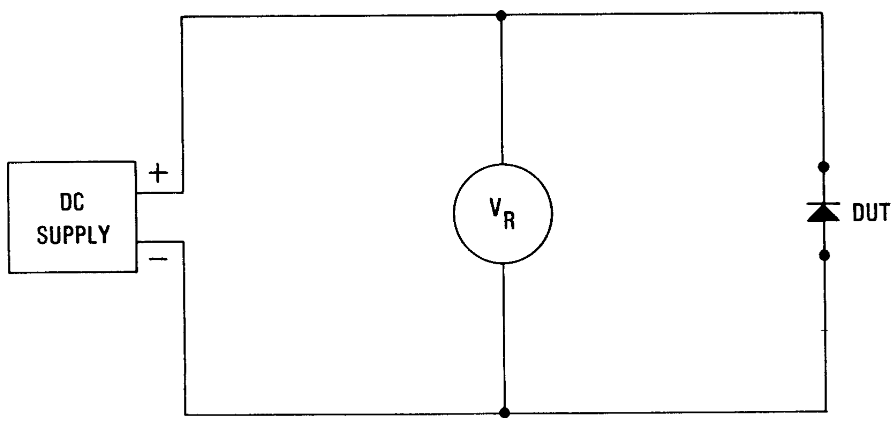


Figure 12 — DC Reverse Voltage Life Test

5.2.1.4 Thermal Fatigue Life Test

This is a reference test method used to establish the ability of a diode to withstand the thermal cycling produced by alternately applying and removing forward current. Significant reverse voltages are not involved in the test, except as required by the ac heating current source operating into a very low resistance load. This test method applies to diodes whose temperature reference point is on the device case.

Operating conditions:

1) The heating current source shall be a 60 Hz sinusoidal ac supply.
2) The heating current conduction angle shall be 150º to 180º.
3) The heating current magnitude shall be that value registered at temperature T_3.
4) The case temperature reached at the end of the heating period shall be T_3 plus 10 ºC, minus 0 ºC.
5) The case temperature reached after the cooling period shall be 30 ºC $\pm$ 10 ºC.
6) The change in case temperature produced by the conditions specified in 4 and 5 must be 50 ºC minimum. If this cannot be achieved using the heating current case temperature specified in chapter 3, the current may be reduced (but not less than 50% of the registered value) so that the case temperature can be raised. Consult manufacturer's current rating curves.
7) The heating period shall be long enough to allow the case temperature to reach the value specified in bullet 4 above.
8) The cooling period shall be long enough to allow the case temperature to reach the value specified in bullet 5 above.
9) The total time for one heating-cooling cycle shall be a maximum of 10 minutes. (See Figure 13).
10) A suggested circuit for testing many devices at a time is shown in Figure 13. To obtain case temperature excursions within tolerance, the power dissipation and thermal resistance of the test devices may be matched or the thermal resistance of the heat dissipaters may be made adjustable.

Duration of the life test: To be specified as a number of complete thermal cycles.

Post-test measurements: All of the characteristics given in clause 5.4 that are indicated as being applicable to the device type in addition to thermal resistance shall be measured to establish the rating.

5.2.1.4 Thermal Fatigue Life test (cont'd)

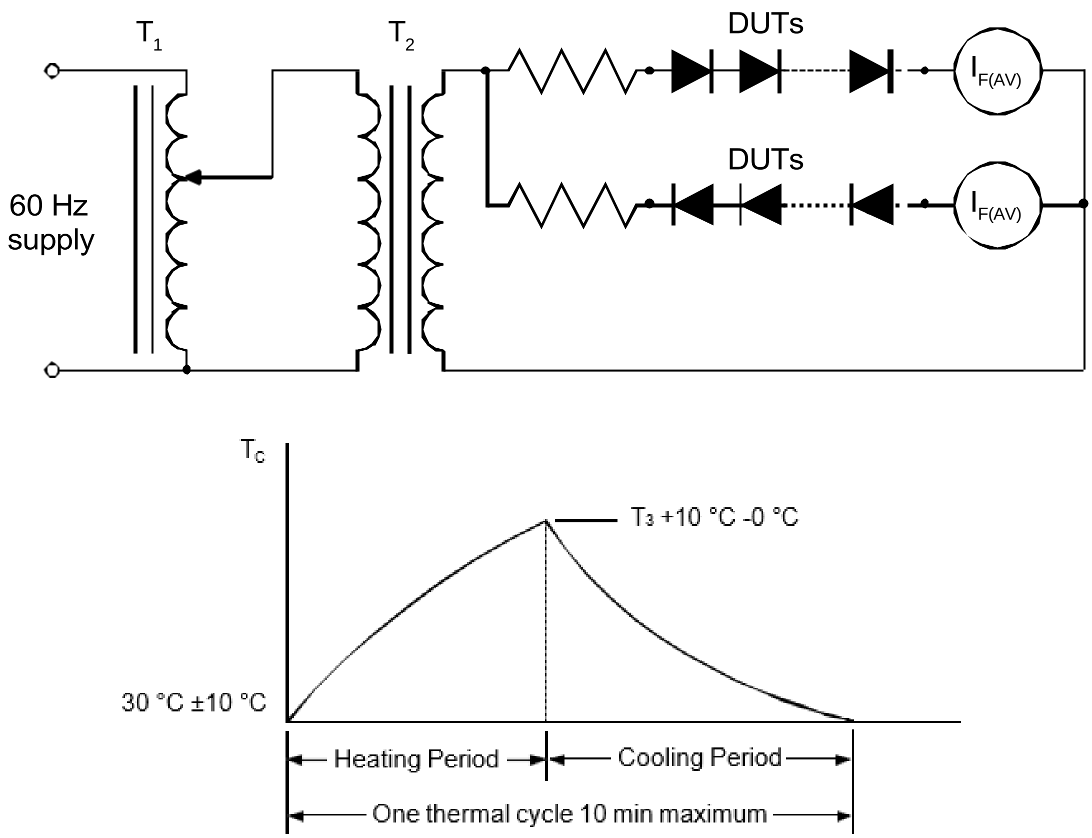


Figure 13 — Diode Thermal Fatigue Life Test Circuit and Waveform

5.2.1.5 Repetitive Peak Reverse Voltage Test

This test method is used for establishing the repetitive peak reverse voltage rating for diodes. This is a repetitive rating and it represents the maximum value of reverse voltage that may be applied repetitively to a diode without causing permanent damage.

Test method: The test device shall be connected in parallel with resistance R_2 and also to a source of voltage capable of delivering a single voltage pulse of peak value equal to the repetitive peak reverse voltage rating of the device. The test voltage shall be a half-sinewave 100µs pulse at a repetitive rate of 60 Hz. See Figure 14 for repetitive peak reverse voltage test circuit. The series resistor R_1 must limit conduction current to within the voltage source rated value in the event of a device failure.

Operating conditions:

1) The peak test voltage shall be specified as the repetitive peak reverse voltage rating of the device.
2) The steady-state thermal equilibrium test temperature shall be T_5.

Post-test measurements: All of the characteristics given in that are indicated as being applicable to the device type shall be measured to establish the rating.

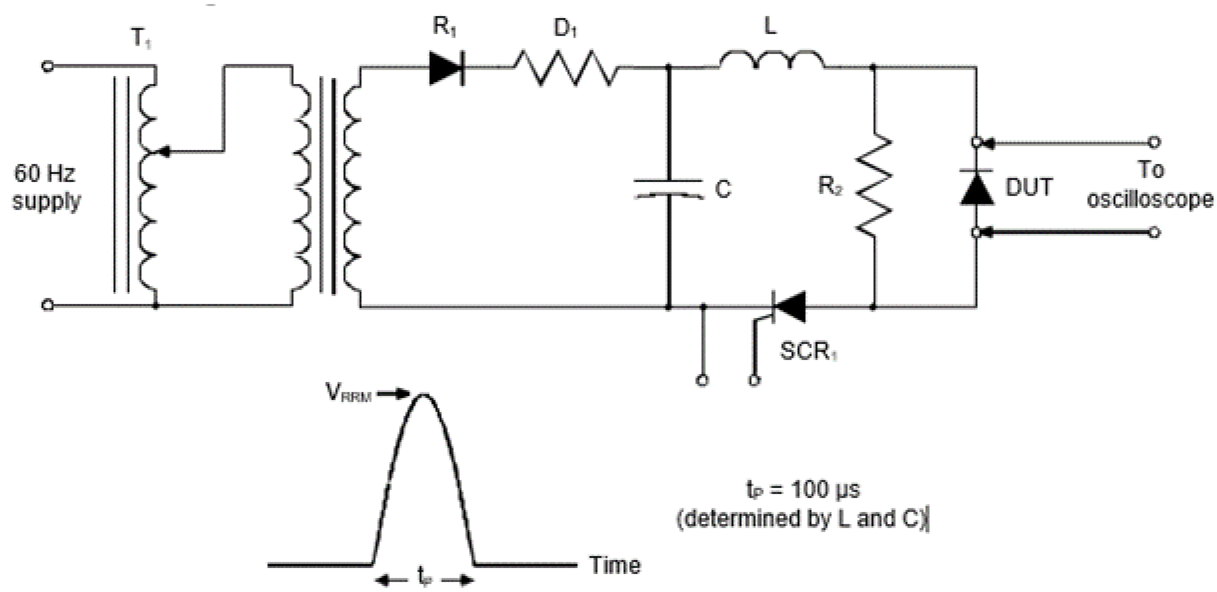


Figure 14 — Diode Repetitive Peak Reverse Voltage Test Circuit and Waveform

5.2.2 Non-Repetitive Ratings Tests

5.2.2.1 Non-repetitive Reverse Energy, Power, and Current Rating Tests for Schottky Barrier Rectifier Diodes

These two methods are used to establish the reverse current, power, and energy ratings of Schottky Barrier Rectifier Diodes

Test method 1: The test device shall be connected in the circuit as shown in Figure 15 or to a pulse source which will produce the same waveform. The initial reverse current pulse train shall have an amplitude that shall not degrade the test device from its initial characteristics. The reverse current pulse train shall be incremented in amplitude until the maximum amplitude the test device can withstand without being degraded is found. With each increment in reverse current, the test device shall be tested for a period no shorter than one second. The time before subjecting the test device to the next incremental reverse current pulse train shall be long enough to allow the device junction temperature to return to its initial temperature.

Test method 2: The test device shall be connected in the circuit as shown in Figure 16. With Switch “S” open, choose an initial input pulse width that shall not degrade the test device from its original characteristics. After closing “S” the input pulse width shall be incremented in time duration, which will increment the test current as measured across R_S. Increment the test current until the maximum test current the test device can withstand without being degraded is found. With each increment in test current, the test device shall be tested for a period no shorter than one second. The time before subjecting the test device to the next incremental test current shall be long enough to allow the device junction temperature to return to its initial temperature.

Operating conditions for test method 1:

1) The reverse current pulse train shall consist of square waves or 2.0 µs pulses and a period of 1000 µs. The rise time shall be a maximum of 350 ns.

2) The test is to be performed at 25 °C ambient temperature.

3) The minimum number of current pulses to be applied shall be 1000 pulses.

4) The reverse current rating is the measured parameter, as determined by a current sense resistor. The reverse power rating is determined by obtaining the product of reverse current and reverse voltage of the device under test. The reverse energy rating is determined by obtaining the product of reverse power and the pulse width applied to the device under test.

Operating conditions for test method 2:

1) The input pulse shall be square wave of a specified pulse width with rise and fall times of 350 ns maximum. The duty cycle shall be 1% maximum.

2) The test is to be performed at 25 °C ambient temperature.

3) The device under test shall be subjected to this test for one second minimum test time.

4) The reverse current rating at a specified pulse width is the measured parameter as determined by a current sense resistor. The reverse power rating at a specified pulse width is determined by obtaining the product of reverse current and reverse voltage of the device under test. The reverse energy rating at a specified pulse width is determined by integrating, with respect to time, the product of reverse power and time. An alternative method for determining reverse energy is from the relationship: $\text{Energy} = (1/2)\, Li^2$

5.2.2.1 Non-repetitive Reverse Energy, Power, and Current Rating Tests (cont'd)

Characteristics to be measured for test method 1:

a. Test device reverse voltage during application of reverse current pulse, V_R =_____V

b. Reverse Current, I_R =_____A

NOTE Reverse current is obtained by dividing the voltage measured across 0.1 ohm sense resistor by 0.1.

Characteristics to be measured for test method 2:

a. Reverse Test Current, I_T =_____A

b. Test Device Reverse Current, I_R =_____A

c. Test Device Reverse Voltage during application of reverse current pulse, V_R =_____V

NOTE Reverse Test Current is obtained by dividing the voltage measured across R_5 by the value of R_S in ohms.

Post-test measurements: All of the characteristics given in clause 4.4 that are indicated as being applicable to the device type shall be measured to establish the rating.

5.2.2.1 Non-repetitive Reverse Energy, Power, and Current Rating Tests (cont'd)

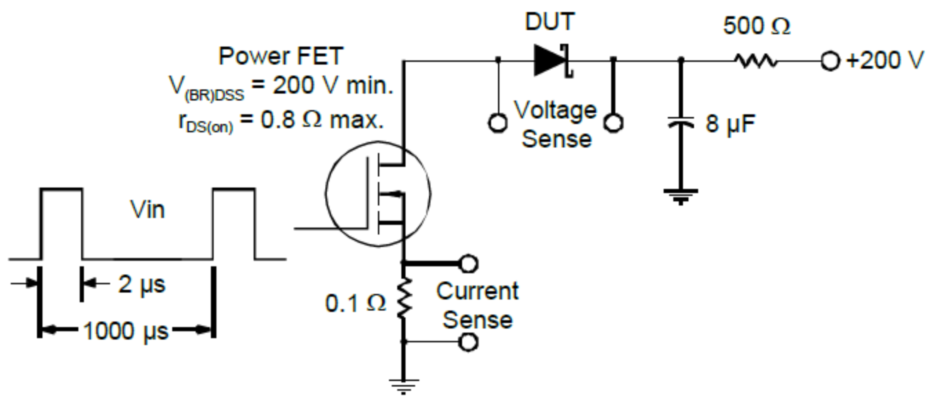
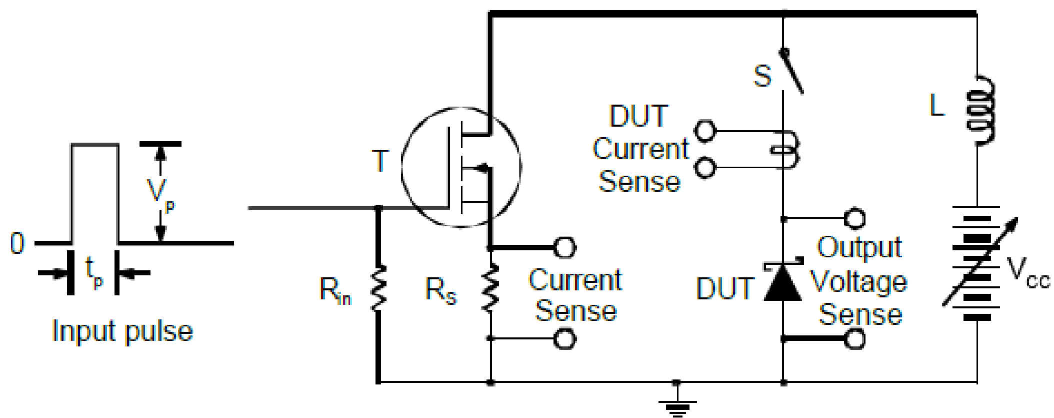


Figure 15 — Reverse Energy Test Circuit for Schottky Rectifiers - Test Method 1



$V_P = 10$ V

$R_S = 0.1\ \Omega$, 1 W

$t_p = .\ 30\ \mu s$

V_{CC} . 10 V

$R_{in} = 50\ \Omega$, 1 W

$L = 260\ \mu H$, 0.1 Ω

Duty Cycle < 1%+

T = Power MOSFET with $V_{(BR)DSS} \geq 100$ V, $r_{DS(on)} \leq 0.18\ \Omega$

Figure 16 — Reverse Energy Test Circuit for Schottky Rectifiers - Test Method 2

5.2.2.2 60 Hz Sinewave Surge Current Test and Non-Repetitive Peak Reverse Voltage Test With Average Forward Current

This test method is used to establish the sinewave surge current rating for diodes and is performed with rated average forward current. The diode is required to block rated non-repetitive peak reverse voltage immediately following this surge current test.

Test method: The device is operated under steady-state rated current and voltage conditions before and after the application of the surge current. Immediately following the half-cycle surge current, a half sinewave of rated non-repetitive reverse voltage is applied. For surge test circuit and waveforms, see Figure 17. The time between current surges shall be long enough to permit the device case temperature to return to its original thermal equilibrium value.

Operating conditions:

1) The power sources shall be 60 Hz sinusoidal waveform sources.

2) The test devices shall be made to conduct rated average forward current at T_3, and rated working peak reverse voltage, half wave, shall be applied. The half-cycle conduction angle of the test current and voltage must be 150º to 180º.

3) The steady-state thermal equilibrium test temperature shall be T_3.

4) The peak value of the surge current shall be specified. The test current waveform is a single half- cycle sinewave. The test current half-cycle conduction angle must be 150º to 180º.

5) Rated half sinewave non-repetitive peak reverse voltage shall be applied during the half cycle immediately following the half cycle of rated surge current.

NOTE If a device does not have this voltage rating registered, use the half sinewave repetitive peak reverse voltage rating as the test voltage.

6) The number of current surges to be applied shall be 100 surges.

Post-test measurements: All of the characteristics given in clause 4.4 that are indicated as being applicable to the device type shall be measured to establish the rating.

5.2.2.2 Surge Current Test and Non-Repetitive Peak Reverse Voltage Test With Average Forward Current (cont'd)

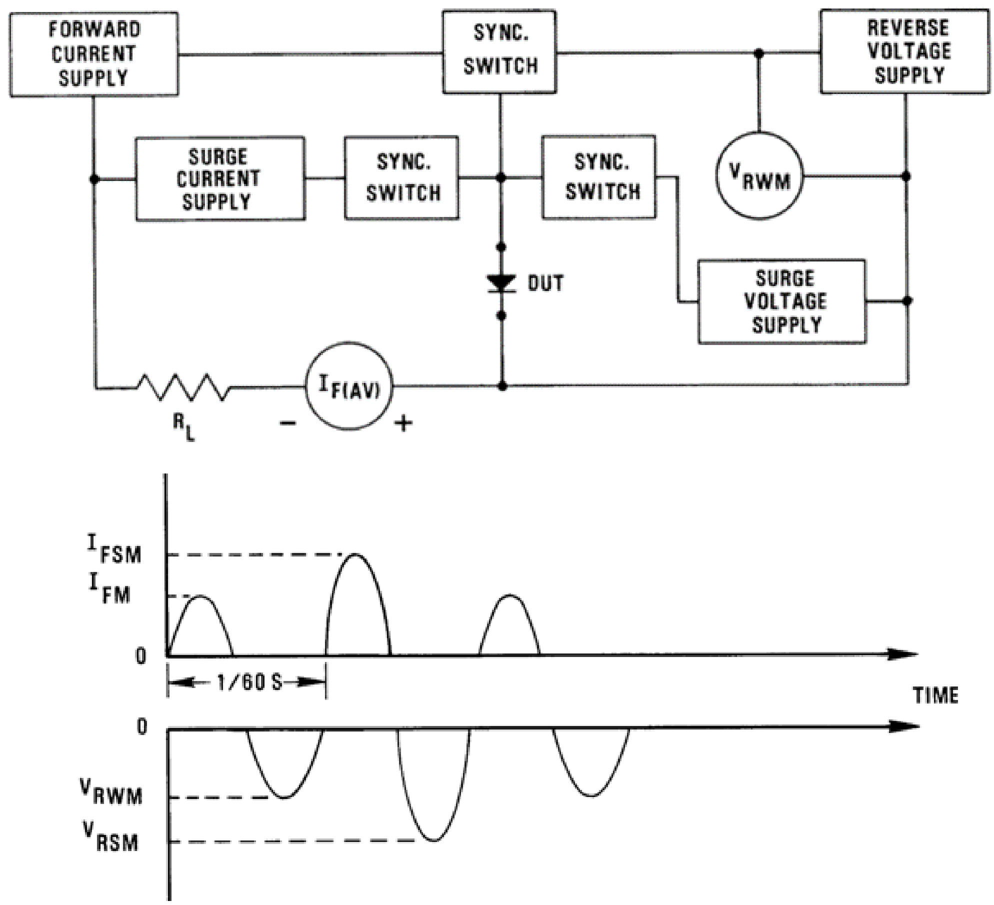


Figure 17 — Diode Surge Current and Non-Repetitive Peak Reverse Voltage Test Circuit and Waveforms

5.2.2.3 60 Hz Sinewave Surge Current Test and Non-Repetitive Peak Reverse Voltage Test Without Average Forward Current

This test method is used to establish the sinewave surge current ratings for diodes and is performed without rated average forward current being present. The ambient, case or reference point temperature is at the maximum operating temperature of the diode. The diode is required to block rated non-repetitive peak reverse voltage immediately following this current surge test.

Test method: The test device is operated under steady rated reverse voltage conditions before and after the application of the surge current. Immediately following the half-cycle surge current, a half sinewave of rated non-repetitive reverse voltage is applied. For surge test circuit and waveform, see Figure 18. The time between current surges shall be long enough to permit the device reference point temperature to return to its original thermal equilibrium value.

Operating conditions:

1) The power sources shall be 60 Hz sinusoidal waveform sources.

2) The test device shall be made to block rated working peak reverse voltage, half-wave at maximum operating temperature (T_5).

3) The steady-state thermal equilibrium test temperature shall be T_5.

4) The peak value of the surge current shall be specified. The test current waveform is a single half-cycle sinewave. The half-cycle test current conduction angle must be 150º to 180º.

5) Rated half-sinewave non-repetitive peak reverse voltage shall be applied during the half cycle immediately following the half cycle of rated surge current.

NOTE If a device does not have this voltage rating registered, use the half sinewave working peak reverse voltage rating as the test voltage.

6) The number of surges to be applied shall be 100 surges.

Post-test measurements: All of the characteristics given in clause 4.4 that are indicated as being applicable to the device type shall be measured to establish the rating.

5.2.2.3 Surge Current Test and Non-Repetitive Peak Reverse Voltage Test Without Average Forward Current (cont'd)

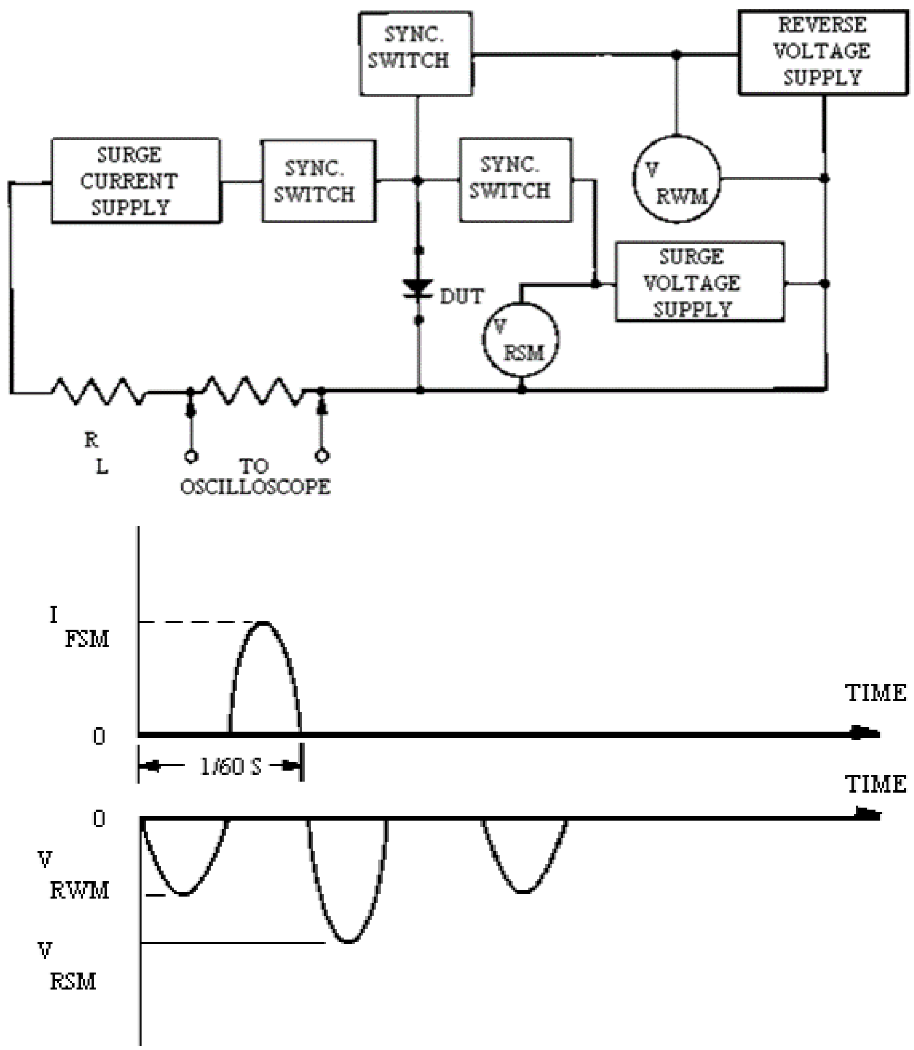


Figure 18 — Diode Surge Current and Non-Repetitive Peak Reverse Voltage Without Average Forward Current Test Circuit and Waveforms

5.2.2.4 Non-Repetitive Peak Reverse Voltage Test

This test method is used for establishing the non-repetitive peak reverse voltage rating for diodes. This is a non-repetitive rating and it represents the maximum value of reverse voltage which may be applied non-repetitively to a diode without causing permanent damage.

Test method: The test device shall be connected as shown in Figure 19. The synchronous switch is opened, and the ac source voltage is increased to the specified value of non-repetitive peak reverse voltage. The specified temperature conditions are checked. The specified non-repetitive peak reverse voltage is applied by the closing the synchronous switch for approximately 180º. Proof of the ability of the diode to withstand the non-repetitive peak reverse voltage rating is obtained from the post-test measurements. Diode D is provided to prevent forward conduction of the DUT. Limiting resistor R is provided to limit fault current in case of a blocking failure of the DUT. It is chosen so as not to significantly affect the reverse voltage applied to the DUT.

Operating conditions:

1) The peak test voltage shall be specified as the non-repetitive peak reverse voltage rating of the device.
2) The steady-state thermal equilibrium test temperature shall be T_5.
3) The test voltage waveform is a single-cycle 60 Hz sinewave. The test voltage half-cycle conduction angle must be 150º to 180º.
4) The number of voltage surges to be applied shall be 100 surges.
5) The time between voltage surges shall be long enough to permit the device virtual junction temperature to return to its original thermal equilibrium value.

Post-test measurements: All of the characteristics given in clause 4.4 which are indicated as being applicable to the device type shall be measured to establish the rating.

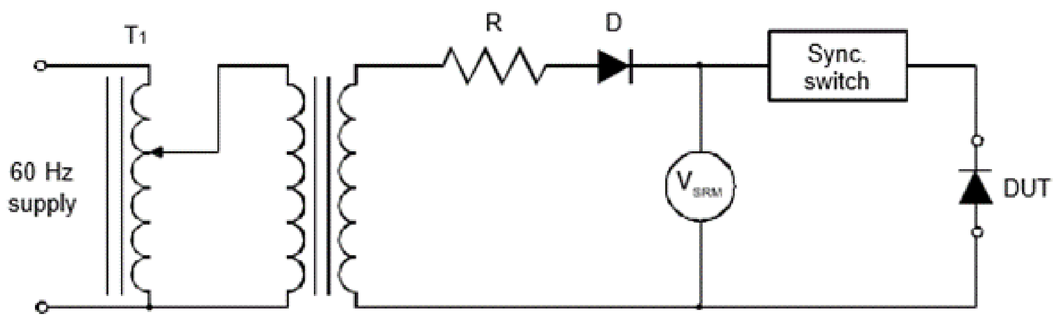


Figure 19 — Non-Repetitive Peak Reverse Voltage Test Circuit

5.2.2.5 Surge (Non-Repetitive) Forward Current, 1.5 ms Duration Test

This test method is used to establish the 1.5 ms half-sinewave surge current rating for a diode. The diode is not required to block voltage immediately following this current surge test. However, the diode must regain rated reverse voltage capabilities after it has cooled to its original thermal equilibrium conditions.

Test Method: The test device is to be brought up to steady-state thermal equilibrium temperature before the application of the surge current. Following the current surge, no reverse voltage or additional current surges shall be applied to the device until its virtual junction temperature returns to its original thermal equilibrium value. For surge current test circuit, see Figure 20. The gate signal duration to the initiating device (SCR_1) should be less than 1.5 ms to prevent a possible second pulse due to circuit oscillations. The value of L (total discharge circuit inductance), C and E_C must be set to produce the specified peak surge current and specified pulse width.

Operating conditions:

1) The power source shall be capable of charging C to the necessary value to produce the specified peak surge current.

2) Prior to the application of surge current, the device temperature shall be brought up to the specified case temperature by use of an external heat source, such as a temperature-controlled mounting block.

3) The specified case temperature shall be T_5.

4) The peak value of the surge current shall be specified. The test current waveform is a single half- cycle sinewave. The single half cycle sinewave test current pulse width must be 1.50 ms $\pm$ 0.15 ms.

5) No voltage shall be applied immediately following the half cycle of surge current.

6) The time between each surge current pulse shall be sufficient to allow the junction to return to thermal equilibrium (20 seconds is recommended).

7) The number of current surges to be applied shall be 100 surges.

Post-test measurements: All of the characteristics given in clause 5.4 which are indicated as being applicable to the device type shall be measured to establish the rating.

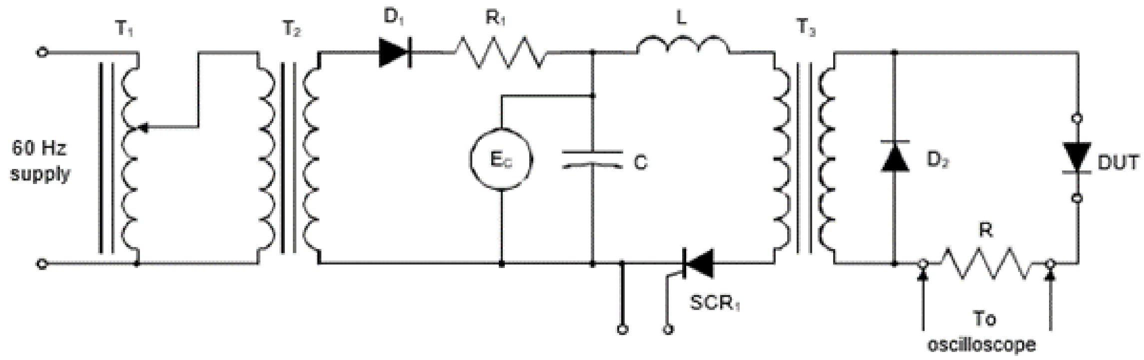


Figure 20 — Basic Test Circuit for Surge (Non-Repetitive) Forward Current, 1.5 ms Duration

5.2.2.5 Surge (Non-Repetitive) Forward Current, 1.5 ms Duration Test (cont'd)

R_1 = Charging current limiting resistors

R = Non-inductive current viewing resistor

T_1 = Variable autotransformer

T_2 = Isolation transformer

T_3 = Current step-up transformer

D_1 = Charging diode

D_2 = Bypass diode

C, L = Values set for specified surge current and pulse width. L includes total discharge circuit inductance.

SCR_1 = Initiating or trigger SCR.

5.2.2.6 Triangular Pulse Non-Repetitive Reverse Power Test

This test method is used to establish the 40µs triangular wave reverse peak power rating of controlled avalanche diodes.

Test method: The test device shall be connected in the circuit as shown in Figure 21. The value of $V_{(BR)}$ of the DUT shall be estimated. Calculate an approximate value of R_1 from:

$$R_1 = \frac{(V_{C1} - V_{(BR)})V_{(BR)}}{P_{RM}}$$

- Estimate C_1 from C_1 x R_1 = (1/2) t_w.
- Adjust the dc supply until V_R = rated V_{RWM}.
- The voltage across C_1 (V_{C1}) should be 3000 V or 3 × $V_{(BR)}$ of DUT (whichever is greater); the spark gap should not arc over.
- Open SW_1; the gap should arc over.

The initial reverse voltage pulse shall be low magnitude and then increased on successive pulses until the maximum peak reverse power specified is reached. Readjust, if necessary, the values of C_1, R_1 and V_{C1} until the specified values of peak reverse power and average width of the current pulse are obtained.

NOTE $P_{RM} = V_{(BR)SM} \times I_{(BR)SM}$.

The time between pulses shall be long enough to allow the device virtual junction temperature to return to its initial temperature.

5.2.2.6 Triangular Pulse Non-Repetitive Reverse Power Test (cont'd)

Operating conditions:

1) The reverse current shall be a triangular wave with a maximum rise time of 1.5 µs and a maximum width of 40 ± 4 µs, measured at the 50% amplitude points.

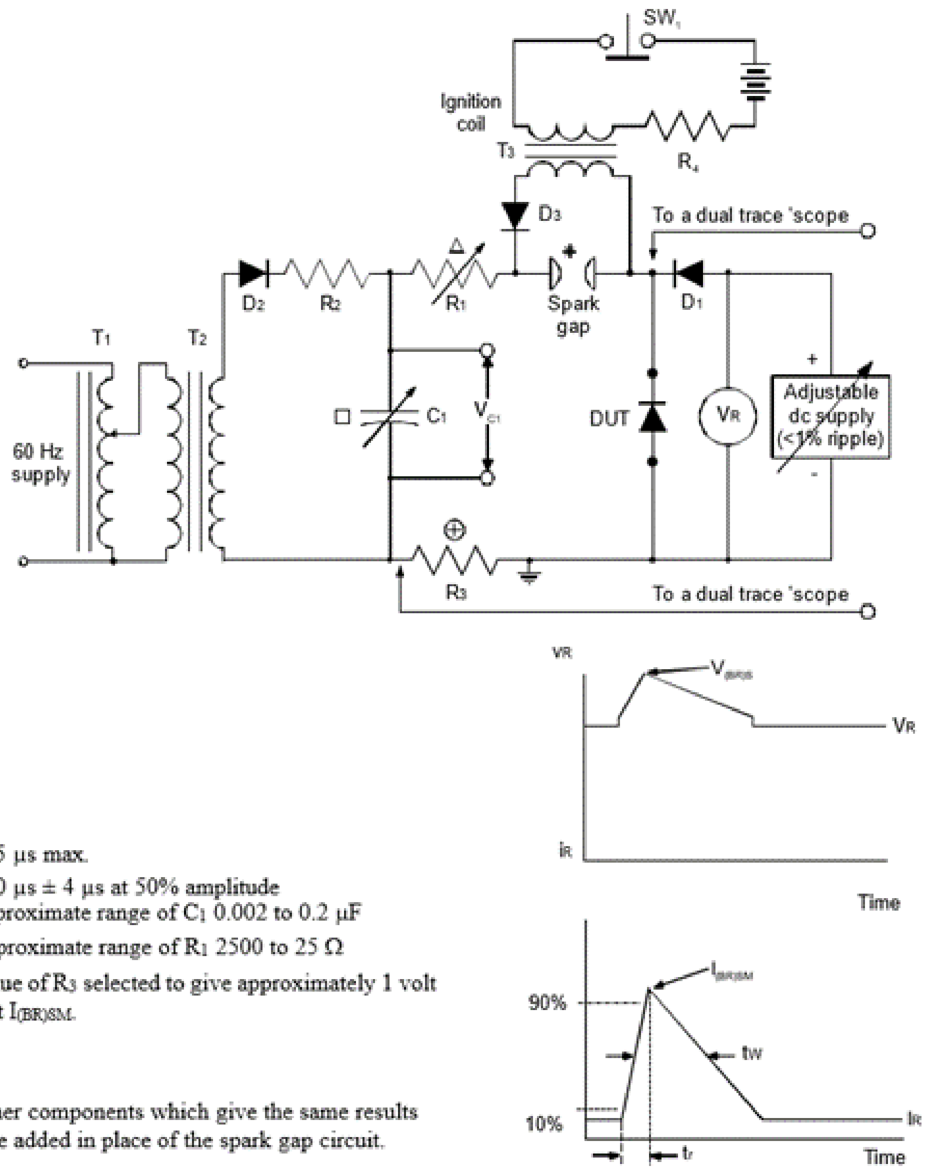
2) The peak reverse power is determined from the reverse voltage and current through the device.

3) The test is to be performed at 25 ºC case temperature.

4) The minimum time between each pulse shall be one second.

5) The number of pulses to be applied shall be 100 pulses.

Post-test measurements: All of the characteristics given in clause 4.4 which are indicated as being applicable to the device type shall be measured to establish the rating.



t_r = 1.5 µs max.
t_w = 40 µs ± 4 µs at 50% amplitude
• Approximate range of C_1 0.002 to 0.2 µF
Δ Approximate range of R_1 2500 to 25 Ω
⊕ Value of R_3 selected to give approximately 1 volt drop at $I_{(BR)SM}$.

* Other components which give the same results may be added in place of the spark gap circuit.

EXAMPLES — Thyratron, Series SCR string, etc.

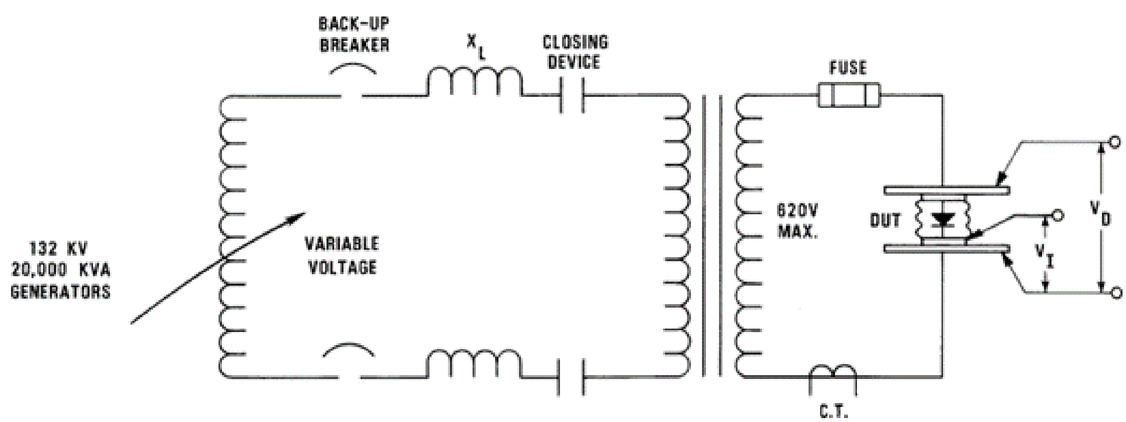
Figure 21 — Non-Repetitive Reverse Power Test Circuit

5.2.2.7 Destructive Current (Rupture) Rating Test for Disc-Type and Stud- and Base-Mounted Rectifier Diodes

This test method is used to establish the maximum overload current that a rectifier diode can withstand without rupturing the device package. The device is electrically shorted by exceeding the device reverse breakdown voltage with a low energy pulse such that the failure location is on the device periphery near the active area. Other failure modes, such as bulk voltage breakdown or open circuit between anode and cathode terminals, are not subjects of this test proposal.

Test method: Initially the test device is ascertained to be hermetic (Leak Rate $\leq 1 \times 10^{-6}$ atm cc/s) and to be an electrical short in the blocking junction on the periphery of the device. The test device is mounted in a fixture per the manufacturer's recommended mounting procedure. At these high current levels, the location and rigidity of mounting is important since tremendous magnetic forces could alone cause assembly damage and loosening of hardware.

Operating conditions: The circuit shown in Figure 22 is one means to generate current levels to cause rupture. A high voltage alternator is used to give a short term power capability in excess of 470,000 kVA. The test device is located in the secondary of the transformer in series with a fuse.



V_I = interface voltage
V_D = device voltage

Figure 22 — Destructive Current Test Circuit

The magnitude and shape of the peak let-thru current is determined by fuse selection. The series fuse is used to limit the peak let-thru current to the selected value. The asymmetry is controlled by a pilot alternator on the same shaft with the main alternator. The output of the pilot device is fed into electronic circuitry that controls the closing device. The back-up breakers perform should the closing device fail to operate from its over- current trip.

1) The power shall be from a 60 Hz sinusoidal waveform source with fault current applied in the reverse direction to the reverse blocking junction.
2) The initial device case temperature shall be 25 ºC.
3) No peak reverse voltage is necessary after the destructive half-sinewave of current is interrupted.
4) The number of destructive current surges to be applied shall be 1.
5) The peak destructive current and the fault clearing time causing rupture shall be defined.

5.2.2.7 Destructive Current (Rupture) Rating Test for Disc-Type and Stud- and Base-Mounted Rectifier Diodes (cont'd)

Post-test measurements: The hermetic leak rate test shall be repeated on a device that has been rupture current tested. A device is defined as ruptured if there is a visible puncture in the package or if the leak rate exceeds 1×10^{-6} atm cc/s.

5.2.2.8 Rectangular Pulse Non-Repetitive Power Test

This test method is used to establish the rectangular wave shape reverse power rating of avalanche diodes for any specified pulse width.

Test method: The test device shall be connected in the circuit as shown in Figure 23. The initial reverse voltage pulse shall be adjusted to provide the reverse power specified. For the desired time interval the time between pulses shall be long enough to allow the device junction temperature to return to its initial temperature.

Operating conditions:

1) The reverse current pulse shall have a maximum rise time and fall time specified and a specified pulse width measured at the 50% amplitude points.
2) The reverse voltage pulse shall be adjusted to provide the reverse power specified. Both R_1 and V_P can be controlled to adjust power level.
3) The test is to be performed at 25 °C ambient temperature.
4) The minimum time between each pulse shall be one second, or longer when required to allow the device junction temperature to return to its initial value.
5) The number of pulses to be applied shall be 100 pulses.

Characteristics to be measured:

1) Test Device Reverse Voltage, V_{out} =______V.
2) Reverse Current, I_{out} =______A.

NOTE 1 Reverse current is obtained by dividing the voltage measured across 0.1 µ sense resistor by 0.1.

NOTE 2 Test device reverse power in watts is obtained by taking the product of V_{out} and I_{out}.

Post-test measurements: All of the characteristics given in clause 4.4 which are indicated as being applicable to the device type shall be measured to establish the rating.

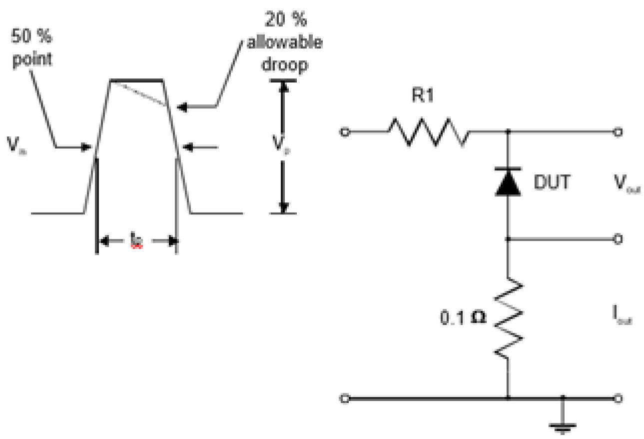


Figure 23 — Rectangular Pulse Power Test Waveform and Circuit

5.3 Non-Electrical Tests

5.3.1 Storage Life test

This test method is used to establish the storage temperature range rating for diodes. The maximum and minimum storage temperatures (T_7 and T_6) represent the greatest stress conditions to the test device. Storage life tests are usually performed at these temperatures.

Operating conditions:

1) The storage temperature, normally either T_6 or T_7, shall be specified.
2) The test duration shall be 1000 hours for T_7, 168 hours for T_6.

Post-test measurements: All of the characteristics given in chapter 5 that are indicated as being applicable to the device type shall be measured to establish the rating.

5.3.2 Lead or Terminal Temperature Test

This test is to be used to verify the maximum lead or terminal temperature rating for soldering purposes at specified distance from the case of the device for a specified time.

Operating conditions: A solder pot, containing lead-tin alloy with a nominal tin content of at least 50% shall be used. This apparatus shall be capable of maintaining the liquid at the temperature specified. The device leads shall be immersed for the specified time at the specified temperature and to the specified distance from the case of the device. Whether the leads are to be immersed individually or simultaneously, should be specified. After immersion, the unit shall be allowed to cool and stabilize at room ambient conditions before final examination and measurement are made.

Post-test measurements: All of the characteristics given in clause 4.4 that are indicated as being applicable to the device type shall be measured to establish the rating.

5.4 Post-Test Measurements

Measurements of the characteristics given in this clause shall be made following any of the Rating Performance Tests of clause 5.2 and clause 5.3 to establish the ratings. Only those characteristics that are indicated as being applicable to the device type being tested shall be measured. The test conditions for measurement of each characteristic shall preferably be as registered.

Reverse current test conditions to be specified:

1) Temperature
2) Reverse Voltage

Forward voltage (peak value under pulse conditions shall be used) test conditions to be specified:

1) Temperature (25 ºC ambient)
2) Pulse width ($\leq$ 1 ms)
3) Duty cycle ($\leq$ 2%)
4) Peak forward current

6 Characteristics Tests

6.1 Introduction

The purpose of this clause is to set forth accepted test methods and general guidelines of techniques and instrumentation for performing rectifier diode characteristics tests. The methods chosen minimize measurement errors, thereby improving correlation probability. It is incumbent upon the user to verify correlation when deviations from these recommendations are deemed necessary.

The listing of tests herein does not imply that any or all of the tests are performed by the individual manufacturer. However, for registered types, the results of these tests are implied to be guaranteed within specified limits by the manufacturer. These are contained in the registration data of the particular devices as directed by the applicable formats.

Table 7 — Reference Table of Electrical Characteristics, Symbols and Test Methods

Electrical Characteristics Test	Symbol	Test Circuit	Reference
Peak Reverse Current	I_{RM}	Figure 25	6.6.1
DC Reverse Current	I_R	Figure 26	6.6.2
Average Reverse Current w/o I_F	$I_{R(AV)}$	Figure 27	6.6.3.3
Average Reverse Current with I_F	$I_{R(AV)}$	Figure 28	6.6.3.6
Peak Forward Voltage 60 Hz	V_{FM}	Figure 29	6.6.4.2
Peak Forward Voltage Pulse	V_{FM}	Figure 30	6.6.4.6
DC Forward Voltage	V_F	Figure 31	6.6.5
Average Forward Voltage	$V_{F(AV)}$	Figure 29	6.6.6
Reverse Breakdown Voltage (min)	$V_{(BR)}$	Figure 32	6.6.7.2
Reverse Breakdown Voltage (max)	$V_{(BR)}$	Figure 34	6.6.7.6
Forward Switching Characteristics	t_{fr}, V_{FRM}, V_F	Figure 35	6.6.8
Reverse Recovery Characteristics (cond. A)	t_{rr}	Figure 37	6.6.9.3.A
Reverse Recovery Characteristics (cond. B)	t_{rr}	Figure 39	6.6.9.3.B
Reverse Recovery Characteristics (cond. C)	t_{rr}, $I_{RM(REC)}$	Figure 42	6.6.9.3.C
Reverse Recovery Characteristics (cond. D)	t_{rrr}, t_{rrf}, $I_{RM(REC)}$, RRSF	Figure 44	6.6.9.3.D
Total Capacitance	C_t	Figure 47	6.6.10

NOTE The test circuit of Figure 29 may be used except that an average reading voltmeter replaces the peak reading instrument.

Table 8 — Reference Table of Thermal Characteristics, Symbols and Test Methods

Thermal Characteristics Tests	Symbols	Test Circuit	Reference
Steady State Thermal Resistance (j - ref. Pt.)	R_{thJR}	Figures 51, 52	6.7.5.7
Transient Thermal Impedance (Heating Pulse T.M.)	$Z_{thJR(t)}$	Figure 55	6.7.6.1
Transient Thermal Impedance (Cooling Curve T.M.)	$Z_{thJR(t)}$	Figure 55	6.7.6.2
Thermal Resistance of Bridge Rectifier Assemblies	R_{thJR}	Figures 56, 57	6.7.7

6.1.1 Automatic Test Equipment (ATE)

The methods of this clause have historically been the basis for standardization. Since economic considerations often dictate the use of methods compatible with ATE, the selection and programming of such automatic measuring equipment should satisfy the following principles:

1) The pulse width and "time-to-test" window should be long enough to ensure acceptable electrical stability.

2) The pulse width and time to test must not be so long as to cause device heating that would affect measurement accuracy.

3) The sequence of measurements shall be chosen such that the resultant pulsing has minimal effect on the accuracy of subsequent measurements.

NOTE 1 When measured values most closely approximating those obtained by historical methods are desired, identical current and voltage as well as similar junction temperature must be achieved. This may require estimation of the junction temperature achieved by the historical method and elevating the ambient temperature for the ATE measurement.

NOTE 2 The use of peak reading instrumentation is implicit.

6.2 General Guidelines

Characteristics test systems are comprised of major block functions such as driving sources, the device under test (DUT), monitoring/measuring instrumentation, thermal management fixtures and the associated interconnections.

Driving sources may be voltage or current, ac, dc, pulse or a combination thereof. Voltage sources should exhibit sufficiently low output impedance as compared to the DUT such that their net effect is negligible error contribution to the particular test. Current sources similarly exhibit sufficient high output impedance. The error contribution shall be considered negligible if its magnitude is no greater than the accuracy tolerance required of the measurement. If the effect of the relative impedances is not negligible, their effect shall be factored into the test results.

Monitoring/measuring instrumentation should exhibit impedances (e.g., voltmeters high, ammeters low) compared to the DUT such that the contribution to the error in the measurement is small compared to any other sources of error.

Test systems utilizing both ac and dc sources or monitoring/measuring instruments shall incorporate into the interconnecting circuitry means whereby their interaction does not affect their individual characteristics. Isolation techniques using inductors as high ac and low dc impedances, and capacitors as high dc and low ac impedances can be effective.

Unless otherwise specified all characteristics measurements shall be made with the DUT under conditions of thermal equilibrium. Maximum thermal ratings shall not be exceeded during any test. If external thermal management is utilized, it shall be specified.

Interconnecting circuitry shall be such that "ground loops" and "crosstalk" are negligible. Shielding and filters shall be used as deemed necessary to render external electrical influences harmless. Under no circumstances shall the DUT be subjected to transients that permit the maximum ratings to be exceeded.

6.3 Types of Electrical Tests

6.3.1 Alternating Current or Dynamic Tests

Alternating current (ac) tests are dynamic tests in which the diode under test is usually subjected to conditions of rated voltages, currents, and/or temperatures simulating actual usage in rectifying applications, while monitoring diode characteristics.

Alternating voltage and current sources are normally sinusoidal at 60 Hz; however, when desired, 50 Hz or other frequencies may be specified

6.3.2 Continuous Current or Static Tests

Direct current (dc) tests are sustaining tests in which the DUT is usually subjected to steady-state conditions of rated voltages, currents and/or temperatures, while monitoring device characteristics.

The rms value of any ripple superimposed on dc power sources shall not exceed 1% of the dc value.

6.3.3 Pulse Tests

Pulse tests included herein are normally used for measuring isothermal, instantaneous volt/ampere characteristics of devices under test.

They yield the advantages of obtaining characteristics under conditions of negligible self-heating and measuring characteristics at current levels that would damage the device under test if sustained for a significant period.

Normally sinusoidal pulses are used to obtain the desired peak, rms and average relationships, but rectangular, triangular, trapezoidal, etc. pulses may be used when their special features are necessary.

Pulse tests also afford the distinct time element advantage in that many tests can be performed within short time intervals. This is primarily of interest for automation. Here, extreme care is recommended regarding data correlation between the standardized methods and other pulse techniques.

Pulses can be applied singly or repetitively, providing the duty factor is sufficiently low so as to retain negligible self-heating.

The pulse width shall be short enough such that thermal equilibrium is maintained, yet long enough to ensure that the relevant measurement is taken after carrier equilibrium has been achieved.

6.4 Thermal Considerations

A consequence of subjecting a DUT to voltages and currents during a test is that power dissipated within the device as heat affects its characteristics. This effect can range anywhere from a slight, even negligible, change in characteristics to a catastrophic failure. In order to standardize the characteristics tests they are to be performed at specified temperatures under conditions of thermal equilibrium, thereby removing the thermal dependency. It is then necessary to implement some form of thermal management to attain these conditions.

6.4.1 Thermal Equilibrium

Thermal equilibrium, as the term implies, is a state of temperature quiescence. In the context of this discussion the temperature of the DUT junction remains unchanged for the duration of the test measurement. True thermal equilibrium is achieved only in steady-state dc measurements.

In dc tests a condition of thermal equilibrium may be considered to have been achieved if halving the time between the application of power and the taking of the relevant reading causes no error greater than the required accuracy tolerance of measurement. For these purposes sufficiently long pulses or step functions may be considered as steady-state dc.

In pulse tests a practical thermal equilibrium condition may be considered to have been achieved immediately upon application of power provided that the pulse width is sufficiently short such that doubling it causes no error greater than the accuracy tolerance required of measurement.

In ac tests the thermal equilibrium condition is one of an average temperature and may be considered to have been achieved if halving the time between the application of power and the taking of the relevant reading causes no error greater than the accuracy tolerance required of measurement.

6.4.2 Thermal Monitoring

Generally, the means of monitoring the various device temperatures while the measurement is performed is thermocouples. Detailed considerations of the procedures involved can be found in clause 6.8.

6.4.3 Thermal Management

One form of thermal management required is that of elevating the temperature of the DUT. The most expeditious means of accomplishing this is to place the DUT in a controlled temperature chamber having the required capability. This same chamber could also have a low temperature capability. Another method, less precise and relatively uncontrolled, would be to subject the DUT to current conduction such that self-heating produces the desired temperature.

In the practical realm it is more often desired to remove self-generated heat from the DUT in order to maintain a safe junction temperature. This is particularly the situation in dc tests such as breakdown voltage, where the DUT is operating at maximum power dissipation. Here it is expedient to attach the DUT to a suitable heat dissipator. Heat dissipator and DUT attachment or clamping recommendations of the manufacturer should be followed.

6.5 Instrumentation

6.5.1 Analog Instruments

Voltage, current, and resistance measurements are easy, fast and accurate with instruments using meter movements and associated electronics. Most electronic voltmeters, ammeters and ohmmeters use rectifiers, amplifiers and other circuits to generate a current proportional to the quantity being measured, which then drives a meter movement.

6.5.1 Analog Instruments (cont'd)

The dc voltmeter usually has a dc attenuator-amplifier preceding the meter movement. For most direct current measurements, the meter movement itself serves the purpose. For lower current measurements, the sensitivity is increased by measuring the small voltage drop across a low value resistance placed in series with the current being measured. Many of the circuits shown herein indicate this technique.

AC voltmeters fall into three broad categories: average-responding, peak-responding and rms-responding. AC voltmeters in general use are average- and peak-responding.

The average-responding voltmeter is probably the most widely used measurement technique.

Since the equivalent dc or energy content in the waveform usually is the quantity of interest, the average value of sinewave is taken to mean the average rectified value. The average value of one-half cycle (half-wave rectified) of a full sinewave is 0.318 times the peak value. The average of a full cycle (full wave rectified) of a full sinewave is 0.636 times the peak value. The average-responding meter is calibrated in rms volts and provides reliable indication of rms if the input is a sinewave. Its indication is affected no more than 3% by as much as 25% second harmonic content in the input waveform.

Peak-responding circuits allow a voltmeter to serve as a multifunction meter and enables it to be used at much higher frequencies. As long as the input waveform is a sinewave, the peak-responding meter is proportional to the rms value and is thus calibrated. However, it is more susceptible to errors caused by harmonic distortion in the input waveform than the average-responding meter.

The maximum error will occur when the peak of a harmonic coincides with the peak of the fundamental, and is dependent only on magnitude, not the order of the harmonic. A 25% harmonic content would produce a maximum error of 25%.

Transients could similarly be directly additive.

The true-rms measurement technique is most often used when a high degree of accuracy is required. Instrument indication is proportional to the rms value of the impressed waveform.

This operation is usually performed by sensing the waveform's heating power. Heating power is measured by feeding an amplified version of an input waveform to the heater of a thermocouple. The voltage output is proportional to the waveform's heating power. The true rms value is measured independently of the waveshape, provided that the peak excursions of the measured waveform not exceed the dynamic range of the instrument. Harmonic distortion is not an error-contributing factor. The primary limitation is expressed by a term, crest factor, which is defined as the ratio of peak voltage to rms voltage of a waveform with the dc component removed. A voltmeter with a high crest factor is able to read accurately the rms values of periodic signals that have waveforms significantly different from sinusoidal.

6.5.2 Digital Voltmeters

Digital voltmeters offer many advantages over other types. Among the advantages are greater speed, greater accuracy and resolution, reduction of operator errors and the ability to be remotely controlled. They display measurements as discrete numerals, rather than as a pointer on a continuous scale. Their basic measuring techniques are similar to those described for analog meters.

6.5.3 Power Supplies

Regulated ac and dc outputs, both voltage and current, are available using many regulation techniques. In many circuits ac sources line-derived through transformers and autotransformers are adequate.

6.5.4 Pulse Generators

In the selection of a pulse generator, the quality of the output pulse is of primary importance. High-quality test pulses ensure that degradation of the displayed pulse may be attributed to the test circuit of device alone. Rise and fall times of test pulses should be, at most, one-fifth of the rise and fall times of the device to be tested. For rectangular pulses any overshoot, ringing and droop in the test pulse should be known, so as not to be confused with similar phenomena caused by the test circuit or device.

Some characteristics tests use a half cycle of standard 60 Hz line frequency. This is simply accomplished.

When narrower pulse widths are desired, pulse forming networks (PFN) with suitable switching arrangements can be used. The simplest PFN is a capacitor being discharged through an inductor to the DUT.

Figure 24 illustrates a simple circuit technique for generating such a pulse.

Here, a number of definitions are offered.

Critical damping resistor, $R_{cr} = 2\sqrt{L/C}$

Damping ratio, $\zeta = \frac{R}{R_{cr}} = \left(\frac{R}{2}\right)\sqrt{C/L}$

Undamped natural frequency, $\omega_n = \frac{1}{\sqrt{LC}}$

For the underdamped, or oscillatory case, $R < R_{cr}$ and the solution is given by:

$$i = \frac{V_o}{\omega_n L\sqrt{1-\zeta^2}} e^{-\zeta\omega_n t} \sin (\omega_n t\sqrt{1-\zeta^2}$$

The operation of the circuit is described: With switch S in position 1, capacitor C is charged to voltage V_O. The moment S is placed in position 2, C discharges through resistance R (the total circuit resistance), ideal diode D and inductance L. With the circuit resistance less than the critical damping resistance, the circuit will yield a damped oscillation at the natural frequency. After the first half cycle, the diode inhibits further conduction, thereby providing a single sinusoidal pulse.

Let R be equal to or less than one-fifth R_{cr}, and t_p be equal to $\frac{\pi}{\omega_n}$.

Then: $LC = t_n^2/\pi^2$, and $i_{max} = KV_o/\omega_n L$

where: $K = e^{-\zeta\omega_n t}$

6.5.4 Pulse Generators (cont'd)

The constant K, evaluated when $\zeta = 0.2$ and $\omega_n t = \pi/2$, is approximately 0.73. Similarly, when $\zeta = 0.5$, K is approximately 0.45.

In practice it is advisable to make the numerical value of C large compared to that of L. This minimizes the demand for higher voltage supplies to attain the desired current amplitude.

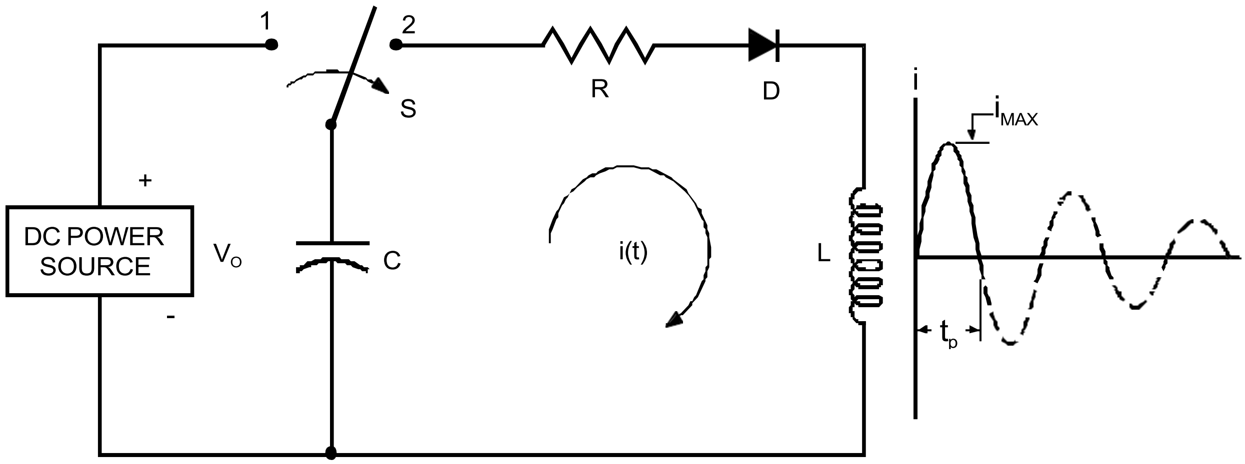


Figure 24 — Pulse Generator Circuit and Waveform

6.5.5 Oscilloscopes

An oscilloscope is a universal measuring instrument capable of measuring a very wide variety of rapidly changing electrical phenomena, even if the phenomenon occurs only once and lasts only a fraction of a millionth of a second.

Its display is in the form of a visual presentation on the face of a cathode ray tube, with vertical and horizontal deflection representing the ordinate (Y) and abscissa (X), respectively, of a rectangular coordinate display.

Generally, oscilloscopes have built-in sawtooth sweep generators for producing constant-speed horizontal beam deflection. In most cases sweeps are calibrated in terms of a direct unit of time for a given distance of spot travel across the screen. Special oscilloscopes permit deflections to be adapted to a variety of electrical and physical variables.

The first characteristic generally sought in an oscilloscope is adequately short rise time (t_r) for observing fast rising pulses, or sufficient bandwidth (BW) for high frequency sinewaves. When selecting an oscilloscope, the suggested requirements for its bandwidth can be estimated using the following rule of thumb:

$$\text{Bandwidth (minimal)} = 5\,\frac{Bandwidth\ Factor}{Fastest\ Rise\ Time}$$

6.5.5 Oscilloscopes (cont'd)

For sinewaves, the *Bandwidth Factor* is approximately 0.35.

Then Bandwidth = 1.75 / t_r

When observing pulses on an oscilloscope whose rise time is one-fifth or less of the rise time of the device to be observed, the error will be 2% or less.

The actual rise time of the DUT can be expressed as:

$$t_{r(DUT)} = \sqrt{t_{r(obs)}^2 - t_{r(scope)}^2}$$

where: $t_{r(DUT)}$ = rise time of DUT
$t_{r(obs)}$ = rise time of observed (displayed) pulse
$t_{r(scope)}$ = rise time of the oscilloscope

Digital oscilloscopes shall have sample times at least $30/t_X$ samples/sec where t_X is the time interval to be measured. A rated resolution of 0.4% of full-scale deviation (2^{-8} full-scale deviation) or better is recommended for routine tests. For referee test which require comparison of records, a rated resolution of 0.2% of full-scale deviation (2^{-9} full-scale deviation) or better shall be used.

6.5.6 Temperature Measuring instruments

Temperature measuring instruments are many and varied. Table 9 lists the more significant ones. Temperatures measured range from close to absolute zero to in excess of 5000 ºC, with traceability to the National Institute of Science and Technology (NIST).

Thermocouples are by far the most widely used temperature measuring device. Their advantages include low cost, expendability, small size, wide range, ruggedness, use with long transmission distances, fast response and good long-term reproducibility. Their disadvantages include susceptibility to electrical noise, need to avoid temperature gradients, small signal output, need to reference to a known temperature and poor linearity. Modern instruments include electronic ally compensated thermocouples with digital readouts.

The more commonly used thermocouples include ANSI symbol types T, K, J and R. The type T, copper/constantan thermocouple is used effectively from -269 ºC to about 500 ºC, is excellent for the lower temperatures and resists moisture corrosion. The type K, chromel/alumel, is used from -269 ºC to about 1300 ºC, is most nearly linear, and is good for clean oxidizing atmospheres. The type J, iron/constantan, is used from 0 ºC to 750 ºC. The type R, 87% platinum, 13% rhodium, is good in the 0 ºC to about 1650 ºC range, is highly resistant to oxidation and corrosion, and is usually physically small for fast response.

For further information concerning temperature measuring instruments, refer to clause 7.8.

6.5.6 Temperature Measuring Instruments (cont'd)

Table 9 — Temperature Measuring Instruments

Name	Physical Quantity	Form	Associated Instruments	Range	Resolution
Thermistor	Electrical resistance	Semiconductor metal oxide chip or bead with two leads	Wheatstone Bridge	-269 ºC to 200 ºC	0.01 ºC selected units
Quartz Thermometer	Frequency of mechanical oscillations	Quartz crystal with "Y" cut	Oscillator and frequency counter	-262 ºC to 250 ºC	0.001 ºC
Resistance Thermometer	Electrical resistance	Platinum wire	Potentiometers or ac and dc bridges (Mueller, Smith, Kelvin)	-259 ºC to 1064 ºC	0.00001 ºC in lab standards. 0.1 ºC typically in industrial instruments
Thermocouple	Thermal	Two dissimilar metal or alloy wires joined at one end for temperature under measurement, the other end used for referencing and measuring	Potentiometers, recorders or millivoltmeters	-253 ºC to 2400 ºC	0.01 ºC in lab standards. 0.5 ºC typically in industrial instruments
Liquid-in-Glass Thermometer	Thermal expansion	Glass bulb filled with mercury, toluene, ethyl alcohol or xylol	Graduated capillary as an integral part of the instrument	-148 ºC to 600 ºC	0.01 ºC (narrow ranges)
Total Radiation Pyrometer	Total radiance	Total radiance detector (thermopile)	Optical systems with potentiometer	0 ºC to 5000 ºC and up	Several ºC
Automatic Monochromatic Optical Pyrometer	Special concentration of radiance (ratios)	Photoelectric detector (photo-multiplier or photodiode)	Calibrated filament lamp, telescope, interference filter, electronic serve system, red filter, potentiometer or recorded	750 ºC to 5000 ºC and up	0.03 ºC in lab standards. 0.25 ºC in industrial instruments
Manual Monochromatic Optical Pyrometer	Spectral concentration of luminance (ratios)	Human eye (vision observation)	Calibrated filament lamp, telescope, red filter, potentiometer or millivoltmeter	750 ºC to 5000 ºC and up	1.5 ºC

6.6 Electrical Characteristics Tests

In this clause the general test method is described first, followed by the modifications necessary to comply with registration specifications. In some cases a separate test circuit is required.

6.6.1 Peak Reverse Current, I_{RM}

6.6.1.1 Terms and Definitions

peak reverse current: the maximum instantaneous value of reverse current that results under specified conditions of temperature and reverse voltage.

repetitive peak reverse current, I_{RRM}: the same current as defined above, only under a repetitive reverse voltage.

registered repetitive peak reverse current, I_{RRM}: the maximum instantaneous value of reverse current that results under the condition of the registered values of the maximum operating temperature (at which point the output current is derated to zero) and the working peak reverse voltage.

6.6.1.2 Procedure

A half cycle of 60 Hz sinusoidal reverse voltage is applied to the DUT and the resulting peak reverse current is measured.

The measurement shall be performed under conditions of thermal equilibrium. Thermal management may be necessary.

Pulses other than that specified may be used. However, direct correlation must exist to this Standard.

6.6.1.3 Test Circuit

The test circuit is shown in Figure 25.

The peak value of the applied waveform is read on the peak reading voltmeter, V_{P1}, or oscilloscope. The peak value of the resulting current is measured by a peak reading ammeter, or more practically the peak current is calculated from the values of the peak voltage as measured by V_{P2}, and the current viewing resistor R_2.

Resistor R_1 is a current-limiting resistor. Diode D_1 passes the applied reverse voltage, while diode D_2 bypasses the normally forward voltage around the DUT. Negligible forward current flows through the DUT, thereby producing negligible power dissipation.

6.6.1.4 Test Conditions to be Specified

a. Case temperature, T_C, or Lead temperature, T_L =______ºC
b. Peak ac reverse voltage, V_{RM} =______V
c. Thermal resistance of minimum heat dissipator upon which the DUT is to be mounted, R_{thSA}. =______ºC/W

6.6.1.5 Characteristic to be Measured

a. Peak reverse current, I_{RM} =______mA
or

b. Repetitive peak reverse current, I_{RRM} =______mA

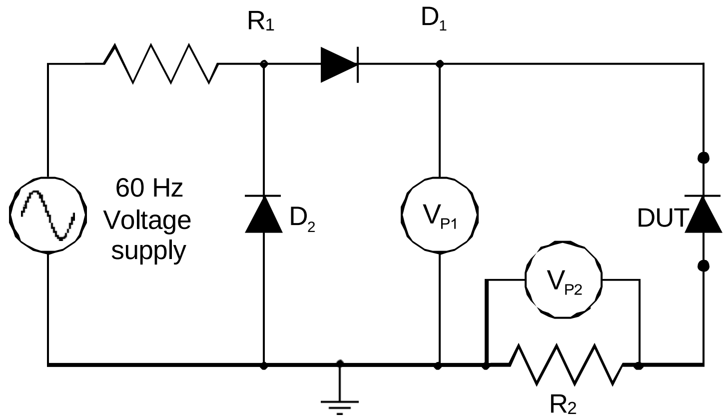


Figure 25 — Peak Reverse Current Test Circuit

6.6.2 DC Reverse Current, I_R

6.6.2.1 Terms and Definitions

DC reverse current: the value of current flowing in the reverse direction under specified conditions of temperature and reverse voltage.

registered dc reverse current: the value of current flowing in the reverse direction under conditions of the registered values of maximum dc reverse voltage and maximum operating temperature.

6.6.2.2 Procedure

A dc reverse voltage is applied to the DUT, and the resultant dc current is measured.

The measurement shall be performed under conditions of thermal equilibrium. Thermal management will probably be necessary.

6.6.2.3 Test Circuit

The test circuit is shown in Figure 26.

R is a current-limiting resistor. The applied voltage and resulting current are read on dc voltmeter, V, and dc milliammeter, I, respectively.

6.6.2.4 Test Conditions to be Specified

a. Case temperature, $T_{C,}$ or Lead temperature, T_L =______ºC

b. DC reverse voltage, V_R =______V

c. Thermal resistance of minimum heat dissipator upon which the DUT is to be mounted, R_{thSA} =______ºC/W

6.6.2.5 Characteristic to be Measured

a. DC reverse current, I_R =______mA

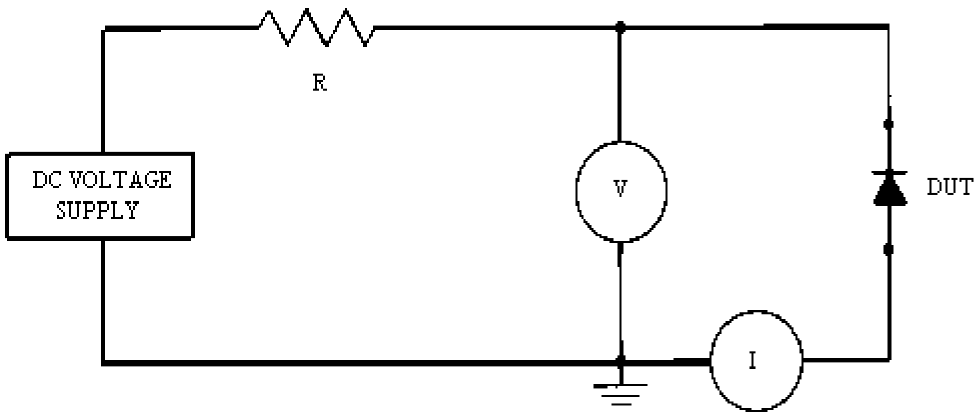


Figure 26 — DC Reverse Current Test Circuit

6.6.3 Average Reverse Current, $I_{R(AV)}$

6.6.3.1 Terms and Definitions

average reverse current: the value of the reverse periodic current averaged over a full-cycle under specified conditions of temperature and reverse voltage. A condition of forward current may be included.

registered average reverse current: the value of the reverse periodic current averaged over a full-cycle, with the DUT operating under the conditions of registered values of maximum operating temperature with no derating, working peak reverse voltage, and maximum average forward current.

6.6.3.2 Procedure (Without Forward Current)

A half-cycle 60 Hz ac voltage is applied repetitively to the DUT in the reverse direction and the resulting full-cycle average reverse current flowing through the device is measured with an averaging ammeter, I.

A rectifying component, D, of known average reverse current is used to block the applied ac voltage when it otherwise would be applied in the forward direction across the DUT. This component should have an average reverse current that is low compared to that of the DUT, since its reverse current subtracts directly from the reverse current indicated on the ammeter. The full-cycle average current of D should be added to the indicated ammeter reading for a true measurement of the average reverse current of the DUT.

Reverse current is quite temperature sensitive. If testing is performed at elevated temperature, thermal management may be necessary to prevent thermal runaway.

6.6.3.3 Test Circuit (Without Forward Current)

The test circuit is shown in Figure 27.

The peak value of the applied half-sine 60 Hz waveform is read on the peak reading voltmeter, V_P, or an oscilloscope. Ammeter, I, measures the full-cycle average reverse current. The voltage drop across I shall not exceed 1% of the reverse voltage across the DUT.

R is a current-limiting resistor.

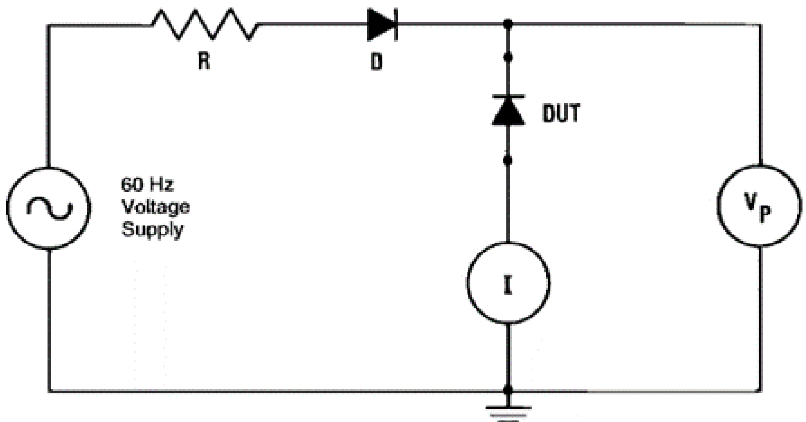


Figure 27 — Average Reverse Current Test Circuit, Without Forward Current

6.6.3.4 Test Conditions to be Specified

a. Case temperature, T_C, or Lead temperature, T_L =_____ºC
b. Peak ac reverse voltage, V_{RM} =_____V
c. Maximum thermal resistance of heat dissipator upon which the DUT is to be mounted, R_{thSA} =_____ºC/W

6.6.3.5 Characteristic to be Measured

a. Average reverse current, $I_{R(AV)}$ =_____mA

6.6.3.6 Procedure (With Forward Current)

A half-cycle 60 Hz sinusoidal current is applied repetitively to the DUT in the forward direction. During the alternate half cycles a half-wave 60 Hz ac voltage is applied to the DUT in the reverse direction. During the forward conducting half cycle, the full-cycle average forward current is measured with an averaging ammeter. During the reverse blocking half cycle, the full-cycle average reverse current is measured with an averaging ammeter and the peak reverse voltage is measured with a peak-reading voltmeter or an oscilloscope.

The measurement shall be performed under conditions of thermal equilibrium. Thermal management is generally necessary.

6.6.3.7 Test Circuit (With Forward Current)

The test circuit is shown in Figure 28.

The synchronous switch alternately applies forward current for one half cycle and reverse voltage for the other half cycle. The ammeter, $I_{R(AV)}$, measures the full cycle average reverse current. Voltmeter or oscilloscope, V_P, measures the peak reverse voltage across the DUT. The leakage current of the synchronous switch shall be negligible compared to the current through the DUT, during the application of the reverse voltage. R is a current limiting resistor, required if a voltage source is used. The drop across R should be at least 5 times the observed forward voltage of the DUT.

6.6.3.8 Test Conditions to be Specified

a. Case temperature, $T_{C,}$ or Lead temperature, T_L =______ºC

b. Peak ac reverse voltage, V_{RM} =______V

c. Average dc forward current, $I_{F(AV)}$ =______A

d. Maximum thermal resistance of heat dissipator upon which the DUT is to be mounted, R_{thSA} =______ºC/W

NOTE When testing for registered $I_{R(AV)}$;

- T_C or T_L = T_3
- V_{RM} = Rated V_{RWM} and
- $I_{F(AV)}$ = Rated $I_{F(AV)}$ or I_O

6.6.3.9 Characteristic to be Measured

a. Average reverse current, $I_{R(AV)}$ = ______mA

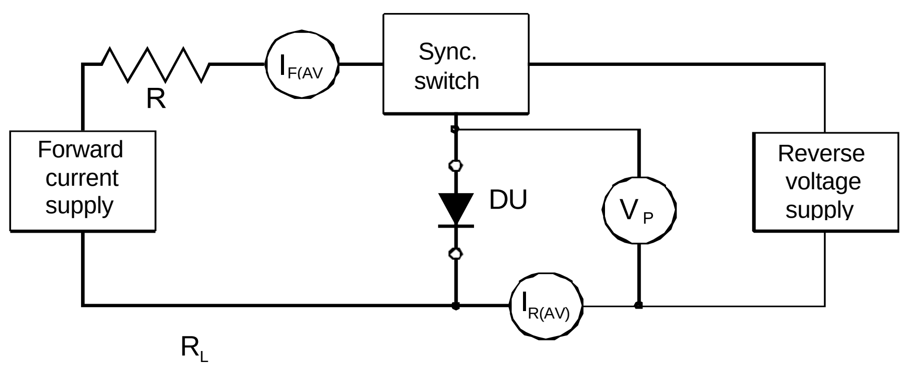


Figure 28 — Average Reverse Current Test Circuit With Forward Current

6.6.4 Peak Forward Voltage, V_{FM}

6.6.4.1 Terms and Definitions

peak forward voltage: the value of maximum instantaneous forward voltage measured under specified conditions of temperature and forward current.

registered peak forward voltage: the value of maximum instantaneous forward voltage measured with the DUT operating under conditions of (a) the peak value of the registered maximum average forward current, and the registered maximum operating temperature with no derating; or (b) a specified current pulse with peak value equal to pi times the registered maximum average forward current, and temperature of 25 ºC.

6.6.4.2 60 Hz Procedure

A half-cycle 60 Hz sinusoidal waveform of forward current is applied to the DUT, and the resulting peak forward voltage is measured.

The measurement shall be performed under conditions of thermal equilibrium. Thermal management may be necessary.

6.6.4.3 60 Hz Test Circuit

The test circuit is shown in Figure 29.

Diode D_1 passed the applied forward current waveform to the DUT, while diode D_2 by-passes the normally opposite half cycle current around the DUT.

The current supply can be implemented with a voltage supply and a series resistance. The supply voltage should be of sufficient compliance to ensure a test current conduction angle of not less than 175º. The forward voltage is read on the peak reading voltmeter, V_p, or an oscilloscope. The voltmeter connections are made at specified points on the DUT and always within the ammeter connections.

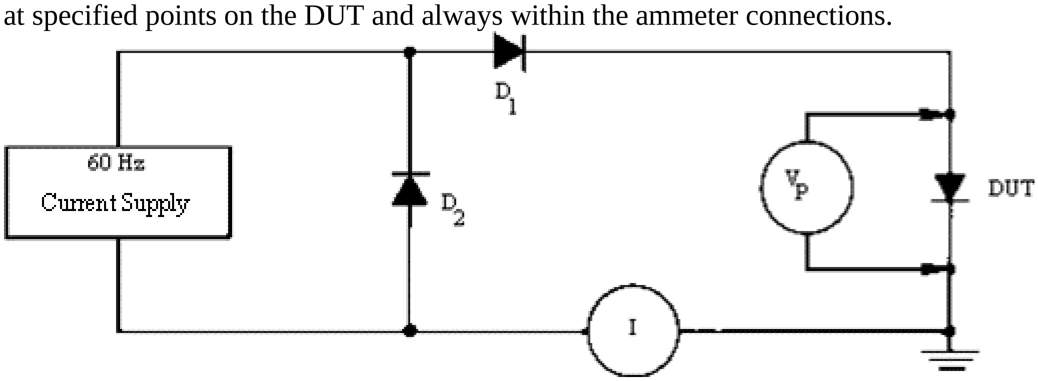


Figure 29 — 60 Hz Peak Forward Voltage Test Circuit

6.6.4.4 Test Conditions to be Specified

a. Case temperature, T_C, or Lead temperature, T_L =______ºC
b. Average forward current, $I_{F(AV)}$ =______A
c. Thermal resistance of heat dissipator, R_{thSA} =______ºC/W

6.6.4.5 Characteristic to be Measured

a. Peak forward voltage, V_{FM} =______mA

6.6.4.6 Pulse Test Procedure

A forward pulse of specified duration and peak current is applied to the DUT, and the resulting peak forward voltage is measured.

When this pulse test is used to measure registered peak forward voltage the current pulse amplitude must equal pi times the registered maximum average forward current, the pulse width shall be equal to or less than one millisecond, and the duty cycle shall be equal to or less than 2%. The temperature of the DUT shall be 25 ºC.

The measurement shall be performed under conditions of thermal equilibrium. Thermal management is generally unnecessary.

6.6.4.7 Pulse Test Circuit

The test circuit is shown in Figure 30. A pulse of forward current with specified amplitude, pulse width and duty cycle is applied to the DUT. The peak value of the applied waveform is calculated from the values of R_2 and the peak voltage as read on V_{P2}. The resultant peak forward voltage is measured by the peak reading voltmeter, V_{P1}. Either voltmeter may be an oscilloscope. The voltmeter connections are made directly to the DUT, using procedures to minimize inductive pickup.

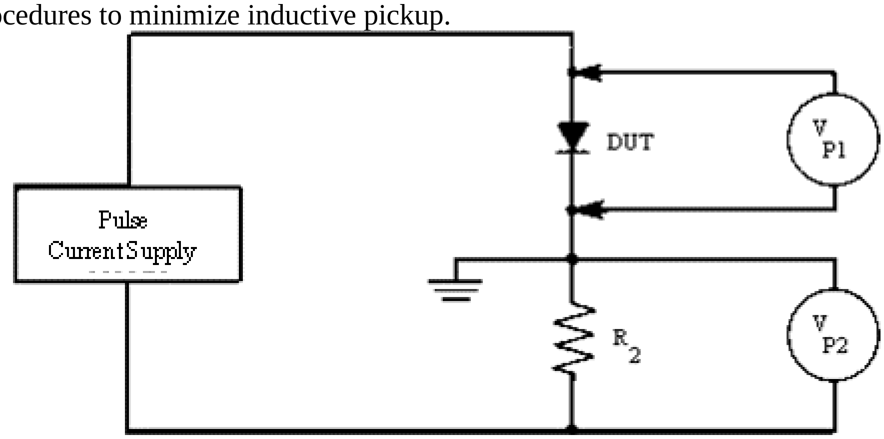


Figure 30 — Peak Forward Voltage Pulse Test Circuit

6.6.4.7 Pulse Test Circuit (cont'd)

Figure 31 details the implementation of a practicable pulse current supply. The thyristor switch, SCR, is normally in its off-state (high impedance). The dc voltage supply charges capacitor C, through R_1 and D_1. After the SCR is triggered (low impedance), C discharges through inductor L, the DUT and resistor R_2, producing a current wave at the peak value of which the forward voltage is measured. A sinusoidal pulse of current will result, providing R_1 is sufficiently large so as not to contribute significant current during the discharge of C, and the circuit values meet the prescribed criteria (clause 6.5.4).

A diode bypasses the reverse current around the DUT, while the SCR, after reverse recovery, inhibits current oscillation from continuing past the first zero current point after current initiation.

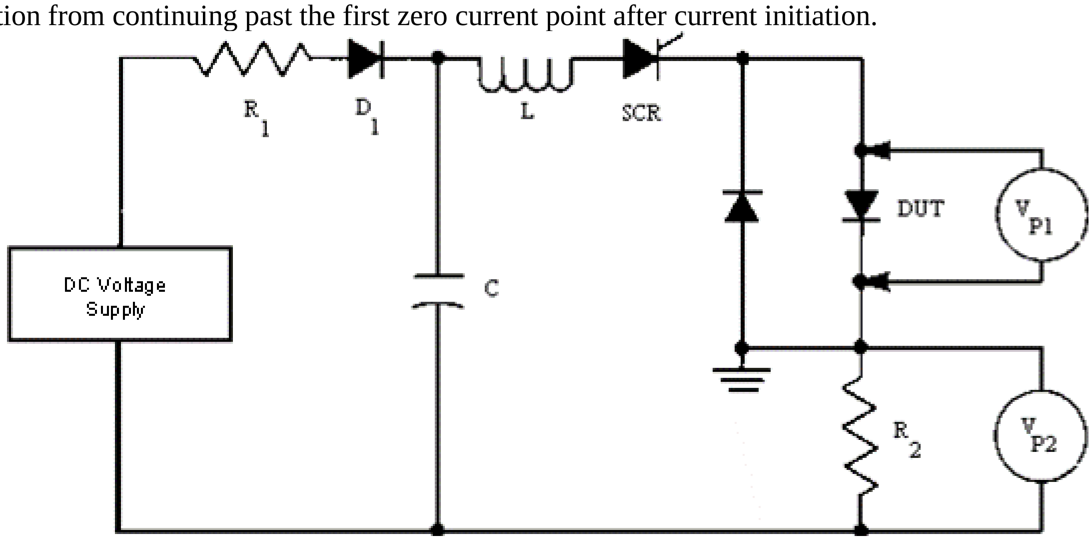


Figure 31 — Detailed Peak Forward Voltage Pulse Test Circuit

6.6.4.8 Test Conditions to be Specified

a. Case temperature, T_C, or Lead temperature, T_L =______ºC
b. Peak forward current, I_{FM} =______A
c. Forward curret pulse width, t_p =______µs
d. Duty factor =______%
e. Location of voltage meaasuring probes

6.6.4.9 Characteristic to be Measured

a. Peak forward voltage, V_{FM} =______V

6.6.5 DC Forward Voltage, V_F

6.6.5.1 Terms and Definitions

DC forward voltage: the value of forward voltage measured under specified conditions of temperature and dc forward current.

6.6.5.2 Procedure

A dc forward current is applied to the DUT and the resulting dc voltage is measured. The measurement is performed under conditions of thermal equilibrium; thermal management is usually necessary, therefore the test is seldom used.

Registered dc voltage is the maximum forward voltage measured with the DUT operating under registered values of continuous forward current and case temperature.

6.6.5.3 Test Circuit

The circuit of Figure 30 may be used except the supply is then a dc source and the meters are dc instruments.

6.6.5.4 Test Conditions to be Specified

a. Case temperature, T_C, or Lead temperature, T_L =______ºC
b. DC forward current, I_F =______A

6.6.6 Average Forward Voltage, $V_{F(AV)}$

6.6.6.1 Terms and definitions

average forward voltage: the value of forward voltage averaged over one complete cycle under specified conditions of temperature and forward current.

Registered average forward voltage is measured under conditions of rated current at registered temperature.

This specification is no longer a registration requirement. This test method is included for reference purposes only.

6.6.6.2 Procedure

A half cycle of 60 Hz sinusoidal forward current is applied to the DUT and the resulting average forward voltage measured.

The measurement is performed under conditions of thermal equilibrium. Thermal management is usually required.

6.6.6.3 Test circuit

The test circuit of Figure 29 may be used except that an average reading voltmeter replaces the peak reading instrument.

6.6.6.4 Test conditions to be specified

a. Case temperature, T_C, or Lead temperature, T_L =______ºC
b. Average forward current, $I_{F(AV)}$ =______A
c. Thermal resistance of heat dissipator, R_{thSA} =______ºC/W

6.6.6.5 Characteristic to be Measured

a. Average forward voltage, $V_{F(AV)}$ =______V

6.6.7 Reverse Breakdown Voltage

These characteristics are applicable only to controlled avalanche rectifiers and transient voltage suppressor diodes.

6.6.7.1 Terms and Definitions

minimum reverse breakdown voltage: the value of voltage measured in the reverse volt-ampere region of low incremental resistance under specified conditions of temperature and low reverse current.

maximum reverse breakdown voltage: the value of maximum instantaneous voltage measured in the reverse volt-ampere region of low incremental resistance under conditions of a specified peak reverse current and operating temperature. The product of the maximum breakdown voltage times the peak reverse current must be equal to the registered non-repetitive reverse power dissipation rating in the breakdown region.

6.6.7.2 Method for Minimum Reverse Breakdown Voltage

The voltage applied to the DUT sufficient to result in a specified reverse current is measured. The specified current must be in the region of low incremental resistance immediately past the region of high incremental resistance.

The measurement shall be performed under conditions of thermal equilibrium. Thermal management may be necessary.

6.6.7.3 Test Circuit

The minimum reverse breakdown voltage can be determined by using a dc or an ac signal source. The test circuit is shown in Figure 32.

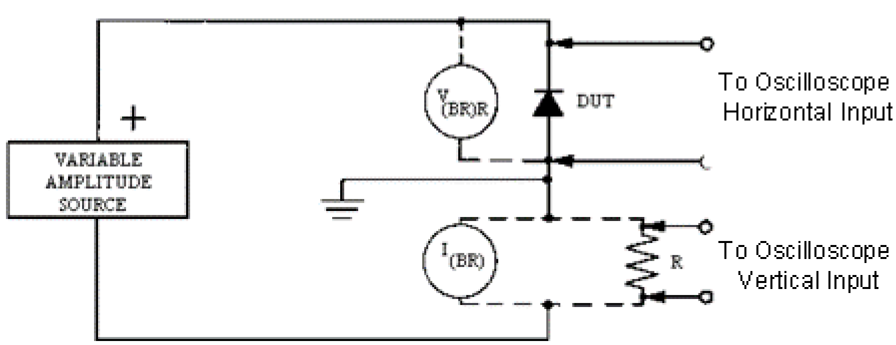


Figure 32 — Minimum Reverse Breakdown Voltage Test Circuit

6.6.7.3 Test Circuit (cont'd)

The variable amplitude signal source may be a current or voltage source; dc, rectified ac, or pulse. In any case its current magnitude shall be limited to the specified current.

If a dc source is used, a dc voltmeter and ammeter shall be used to measure the voltage directly across the DUT, and the current through the DUT.

If an ac or a pulse technique is used it is expedient to apply the voltage across the DUT to the horizontal input of an oscilloscope and apply the voltage drop across the current viewing resistor, R_2, to the vertical input.

The resulting display of the volt-ampere characteristic is used to read the desired characteristic values.

Figure 33 details an implementation of standard line voltage for the ac method.

Diode D_1 passes a half cycle current, which can be varied in amplitude by autotransformer T_2. R_1 is a current-limiting resistor. D_2 bypasses the normally opposite half cycle from the output.

6.6.7.4 Test Conditions to be Specified

a. Case temperature, T_C, or Lead temperature, T_L = 25 ºC
b. Minimum breakdown current, $I_{(BR)}$ =_____A
c. Maximum thermal resistance of heat dissipator upon which the DUT is to be mounted, R_{thSA} =_____ºC/W

6.6.7.5 Characteristic to be Measured

a. Minimum reverse breakdown voltage, $V_{(BR)}$ =_____V

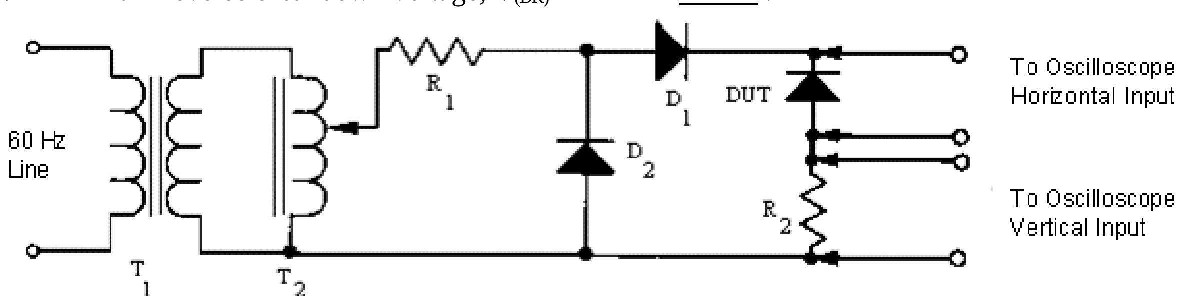


Figure 33 — Variable Amplitude AC Source for Reverse Breakdown Voltage Test

6.6.7.6 Method for Maximum Reverse Breakdown Voltage

This method is applicable only to controlled avalanche diodes.

A voltage pulse that results from a specified reverse current is measured. The specified current must be a maximum instantaneous value in the region of low incremental resistance.

The measurement shall be performed under conditions of thermal equilibrium. Thermal management may be necessary.

6.6.7.7 Test Circuit

The test circuit is shown in Figure 34. It is required by definition that the product of the voltage and current to which the DUT is subjected is equal to the registered maximum non-repetitive reverse power dissipation rating of the device under test. In addition, the circuit in Figure 34 will produce the current waveform that is required for this test.

6.6.7.8 Procedure

The initial reverse pulse applied to the test device connected in the circuit in Figure 24 shall be of low magnitude and shall be increased on successive pulses until the maximum reverse power specified is reached. The value of $V_{(BR)}$ of the DUT shall be estimated and R_1 shall be calculated from:

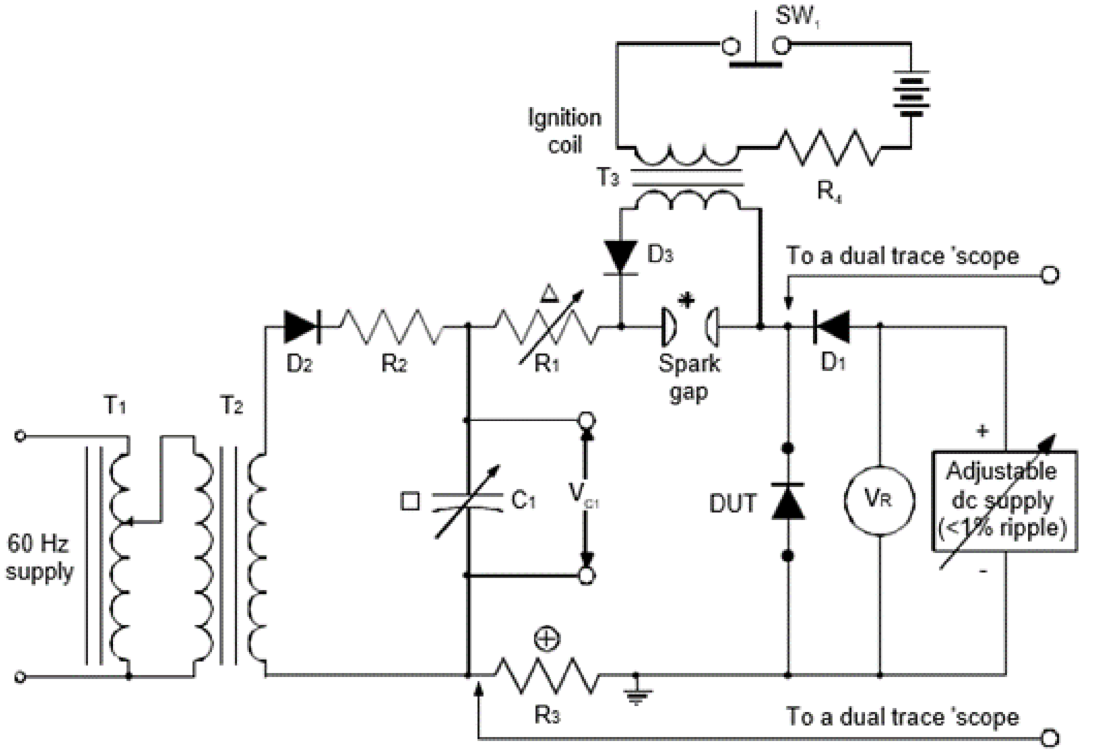
$$R_1 = \frac{(V_{c1} - \mathrm{V}_{BR}\ )V_{BR}}{P_{RM}}$$

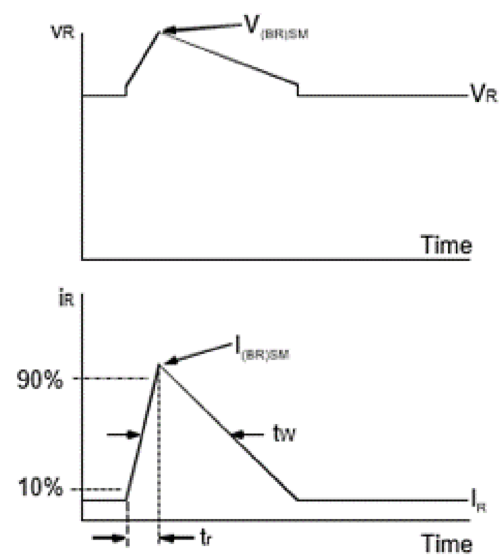
Estimate C_1 from $C_1R_1 = 1/2\ t_w$. Adjust the dc supply until V_R = rated V_{RWM}. The voltage across C_1 (V_{C1}) should be 3000 V or $3xV_{(BR)}$ of the DUT (whichever is greater); the spark gap should not arc over. Open SW_1 - the gap should arc over. Readjust, if necessary, the value of C_1, R_1 and V_{C1} until the specified value of Peak Reverse Power and average width of the current pulse are obtained.

NOTE $P_{RM} = V_{BR}\ x\ I_{BR}$

The time between pulses shall be long enough to allow the device virtual junction temperature to return to its initial temperature.

6.6.7.8 Procedure (cont'd)





t_r = 1.5 µs max.

t_w = 40 µs ± 4 µs at 50% amplitude

• Approximate range of C_1 0.002 to 0.2 µF

Δ Approximate range of R_1 2500 to 25 Ω

⊕ Value of R_3 selected to give approximately 1 volt drop at $I_{(BR)SM}$.

* Other components which give the same results may be added in place of the spark gap circuit.

EXAMPLES — Thyratron, Series SCR string, etc.

Figure 34 — Maximum Reverse Breakdown Voltage Test Circuit

6.6.7.9 Test Condition to be Specified

a. Case temperature, $T_{C,}$ or Lead temperature, T_L =______ºC
b. Peak reverse breakdown current, $I_{(BR)M}$
($V_{(BR)M}$ x I $_{(BR)M}$ must equal the specified P_{RM}). =______A
c. Reverse breakdown curret pulse width, t_p =______µs
d. Maximum thermal resistance of heat dissipator
upon which the DUT is to be mounted, R_{thSA} =______ºC/W

6.6.7.10Characteristic to be Measured

a. Maximum Reverse Breakdown Voltage, $V_{(BR)}$ =______V

6.6.8 Forward Switching Characteristics

When a step function of forward current (high *di/dt*) is applied to a semiconductor rectifier diode the carrier gradient does not develop immediately, resulting in an overshoot voltage, which decreases with time to the dc static level. The diode appears to be inductive; however, transit time and conductivity modulation, not inductance, are normally responsible for the effect.

Forward switching voltage-current characteristics may have to be considered in analyzing the effectiveness of clamping transient voltages (as in bypass or free-wheeling applications) and in the calculation of diode average power dissipation in high frequency pulse circuits (as in some inverters and switching regulators).

6.6.8.1 Relevant Parameters

Forward recovery time, t_{fr}, is the time interval between the instant when the forward voltage rises through a specified first value, usually 10% of its final value, and the instant when it falls from its peak value, V_{FRM}, to a specified low second value, v_{FR}, upon the application of a step of current following a zero voltage or a specified reverse voltage condition.

Peak forward recovery voltage, V_{FRM}, is the maximum instantaneous value across the DUT resulting from the application of a specified step function of forward current. This characteristic is sometimes referred to as modulation voltage. Also, $V_{F(PK)}$, $V_{FM(DYN)}$ and V_{FM} are sometimes used, but V_{FRM} is preferred.

6.6.8.2 Procedure

The DUT is subjected to a specified step function of forward current. The resulting current waveform through the device and voltage waveform across the device are graphically monitored with amplitude displayed versus time. The desired characteristics are obtained from the display.

6.6.8.3 Test Circuit and Waveform

The general test circuit is shown in Figure 35 and the waveforms in Figure 36.

The current pulse source may be a pulse generator, charged line, pulse forming network, an arc-gap circuit, or the like. If the nature of the source requires an internal switch, devices such as a mercury switch, thyratron, thyristor, power transistor, power MOSFET or similar devices may be used. Compliance voltage (open circuit output voltage) of the pulse current source shall be 50 V, or 3 times V_{FM} whichever is greater. In any event, the combination must provide the specified conditions of the pulse to the DUT.

Aberration of the pulse top shall not exceed $\pm$10% of I_{FM}. The *di/dt* of the leading edge shall be measured between the 10% and 90% amplitude points.

6.6.8.3 Test Circuit and Waveform (cont'd)

R is a non-inductive shunt or current viewing calibrated resistor. A suitable high frequency current probe may be used instead. The external switch shown is electronic and is left open if no reverse voltage is specified, otherwise it is synchronized to be open only for the duration of the current pulse.

It is expedient to observe the waveforms on a suitable dual-channel oscilloscope. The common connection shown will result in the inversion of the current waveform. Most oscilloscopes provide a method by which a trace can be inverted to display the waveforms as shown in Figure 35.

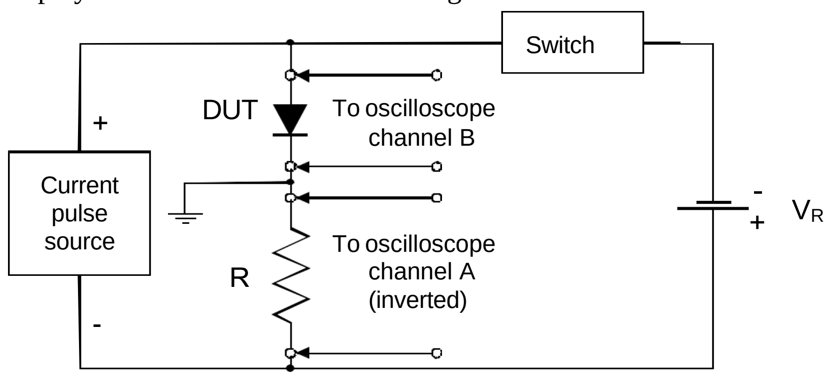


Figure 35 — Forward Switching Characteristics Test Circuit

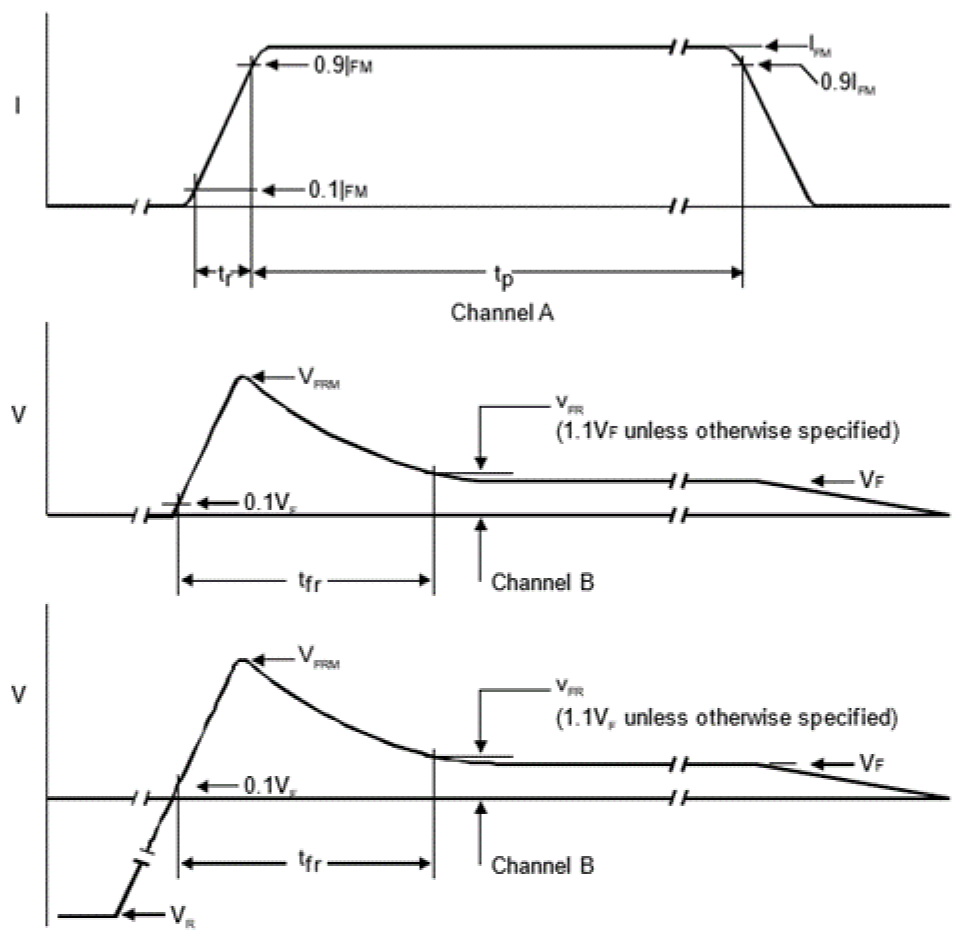


Figure 36 — Forward Switching Characteristics Waveforms

6.6.8.4 Test Conditions to be Specified

a. Rise time of current pulse.
(Measured from 10% to 90% of I_{FM}), t_r =______µs

b. Peak forward current, I_{FM} =______A

c. Forward recovery voltage defining the end of the forward recovery time, if different from 1.1 V_F, v_{FR}. =______V.

NOTE 1 If V_{FRM} is expected to exceed 10 V, select v_{FR} = 3 times the expected maximum value of V_F.

NOTE 2 If V_{FRM} is expected to be less than 1.3 V, select $v_{FR} = 0.5 (V_{FRM} - V_F) + V_F$.

d. Test current pulse duration, t_p =______µs

e. Test repetition rate, f (1000 max.) =______pps

f. Reverse voltage prior to application of current pulse V_R. =______V

g. Case temperature, $T_{C,}$ or Lead temperature, T_L =______ºC

h. Maximum thermal resistance of heat dissipator upon which the DUT is to be mounted, R_{thSA} =______ºC/W

6.6.8.5 Characteristics to be Measured

a. Forward recovery time, t_{fr} = _____µs

b. Peak Forward Recovery voltage, V_{FRM} = _____V

c. DC forward voltage, V_F = _____V

6.6.9 Reverse Recovery Characteristics

When a forward current is flowing in a semiconductor diode, a carrier gradient is produced in the high-resistance side of the junction, resulting in an apparent storage of charge. If the source of forward bias is suddenly changed to a reverse bias, the stored charge maintains a current flow (now a reverse current) until the charge is depleted by a combination of reverse current flow and internal carrier recombination.

Power rectifier diodes can possess different degrees of recovery characteristics. After the test current reaches its peak reverse value, it may immediately, or a short time later in the recovery period, decrease very abruptly (abrupt recovery) or it may decrease slowly and smoothly to its steady state reverse blocking value (soft recovery). In the former case, the effect of the rapid current change and the loop inductance producing transient voltages across the test device must be considered. It should be further noted that the abrupt rectifier diodes can exhibit a reverse current waveform that crosses the zero axis and/or have a *di/dt* that is greater at some period in the t_{rrf} portion of the recovery curve compared to t_{rrr} so as to produce a voltage that meets or exceeds the rated reverse breakdown voltage of the device (optionally monitored), or an excessive RF noise condition. Therefore, the abrupt classification of a diode in an application, or in a given test circuit, cannot be exclusively defined by the test current reverse recovery waveforms, illustrated in Figure 43.

6.6.9.1 Terms and Definitions

reverse recovery time, (t_{rr}): The time interval required for the reverse current to recover to a specified value as the result of the driving source having been switched from a forward-current to a reverse-voltage condition.

6.6.9.1 Terms and Definitions (cont'd)

NOTE For conditions C and D of the test method in clause 6.6.9.3, t_{rr} is the sum of the two intervals, t_{rrr} and t_{rrf}, as shown in Figure 43 and Figure 46. Note that for go-no-go reverse recovery testing, limit points $I_{RM(REC)}$ and 0.25 $I_{RM(REC)}$ should be based upon the actual $I_{RM(REC)}$ maximum value.

peak reverse recovery current, ($I_{RM(REC)}$): The maximum instantaneous value of reverse current that occurs when switching from a forward current condition to a reverse voltage condition.

NOTE It applies to the methods of conditions C and D only because conditions A and B use a reverse current, I_{RM}, that is to be specified and is controlled by the test circuit. Recovered charge, Q_{rr}, is the quantity of excess electrical charge within the device structure that is delivered externally when switching from a forward current to a reverse voltage condition.

6.6.9.2 General Description

A specified pulse of forward current is applied to the DUT. The resulting current waveform enables the desired characteristics to be measured.

It is expedient to graphically monitor the waveform by observing current versus time. A suitable oscilloscope may be used.

The measurement shall be performed under conditions of thermal equilibrium. Thermal management may be necessary.

The recovered charge is represented by the area under the reverse current-time curve. An approximate value of the recovered charge when using Conditions C or D of the test method in clause 6.6.9.3 can be calculated by the expression:

$$Qrr = (1/2)\ trr\ I_{RM(REC)}$$

It may be measured by some integration (graphical or electronic) process if the beginning and ending time point for the integration are defined. For our purposes, the starting point is the instant of current reversal and the ending point is at some specified reverse current point I_{RX} or time t_{rx}.

6.6.9.3 Test Methods, Circuits, and Waveforms

The purpose of this test is to measure the reverse recovery time and other specified recovery characteristics related to signal, switching and rectifier diodes by observing the reverse transient current vs. time when switching from a specified forward current to a reverse biased state in a specified manner.

Four conditions are given to include recommended practice for the range of diodes considered. A general guide for selecting the appropriate condition letter is:

A. Signal diodes with reverse recovery time less than 6 ns.
B. Low to medium current rectifiers with maximum specified recovery times of 50 ns to 3,000 ns.
C. High current rectifiers with maximum specified recovery times of 350 ns or greater.
D. Ultra-fast rectifiers, particularly on new specifications.

Further, detailed guidance is given under each condition below.

6.6.9.3 Test Methods, Circuits, and Waveforms: Test Condition A (cont'd)

Test Condition A:

This condition is particularly relevant to low-current, signal diodes faster than 6 ns and tested at 10 mA. However, it is practicable for measurements up to 20 ns and 100 mA.

Circuit Notes for Test Condition A:

a. Rise time of the reverse voltage pulse across a noninductive calibration resistor in place of the DUT shall be less than 1/5th the recovery time of the DUT, for greatest accuracy.

b. Oscilloscope rise time shall be less than 1/5th of device recovery time, for greatest accuracy.

c. Proper coaxial networks and terminations shall be employed to ensure against error-producing pulse reflections.

d. $R > 10\ R_L$

e. $R_L = Z_{PG} + Z_{scope} = 100\ \Omega$, unless otherwise specified.

f. $C > 10\ PW \div R_L$

g. PW > 2 x maximum specified t_{rr} (See Figure 37)

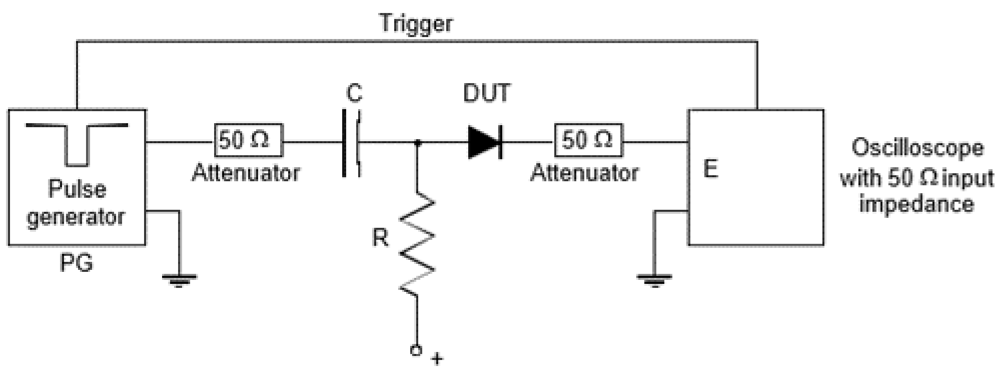


Figure 37 — Test Circuit for Reverse Recovery Condition A

NOTE The test circuit shall comply with the test conditions, and circuit notes stated under clause 6.1.

PW = Pulse width of reverse voltage pulse. (See Figure 38)
R_L = Load resistance.
C = Coupling capacitance.

Procedure for Test Condition A:

The specified forward current shall be adjusted by resistor R and the + supply. Voltage E, developed across the 50 Ω oscilloscope input impedance shall be measured. Specified forward current shall be calculated by the expression $I_F = E/50$. The time duration of I_F shall be at least 10 times the device recovery time. The oscilloscope trace deflection above zero reference shall be adjusted by the oscilloscope vertical sensitivity to produce an amplitude of 2 cm minimum vertical deflection. Adjustment of the reverse transient current (I_{RM}) shall be made by varying the pulse generator output, observing the voltage E across the 50 Ω oscilloscope input impedance, and calculating I_{RM} by the expression $I = E/50$. When reverse bias voltage V_R is specified, and I_{RM} is not, the DUT shall be replaced with a shorting bar and I_{RM} shall be calculated by the expression $V_R/50$. (See Figure 39)

6.6.9.3 Test Methods, Circuits, and Waveforms: Test Condition A (cont'd)

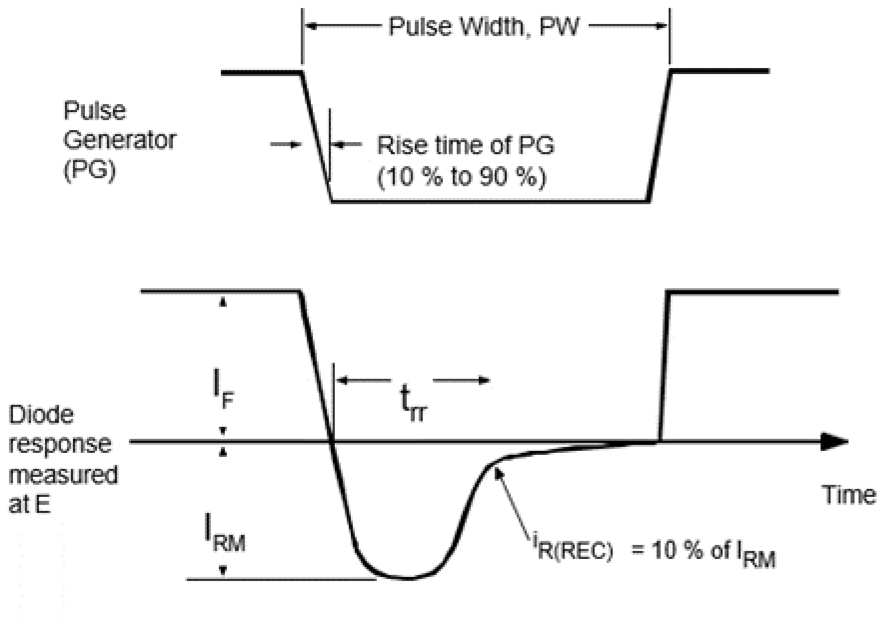


Figure 38 — Response Pulse Waveforms for Condition A

Summary for Condition A:

The following conditions shall be specified in the detail specification:

a. Forward current, I_F.

b. Reverse current I_{RM} (preferred), or reverse voltage (optional alternative).

c. Load resistance, if other than 100 Ω. (This is the sum of Z_{PG} and Z_{scope}).

d. Ambient temperature in ºC.

e. Generator impedance, if other than 50 Ω.

f. Recovery current measuring point, $i_{R(REC)}$, if different from 10% of I_{RM}.

The following measurement shall be made:

a. t_{rr} (See Figure 38)

6.6.9.3 Test Methods, Circuits, and Waveforms (cont'd)

Test Condition B:

See suggested conditions, B1, B2, etc. in Table 10. This condition is particularly relevant to medium current (axial and similar) types of standard and fast rectifiers with maximum specified recovery times between 50 ns and 3,000 ns that are measured at peak forward currents greater than 100 mA and less than or equal to 1.0 ampere. It is readily adapted to lower test currents. This test is also appropriate for devices with recovery times less than 50 ns that are measured at peak forward currents of 1 A or less; below 25 ns, or at higher current, particular care must be used to achieve low loop inductance and low circuit rise times to achieve acceptable repeatability.

This condition differs from condition D in that the reverse current (I_{RM}) is limited by the test circuit, not by the DUT.

Table 10 — Reverse Recovery: Test Condition B

Designation (condition)		B1	B2	B3	B4	B5
Test currents (A), See Figure 40	I_F	0.5	0.5	1.0	1.0	0.01
	I_{RM}	1.0	0.5	1.0	1.0	0.01
	$i_{R(REC)}$	0.25	0.1	0.5	0.1	0.005
Circuit resistors.*	R_F (□)	33	33	50	50	1200
	R_R	9	9	15	15	200
	R_4	1.00	1.00	1.00	1.00	10.0
NOTE Preferred nominal resistance values are shown; modification of R_F and R_R may be needed to achieve the rise time noted in a, below, and the I_{RM} specified above.						

6.6.9.3 Test Methods, Circuits, and Waveforms: Test Condition B (cont'd)

Circuit Notes for Test Condition B:

The timing and test circuit of Figure 39 is a guide to that needed. An equivalent circuit may be used.

a. The rise time of the reverse voltage pulse across a noninductive calibration resistor in place of DUT shall be less than 1/5th the recovery time of DUT.

b. The oscilloscope rise time shall be less than one half of the pulse generator rise time.

c. V_3 and R_F control forward current I_F

d. V_4 and R_R control reverse current I_{RM}

e. t_{rr} (max) is the longest to be measured

f. t_{rr} (min) is the shortest expected

g. DUT Current $i = V_o / R_4$

h. $t_1 > 5\ t_{rr(max)}$

i. $t_2 > t_{rr}$

j. $t_3 > 0$

k. $L_1 / R_4 < i_{rr(min)} / 10$

l. L_1 is the self-inductance of R_4

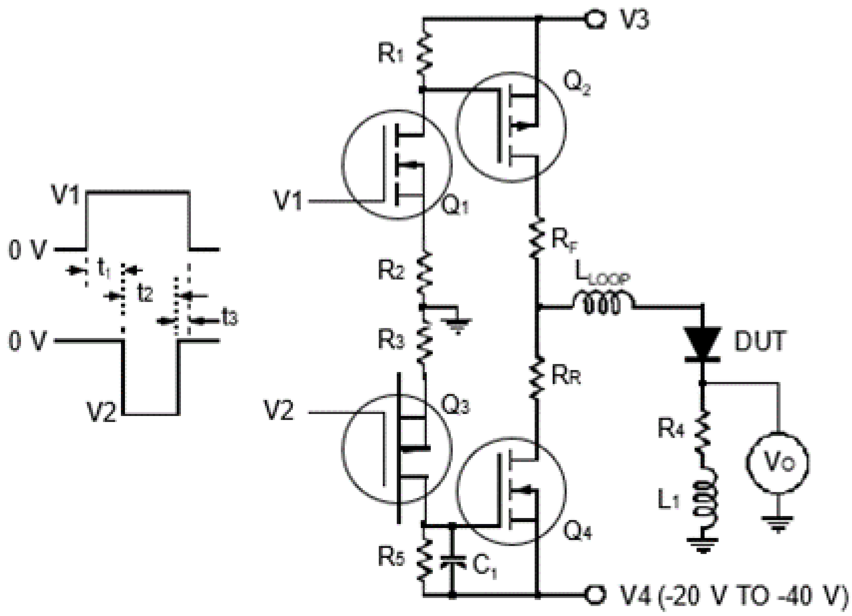
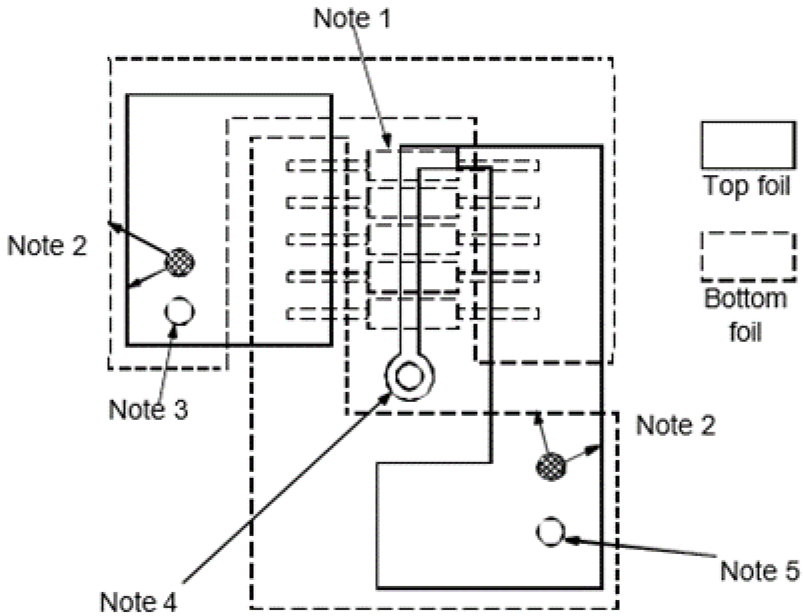


Figure 39 — Test Circuit for Reverse Recovery Condition B

6.6.9.3 Test Methods, Circuits, and Waveforms: Test Condition B (cont'd)

Figure 40 shows a suggested configuration for R_4. Duty factor shall be 5% maximum.



NOTE 1 Resistor assembly R_4 is made from ten 1 Ω, 1/4 W metal film resistors, 5 on top and 5 on the bottom foils. The center of resistor bodies is not shown, and leads are shown dotted so that conducting foils may be more clearly shown. Bottom resistor current flow L to R (→) is opposite to top resistor current flow R to L (←), providing magnetic field cancellation. Sense lead to the center conductor of the probe jack exits at right angle to resistor axes and is located between the top and bottom resistor layers.

NOTE 2 Cross hatched circular areas show the connections between those top and bottom foil regions indicated by arrows.

NOTE 3 To ground of circuit and probe.

NOTE 4 To center conductor of miniature probe jack.

NOTE 5 To cathode of DUT.

Figure 40 — Suggested Board Layout for Low L_1/R_4 for Condition B

6.6.9.3 Test Methods, Circuits, and Waveforms: Test Condition B (cont'd)

Procedure for Test Condition B:

Specified forward current (I_F) shall be adjusted by varying positive voltage, V_3. Reverse current (I_{RM}) shall be controlled by varying the negative voltage, V_4, see Figure 39 and Figure 41. With the DUT in place the circuit must be capable of higher than specified I_{RM}; the circuit, and not the diode, must limit I_{RM}.

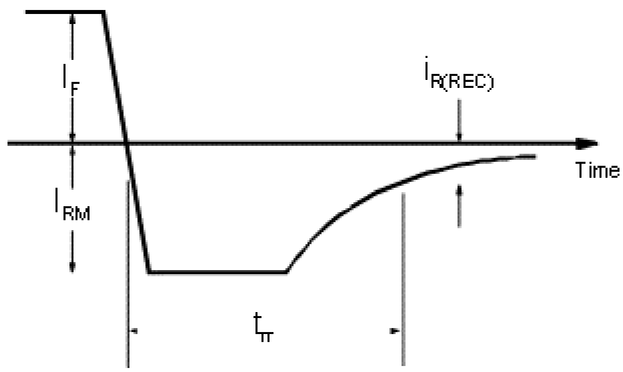


Figure 41 — DUT Current Waveform for Condition B

Summary for Test Condition B:

a. Test condition (B1, B2, etc. - see Table 10). If not in Table 10, specify bullet c through bullet f.
b. Ambient temperature, if other than 25ºC.
c. Forward current, I_F.
d. Reverse current, I_{RM}.
e. Load resistances R_F and R_R.
f. Recovery measuring point, $i_{R(REC)}$.

NOTE Specify bullet c through bullet f only if not using a condition designated in Table 10.

The following measurement shall be made:

a) t_{rr} (See Figure 41).

6.6.9.3 Test Methods, Circuits, and Waveforms (cont'd)

Test Condition C:

This test is intended for high-current rectifiers with reverse recovery times equal to or greater than 350 ns and tested at peak forward currents greater than 10 amperes.

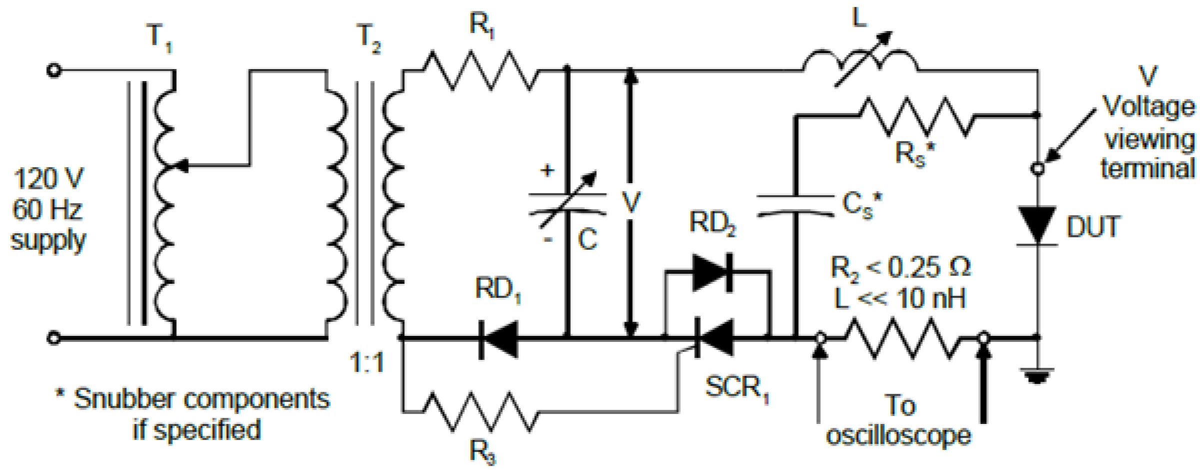


Figure 42 — Circuit for Measuring Reverse Recovery Characteristics: Test Condition C

Circuit Notes for Test Condition C:

a. The circuit is designed to simulate the commutation duty encountered in power rectifier diode circuits while also keeping average power dissipation low to minimize the need for thermal management.

b. The resistance of the C, L, and DUT loop (R_2 and parasitics) must be small, e.g., $2\pi\sqrt{L/C} >> R$, so the test current will essentially be sinusoidal, possessing a width $\pi\sqrt{LC}$, a *di/dt* of *V/L* and a peak value of $V/\sqrt{L/C}$. The peak voltage across the capacitor shall be as small as practicable to achieve the desired test conditions. The effect of reverse voltage magnitude on the test device recovery characteristics are neglected.

c. The minimum forward current pulse time (t_p) shall be at least 5 times the recovery time (t_{rr}) of the DUT so that the *di/dt* will be linear and of the same value before and after current reversal.

d. The oscilloscope rise time shall be less than 1/5th of t_{rrr} or t_{rrf} (See Figure 43), whichever is less.

e. The inductance of the current viewing resistor shall be extremely low, e.g., 0.01 µH. Abrupt recovery rectifiers (See Figure 43) can cause current oscillations which may be reduced by using a lower inductance current viewing resistor and by properly terminating the oscilloscope cable. A current transformer with suitable rise time (Pearson Electronics, Inc., or equivalent types) may be substituted for the current viewing resistor. Rectifier diode RD_2 provides a very low inductance path around SCR_1 if the reverse recovery time of SCR_1 is shorter than that of the DUT. An external SCR triggering source may be required to achieve stable triggering.

6.6.9.3 Test Methods, Circuits, and Waveforms: Test Condition C (cont'd)

f. A slight oscillation may appear on the waveform following device recovery. This may be reduced by reducing the current viewing resistor's inductance, or properly terminating the viewing cable. The oscillation, however, does not affect the measured recovery time.

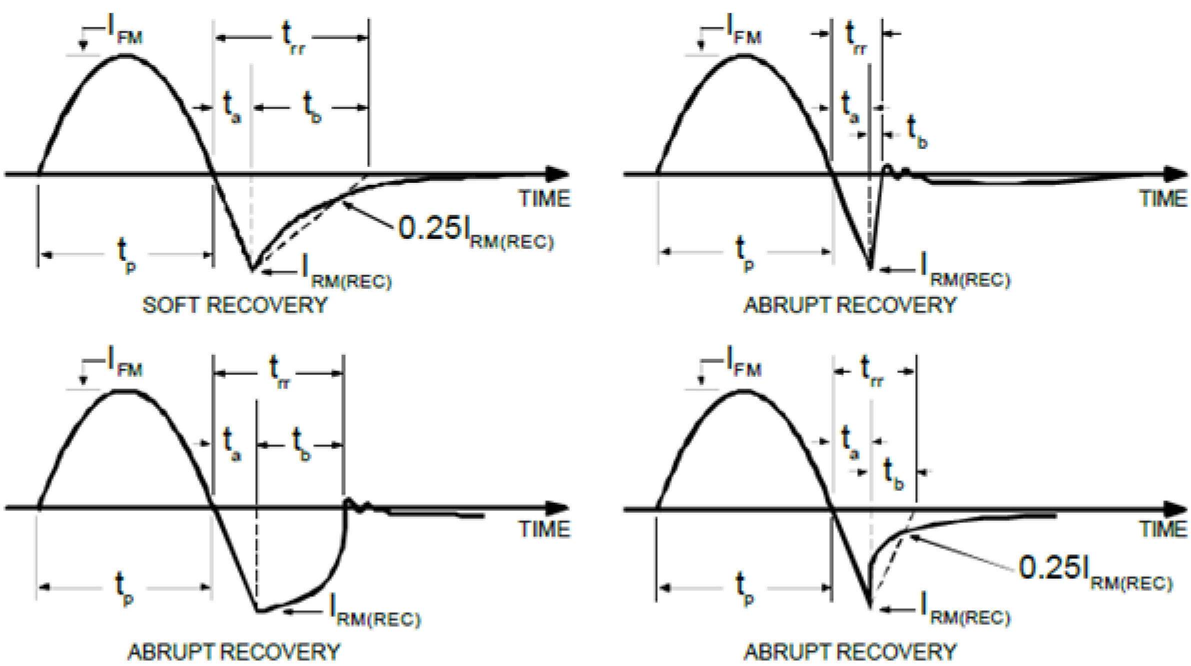
g. D_2 and its circuit branch should provide a very low inductance path around the SCR if the reverse recovery time of the SCR is shorter than that of the DUT.

h. R_3 must be sufficiently large such that the SCR triggers only after the capacitor, C, has had ample time to charge to its desired value. If stable triggering or ample charging is a problem, a momentary pushbutton switch may be inserted in line with R_3 to provide triggering. A pulse transformer technique is also acceptable in the triggering circuit.

Procedure for Test Condition C:

C, L, and V are adjusted to obtain the specified test current *di/dt* and magnitude, I_{FM}. The recovery time for rectifier diodes is defined as $t_{rr} = t_{rrr} + t_{rrf}$ (See Figure 44). t_{rrr} is measured from the instant of current reversal to the instant that current reaches its peak reverse value, $I_{RM(REC)}$ and t_{rrf} is measured from $I_{RM(REC)}$ to the instant the straight line connecting $I_{RM(REC)}$ and 0.25 $I_{RM(REC)}$ intercepts the zero current axis. Alternatively, the end point of the t_{rrf} may be specified as a point on the i vs t waveform, such as the actual 0.25 $I_{RM(REC)}$, without extrapolation. The recovery time for devices with abrupt recovery characteristic is defined in the same manner except t_{rrf} is measured from $I_{RM(REC)}$ to the instant the test current waveform intercepts the zero current axis, if applicable.

$$\frac{L_1}{R_4} < \frac{t_{rr}(\min)}{10}$$



NOTE t_{rrr} is now the preferred symbol for t_a and t_{rrf} is preferred for t_b.

Figure 43 — Current Waveforms for Various Types of Rectifier Diodes in the Circuit of Figure 42

6.6.9.3 Test Methods, Circuits, and Waveforms: Test Condition C (cont'd)

Summary for Test Condition C:

The following conditions shall be specified in the detail specification:

a. Case or lead temperature in ºC.

b. Test repetition rate, in Hz.

c. Peak forward current, I_{FM}, in amperes.

d. Rate of decrease of forward current, *di/dt* in A/ms

e. Minimum test current pulse width, t_p, in microseconds. (Duty factor shall be □ 1%).

The following characteristics shall be specified for measurement in the detail specification as required:

a. t_{rrr}, t_{rrf}. Reverse recovery time shall be computed, $t_{rr} = t_{rrr} + t_{rrf}$.

b. Peak reverse recovery current, $I_{RM(REC)}$ in amperes.

6.6.9.3 Test Methods, Circuits, and Waveforms (cont'd)

Test Condition D:

This condition is intended for ultra-fast medium current rectifiers (axial and case mount, or equivalent style) measured at $I_F \geq$ 1A and with reverse recovery time ≥ 100 ns. With good engineering practice, condition D can adequately measure t_{rr} down to about 10 ns; it can also utilize I_F up to at least 10 A. See suggested conditions D1, D2, D3, etc. below.

Table 11— Reverse Recovery: Test Condition D

Device Ratings			Values for Testing	
I_O or I_F (AV) (A)	t_{rr} (ns)	Designation (condition)	I_F (A)	*di/dt* (A/µs)
1 to 4	>65 to 100	D1	2	100
to 20	>65 to 100	D2	6	100
over 20	>65 to 100	D3	10	100
1 to 4	≤ 65	D4	2	200
to 20	≤ 65	D5	6	200
over 20*	≤ 65	D6	10	200
NOTE For devices with substantially higher rated current it is desirable to use test conditions for I_F close to rated current, and higher values of *di/dt*.				

Circuit Notes for Test Condition D:

Refer to Figure 44 and Figure 45 for circuit and construction details. Equivalent circuits may be used. The forward current generator consisting of Q_1, Q_2, R_1, and R_2 may be replaced with any functionally equivalent circuit, as can the current-ramp generator consisting of Q_3, Q_4, R_3 and C_1. The duty factor shall be ≤ 5%

a. This method presumes that good engineering practice will be employed in the construction of the test circuit, e.g., short leads, good ground plane, minimum inductance of the measuring loop and minimum self-inductance (L_1) of the current sampling resistor (R_4). Also, appropriate high speed generators and instruments must be used.

b. The measuring-loop inductance (L_{LOOP}, see Figure 44) represents the net effect of all inductive elements, whether lumped or distributed, e.g., bonding wires, test fixture, circuit board foil, inductance of energy storage capacitors, etc. The value of L_{LOOP} should be 100 nH or less. The reason for controlling this circuit parameter is that it, combined with diode characteristics including C_T, determines the value of t_{rrf}.

c. The turn-off reverse-voltage overshoot shall not be allowed to exceed the device rated breakdown voltage. Ringing and overshoot may become a problem with $R_{LOOP} << 2\sqrt{L/C}$, where L = L_{LOOP}. That is another reason for minimizing L_{LOOP}.

d. Regarding breakdown voltage, V_4 should be kept as low as practicable, especially when testing low voltage devices. A value of approximately -30 V is recommended.

6.6.9.3 Test Methods, Circuits, and Waveforms: Test Condition D (cont'd)

e. The time constant of the self-inductance of the current sampling resistor R_4 (See Figure 44) must be kept low relative to t_{rrr} because the observed values of t_{rrr} and $I_{RM(REC)}$ increase with increasing self-inductance. Since the value of R_4 is not specified, the recommended maximum inductance is expressed as a time constant (L_1/R_4) with a maximum value of t_{rrr} (minimum) /10, where t_{rrr} (minimum) is the lowest t_{rrr} value expected. This ratio was chosen as a practical compromise and would yield an observed t_{rrr} which is a maximum of 10% high ($\Delta t_{rrr} = L_1/R_4$). The $I_{RM(REC)}$ error is a function of the L_1/R_4 time constant and *di/dt*. For a *di/dt* of 100 A/µs the observed I_{RM} would also be 10 percent high. $\Delta I_{RM(REC)} = [L_1/R_4 \text{ x } di/dt]$.

f. The *di/dt* of 100 A/µs was chosen so as to provide reasonably high signal levels and still not introduce the large I_{RM} errors caused by higher *di/dt*. Higher values of *di/dt*, without large errors, can be achieved with lower L_1/R_4

g. V_1 amplitude controls forward current I_F

h. V_2 amplitude controls *di/dt*

i. t_{rrr} (max) is the longest to be measured

j. t_{rrr} (min) is the shortest t_{rrr} to be measured

k. DUT Current $i = V_o / R_4$

l. $t_1 > 5\ t_{rr(max)}$

m. $t_2 > t_{rr}$

n. $t_3 > 0$

o. $L_1 / R_4 < i_{rr(min)} / 10$

p. L_1 is self=inductance of R_4.

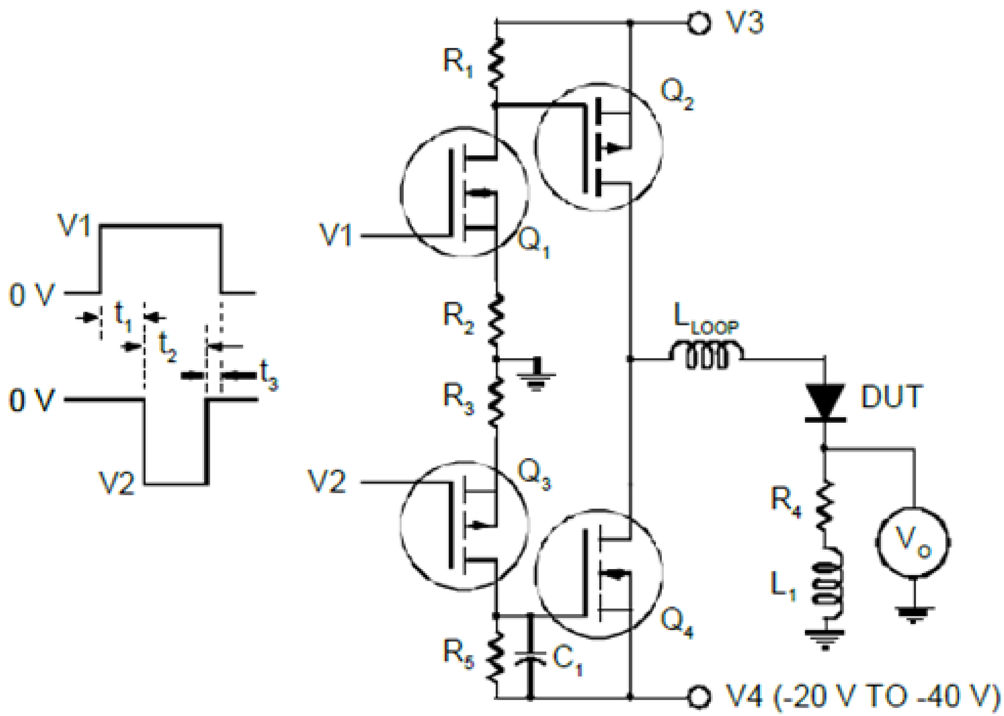
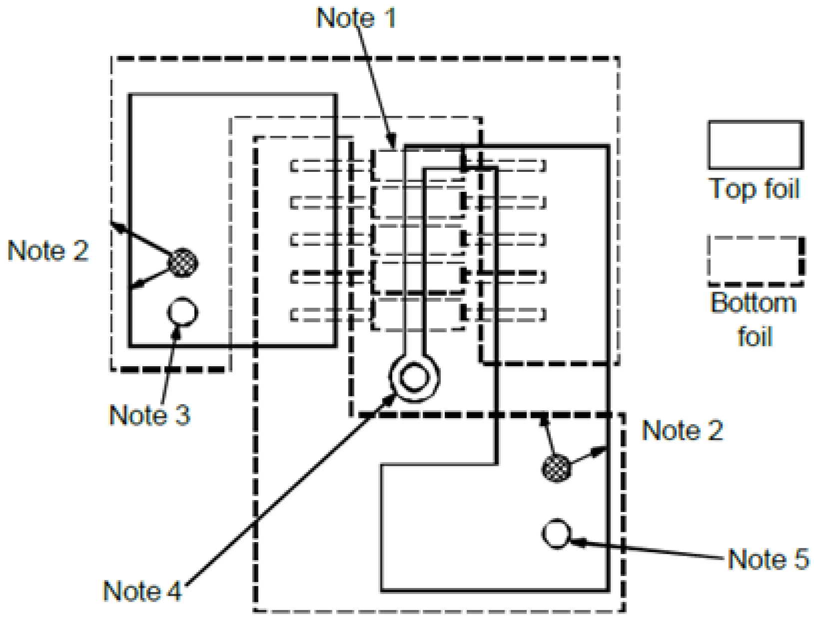


Figure 44 — t_{rr} Test Circuit for Test Condition D

6.6.9.3 Test Methods, Circuits, and Waveforms: Test Condition D (cont'd)



NOTE 1 Resistor assembly R_4 is made from ten 1 Ω, 1/4 W metal film resistors, 5 on top and 5 on the bottom foils. The center of resistor bodies is not shown, and leads are shown dotted so that conducting foils may be more clearly shown. Bottom resistor current flow L to R (→) is opposite to top resistor current flow R to L (←), providing magnetic field cancellation. Sense lead to the center conductor of the probe jack exits at right angle to resistor axes and is located between the top and bottom resistor layers.

NOTE 2 Cross hatched circular areas show the connections between those top and bottom foil regions indicated by arrows.

NOTE 3 To ground of circuit and probe.

NOTE 4 To center conductor of miniature probe jack.
NOTE 5 To cathode of DUT.

Figure 45 — Suggested Board Layout for Low L_1/R_4 for Test Condition D

Procedure for Test Condition D:

Adjust V_1 for the specified forward current I_F. Adjust V_2 for the specified *di/dt*. (See Figure 44 and Figure 45)

6.6.9.3 Test Methods, Circuits, and Waveforms: Test Condition D (cont'd)

Summary for Test Condition D:

The following conditions shall be specified:

a. Designation (condition, See Table 11 for Condition D). If another is desired, d. and e. must be specified.

b. V_4, Reverse ramp power supply voltage.

c. T_C, Case temperature, if other than 25 ºC.

d. I_F, One-half continuous rated current is the suggested alternative.

e. *di/dt*, 100 A/µs is the suggested alternative.

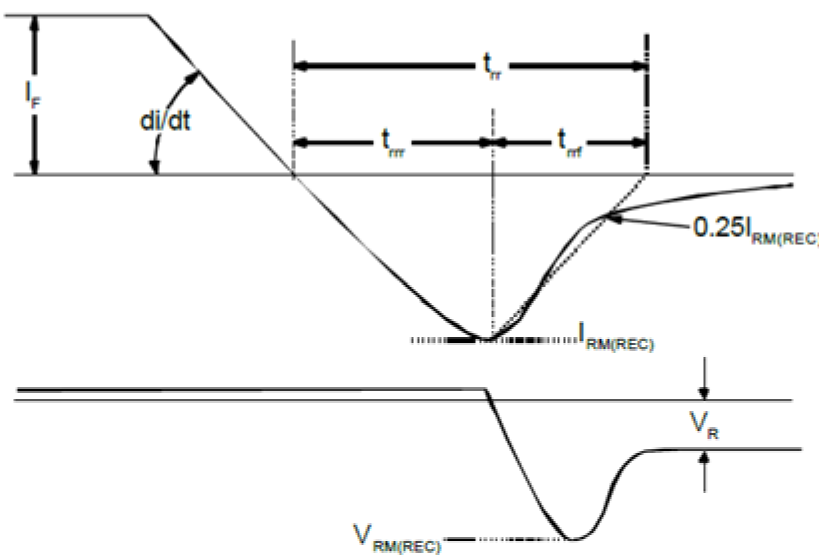
f. Choice of criterion for terminating t_{rr}, extrapolated (See Figure 46) or the specified point on the waveform.

The following measurements shall be taken:

a. t_{rrr}, t_{rrf}. Reverse recovery time shall be computed, $t_{rr} = t_{rrr} + t_{rrf}$.

b. $I_{RM(REC)}$ (See Figure 46).

c. Reverse Recovery Softness Factor may be computed (See Figure 9).



NOTE The figure shows the extrapolated criterion for terminating t_{rrf}. Alternatively, a specified point on the waveform may be used, e.g., 0.25 $I_{RM(REC)}$. The choice shall be specified, as it may affect the value of t_{rr}

Figure 46 — Generalized Reverse Recovery Waveforms for Test Condition D

6.6.10 Total Capacitance, C_T

In a semiconductor diode's transition region from p-type to n-type material there exists a charge dipole region or depletion layer with ionized impurity atoms on either side. As the junction bias is varied the width of the depletion layer varies. It is the effect in this region which gives rise to the apparent behavior like a charge capacitance. This effect is measured as junction capacitance; is it essentially independent of frequency over the range of test frequencies normally used (100 Hz to 10 MHz).

6.6.10.1Definitions

Total capacitance, C_T, is the sum of junction capacitance, C_J, and case capacitance, C_C, and is the small-signal capacitance between the diode terminals of the complete device under specified conditions of temperature, dc bias voltage and test signal amplitude and frequency.

6.6.10.2Procedure

As a dc bias voltage is applied to the DUT the capacitance is measured using any of a variety of suitable bridge techniques.

Test temperature (25 ± 5 C), although specified, is not critical as capacitance is not very sensitive to temperature. Thermal management is normally unnecessary, unless the bias is such that excessive heating could be experienced.

Junction capacitance is principally voltage dependent: recognizing this, the small signal test voltage shall be such that doubling or halving it shall cause no error greater than the required accuracy of the measurement

6.6.10.3Test Circuit

The test circuit is shown in Figure 47.

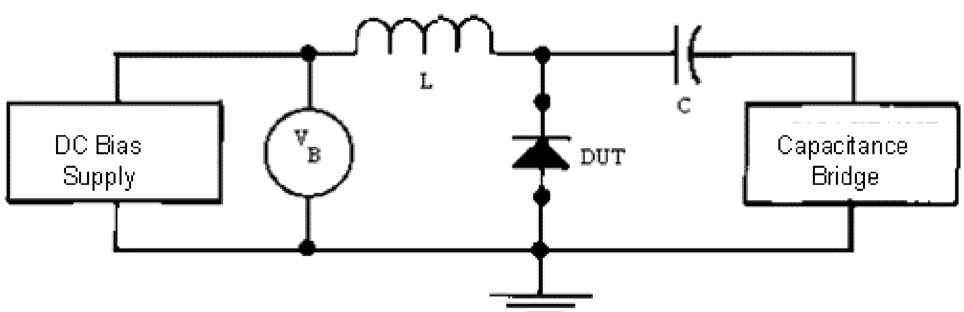


Figure 47 — Capacitance Test Circuit

6.7 Thermal Characteristics Test

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. Therefore, thermal resistance is an important factor in establishing the power handling ability of a semiconductor device.

6.7 Thermal Characteristics Test (cont'd)

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. Therefore, transient thermal impedance is an indication of the short-pulse-duration power handling ability of a semiconductor device.

One dimension heat flow is assumed in thermal resistance and 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 temperature is usually established at one of the following:
A specified point on the case
A specified point on a lead
The ambient air.

When the semiconductor may be either single- or double-side cooled, as with a disk or axial lead package, the applicable type of cooling must be specified.

6.7.1 Terminology

6.7.1.1 Definitions

Thermal resistance of a semiconductor device is defined as the temperature difference between two specified points or regions of the device divided by the power dissipated which causes the temperature difference under conditions of thermal equilibrium.

Transient thermal impedance of a semiconductor device is defined as the change in temperature difference between two specified points or regions of the device at the end of a time interval divided by the step function change in power dissipation which causes the change in temperature difference during the same time interval.

6.7.1.2 Letter Symbols

R_{thJR} = Thermal resistance, junction to reference point, in °C/Watt.
$Z_{thJR(t)}$ = Transient thermal impedance, junction to reference point, in °C/Watt.
T_J = Virtual junction temperature, in °C.
T_R = Reference point temperature, in °C.
$P_{P(AV)}$ = Magnitude of average heating power causing temperature difference T_J - T_R, in Watts.
$I_{F(MET)}$ = Value of metering current, in milliamperes.
$V_{F(MET)}$ = Value of forward voltage at $I_{F(MET)}$ (the temperature sensitive parameter), in millivolts.
$\Delta T_{(CAL)}$ = Difference between two calibration temperatures applied to the reference point, in °C
$\Delta V_{F(MET)}$ = Difference in $V_{F(MET)}$ when measured at two calibration temperatures, in millivolts.

Other symbols are defined in clause 6.7.2 and clause 6.7.5.2 as they relate to the equations used.

6.7.2 General Test Description

Since virtual junction temperature is difficult to measure directly, a temperature sensitive device parameter is used as its indicator. Forward voltage at a small percentage of rated current, $V_{F(MET)}$, is the parameter used. The corresponding value of the low level forward current used in this test method is called metering current, $I_{F(MET)}$.

To measure thermal resistance, R_{thJR}, or transient thermal impedance, Z_{thJR}, measurements are taken to satisfy the appropriate equations given below

6.7.2.1 Thermal Resistance

Two methods of measuring junction temperatures in order to determine thermal resistance are described herein. For the first method, referred to as the constant Junction Temperature Method (external heating method), thermal resistance is defined as:

$$R_{thJR} = \frac{T_J - T_R}{P_{F(AV)}} = \frac{T_{R1} - T_{R2}}{V_{F(HTG)} \times I_{F(HTG)} \times DF}$$

where:

T_{R1} = Measured reference (case, lead, 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, or ambient) temperature when operated with power applied.

$I_{F(HTG)}$ = Heating current used to produce the power dissipated in the active element of the diode.

$V_{F(HTG)}$ = Measured value of forward voltage when $I_{F(HTG)}$ is applied.

DF = Duty Factor

A more commonly used method is the Calibration Curve Method. Thermal resistance is defined as:

$$R_{thJR} = \frac{T_J - T_R}{P_{F(AV)}}$$

$$R_{thJR} = \left[\frac{(V_{F(MET)1} - V_{F(MET)2})K}{V_{F(HTG)} \times I_{F(HTG)} \times DF}\right] - \left[\frac{\Delta T_R}{V_{F(HTG)} \times I_{F(HTG)} \times DF}\right]$$

where:

$V_{F(MET)1}$ = Value of the temperature-sensitive parameter at the reference temperature used in the test procedure.

$V_{F(MET)2}$ = Value of the temperature-sensitive parameter immediately after the $I_{F(HTG)}$ pulse is terminated.

DF = Duty Factor.

ΔT_R = Rise in reference point temperature due to the application of heating current.

K = Thermal Calibration Factor = $\Delta T_{(CAL)} / \Delta V_{F(MET)}$

6.7.2.1 Thermal Resistance (cont'd)

Data to calculate thermal resistance are obtained by using a switching circuit which applies pulsed power at a high duty factor. The metering voltage is read out and from this the virtual junction temperature at the end of each power pulse is determined.

The calibration curve method, which requires a somewhat more involved calibration procedure uses simpler apparatus.

6.7.2.2 Transient Thermal Impedance

Transient thermal impedance is defined as:

$$Z_{thJR(t)} = \frac{T_{J(t)} - T_R}{\text{Peak Power}} = \frac{T_{J(t)} - T_R}{V_{F(HTG)} \times I_{F(HTG)}}$$

where:

T_R is the reference junction temperature prior to the heating pulse and $T_{J(t)}$ is the junction temperature at the conclusion of the heating pulse of duration t.

$$Z_{thJR(t)} = \frac{T_{J(t)} - T_R}{\text{Peak Power}} = \frac{(V_{F(MET)1} - V_{F(MET)2})K}{V_{F(HTG)} \times I_{F(HTG)}}$$

Either of these two methods may be used to determine transient thermal impedance. A typical curve is shown in Figure 48.

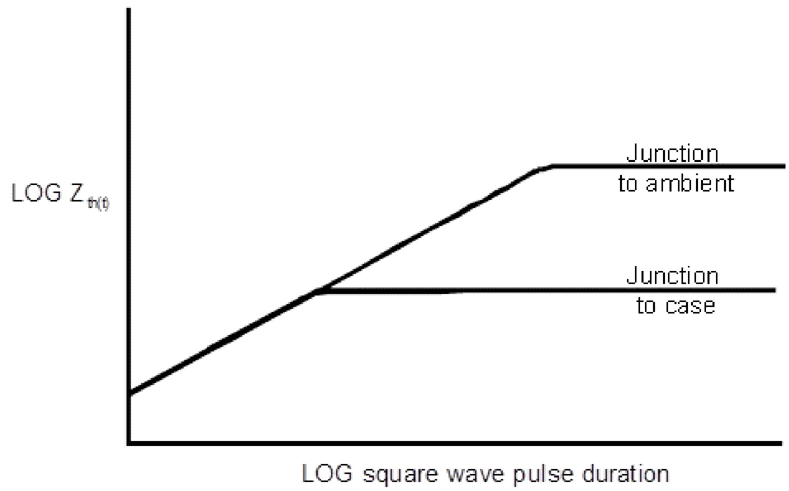


Figure 48 — Typical Transient Thermal Impedance Characteristic

6.7.2.2 Transient Thermal Impedance (cont'd)

Although the curve represents the junction temperature response to heating provided by the application of single rectangular power pulses of specified time durations, the curve can also be arrived at from the cooling curve of the active semiconductor element following interruption of continuously applied steady-state power. This cooling method is generally recommended for high current rectifier diodes since it is easier to perform than the heating pulse method which requires very high level power pulses to give significant junction temperature rise, particularly for short pulse durations.

Since measurements of thermal resistance, or of transient thermal impedance by the cooling method, involves high average power levels, considerable attention must be given to the heat dissipator used and the diode mounting arrangement

6.7.3 Heat Dissipator Requirements

6.7.3.1 Stud- and Based-Mounted Types

An acceptable type of heat dissipator for the junction-to-case thermal resistance test on stud-mounted rectifier diodes is a flat plate with the test device centrally mounted on it. For stud types, the mounting shall be through a clearance hole in the plate with the device fastened by means of a nut. The clearance hole in the plate should only be large enough to allow free passage of the stud. The plate thickness should be no more than one-half the stud length to allow the mounting nut to be properly attached. The mounting surface should be flat, burr-free, etc., as described in chapter 6. The device should be mounted using the manufacturer's recommendations regarding torque values, thread lubricants (or absence of same) and thermal compound applied to the device and heat dissipator interface.

For base-mounted rectifier diodes a similar flat plate should be used, drilled to accept the mounting hardware required by the DUT. The plate thickness should be the same as it would be for a stud-mounted rectifier of similar mounting dimensions at the seating plane.

The conductor connected to the top terminal of a stud- or base-mounted rectifier diode should be such that its heat dissipation does not add to the virtual junction temperature of the rectifier diode under test. For solder terminal devices, it is recommended that the wire size used be the largest size doubled back to its point of origin is recommended. Devices with flexible top leads should have the lead bolted to a heavy copper bus.
For all types of devices there should be no forced air cooling of the device case, lead or terminal.

6.7.3.2 Lead-Mounted Types

The recommended type of heat dissipator for the junction-to-lead thermal resistance test on axial lead type devices consists of two flat plates with the test device centrally mounted. The plate thickness should be much larger than the device lead diameter.

If forced air cooling is used, the cooling air should blow over the heat dissipators only and the device case and lead structures should be isolated. The connections to the leads should be such that heat dissipated there does not add to the virtual junction temperature of the diode under test; similarly, the leads should not be cooled so as to remove heat from the device.

6.7.3.2 Lead-Mounted Types (cont'd)

If natural convection cooling is used, the following conditions must be met:

a. The diode shall be mounted horizontally in a cubic enclosure of volume of not less than 0.028 cubic meter (1 cubic foot). If the diode is mounted on heat dissipators, e.g., square metal plates, they should be suspended vertically in the cubic enclosure. Each dimension of the enclosure should be a minimum of four times the dissipator height.

b. There shall be no radiation sources in the enclosure other than the diode under test.

c. The interior enclosure wall shall have a low reflectance finish. (Emissivity = 1.0).

d. More than one diode may be put in the enclosure, but all must be mounted on the same horizontal plane and they shall be at least five case dimensions away from each other and from the walls. Only one may be energized at time.

e. The ambient temperature should be measured by means of a thermocouple mounted at a distance approximately 1.3 cm (0.5 inch) directly beneath the device under test

6.7.3.3 Disk Types

It is recommended that water cooled heat dissipator(s) be used with disk type rectifier diodes. Thermal compound shall be applied between the rectifier diode pole piece(s) and the mounting surface(s) of the heat dissipator(s), which shall be flat and smooth, as described in clause 6.7.1.1 The mounting force recommended by the device manufacturer shall be applied perpendicularly to the rectifier diode pole pieces using a recommended clamping arrangement.

Since thermal resistance is affected somewhat by junction temperature, it is recommended that the thermal resistance test be performed so that the test device virtual junction temperature is within 20% of its maximum rated value. The size of the heat dissipator used for the power application test must be chosen to accomplish this or a controlled temperature system must be employed. The approximate case, lead or ambient temperature, T_{R2}, at which the device must be operated can be determined from the basic thermal resistance equation in clause 6.7.2.1.

6.7.4 Determining Reference Temperature

Stud- and Base-Mounted Rectifier Diodes:

The measurement of T_R (or T_{R1} and T_{R2}) is made by means of a thermocouple attached to the specified reference point. For details on reference points, types of thermocouples and methods of thermocouple attachment, see clause 7.8.

Lead-Mounted Rectifier Diodes:

The measurement of both T_{R1} and T_{R2} is made by means of a thermocouple attached to the diode on either the anode or the cathode lead at the specified reference point. Clause 7.8 has details on reference points, types of thermocouples and methods of thermocouple attachment.

6.7.4 Determining Reference Temperature (cont'd)

Disk-Type Rectifier Diodes:

Single Side Cooling: The device is mounted between a flat plate of minimum size and thickness and a heat dissipator which is usually liquid cooled. See clause 7.8 for details on reference points, type of thermocouples and methods of thermocouple attachment. The anode is cooled by placing the anode side of the rectifier against the heat dissipator while the opposite (cathode) side is not cooled. T_{R1} and T_{R2} are obtained from a thermocouple located in the anode reference point. To measure the thermal resistance with the cathode side cooled the disk type rectifier is removed, turned over and remounted. The thermocouple used to obtain T_{R1} and T_{R2} is now located on the cathode pole piece of the rectifier diode.

Double Side Cooling: The disk type rectifier diode is placed between two heat dissipators of equal cooling efficiency with thermocouples for measuring T_{R1} and T_{R2} located on both the anode and cathode pole pieces. Thermal resistance based on both the anode pole piece and the cathode pole piece thermocouple readings should be obtained and then averaged to determine the double side cooled thermal resistance. Alternatively, single side cooled values of T_{R1} and T_{R2} can be used to calculate the double side cooled value by using a parallel thermal resistance analog.

6.7.5 Thermal Resistance Test Methods

These test methods consist of two distinct steps; a power application test and a calibration test.

6.7.5.1 Constant Junction Temperature Test Method

Clause 6.7.5.2 through clause 6.7.5.5 describe the constant junction temperature test method.

6.7.5.2 Test Procedure

Step 1 - Power Application Test

First, the device is operated with power intermittently applied, but at a very high duty factor. During the interval between power pulses (when the heating current has been removed), the metering current continues to flow and the forward voltage is measured. The diode current and voltage waveforms are shown in Figure 49 for a 60 Hz repetition rate. For testing very high current devices, a slower repetition rate may be required (thereby lengthening time interval $t_{1'}$ - t_1) in order that the interval t_4 - t_1 can be made greater than 0.333 ms and still meet the requirement of a minimum duty factor of 98%. The metering current which flows continuously must be held constant. This is particularly important during the metering interval between power pulses because the test device impedance will vary considerably during that time.

It would be desirable to arrive at the diode virtual junction temperature at the exact instant when heating current removal is initiated since the virtual junction temperature will be maximum at that time. However, this is not possible by direct measurement. First it takes a finite time for the diode current to decay from the heating current value to the metering current value (t_2 - t_1 in Figure 49). This fall time must be controlled and the rate of forward current decay is listed as a test condition. Secondly, transients will exist in the forward voltage waveform for some time after the metering current value has been reached. These induced voltages are due primarily to the reduction in forward current and may also cause some forward voltage waveform distortion. Consequently the forward voltage cannot be used as an indicator of virtual junction temperature until after these transients have subsided.

6.7.5.2 Test Procedure (cont'd)

The time t_3 on the waveforms represents the shortest time after the removal of heating current at which forward voltage may be measured. Time t_3 should be expected to be in the range of 100 µs to 200 µs for diodes up to DO-205AA(DO-8) size and up to 400 µs and longer for larger devices. For a particular device type, the time t_3 is best found by performing the test at various power levels and noting the shortest time where the measured value of thermal resistance is essentially independent of the power dissipated. Power levels of 25% above and below the power corresponding to the specified heating current are recommended for this determination.

Since some active element cooling occurs between the time when the heating current is removed (t_1) and time t_3, the thermal resistance value determined from a voltage measurement at t_3 will be in error. It is therefore desirable to extrapolate the voltage waveform back to t_1 from t_3 based on the shape of the waveform from t_3 to t_4 where the waveform is a true representation of the junction temperature cooling curve.

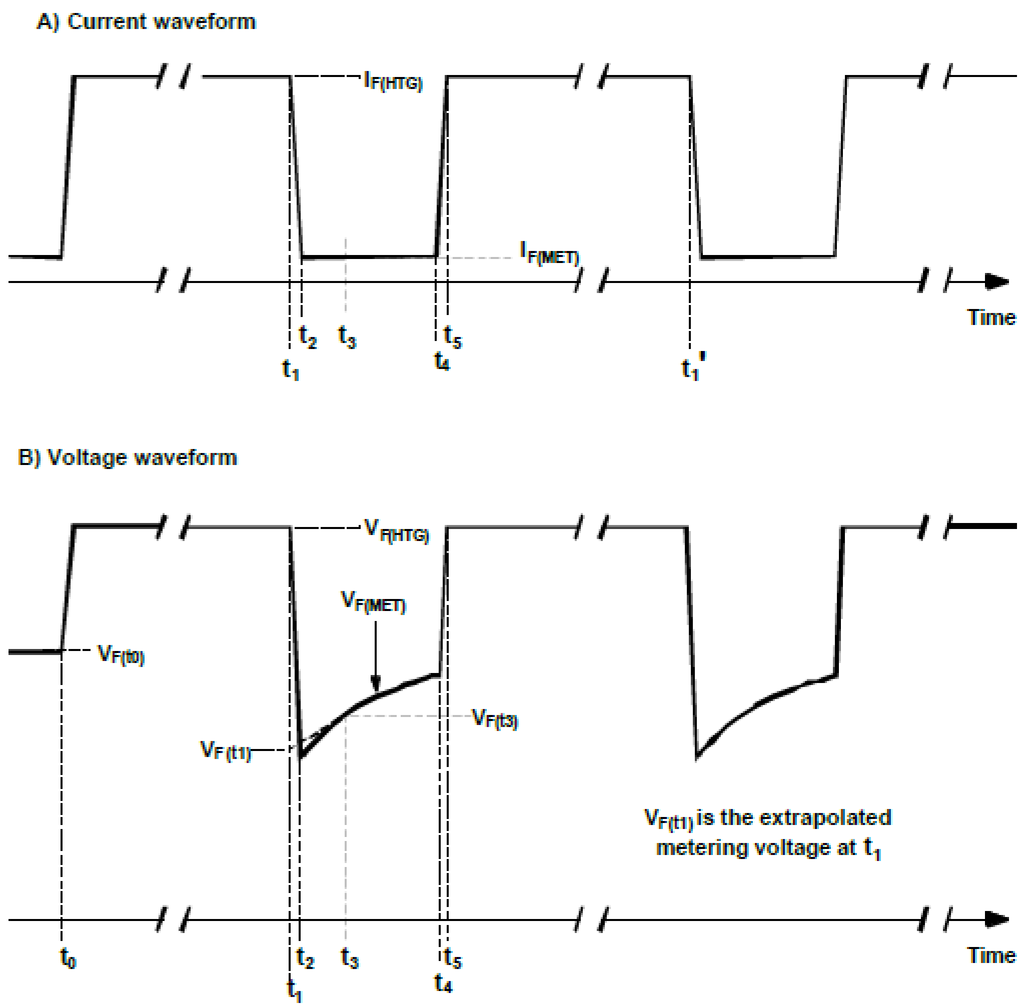


Figure 49 — Current and Voltage Waveforms During Thermal Resistance Test

6.7.5.2 Test Procedure (cont'd)

Time constants of the device cooling curve are relatively long. Linear extrapolation of the actual cooling curve from time t_3 back to time t_1 results in little error and is recommended. Figure 50 illustrates the extrapolation.

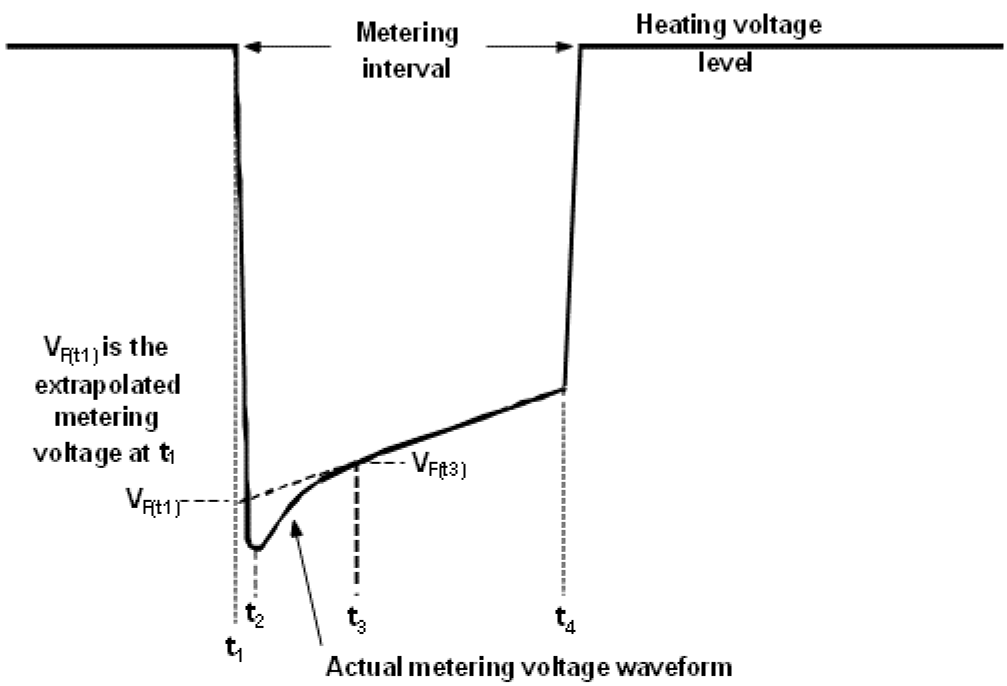


Figure 50 — Illustration of Forward Voltage Waveform Extrapolation

The heating current magnitude should be between one and two and one-half times the average current rating of the device. It must be applied for a time duration long enough for the diode active element and case to reach thermal equilibrium. The DUT junction temperature shall be considered stabilized when halving the time between the initial application of power and the taking of the reading causes no change in the indicated results within the required accuracy of measurement. The metering current magnitude should be low enough so that the resultant active element heating is negligible. A recommended procedure is to use 0.1% to 1.0% of rated current to put the diode in the linear portion of its voltage-temperature characteristic.

In addition to recording the metering voltage waveform, the value of heating current, $I_{F(HTG)}$, and the diode reference (case, lead or ambient) temperature are to be recorded during Step 1.

6.7.5.2 Test Procedure (cont'd)

Step 2 - Calibration Test:

The power application test (Step 1) produces a value of forward voltage at the metering current level (extrapolated back to time t_1) which corresponds to the maximum virtual junction temperature attained.

Step 2 consists of operating the test device with no significant power dissipation so that for all practical purposes, the diode virtual junction temperature and the reference temperature are equal. The diode is operated at the same value of metering current as in Step 1. The forward voltage is monitored while the diode is externally heated on a temperature controlled block or in an oven until the measured value of forward voltage equals the extrapolated value, $V_{F(t1)}$, obtained previously. When the forward voltage has stabilized, the rectifier diode reference temperature is recorded. This is the value of T_{R1}. In the event that the determined value (in ºC) is not within 20% of maximum rated temperature, which is a specified test condition, Step 1 must be repeated using a different heating current amplitude. However, since thermal resistance is not strongly dependent upon junction temperature, the thermal resistance value computed may be used as a fairly accurate estimate for the second trial

6.7.5.3 Test Circuit

A basic circuit which may be used for testing the rectifier diode in Step 1 with high-level (heating) current present is shown in Figure 51. The active element of the device under test is heated by a direct current having an rms ripple content of 5% or less which is passed continuously through the device under test except for the metering periods. During the metering periods, the junction temperature is determined by reducing the forward current to the metering current value and measuring the forward voltage. This circuit will produce the forward current and forward voltage waveshapes shown in Figure 49. Variations of this circuit that produce the same waveforms are permissible.

Control of the heating current through the device under test is accomplished by SCR_1 and SCR_2 (refer to Figure 51) which functions as a flip-flop switching with a sufficient repetition rate to facilitate oscillography observations. Current is carried by SCR_1 only during the forward voltage metering interval so this SCR may be considerable smaller than SCR_2. Capacitor C, which is charged by a low current dc power supply, has the function of turning off SCR_2 when SCR_1 is triggered.

Unavoidable inductance in the heating current power supply and associated circuit wiring makes it impossible to turn off the heating current abruptly without creating transient voltages which would interfere with the measurement of forward voltage. To overcome this, the diverter circuit consisting of rectifier diodes D_1 through D_5 is included so that heating current is not interrupted by SCR_2, but simply finds a different path. The inductor L may be included to make certain that the heating current does not vary while it transfers from one path to the other. This inductor also serves to reduce, to a negligible amount, undesired flow of current C through the device under test and the heating current supply. The inductance in the diverter circuit should be kept low so that after SCR_1 begins to conduct, all heating current will be diverted away from the device under test fast enough to allow the specified rate of forward current decay to be achieved. In Figure 51 the portion of the circuit in which inductance must be carefully controlled is indicated by heavy lines.

6.7.5.3 Test Circuit (cont'd)

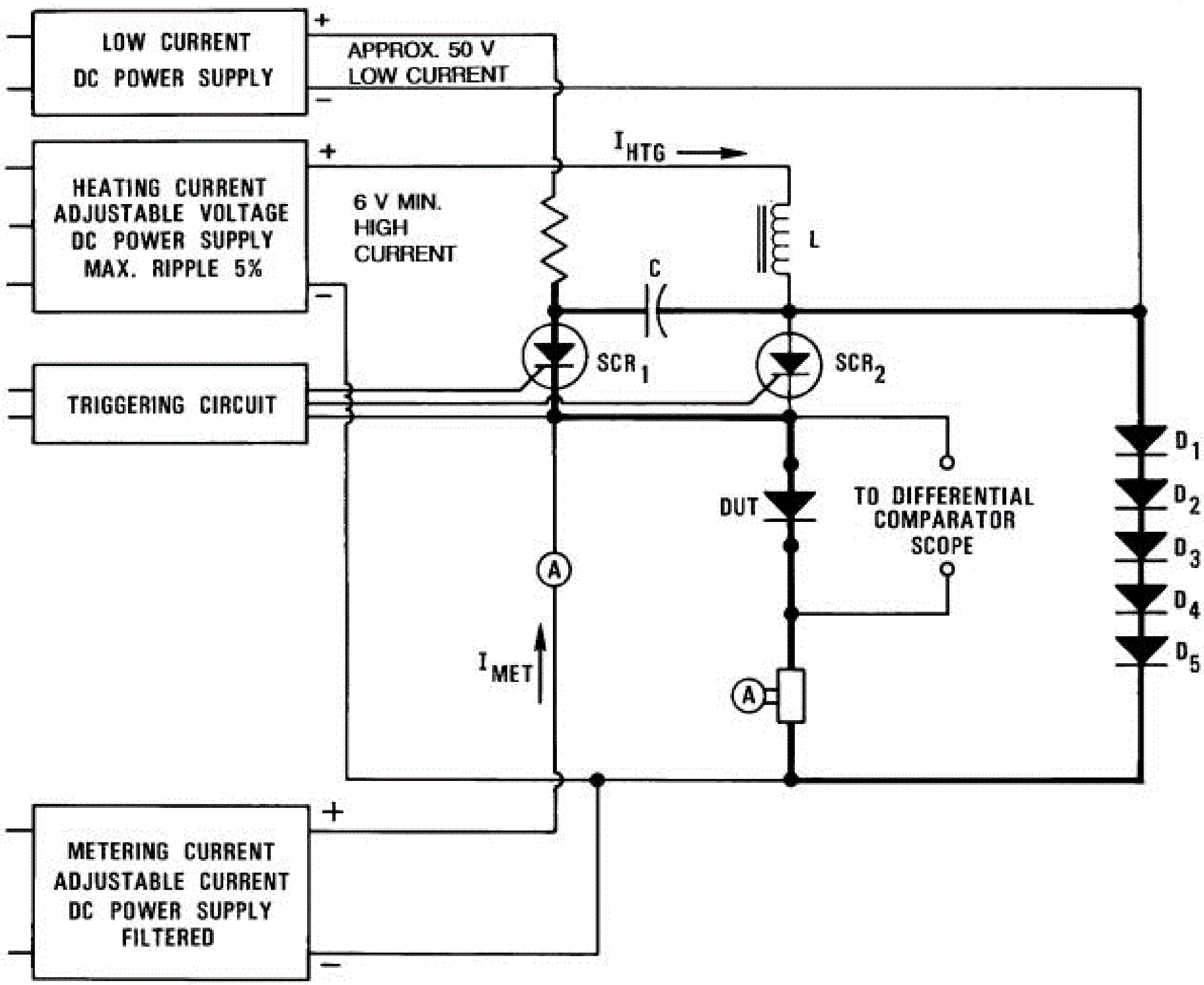


Figure 51 — Thermal Resistance test Circuit (High-Current Devices)

In order to observe the forward voltage of the test device during the metering current interval, the use of a differential comparator oscilloscope preamp is recommended. With care, this should allow magnification of the forward voltage waveform during the metering current interval without distortion or zero shift being introduced due to the presence of the heating voltage waveform. Care must be taken to ensure that distortion or zero shift is not significant compared to the signal being measured. A DSO or oscilloscope camera is extremely useful for recording the waveform so that the pictures can be used to obtain the data for the necessary extrapolation of the metering voltage waveform.

6.7.5.4 Test Conditions to be Specified

a. Metering Forward Current Amplitude =______A dc

b. Heating Forward Current Amplitude =______A pk

c. Heating Forward Current Duty Factor = 98% min.

d. Heating Forward Current Repetition Rate =______Hz

e. Rate of Forward Current Decay
(90% point to metering current level)
(See NOTE) = 100 A/µs min.

f. Measurement time t_3
(After metering current level is reached.) =______µs

g. Total Heating Time Duration =______s min.

h. Reference Temperature Measurement Point
(Point on Case or Pole Piece, or Point on Lead at
stated distance from Device Body.
Refer to clause 7.7) =______

i Reference Temperature, T_{R1} (ºC)
Maximum rated T_J + 0% to 20%. =______

NOTE It may be necessary to take exception to this condition. This is particularly true for large rectifier diodes, which are operated at heating currents in excess of 100 A. When exception is taken, the actual rate of decay used must be specified.

6.7.5.5 Characteristic to be Determined

Steady State Thermal Resistance,
Junction to Specified Reference Point =______ºC/W

6.7.5.6 Calibration Curve Test Method

Clause 6.7.5.7 through clause 6.7.5.10 describe the calibration test method

6.7.5.7 Test Procedure

Step 1 - Power Application Test:

The power application test shall be performed in two parts. For both portions of the test, the reference point (case or lead) temperature shall be held constant at a specified value. (a) The value of the temperature-sensitive parameter $V_{F(MET)}$ shall be measured for the specified metering current $I_{F(MET)}$ at T_R. (b) The diode under test shall then be operated with heating power ($P_{F(AV)}$) intermittently applied at a greater than 98% duty factor, maintaining the reference point at T_R. The temperature-sensitive parameter $V_{F(MET)}$ shall be measured during the interval between heating pulses ($\leq$300 µs) with constant measuring current $I_{F(MET)}$ applied.

If, as can be the case with lead mounted devices, it is not possible to maintain the reference point (lead) temperature constant during the power application test, the difference in the reference point (lead) temperature at which $\Delta V_{F(MET)1}$ and $\Delta V_{F(MET)2}$ are measured should be recorded.

6.7.5.7 Test Procedure (cont'd)

This lead temperature difference (ΔT_R) divided by the heating power ($P_{F(AV)}$), shall be subtracted from the calculated thermal resistance to correct for the error. Refer to the calibration curve method equations for thermal resistance, R_{thJR}, in clause 6.7.2.1.

In the case of thermally unsymmetrical devices where the reference point temperature on one lead is higher than on the other the correction factor should be based on the average of the two reference point temperatures.

It would be desirable to arrive at the diode virtual junction temperature at the exact instant when heating current removal is initiated since the virtual junction temperature will be maximum at that time. However, as explained in clause 6.7.5.2, this is not possible.

Time t_3 represents the shortest time after the removal of heating current that forward voltage may be measured. (Figure 49) Time t_3 should be expected to be in the range of 10 µs to 50 µs for lead mounted diodes. For a particular device type, time t_3 is best found by performing the test at various power levels and noting the shortest time where the measured value of thermal resistance is essentially independent of the power dissipated. Power levels of 25% above and below the power corresponding to the specified heating current are recommended for this determination.

In general, since some active element cooling occurs between the time when the heating current is removed and time t_3, the thermal resistance value determined from a voltage measurement at t_3 will be found in error. Nevertheless, in the case of lead mounted diodes this error in the calculated junction-to-lead thermal resistance is negligible since most of the thermal resistance (>95%) is in the terminal pins and leads of the device under test. The junction-to-lead thermal resistance may therefore be calculated from the value of the temperature- sensitive parameter $V_{F(MET)}$ as measured at time t_3. For other than lead mounted diodes the procedure given in clause 6.7.5.2 should be followed.

The heating current magnitude should be between one and two and one-half times the average current rating of the device. It must be applied for a time duration long enough for the diode active element and case to reach thermal equilibrium. The DUT 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 measurement. The metering current magnitude should be low enough so that the resultant active element heating is negligible. A recommended procedure is to use 0.1% to 1.0% of rated current to put the diode in the linear portion of its voltage-temperature characteristic.

Step 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 specified measuring current $I_{F(MET)}$ used during the Power Application Test. Under this condition T_R T_J. The device under test shall be externally heated in an oven or on a temperature-controlled block. The reference point temperature range used during calibration shall encompass the temperature range encountered in the Power Application Test. The value of the temperature-sensitive parameter temperature coefficient $\Delta V_{F(MET)} / \Delta T_{(CAL)}$ shall be calculated from the calibration curve

6.7.5.8 Test Circuit

The test circuit described in clause 6.7.5.3, Figure 51, may be used when testing high current devices by the calibration curve test method. For lead-mounted rectifier diodes, the circuit shown in Figure 52 is more appropriate.

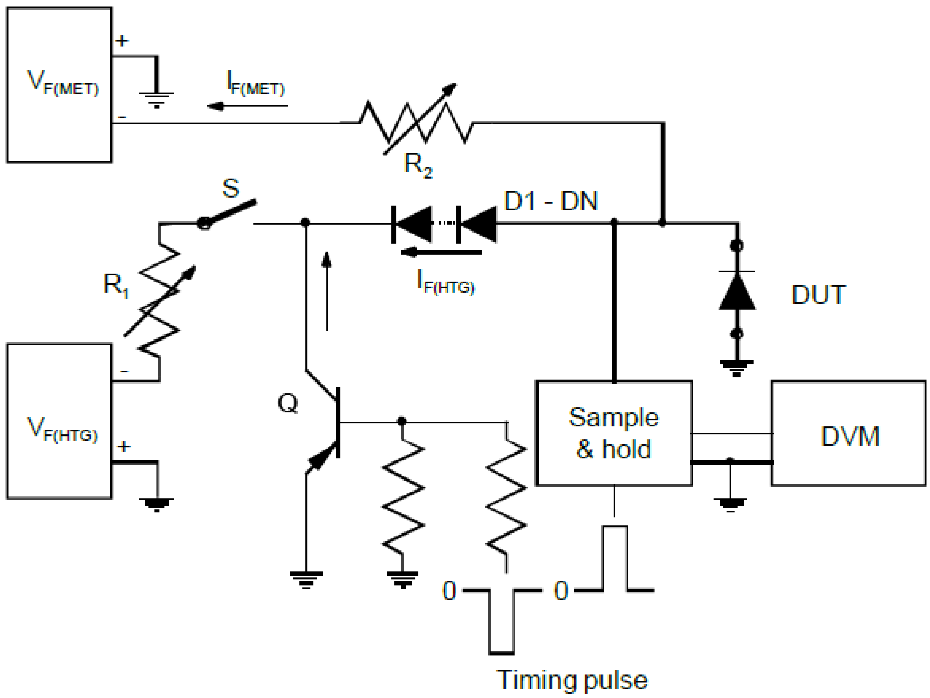


Figure 52 — Thermal Resistance Test Circuit (Low Current Devices)

The circuit is controlled by a timing pulse with a width of ≤300 s and a repetition rate ≤60 Hz (sufficient to facilitate oscillography observations). When the voltage level of the timing pulse is zero, the transistor Q is off and the forward current through the diode under test (DUT) is the sum of the constant heating current and the constant measuring current. Biasing transistor Q on shunts the heating current to ground and effectively eliminates conduction through D_1 - D_N.

The sample-and-hold unit (or cathode ray oscilloscope) is triggered when the heating current is removed and is used to monitor the forward voltage of the diode under test. During calibration (Step 2), switch S is open.

6.7.5.9 Test Conditions to be Specified

a. Metering Current Amplitude	=______A dc
b. Heating Current Amplitude	=______pk
c. Heating Current Duty Factor	= 98% Min.
d. Heating Current Repetition Rate	=______Hz Max.
e. Rate of Forward Current Decay (90% Point to Metering Current Level)	= 5 A/µs Min.
f. Measurement time t_3 (After Metering Current Level is reached)	=______s
g. Total Heating Time Duration	=______s Min.
h. Reference Point Temperature Measurement Point (Point on case or lead at stated distance from device body (See clause 7.8)	=______
i. Reference Point Temperature for Power Application Test	=______ºC

6.7.6.10Characteristic to be Determined

Steady State Thermal Resistance, Junction to Specified Reference Point	=______ºC/W

6.7.6 Transient Thermal Impedance Test Methods

Measurement of transient thermal impedance by the Heating Pulse Method is very similar to the measurement of thermal resistance, except that the heating current is applied as a single pulse. For the Cooling Curve Method, a steady-state condition is established under dc power conditions; upon power removal the forward voltage with metering current applied is displayed on an oscilloscope and recorded.

6.7.6.1 Heating Pulse Test Method Procedure

Considerations to be given to the metering current and proper extrapolation of the metering voltage waveform are discussed in 5.7.5.2. Two distinct steps are utilized; a power application test and a calibration test.

Step 1 - Power Application Test

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. Care must be taken, when applying heating current pulses, to avoid exceeding device non-repetitive surge current capabilities.

The heating pulse current amplitude should be high enough to raise the test device virtual junction temperature to its maximum rated value +0% - 20% in ºC. 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. If the current pulse is so short that an excessive current amplitude would be required to attain rated junction temperature, external heating of the test device to an intermediate temperature may be employed.

6.7.6.1 Heating Pulse Test Method 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 temperature rise during the interval when power is applied. When an external heat dissipator is employed, the information regarding heat dissipators, mounting, and connection to the top terminal given in clause 6.7.3 should be adhered to.

When an approximate value for the test device transient thermal impedance is known, the equation for $Z_{thJR(t)}$ in clause 6.7.2.2 may be employed to calculate the approximate value of heating current required to raise the device virtual junction temperature to maximum rated value; otherwise, the required current magnitude must be arrived at by trial and error.

The measured values of heating current magnitude, $I_{F(HTG)}$, heating voltage magnitude, $V_{F(HTG)}$, and rectifier diode reference temperature, T_{R2}, all must be recorded during Step 1. If the heating current waveform deviates much from a truly rectangular pulse, then graphical integration of the product of the heating current and heating voltage waveforms must be employed to determine the rectifier diode power dissipation.

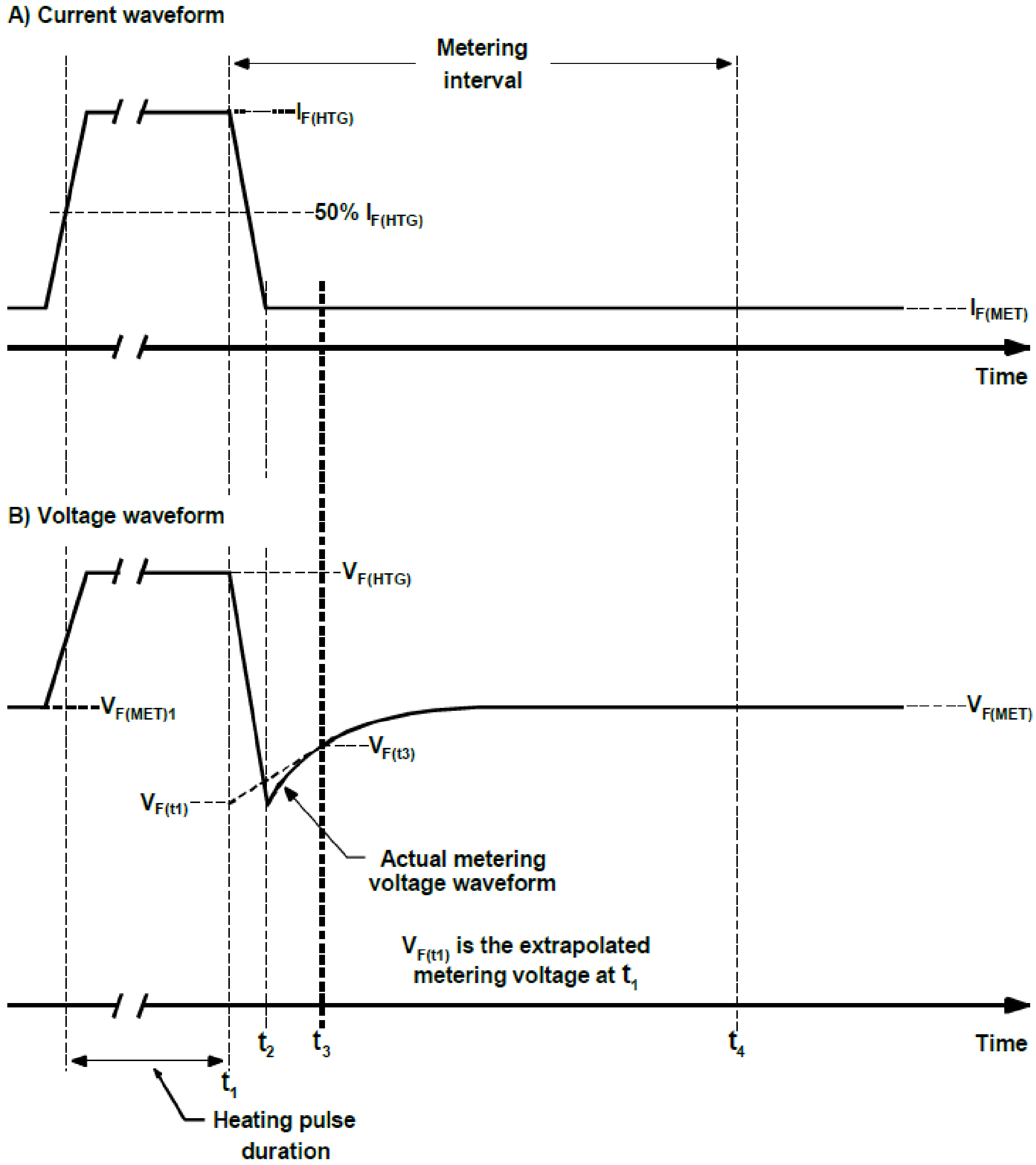
It must be recognized that thermocouple measuring system response time may cause some error in the measurement of T_{R2} for mid-range heating pulse widths. This may cause discontinuity in a transient thermal impedance curve obtained for a wide range of pulse widths. Also, because of an inability of the heat dissipator to respond to the mid-range heating pulse widths, variations in T_{R2} may have to be compensated for.

As noted, Step 1 includes a metering voltage measurement that is used to determined device virtual junction temperature at the exact instant when heating current removal is initiated since the virtual junction temperature will be maximum at that time. However, this is not possible by direct measurement; because of transients which exist on the forward voltage waveform, readout cannot commence until time t_3. It is necessary to use linear extrapolation from time t_3 to t_1 for most accurate results. For an illustration of the waveforms and the extrapolation required, see Figure 53. The discussion in clause 6.7.5.1 provides further details.

Step 2 - Calibration Test

The power application test (Step 1) produces a value of forward voltage at the metering current level (extrapolated back to time t_1) which corresponds to the maximum virtual junction temperature attained. Step 2 consists of operating the test device with no significant power dissipation so that for all practical purposes, the rectifier diode virtual junction temperature and the reference temperature will be equal. The procedure is the same as given for the measurement of thermal resistance in clause 6.7.5.2 under "Step 2 - Calibration Test". The value obtained is T_{R1}. In the event that the determined value of T_{R1} (in °C) is not within the range 100% to 80% of rated junction temperature, which is a specified test condition, Step 1 must be repeated using a higher or lower heating pulse current amplitude as may be required. The transient thermal impedance can now be calculated using the equation for $Z_{thJR(t)}$ in clause 6.7.2.2.

6.7.6.1 Heating Pulse Test Method Procedure (cont'd)



NOTE $V_{F(t1)}$ is equal to $V_{F(MET)2}$ in the equation for $Z_{thJR(t)}$ in clause 6.7.2.2 .

Figure 53 — Current and Voltage Waveforms for Heating Pulse Transient Thermal Impedance Test

6.7.6.2 Cooling Curve Test Method Procedure

Two separate steps are also required for this method: a power application test and a calibration test.

Step 1 - Power Application Test

The heating current is applied as a continuous current for a time duration long enough to establish thermal equilibrium and then is interrupted. The magnitude of the heating current may range from the average current rating of the device up to two and one-half times this rating.

It is recommended that the transient thermal impedance test be performed so that the test device virtual junction temperature (in ºC) before the heating current is interrupted is in the range of maximum rated value +0% -20%. The size of the heat dissipator used must be chosen to accomplish this. The approximate reference temperature can be determined from the basic thermal resistance equation, R_{thJR}, in clause 6.7.2.1.

The recommended heat dissipators and conductors to use with various types of devices when transient thermal impedance, junction to case, is to be measured are given in clause 6.7.3.

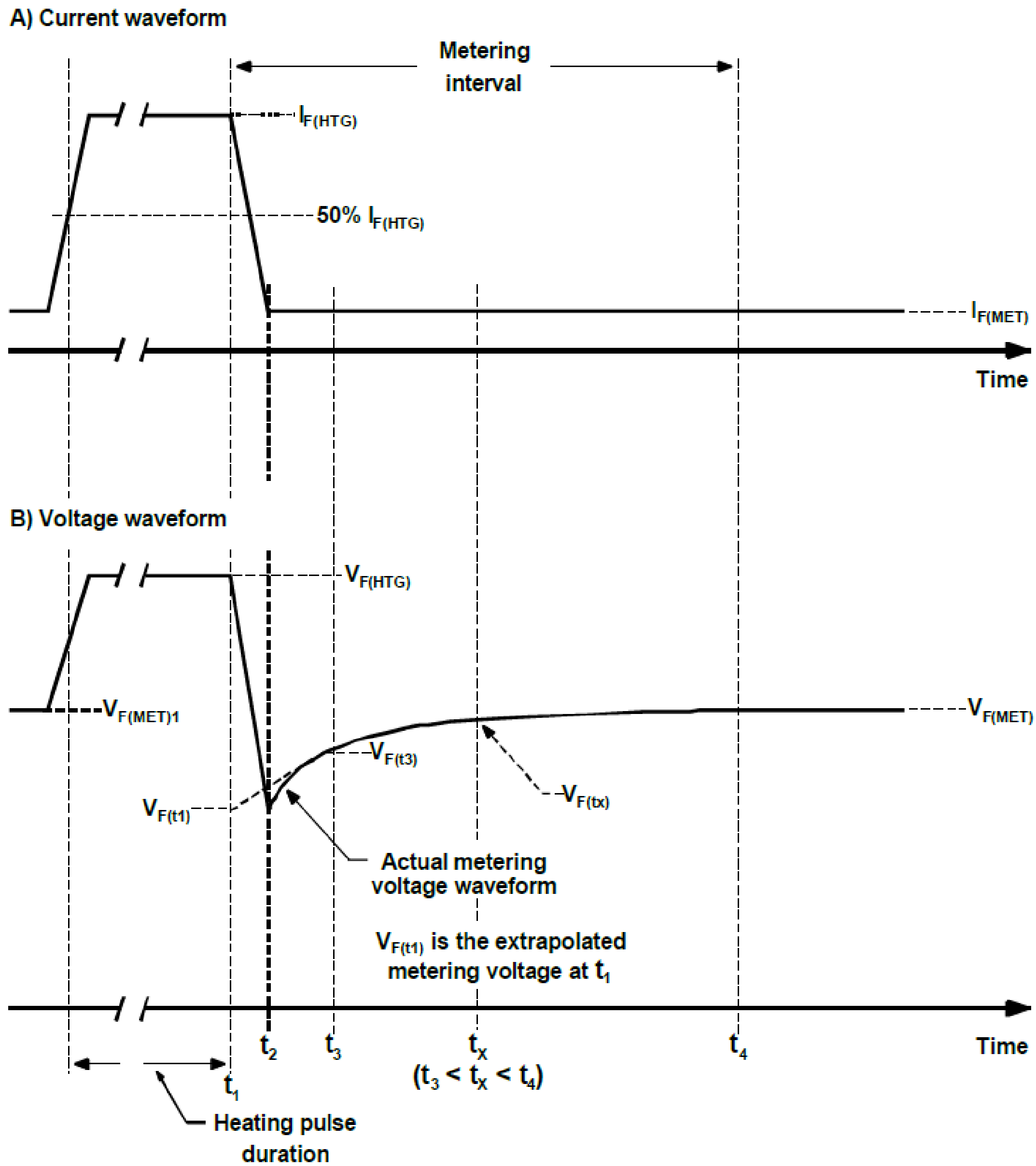
After thermal equilibrium has been reached, the heating current magnitude $I_{F(HTG)}$ and the corresponding heating voltage magnitude $V_{F(HTG)}$ are recorded. The rectifier diode reference temperature T_{R2} must also be recorded. The heating current is then interrupted at the time t_1, so that the test device only conducts the low level metering current. The rate of decay of heating current is an important test condition and must be specified. The forward voltage waveshape from the value when heating current is interrupted to the value at the time t_x, when the transient thermal impedance is to be measured, with metering current flowing, must be recorded as a function of time. This may be accomplished by recording the oscilloscope trace of the voltage change. The trace will be similar to that shown in Figure 54. The test may be repeated several times using a range of oscilloscope sweep rates to accurately record all portions of the voltage decay curve. Again, it is necessary to extrapolate the metering voltage back to time t_1 to obtain the maximum virtual junction temperature. The test device reference point temperature decay with time must also be recorded as it may vary during intermediate portions of the cooling cycle. Mounting the test device on a heat dissipator of large thermal capacity will minimize the change in DUT reference point temperature following the interruption of heating current.

This information allows the virtual junction temperature of the test device to be determined for any specific time duration, $t_x - t_1$, after interruption of the heating current. Information given in clause 6.7.6.1 regarding the metering current supply and choice of metering current magnitude, applies for the cooling curve method also.

Step 2 - Measurement of the Temperature Coefficient of the Temperature Sensitive Parameter (Calibration)

Step 1 produces a curve versus time of low level forward voltage at the metering current level which must be converted by a calibration curve to junction temperature versus time. This calibration curve may be obtained by measuring forward voltage at the metering current level (metering voltage) at various values of case or ambient (reference point) temperature. Since there is no appreciable power dissipation at the metering current level, for all practical purposes the rectifier diode virtual junction temperature will be equal to the measured case, lead or ambient temperature.

6.7.6.2 Cooling Curve Test Method Procedure (cont'd)



NOTE — In the equation for $Z_{thJR(t)}$ in clause 6.7.2.2, $V_{F(MET)2}$ and time (t) are equal to $V_{F(tx)}$ and time t_x - t_1

Figure 54 — Current and Voltage Waveforms for Cooling Curve Transient Thermal Impedance Test

6.7.6.2 Cooling Curve Test Method Procedure (cont'd)

This measurement should be made for at least three values of reference point temperature with the maximum value being equal to the rated operating junction temperature of the rectifier diode. A straight line drawn through the measured points is the desired graph. The general form of this graph is shown in Figure 55.

Transient thermal impedance at any time duration following the interruption of heating current can now be calculated by converting the measured values of $V_{F(tx)}$ from a photograph or digital recording obtained in Step 1 to junction temperatures using the calibration curve obtained as described above. The initial value of T_J (in ºC) (at the instant of interruption of heating current) should be within 20% of rectifier diode maximum rated junction temperature, since this is a specified test condition. If the initial value of T_J determined from the calibration curve does not fall within this range, then Step 1 must be repeated using either a different value of heating current or a different size of heat dissipator in order to satisfy the specified T_J range condition. T_{R2} is the reference temperature at the instant that heating power is removed. If this temperature decays during the period when the junction is cooling, the measured junction temperature must be adjusted upward by the amount of reference temperature cooling that occurs.

A value of transient thermal impedance for the time interval being considered can now be obtained by using the equation for $Z_{thJR(t)}$ in clause 6.7.2.2. However, since a cooling curve has been employed, the above calculated value must be subtracted from the rectifier diode steady-state thermal resistance to obtain a point on the transient thermal impedance curve (such as Figure 48) applicable to a power pulse of width (t_x - t_1) equal to the time interval between the interruption of heating current (t_1) and the point (t_x) where the above temperature determination has been made.

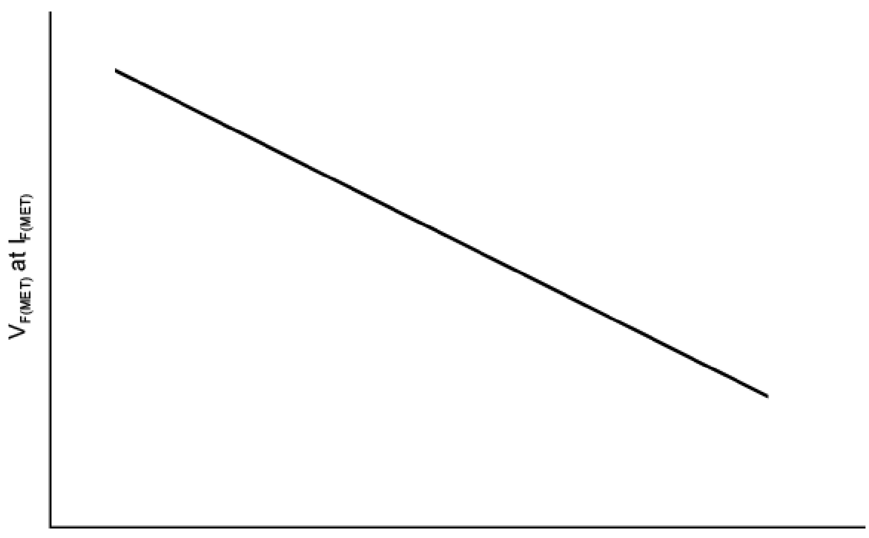


Figure 55 — Rectifier Diode Calibration Curve

For time values less than approximately 100 µs, the calculated values of transient thermal impedance may be in error because of device and equipment transients resulting from the interruption of the heating current. The point in time where the cooling curve starts to be a true representation of rectifier diode virtual junction cooling may be determined by employing heating currents which produce power levels 25% above and below the value which produces maximum rated junction temperature. This procedure, and a method of extrapolation of the curve to the time of interruption of the heating current, are further described in clause 6.7.5.2.

6.7.6.3 Test Circuits

A simplified basic test circuit for testing the rectifier diode in Step 1 is shown in Figure 56. The active element of the device under test is heated by direct current having an rms ripple content of 5% or less. The heating current is applied continuously when the cooling curve method is used for Step 1. When the heating pulse method is used for Step 1, the heating current must be interrupted after flowing for the time interval for which the transient thermal impedance measurement is to be made. See Figure 53 and Figure 54. The metering current supply remains connected throughout the heating current duration so that metering current will be maintained after interruption of the heating current.

Control of the heating current amplitude is accomplished by adjustment of the supply voltage and/or variation of series resistance. Interruption of the heating current is made by opening switch S. S may be a manual switch when the cooling curve method is used. However, the switch must provide positive interruption and be free from contact bounce. The diverter circuit, (D_1, D_2, and D_3), will assure clean interruption of the heating current through the DUT. An SCR, together with a suitable commutation circuit, may be used when the heating pulse is too short to be controlled by manual control. Thus, the basic circuit shown in Figure 51 for the steady-state Thermal Resistance Test Method may be used with a trigger circuit suitable for single pulse operation. Variations of this circuit which will produce the specified test conditions are permissible. In order to achieve control of the rate of decay of heating current, care must be taken to control the inductance in the heating current circuit.

In order to observe the forward voltage of the test device during the metering current interval following heating current interruption, the use of a differential comparator oscilloscope preamp is recommended. With care, this should allow magnification of the forward voltage waveform during the metering current interval without distortion or zero shift being introduced due to the presence of the heating voltage waveform. An oscilloscope is required to record the DUT forward voltage during the time the junction of the DUT is cooling and to extrapolate the metering voltage back to the instant when the heating current was interrupted.

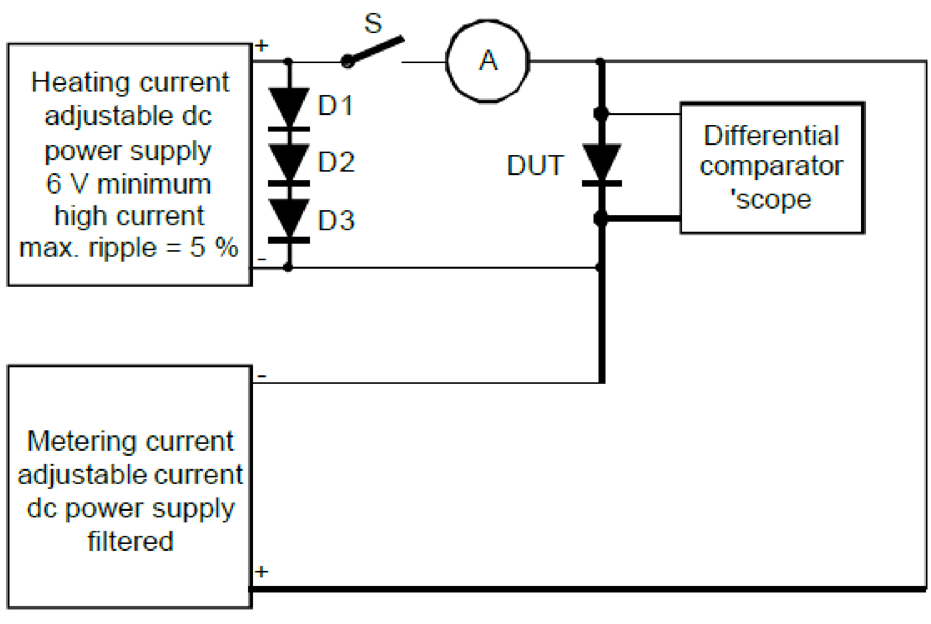


Figure 56 — Basic Test Circuit for Transient Thermal Impedance Test Method

6.7.6.4 Test Condition to be Specified

a. Method: (Heating or Cooling) =

b. Metering Forward Current Amplitude =______A dc

c. Heating Forward Current Amplitude =______A pk

d. Heating Forward Current Pulse Width =______s

e. Rate of Forward Current Decay
(90% Point to Metering Current Level)
(See NOTE) =__100__A/µs min.

NOTE It may be necessary to take exception to this condition. This is particularly true for large rectifier diodes which are operated at heating currents greater than 100 A. When exception is taken, the actual rate of decay used must be specified.

f. Measurement Time t_3
(After Metering Forward Current is Reached) =______µs

g. External Reference Temperature
Measurement Point =______

h. Transient Thermal Impedance,
Junction to Specified Reference Point,
for time duration of _____seconds =______ºC/W

Table 12 — Example for Recording Data

Time Duration (Seconds)							
Transient Thermal Impedance (C°/W)							

6.7.7 Effective Thermal Resistance of Bridge Rectifier Assemblies

This method describes a means to cause current to flow alternately through the legs of a single-phase or three-phase bridge assembly under conditions making it possible to determine its effective thermal resistance. The bridge is operated under steady-state I_O conditions, and the current in each leg is interrupted while readings are taken from which to calculate thermal resistance.

6.7.7.1 Definitions

The following symbols and terminology shall apply for the purposes of this test method:

V_F The forward-biased junction voltage drop of the device under test (DUT) used for junction temperature sensing. For a bridge, this applies to individual legs (i.e. one ac to one dc terminal).

V_{F1} The forward voltage at room temperature at I_{REF}.

V_{F2} The forward voltage at I_{REF} and 100 ºC above the temperature at V_{F1}.

V_{F2A} The computed forward voltage at I_{REF} and at maximum rated T_J.

V_{F3} The initial V_F value at I_{REF} before the application of heating power, with the device at reference case temperature (T_3).

V_{F4} The final V_F value at I_{REF} after stabilization of temperatures due to the application of rated current at rated case temperature.

ΔVF The change in the temperature-sensitive parameter, V_F, in volts, due to the application of heating power to the DUT.

V_{FH} The maximum forward voltage resulting from the application of I_O to the DUT.

I_O The rated average current applied to the DUT.

I_{REF} The low-level measurement dc current used to forward-bias each diode junction for measurement of V_F.

TCVF The voltage-temperature coefficient of V_F with respect to T_J at a fixed value of I_{REF}; in V/ ºC.

T_J The DUT junction temperature.

ΔT_J The change in T_J caused by the application of I_O.

T_N The reference case temperature for measuring V_{FN}. (N = 1, 2, 3, or 4.)

TSP The temperature-sensitive parameter (V_F).

t_{F4} Step trace time.

R_{thJC} The thermal resistance from device junction to a defined reference point on the outside surface of the case; in units of ºC / W.

R_{thJL} Thermal resistance from device junction to a lead, at a specified distance from the body; in units of ºC / W.

6.7.7.2 Test Circuit

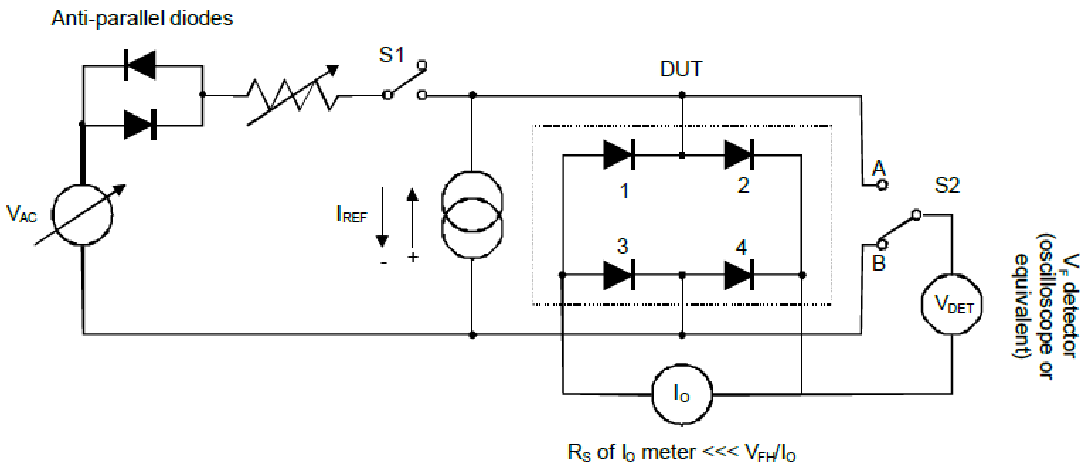
The apparatus required for this test shall include the following, configured as shown in Figure 57 and Figure 58.

- **High current source:** A source for 60 Hz single- or three-phase sinewave ac power capable of being adjusted to the desired value of I_O and able to supply the V_{FH} value required by the DUT. The current source should be able to maintain the desired current to within + or – 2% during the entire time needed for temperature stabilization and measurements.
- **Measuring current:** A constant-current source to supply I_{REF} with sufficient compliance voltage range to turn on fully the junction of the diode leg being measured.
- **Anti-parallel fast recovery:** Anti-parallel fast recovery rectifier diodes with ratings exceeding I_O, to provide isolation of the high-current source from I_{REF} during commutation of I_O between legs.
- **Voltage measurement circuit:** A voltage measurement circuit capable of accurately making the V_F measurements within the available time interval (when the anti-parallel diodes are not conducting), with millivolt resolution .

6.7.7.3 Procedure

Refer to Figure 57 and Figure 58, test circuits for single-phase and three-phase bridges.

6.7.7.4 Compute TCVF and V_{F2} at $T_J$max



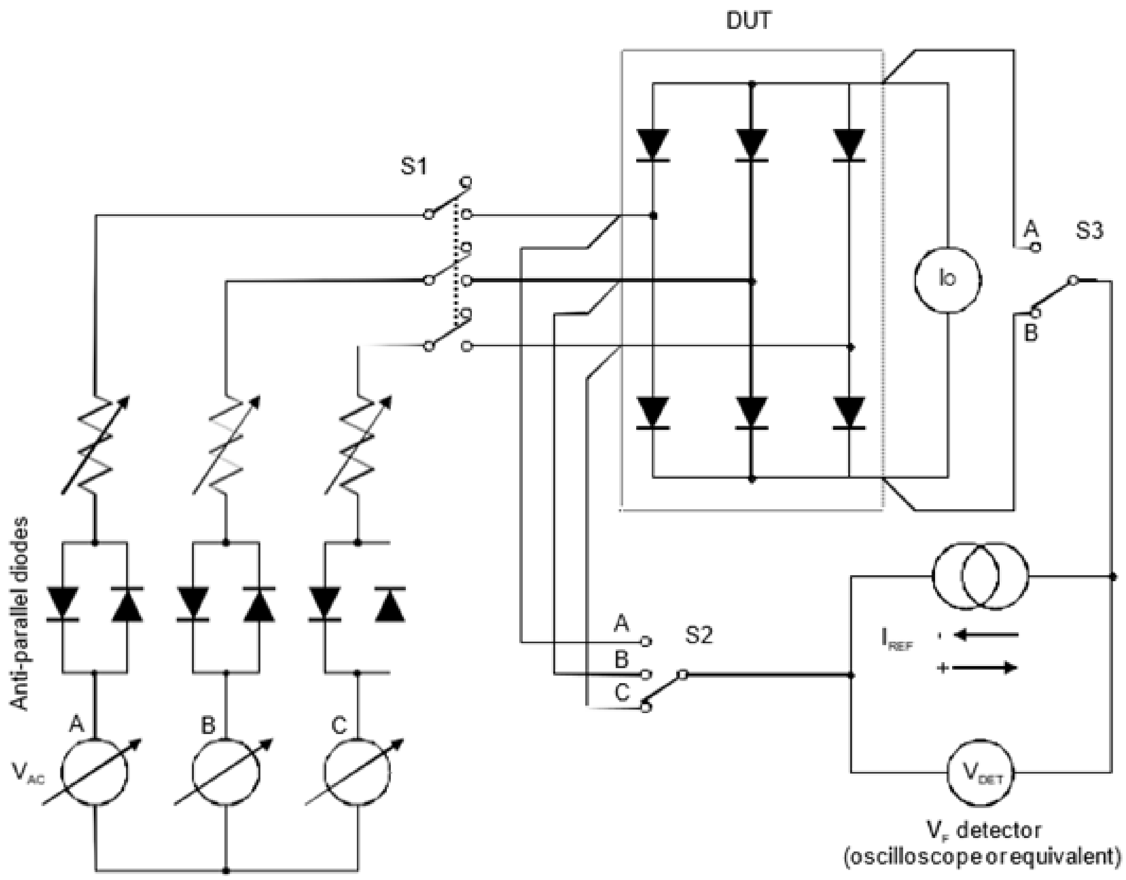
I_{REF}	S2	READ LEG #
+	A	2
+	B	3
–	A	1
–	B	4

NOTE 1 V_{DET} measurements shall be made using leads Kelvin-connected directly to the bridge terminals.

NOTE 2 V_{AC}: See Figure 59, Note 2.

Figure 57 — Single Phase Bridge

6.7.7.4 Compute TCVF and V_{F2} at $T_J$max (cont'd)



I_{REF}	S2	S3	READ LEG #	I_{REF}	S2	S3	READ LEG #
+	A	A	1	–	A	B	2
+	B	A	3	–	B	B	4
+	C	A	5	–	C	B	6

NOTE 1 V_{DET} measurements shall be made using leads Kelvin-connected directly to the bridge terminals.

NOTE 2 V_{AC}: See Figure 59, Note 2.

Figure 58 — Three-Phase Bridge

6.7.7.4 Compute TCVF and V_{F2} at $T_J$max (cont'd)

With S1 open, and DUT at 20 to 30 ºC (temperature T_1), read V_{F1} of each leg at current I_{REF}. Elevate the device temperature to 100 ºC above temperature T_1 (temperature T_2). Allow the device to stabilize until the junction temperature is at T_2. Read V_{F2} of each leg at I_{REF} current. Compute the TCVF of each leg as follows:

$TCVF = (V_{F1} - V_{F2})/100$ ºC

Compute the expected V_{F2} at T_J = max. rated as follows: $V_{F2A} = V_{F1} - [(TCVF) \times (T_{JMAX} - T_1)]$

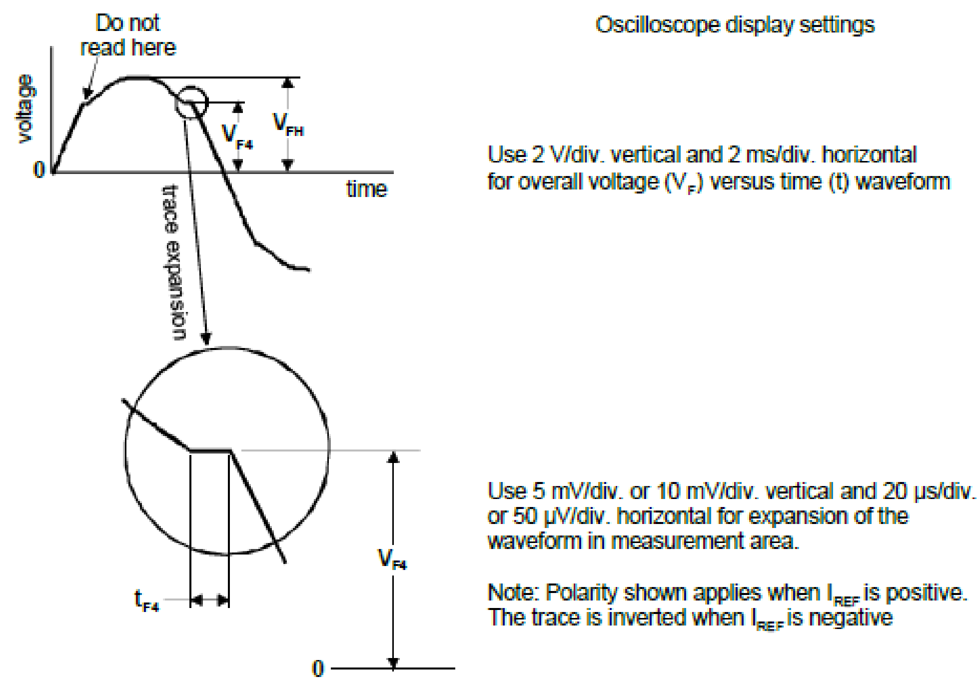
Determine the average TCVF and the standard deviation of the individual TCVFs from the readings on each leg. If the standard deviation is less than or equal to 3 percent of the average value of TCVF, average TCVF may be used for all devices. If the standard deviation is greater than 3 percent of the average value of TCVF, then the individual TCVFs shall be used in determining the performance of the bridge.

6.7.7.5 Measuring V_{F3}

With the device held at or below the rated case temperature for I_O, apply I_{REF} and read V_{F3} for each leg.

6.7.7.6 Application of Rated Current

After closing S_1, adjust the power source and/or the load resistor to obtain maximum rated I_O (depending on the rated T_C selected) and readjust the case temperature to the chosen rated value within + or – 5 ºC. Allow stable junction temperatures to be achieved. See NOTE 1 in clause 6.7.7.10



NOTE 1 "Step trace" is provided when antiparallel diodes in the circuit briefly commutate off (I_{AC} passes through zero) during each cooling cycle of individual bridge legs under ac test conditions.

NOTE 2 V_{AC} is adjusted so that the step t_{F4} is 100 µs ± 50 µs long and is clearly defined. A typical V_{AC} might be 10 volts peak.

NOTE 3 V_{AC} for bridges with parasitic inductive elements must be adjusted so that after the inductive ringing settles, the V_{F4} step is 100 µs ± 50 µs.

Figure 59 — Criteria to Adjust V_{AC}

6.7.7.7 Measuring V_{F4} and V_{FH}

Measure V_{F4} for each leg at the same reference current (+ or – 1%) as in the steps of clause 6.7.7.5 and clause 6.7.7.6. (The instrumentation used to measure V_{F4} must have sufficient resolution to read it within 1 mV or 2% whichever is greater.)

NOTE If V_{F3} for the leg is greater than V_{F2},T_J is less than T_{JMAX}.

Measure V_{FH} for each leg.

6.7.7.8 Thermal Resistance

Compute thermal resistance as follows:

a. Compute $\Delta V_F = V_{F4} - V_{F3}$ for each leg.

b. Compute $\Delta T_j = \Delta V_F / TCVF$, (See NOTE 1 following clause 6.7.7.10)

c. Compute R_{thJC} of the full bridge $R_{thJC} = (\Delta T_J)/(I_O \ x \ 2V_{FH})$

where:

ΔT_J is the average of all legs,

V_{FH} is the average of all legs, and

I_O is the rectified output current of the full bridge.

See NOTE 2, NOTE 3, and NOTE 4 following clause 6.7.7.10.

6.7.7.9 Test Conditions

Test conditions to be specified are I_o, T_c, I_{REF} and frequency (if other than 60 Hz).

6.7.7.10Characteristics

Steady state thermal resistance,
Junction to Case (unless otherwise specified): =_____ºC/W

NOTE 1 If, under power, the case is held to T_4, slightly above T_3, a corrected ΔT_J, ($\Delta T_{J(corr)} = \Delta T_J - (T_4 - T_3)$), should be used for step (b) above.

NOTE 2 Step (c) above gives R_{th} for the bridge. The average per-leg R_{th} for a single-phase bridge is four times this value a three; six times for -phase bridge. (See NOTE 3.)

NOTE 3 If desired, R_{th} of individual legs may be computed from the individual values of ΔT_J and V_{FH}.

NOTE 4 The power calculation, I_O x $2V_{FH}$, is a reasonable approximation of the power.

7 User's Guide

7.1 Introduction

The optimum use of rectifier diodes requires considerable knowledge of the device on the part of the user. The purpose of this chapter is to give some explanations of diode ratings and characteristics and to point out how they must be considered in actual diode applications. This chapter will not give minute device or application details. Rather it will serve as a guide or outline from which the user may proceed to additional technical information sources.

NOTE The word "diode(s)" will be used throughout chapter 7 to indicate power rectifier diode(s).

7.2 Diode Safety Considerations

The designer, maker and user of electrical equipment containing diodes should give attention to the following points relative to the safety of personnel who may operate the equipment:

a. The electrical potentials on the anode and cathode terminals of a diode present an electrical shock hazard when the equipment is energized.

b. The normal operating case temperature of energized diodes is often high enough to present burn hazards to operating personnel and charring of flammable material touching the diode.

c. In the event that equipment output short circuit or internal fault condition develops, very high surge current can be passed through the diodes. If this surge current exceeds diode ratings in magnitude and/or duration, the diode may be damaged; if the surge is severe enough, internal heating can cause the diode to rupture and an arc may occur.

7.3 Voltage Considerations

Two common voltage ratings are assigned to diodes which are discussed below. In addition, the effects of overvoltage and series operation are discussed in this chapter.

7.3.1 Repetitive Peak Reverse Voltage

This is the normal maximum allowable value of reverse voltage which may be applied to the diode. At this voltage, reverse power dissipation is generally small and contributes little to the total dissipation in the diode.

The repetitive peak reverse voltage occurring in a diode circuit is a known or measurable periodic function and may be considered to be under the control of the equipment designer. Any repetitive peak voltage occurring in the circuit even of short duration, such as those due to the switching action of the diode, should be included in this category.

7.3.2 Non-Repetitive Peak Reverse Voltage

For short time intervals, the reverse voltage may be permitted to exceed the steady-state ratings. During this time the instantaneous dissipation may become significant, but will still remain below the level which the manufacturer has found to be destructive. While the energy dissipated during this time causes an increase of junction temperature, the level reached is not sufficient to cause thermal runaway, and removing the excess voltage within the time period specified will allow the junction temperature to rapidly drop back to the steady- state operating level.

7.3.2 Non-Repetitive Peak Reverse Voltage (cont'd)

In addition to considerations of thermal runaway, non-repetitive peak reverse voltage ratings are often limited by the manufacturer for other reasons, such as an abrupt change in slope of the reverse blocking volt-ampere characteristic, or hysteresis, a discontinuity (including a sharp knee) or instability exhibited in the same characteristic. Non-repetitive reverse voltages may occur as random transients, which may or may not originate within the equipment. These voltages may often be minimized by the provision of voltage surge suppression components as discussed in the following clauses.

7.3.3 Overvoltage

Because of the sensitivity of silicon diodes to voltage transients in excess of their ratings, proper circuit design may require some built-in means to afford safe operation. Transient voltages generally are caused by the following:

a. De-energizing a transformer primary.

b. Energizing a transformer primary.

c. External disturbances caused by lightning, motors, solenoids, relay circuits, etc., which share the same alternating current source with the diode circuit.

d. Alternating current supply switching.

e. Diode Reverse Recovery (See clause 7.5.2).

f. Opening dc load switches when using an LC filter with high L/C ratio.

g. Regenerative types of loads.

h. Fuse blowing when used for isolating a defective diode in a parallel-connected group.

Each transient voltage source produces a different degree of voltage oscillation, e.g., some generate up to twice the working peak reverse voltage of a circuit, while others can generate as high as eight or ten times this value.

The surest method to observe transients is with a high-speed storage oscilloscope. It should have a frequency response of at least 40 MHz. Peak reading voltmeters are also used to measure transient voltages but generally with a lesser degree of certainty. However, they are very useful when the occurrence of the transient is unpredictable.

In order to maintain peak voltages within diode ratings, the following points should be considered:

a. The speed of current interruption by the switching elements (circuit breaker, fuse, etc.)

b. The location of switching elements or the sequence of switching.

c. Provision for additional energy storage or dissipation means in the circuit. (Examples: Capacitive filter or voltage clipping devices, such as those made from silicon-carbon, selenium, metal oxide, etc., across transformer windings, across the diode, and, sometimes, across output terminals.)

d. Provision of peak voltage capability equal to the maximum anticipated transient by the use of diodes with adequate voltage ratings or the use of an adequate number of diodes in series.

7.3.4 Series Operation

The usual principles of series operation for obtaining higher voltage ratings can be readily used with diodes without difficulty providing the device manufacturer's recommended procedures are followed. Generally, these procedures depend on the type of electrical characteristics which are considered typical of the device as manufactured and, also on the actual application conditions.

It is important when diodes are operated in series that the proper division of voltage is assured. Generally, manufacturers will recommend one or more of the following procedures:

a. Factory matched reverse and/or reverse recovery characteristics.
b. Resistive and/or varistor voltage dividers shunting the diodes.
c. Capacitive voltage dividers shunting the diodes.
d. Multiple transformer windings supplying rectifier circuits having outputs connected in series.
e. Use of avalanche type rectifier diodes.

Diodes which have been factory-matched with respect to reverse breakdown characteristics and reverse current have operated successfully with no voltage dividers. The use of resistors placed across each diode or group of diodes, the magnitude of which is equal to some fraction, say one-half, of the minimum blocking resistance of the diode, will force voltage division during steady-state operation. Differences in reverse recovery time may also be an important factor as this affects the proper division of voltage during transient switching. Moreover, the variation of the capacitance between the individual devices and even the variation of capacitance to ground (when many units in series are used) can cause an unequal voltage division. A capacitive voltage divider minimizes these effects and can be provided by connecting a capacitor across each diode or group of diodes. When capacitive dividers are used, a damping resistance should be used in series with each capacitor to prevent oscillatory overvoltage

When only a few diodes are operated in series, multiple transformer windings may be used where each winding supplies a diode assembly consisting of one diode in each circuit leg. The outputs of each diode assembly are then connected in series to obtain the desired voltage. Generally, the choice of circuit will depend upon the application and number of units in series.

7.4 Current Considerations

Maximum operating junction temperature, power dissipation and thermal resistance are important factors in determining current ratings. Diodes may be operated in parallel to provide increased current output. (See clause 7.4.6).

7.4.1 Maximum Operating Junction Temperature

Diode steady-state current ratings are ultimately limited by the maximum allowable junction temperature rating of the device. The semiconductor manufacturer determines the maximum junction temperature rating by evaluating the following factors and then deciding upon the best compromise:

a. The melting temperature or temperatures causing other physic al changes of device materials. This consideration places the absolute upper limit on device operating temperatures.

b. The temperature dependence of the blocking current. Reverse blocking current is an exponential function of temperature and this produces an exponential blocking power generation relationship with respect to temperature. If blocking power losses become too high, the device may run away destructively in the reverse direction because of the regenerate relationship between blocking power and junction temperature rise.

c. Reliability considerations. In general, the lower the operating junction temperature, the greater the life expectancy of any semiconductor device.

d. Effect on device characteristics. Since minority carrier lifetime is quite temperature dependent, reverse recovery time, which depends on lifetime, will likewise be temperature dependent.

To complete this discussion of junction temperature effects, it should be mentioned that the low junction temperature limits are generally determined by mechanical stress exerted on the silicon crystal. This stress is produced by imperfect matching of the thermal expansion coefficients of the various materials used in the fabrication of the device.

7.4.2 Junction Heat Generation

The conduction current flowing through the diode causes power dissipation and heat generation. The heat produced in the device by the flow of steady direct conduction current is simply this current multiplied by the voltage drop across the device. The heat produced in the device by a periodic current may be determined by integrating the instantaneous product of device current and voltage as follows:

$$\overline{P} = \frac{1}{T}\int_0^T e(t)\ i(t)\ dt$$

where:

P = Average power dissipated in the device

T = Period of the current

e(t) = Instantaneous voltage across the device

i(t) = Instantaneous conduction current

Since the diode conduction current and voltage are related in a nonlinear manner, this integration must be carried out by such means as graphical integration or by determining a mathematical approximation for the diode volt-ampere characteristics which will permit integration in closed form.

7.4.2 Junction Heat Generation (cont'd)

Other sources of device heat generation include power loss when the device is in the reverse blocking state. Switching losses, except at very high operating frequencies, are quite small compared to the power loss produced by conduction current. To simplify various calculations, all heat generated in the diode is assumed to be uniformly generated at the center plane of the silicon crystal, the virtual junction.

7.4.3 Thermal Resistance

A measure of the effectiveness with which a semiconductor device is able to get rid of heat is called thermal resistance. The lower the device thermal resistance, the lower the junction temperature rise for a given conduction current and resulting junction power generation. When thermal resistance is specified, the beginning and end of the thermal path must be clearly indicated. The common diode device thermal resistance specification is the value from the junction to a particular point on the case or lead. For stud-mounted diodes, this point is generally the center of one of the hex flats. (See clause 7.8.3.)

The heat flow associated with diode junction-to-case thermal resistance may be considered unidirectional. For the direct conduction current situation, Fourier's steady-state heat flow relations are analogous to Ohm's steady-state direct current flow relations.

<u>Ohm's Law</u> <u>Fourier's Law</u>

$$I = \frac{\Delta V}{R} \qquad P = \frac{\Delta T_{JC}}{R_{thJC}}$$

where;

I	= Direct current flow through in amperes
R	= Electrical resistance in ohms
ΔV	=Voltage difference across R in volts
P	= Power or heat flow in watts
R_{thJC}	= Thermal resistance from junction to case in °C/W
ΔT_{JC}	= Temperature difference in °C

When the heat flow (device current flow) is periodic or pulsating, the small thermal capacitance (heat storage capability) of the silicon crystal in the diode permits the junction temperature to rise and fall with the pulsating power generation (See clause 7.8.2).

Thus, if the diode dc or effective junction-to-case thermal resistance is multiplied by the average power generated by a pulsating current, the result will be the average junction temperature rise above the case temperature. To find the peak junction temperature in this instance, the diode transient thermal impedance characteristic must be used in a power superposition calculation. The reader is referred to the literature where this procedure is adequately covered.

7.4.3 Thermal Resistance

For the maximum operating junction temperature rating, different manufacturers may use any one or more of the following:

a) the highest instantaneous junction temperature produced by periodic conduction current waveform.

b) the average junction temperature produced by periodic conduction current waveforms.

c) the instantaneous temperature at the conclusion of the conduction current or the junction temperature at the instant the reverse voltage is applied.

d) the instantaneous temperature when sinusoidal reverse voltage at a specified frequency has reached a given fraction of its rated value.

The most common thermal resistance specification published by diode manufacturers is the dc (sometimes called the effective) thermal resistance parameter. This parameter is measured by using dc device heating current which produces dc device power dissipation. Often a thermal parameter called apparent thermal resistance is also published. This parameter applies only for a specified periodic conduction current waveform. It is useful in that it can eliminate the use of the transient thermal impedance characteristic in determining the diode junction-to-case temperature rise for that current waveform. This is done by multiplying the average power produced by a particular magnitude of the periodic current waveform in question by its corresponding apparent thermal resistance value. Commonly published apparent thermal resistance parameters are for 60 Hz single phase (180° sinusoidal conduction), three phase (120° rectangular conduction), and six phase (60° rectangular conduction).

If a diode manufacturer does not publish apparent thermal resistance parameters, they can be calculated from the following information

a. Average power dissipated, $P_{F(AV)}$, vs current magnitude, $I_{F(AV)}$, for the periodic current waveform in question,

b. Maximum current rating, $I_{F(AV)}$, vs case temperature, T_C, for the same current waveform,

c. Maximum operating junction temperature rating, $T_{J(MAX)}$, for the device.

Therefore, apparent thermal resistance = $(T_{J(MAX)} - T_C) / P_{F(AV)}$

Note that by using the apparent thermal resistance parameter and the current vs power dissipation curve for the current waveform of interest, it is a simple matter to determine the operating junction temperature of a diode for any selected case temperature and conduction current magnitude.

7.4.4 Steady State Current Ratings

The maximum allowable operating current of a diode depends upon its maximum allowable junction temperature rating, the internal power produced in the diode by the conduction and reverse currents, the total thermal resistance from junction to ambient and finally the maximum ambient temperature. Since the diode manufacturer has no control over the user's ambient temperature, the size of the heat dissipator that he attaches to the diode, or how the heat dissipator is cooled, diode current ratings are usually based upon the case (or lead) temperature of the device.

7.4.4 Steady State Current Ratings (cont'd)

Since the maximum operating temperature is fixed, diode current ratings are described by a curve relating maximum allowable current to case (or lead) temperature. The lower the case temperature maintained by the user, the higher the maximum allowable device current, and vice versa. The maximum allowable current will approach zero as the case temperature approaches the maximum operating junction temperature. This is true, of course, because the difference between the case and maximum operating junction temperature is determined by the product of the dissipated power and the junction-to-case thermal resistance. For lead mounted diodes, the current rating curves are often presented as a function of ambient temperature by assuming that no heat dissipator is attached to the device.

Published current rating curves for diodes are generally given in terms of average current with the current waveform being half sine wave of frequency 50 Hz to 400 Hz. In addition, curves for sinusoidal or rectangular waves with various duty factors or conduction periods are often given. These basic current waveforms apply for resistive or inductive loads. Capacitive loads may cause very high peak current for a given average value because the diode can only conduct when the supply voltage exceeds the voltage presented by the capacitor. Derating data for capacitive loads is sometimes given on manufacturer's data sheets.

7.4.5 Overload Current Ratings

Overload current ratings may be divided into two types: Non-repetitive and repetitive.

7.4.5.1 Non-Repetitive Overload

Non-repetitive overloads are those which occur rarely and are not a part of the normal application of the device. Examples of such overloads are faults caused by accidental shorting of the load. Non-repetitive overload ratings permit the device to exceed its maximum operating junction temperature for short periods of time, nevertheless the device must block rated voltage in the reverse direction following the current overload. Only one hundred non-repetitive current overloads are permitted over the life of the device.

The non-repetitive overload ratings just described may be divided into two types: multicycle (which includes single cycle) and sub-cycle. The multicycle overload current rating, or surge current rating as it is commonly called, is a curve giving the maximum peak value of half sine wave forward current pulses of equal amplitude as a function of overload duration based on the number of cycles from a 60 Hz supply. Usually these ratings are given for from one to sixty cycles. For this type of surge rating curve, the current values can be converted from peak to rms values by dividing by $\sqrt{2}$. Multicycle surge curves are used to select proper circuit breakers and series line impedance to prevent damage to the diode in the event of an equipment fault.

The sub-cycle overload or sub-cycle surge rating curve is so called because the time duration of the current is usually from about one to eight milliseconds, which is less than the time of one half cycle of a 60 Hz power source. Again, overload current is given in curve form as a function of overload duration. RMS current is used rather than the peak value in order to make the curve as general as possible. This rating also applies following any rated load condition. However, the reverse blocking capability is not required on the part of the diode immediately following the overload current. The sub-cycle surge current rating is of assistance when selecting the proper current-limiting fuse for protection of the diode in the event of an equipment fault. Note the manufacturer may often publish the I^2t rating for the device for one or more values of t in the one to eight millisecond range in place of the sub-cycle current overload curve. The reason for this is that fuses are commonly rated in terms of I^2t. Incidentally, the "I" in this rating is rms computed over the time base "t" which is the duration of the overload current.

7.4.5.2 Repetitive Overloads

Repetitive overloads are those which are an intended part of the device application. An example of such an overload would be in a dc motor drive application where the motor furnishes the drive for an electric locomotive used for commuter service. This type of overload may occur any number of times during the life of the diode. Therefore, its rated maximum operating junction temperature must not be exceeded during the overload if long diode life is required.

Since this type of overload can have any conceivable complex current waveform and duty cycle, a current rating analysis involving the use of the transient thermal impedance characteristics is the only practical approach. In this type of analysis, the diode junction-to-case transient thermal impedance characteristic is added to the user's heat dissipator transient thermal impedance characteristic. Then by making calculations based upon the superposition theory using the expected power waveforms in conjunction with the composite thermal impedance curve, the overload current rating can be obtained. The exact calculation procedure is found in the power semiconductor literature.

7.4.6 Parallel Operations

Sometimes it is desirable to operate diodes in parallel to obtain higher circuit output current. The primary design consideration to achieve successful paralleling is to balance the current in the parallel paths. This may be accomplished in three ways:

a. Add sufficient identical impedance in each path to force current sharing even if the very low impedance diode conduction V-I characteristics and individual path impedances are grossly mismatched. The addition of resistance to each path will produce this current sharing, but of course it is a very inefficient method. The use of series reactors affords a more efficient method.

b. Introduce “paralleling reactors” (which actually function as transformers) that induce the proper correcting voltages in response to the current unbalance in the parallel paths.

c. Factory match the diode conduction characteristics and very carefully design the parallel paths so that their impedances (self inductance, mutual inductance and resistance) are balanced without the addition of lumped impedances. (A circular device configuration and coaxial power leads may be required to achieve this objective.)

Since diode conduction V-I characteristics are somewhat temperature dependent, it is well to mount all paralleled diodes on a common heat dissipator to ensure the same operating junction temperature. Perfect current sharing seldom can be achieved using any paralleling method, so the average current per diode should be reduced, accordingly, somewhat below the maximum rating. Generally the derating used is about 10%.

7.5 Switching Characteristics

There are two distinct switching conditions which can occur with diodes, forward recovery, and reverse recovery. A recovered charge is associated with reverse recovery.

7.5.1 Forward Recovery and Turn-on Time

Forward recovery time is the time required for voltage across the diode to reach a defined level, close to its steady-state value, when an abrupt forward current pulse is applied. When a step of forward current is applied to a diode, the carrier gradient does not develop immediately, resulting in an overshoot voltage. As carriers begin to cross the junction, they build up the charge gradient and also cause an apparent decrease in the resistivity that is observed as a decrease in the overshoot voltage as time increases.

7.5.1 Forward Recovery and Turn-on Time (cont'd)

Forward recovery is observed only when the step application of forward current is very steep and, for this reason, is seldom seen in 60 Hz power circuits. For forward recovery to be apparent, circuit inductance must be sufficiently low to provide a *di/dt* of at least 10 A/µsec (much higher for some low voltage diodes). High voltage diodes have longer forward recovery times as a result of the higher resistivity and/or thicker silicon material required to make them.

The turn-on time, t_{on}, is the time required for the forward current through the DUT to go from 10% to 90% of the maximum amplitude. Since diodes do not exhibit a delay time, the turn-on time is identical to the rise time of standard pulse symbology. Turn-on time is of concern only in circuits with low forcing voltages, less than several times the v_{FRM} observed herein. It is a consequence of the forward recovery phenomenon but only appears in low voltage, nonconductive applications. As such it is normally of no significance in the use of rectifier diodes in pulse power circuits.

7.5.2 Reverse Recovery

In switching from forward conduction to reverse blocking, a large initial reverse current may flow through a diode. The rate of rise of this current is determined only by the external circuit. After a short interval, usually less than a few microseconds, the diode will become able to block reverse voltage and the reverse current will decay to the normal blocking level. The magnitude of this reverse recovery current may be large enough to warrant consideration in determining the rating of other circuit components which supply this current. In some high frequency circuits, the power generated by this recovery current (the switching losses) may require derating or selection of faster recovery rectifier diodes. In addition, the decay of the peak reverse recovery current may be abrupt enough to generate large transient overvoltage in inductive circuit elements feeding this current. Such overvoltage may be controlled in a variety of ways, the simplest of which is to use a snubber circuit, a series-connected resistor and capacitor, in parallel with the diode. The capacitor must be of sufficient size to accept the stored inductive energy from the circuit without excessive voltage rise.

Power rectifier diodes can possess either of two types of recovery characteristics. After the reverse current reaches its peak value, $I_{RM(REC)}$, it may immediately or a short time later decrease very abruptly (abrupt recovery) or it may decrease slowly and smoothly to its steady-state reverse blocking value (soft recovery).

In the former case, the effect of the rapid current change and the loop inductance producing a transient voltage across the test device must be considered. The recovery time for rectifier diodes possessing "soft" recovery characteristics is defined as $t_{rr} = t_{rrr} + t_{rrf}$ (See Figure 60), where t_{rrr} is measured from the instant of current reversal to the instant the current reaches its peak reverse value, $I_{RM(REC)}$, and t_{rrf} is measured from $I_{RM(REC)}$ to the instant the straight line connecting $I_{RM(REC)}$, and 0.25 $I_{RM(REC)}$ intercepts the zero current axis. The recovery time for a diode possessing "abrupt" recovery characteristics is defined in the same manner, except t_{rrf} is measured to the instant the test current waveform initially intercepts the zero current axis. Note that the shape of the recovery characteristics may be expressed as Reverse Recovery Softness Factor (RRSF) by the ratio of the maximum absolute magnitude of *di/dt* within the t_{rrr} region compared to that in the t_{rrf} region.

Observed values of t_{rr} in a given circuit may differ from the specified value, as this characteristic is circuit dependent, varying principally with *di/dt*, I_{FM}, $I_{RM(REC)}$, and temperature.

7.5.2 Reverse Recovery (cont'd)

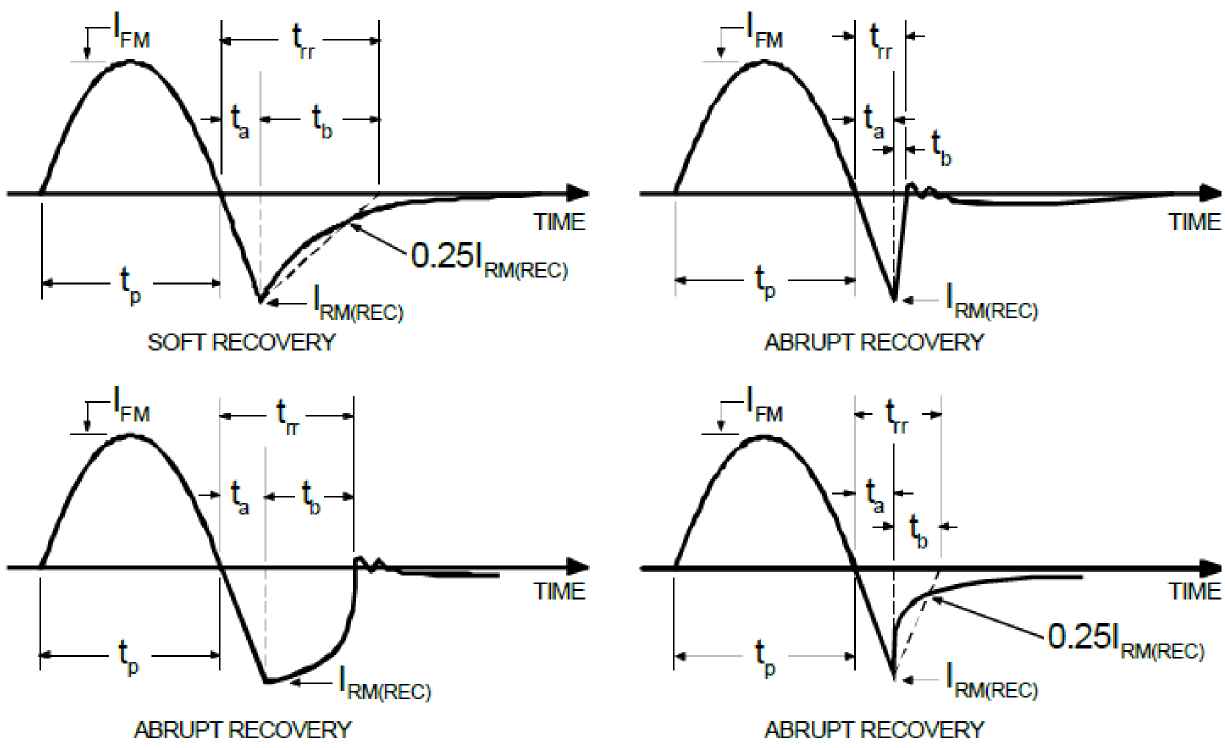
The recovered charge of the device under test is defined as the area under the reverse current - time curve. An approximate value of the recovered charge, in microcoulombs, can be calculated by the expression:

$$Q_{rr} = (1/2)\, t_{rr}\, I_{RM(REC)}$$

where:

t_{rr} = reverse recovery time, in microseconds

$I_{RM(REC)}$ = peak reverse current during the reverse recovery period, in amperes



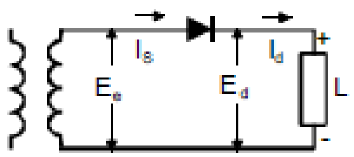
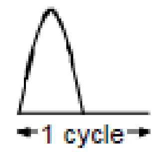
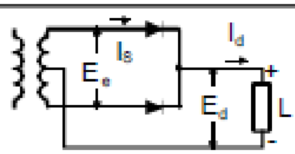
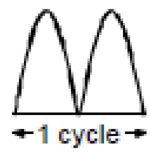
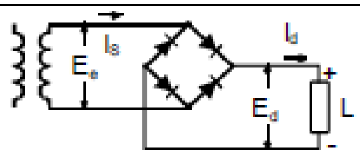
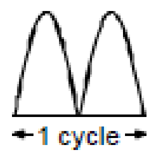
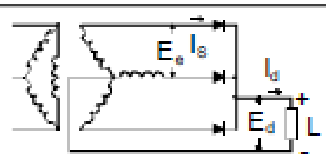
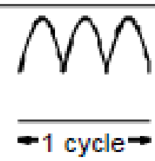
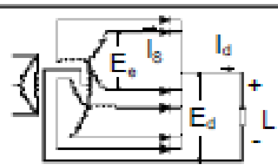
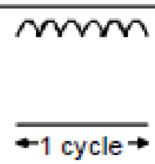
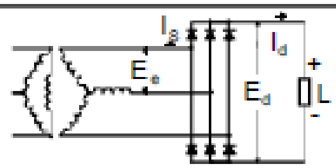
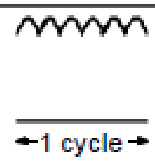
NOTE t_{rrr} is now the preferred symbol for t_a, and t_{rrf} is preferred for t_b.

Figure 60 — Test Current Waveforms for Various Types of Rectifier Diodes Under Test in the Circuit for Measuring Reverse Recovery Characteristics

7.6 Fundamental Rectifier Circuits

The circuits shown in Figure 61 through Figure 64 are presented as an aid to understanding the application of diodes in various rectifier circuits. Data are from theoretical calculations based on undistorted input waveforms, no power loss in the semiconductor device(s), and no reactance or losses in the transformer(s) or associated leads. This circuit table is useful in approximating the values of circuit voltages and currents but the designer must also consider transformer and lead impedance, semiconductor devices(s) losses, voltage transients, surge current conditions, etc., for proper circuit design.

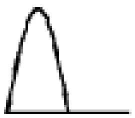
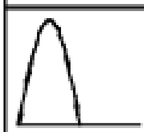
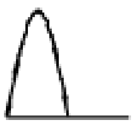
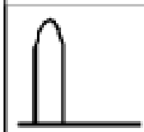
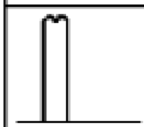
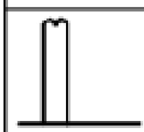
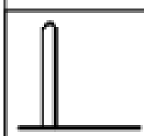
7.6 Fundamental Rectifier Circuits (cont'd)

Type of circuit	Circuit Diagram	Output wave values				
		Wave form	E_d	E_a	F.F.	Ripple Current %
Single phase						
Half-wave (1-1-1-H)			.450 E_e	.707 E_e	1.57	121
Full-wave center tap (2-1-1-C)			.450 E_e	.500 E_e	1.11	48
Full-wave bridge (4-1-1-B)			.900 E_e	1.00 E_e	1.11	48
Three phase						
Wye (3-1-1-Y)			.675 E_e	.688 E_e	1.02	18
Double wye with Interphase (6-1-1-Y)			.675 E_e	.676 E_e	1.00	4
Bridge (6-1-1-B)			1.35 E_e	1.35 E_e	1.00	4
Six phase						
Star (6-1-1-S)			.780 E_e	.781 E_e	1.00	4

NOTE Semiconductor rectifier diode and transformer are assumed to have no losses or reactance. Form factor (F.F.) — Ratio of rms to average value of a wave form. E_a — RMS value of load (L) voltage. E_d — Average value of load voltage. E_e — RMS value of line input voltage (line to line).

Figure 61 — Fundamental Rectifier Circuits – Resistive Load

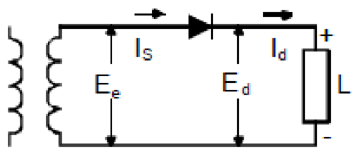
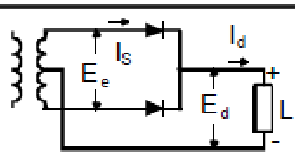
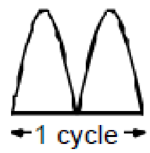
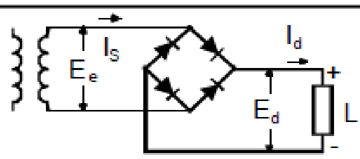
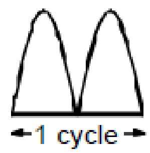
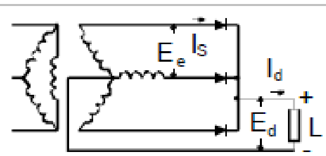
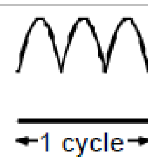
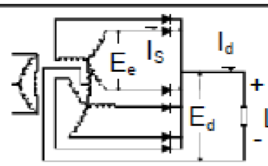
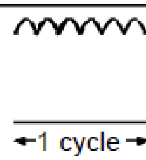
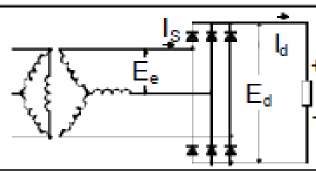
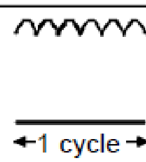
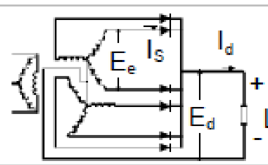
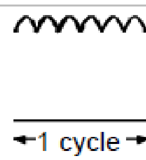
7.6 Fundamental Rectifier Circuits (cont'd)

Rectifier diode wave values						Transformer VA capacity		Current factor C.F.	Voltage factor V.F.	Maximum theoretical conversion efficiency %	Type of circuit
Wave form	$I_{F(AV)}$	$I_{F(AV)}$	$I_{F(RMS)}$	F.F.	V_{RM} (wkg)	Pri.	Sec.				
Single phase											
 $^1/_2$ cycle	.318 I_{FM}	1.00 I_d	1.57 I_d	1.57	1.41 E_e	3.49 E_dI_d	3.49 E_dI_d	1.57	2.22	40.5	Half-wave (1-1-1-H)
 $^1/_2$ cycle	.318 I_{FM}	.500 I_d	.786 I_d	1.57	1.41 E_e	1.24 E_dI_d	1.75 E_dI_d	.786	2.22	81.1	Full-wave center tap (2-1-1-C)
 $^1/_2$ cycle	.318 I_{FM}	.500 I_d	.786 I_d	1.57	1.41 E_e	1.24 E_dI_d	1.24 E_dI_d	1.11	1.11	81.1	Full-wave bridge (4-1-1-B)
Three phase											
 $^1/_3$ cycle	.276 I_{FM}	.333 I_d	.587 I_d	1.76	1.41 E_e	1.51 E_dI_d	1.51 E_dI_d	.587	1.49	96.8	Wye (3-1-1-Y)
 $^1/_3$ cycle	.318 I_{FM}	.167 I_d	.290 I_d	1.76	1.41 E_e	1.07 E_dI_d	1.51 E_dI_d	.290	1.49	99.9	Double wye with Interphase (6-1-1-Y)
 $^1/_3$ cycle	.318 I_{FM}	.333 I_d	.579 I_d	1.76	1.41 E_e	1.05 E_dI_d	1.05 E_dI_d	.816	.741	99.8	Bridge with Interphase (6-1-1-B)
Six phase											
 $^1/_6$ cycle	.159 I_{FM}	.167 I_d	.408 I_d	2.45	1.63 E_e	1.28 E_dI_d	1.81 E_dI_d	.408	1.28	99.8	Star (6-1-1-S)

NOTE Form factor (F.F.) — Ratio of rms to average value of a wave form. Current Factor (C.F.) — Ratio of rms value of input line current (I_S) to average value of load current (I_d). Voltage Factor (V.F.) — Ratio of rms value of input line voltage (line to line) (E_e) to average value of load voltage (E_d).

Figure 62 — Fundamental Rectifier Circuits – Resistive Load

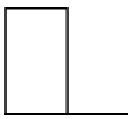
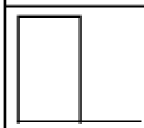
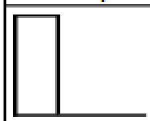
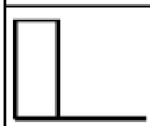
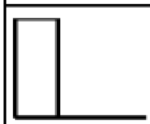
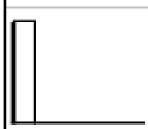
7.6 Fundamental Rectifier Circuits (cont'd)

Type of circuit	Circuit Diagram	Output wave values				
		Wave form	E_d	E_a	F.F.	Ripple Current %
Single phase						
Half-wave (1-1-1-H)		Not applicable				
Full-wave center tap (2-1-1-C)			.450 E_e	.500 E_e	1.11	DC ripple (%) = 100 x Ripple factor of circuit with resistive load / $\sqrt{1+Q^2}$ where $Q = \frac{\omega L}{R}$
Full-wave bridge (4-1-1-B)			.900 E_e	1.00 E_e	1.11	
Three phase						
Wye (3-1-1-Y)			.675 E_e	.688 E_e	1.02	
Double wye with Interphase (6-1-1-Y)			.675 E_e	.676 E_e	1.00	
Bridge (6-1-1-B)			1.35 E_e	1.35 E_e	1.00	
Six phase						
Star (6-1-1-S)			.780 E_e	.781 E_e	1.00	

NOTE Semiconductor rectifier diode and transformer are assumed to have no losses or reactance. Form factor (F.F.) — Ratio of rms to average value of a wave form. E_a — RMS value of load (L) voltage. E_d — Average value of load voltage. E_e — RMS value of line input voltage (line to line). Ripple current — A finite value of inductance in the load is assumed for the calculation of ripple having knowledge of the ratio of L/R.

Figure 63 — Fundamental Rectifier Circuits – Inductive Load

7.6 Fundamental Rectifier Circuits (cont'd)

Rectifier diode wave values						Transformer VA capacity		Current factor C.F.	Voltage factor V.F.	Maximum theoretical conversion efficiency %	Type of circuit
Wave form	$I_{F(AV)}$	$I_{F(AV)}$	I_f	F.F.	V_{RM} (wkg)	Pri.	Sec.				
Single phase											
Not applicable											Half-wave (1-1-1-H)
 $^1/_2$ cycle	.500 I_{FM}	.500 I_d	.707 I_d	1.41	1.41 E_e	1.11 E_dI_d	1.57 E_dI_d	.707	2.22	100	Full-wave center tap (2-1-1-C)
 $^1/_2$ cycle	.500 I_{FM}	.500 I_d	.707 I_d	1.41	1.41 E_e	1.11 E_dI_d	1.11 E_dI_d	1.00	1.11	100	Full-wave bridge (4-1-1-B)
Three phase											
 $^1/_3$ cycle	.333 I_{FM}	.333 I_d	.578 I_d	1.73	1.41 E_e	1.21 E_dI_d	1.48 E_dI_d	.578	1.49	100	Wye (3-1-1-Y)
 $^1/_3$ cycle	.333 I_{FM}	.167 I_d	.289 I_d	1.73	1.41 E_e	1.05 E_dI_d	1.49 E_dI_d	.289	1.49	100	Double wye with Interphase (6-1-1-Y)
 $^1/_3$ cycle	.333 I_{FM}	.333 I_d	.578 I_d	1.73	1.41 E_e	1.05 E_dI_d	1.05 E_dI_d	.816	.741	100	Bridge (6-1-1-B)
Six phase											
 $^1/_6$ cycle	.167 I_{FM}	.167 I_d	.408 I_d	2.45	1.63 E_e	1.28 E_dI_d	1.81 E_dI_d	.408	1.28	100	Star (6-1-1-S)

NOTE Form factor (F.F.) — Ratio of rms to average value of a waveform. Current Factor (C.F.) — Ratio of rms value of input line current (I_S) to average value of load current (I_d). Voltage Factor (V.F.) — Ratio of rms value of input line voltage (line to line) (E_e) to average value of load voltage (E_d). Maximum theoretical conversion efficiency — Load inductance is assumed infinite and current flows continuously through load.

Figure 64 — Fundamental Rectifier Circuits – Inductive Load

7.7 Cooling Considerations

In order to achieve the full current carrying capability of rectifier diodes, consideration must be given to providing proper cooling. Disk and stud- or base-mounted type rectifier diodes have high current ratings and, therefore, a relatively large amount of heat is generated within the junction assembly that must be effectively removed in order to prevent excessive temperature rise of the junction and possible damage to it. Diodes that possess large integral heat dissipators are exceptions, and normally are not attached to heat dissipators.

Heat Dissipator / Rectifier Diode Interface: The two main considerations regarding the heat dissipator / rectifier diode interface are ensuring adequate heat transfer and either very low, or very high electrical resistance (if the diode is to be isolated electrically from the heat sink). Good heat transfer requires high thermal conductance. Thermal conductance is influenced by surface and mounting conditions. Surface conditions apply to both stud- and disk-type semiconductors and are explained in clause 7.7.1.1. The mounting conditions depend on the type of device involved and are explained in later clauses.

7.7.1 General Mounting Considerations

7.7.1.1 Surface Conditions

Air pockets can be trapped in the depressions and voids between two mating surfaces. The majority of these can be avoided with proper care and handling of the two surfaces before mounting. Since devices generally are cooled by the contact of heat dissipators or heat exchangers against device mounting surfaces, the mounting method used must distribute the pressure evenly across the mating surfaces.

In general, the heat dissipator mounting surface should have a flatness and surface finish comparable to that of the mating part of the semiconductor package. In lower power applications, the heat dissipator surface is satisfactory if it appears flat against a straight edge and is free from deep scratches. In high power applications, a more detailed examination of the surface is required.

“Surface Flatness” is determined by comparing the variance in height (h) of the test specimen to that of a reference standard as indicated in Figure 65. Flatness is normally specified as a fraction of the Total Indicator Reading (TIR). The mounting surface flatness, i.e., TIR, is satisfactory in most cases if it is less than 4 micrometers per millimeter (4 mils per inch), which is normal for extruded aluminum. Disk type devices usually require 1 micrometer per millimeter (1 mil per inch) and spot facing of the heat sink may be required to achieve this. “Surface Finish” is the average of the deviations both above and below the mean value of surface height. For minimum interface resistance, a finish in the range of 1.3 to 1.5 micrometers (50 μ-inches to 60 μ-inches) is satisfactory; a finer finish is costly to achieve and does not significantly lower contact thermal resistance.

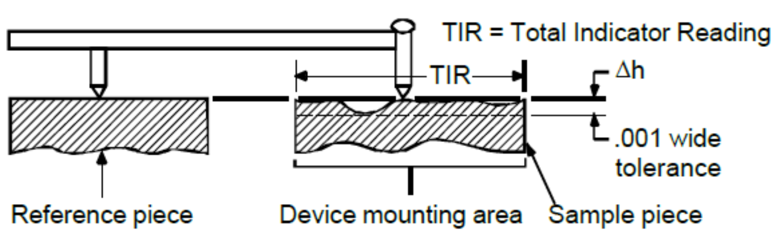


Figure 65 — Surface Flatness

7.7.1.1 Surface Conditions (cont'd)

Care should be taken to ensure that all mating surfaces are free from foreign materials and oxides. If the diodes and heat dissipators are stored, a cleaning operation before use is good practice. A satisfactory cleaning technique is to polish the mounting areas with No. 400-600 grit paper, followed by a solvent rinse. No. 000 steel wool can be used to polish contact areas, but care must be exercised to remove all steel particles so that device flash-over will not occur.

Many aluminum sinks are black anodized to improve heat radiation ability and prevent corrosion. Anodizing results in significant electrical but negligible thermal insulation. It need only be removed from the mounting area when electrical contact is required. Another treated aluminum finish is irradiate, or chromic acid dip, which offers low thermal resistance because of its thin surface, yet has good electrical properties because it resists oxidation. For economy, paint is sometimes used on dissipators; removal of the paint where the semiconductor is attached is required because of paint's high electrical resistance.

However, when it is necessary to electrically insulate the semiconductor package from the heat dissipator, anodized or painted surfaces may be satisfactory.

Even though all the procedures listed are followed, minute air voids between mating surfaces will still exist. To reduce the thermal resistance introduced at these mating surfaces, a thermal joint compound may be used. Such a compound also has the desirable property of keeping moisture away from the mating surfaces, and hence, inhibiting corrosion. These compounds may contain deoxidizers for the purpose of further inhibiting corrosion which may also be done by plating the bare metal surfaces.

7.7.1.2 Thermal Compounds

To reduce thermal resistance, thermal joint compounds or greases are used to fill air voids between mating surfaces. Values of thermal resistivity vary from 0.10 °C inch per watt for copper oxide film to 1200 °C inches per watt for air, whereas satisfactory joint compounds have a resistivity of approximately 60 °C inches per watt. Therefore, the voids, scratches and imperfections that are filled with a joint compound will have a thermal resistance of about 1/20th of the original value, making a significant reduction in the overall interface thermal resistance.

Joint compounds are usually a formulation of fine metallic particles in a silicone oil which maintains a grease- like consistency with time and temperature. Since some of these compounds do not spread well, they should be evenly applied in a very thin layer using a spatula or lint less brush, and wiped lightly to remove excess material. Partial rotation of the device case will help the compound spread evenly over the entire contact area. Experience will indicate whether the quantity is sufficient, as excess will appear around the edges of the contact area. To prevent accumulation of airborne particulate matter, excess compound should be wiped away using a cloth moistened with acetone or alcohol. These solvents should not contact plastic encapsulated devices, as they may enter the package and cause a leakage path or carry in substances which might attack the assembly.

If re-assembly of a disk type semiconductor to a heat dissipator is required where a metal filled joint compound was used, the device and heat dissipator surfaces should be thoroughly cleaned and new joint compound applied. If any indication of damage is evident consult manufacturer. The semiconductor device or joint compound manufacturer may be consulted for more information on these compounds and their application.

7.7.1.3 Insulation Considerations

Since most rectifier diodes have either the anode or cathode electrically common to the case, the problem of isolating the case from ground is a common one. For lowest overall thermal resistance, it is best to isolate the entire heat dissipator/semiconductor structure from ground, rather than to use an insulator between the semiconductor and the heat dissipator. Where heat dissipator isolation is not possible, because of safety reasons or in instances where a chassis serves as the heat sink or where a heat dissipator is common to several devices, insulators may be used to isolate the individual components from the heat dissipator sink.

When such insulators are used, thermal compounds assume greater importance than with a metal-to-metal contact, because two interfaces exist instead of one and some insulating materials, such as mica, have a markedly uneven surface. Reduction of interface thermal resistance by 50% to 70% is typical when a thermal compound is used in such instances.

With some arrangements, the interface thermal resistance may exceed that of the semiconductor junction-to- case thermal resistance. When high power is handled, beryllium oxide is unquestionably the best insulator choice but care must be exercised in handling as small particles are toxic. Polyimide material is fairly popular for low power applications because it is low in cost, withstands high temperatures and is easily handled, in contrast to mica which chips and flakes easily.

When using insulators, care must be taken to keep the mating surfaces clean. Small particles of foreign matter can puncture the insulation, rendering it useless or seriously lowering its dielectric strength. In addition, when voltages higher than 300 V are encountered, problems with creepage may occur. Dust and other foreign material can shorten creepage distances significantly so that having a clean assembly area is important. Surface roughness and humidity also lower insulation resistance. Use of a thermal compound usually raises the breakdown voltage of the insulation system. Because of these factors, which are not amendable to analysis, hi-pot testing should be done on prototype and a large margin of safety employed.

7.7.2 Installation of Stud-Mounted Semiconductor Devices

7.7.2.1 Hole and Surface Preparation

When diodes possessing studs with machine threads are mounted through a clearance hole, optimum heat transfer depends on adequate contact between the diode base and heat dissipator surface. Care should be taken to ensure a clean flat area for contact, free of ridges or high spots, burrs, etc. The diode base should also be checked for removal of all burrs or peened-over corners that may have occurred during previous handling. Mounting holes generally should only be large enough to allow clearance of the stud.

If the mounting holes are punched, care must be exercised so that the area around any punched hole is not depressed in the process. The device can be damaged by distortion of the package as the mounting pressure attempts to conform it to the shape of the heat dissipator depression, or the device may only bridge the depression and leave a significant percentage of its heat dissipating surface out of contact with the heat dissipator. The first effect may often be detected immediately by visible cracks in the package but usually an unnatural stress is imposed on the junction assembly, resulting in an early-life failure. The second effect results in hotter operation and may not be manifested until much later.

When mounting holes are drilled, surface cleanup is important. Chamfers must be avoided because they reduce heat transfer surface and increase mounting stress. However, mounting hole edges should be “broken” to remove burrs which cause poor contact between device and heat dissipator and may puncture insulation material.

7.7.2.2 Mounting Torque

Good thermal contact between the base of the diode and the heat dissipator requires adequate pressure between the two contact surfaces. This is a produced by torque on the threads of the device. However, a torque beyond a certain value no longer significantly improves the thermal contact and may mechanically stress the semiconductor crystal and associated materials inside the housing. The torques specified for lubricated and nonlubricated stud threads are normally different. Most torques specifications are for dry threads and care must be exercised when applying thermal compounds to avoid contact with the threads. Precise adherence to the manufacturer's torque recommendation is necessary and should be verified using a torque wrench.

7.7.2.3 Mounting Procedure – Stud-Mounted Devices

Unequal thermal expansion of the mounting stud and the heat dissipator, e.g., a copper stud and an aluminum heat dissipator, can cause the mounting to gradually loosen as the assembly is cycled through temperature extremes. A spring washer on the reverse side of the heat dissipator minimizes this effect by allowing the aluminum to expand against the washer compression rather than the copper.

7.7.3 Installation of Disk-Type Semiconductor Devices

7.7.3.1 Mounting Procedure – Disk-Type Devices

A self-leveling type mounting clamp is recommended to ensure parallelism and an even distribution of force on each contact area. A swivel type clamp will apply the mounting force in the desired manner. Other configurations such as narrow leaf springs in contact with the heat dissipator can provide acceptable performance. Also the material thickness of the heat dissipator must be sufficient to make possible uniform force over contacting surfaces.

7.7.3.2 Force Application

The clamping force should be applied gradually, evenly and perpendicularly to the semiconductor device to ensure that there is no deformation of either the device or the heat dissipator mounting surfaces during installation. The spring used should provide a mounting force within the range recommended by the device manufacturer.

7.7.3.3 Clamping Procedure

Installation of an assembly of a disk-type semiconductor device mounted between two heat dissipators should be done in a manner to permit one heat dissipator to move with respect to the other. This will avoid stresses being built up, due to thermal expansion, which could damage the semiconductor junction. However, the clamping structure must be such that proper pressure is maintained throughout the temperature range of the system.

Similarly, when two or more disk-type devices are to be operated electrically in parallel, one of the heat dissipators used may be common to all the devices, but it is preferred practice to provide individual heat dissipators against the other mounting surfaces of the semiconductor devices so that the mounting force applied to each device is independent of the force(s) applied to the other(s).

7.7.4 Installation of Lead-Mounted Semiconductor Devices

7.7.4.1 Devices Storage, Cleaning and Handling – Lead Mounted Devices

Storage of devices should be under conditions which minimize lead contamination. When handling devices, avoid coating leads with foreign materials such as oils or grease. Many solvents are available for lead degreasing or flux removal. Care should be taken to choose a solvent that will not damage the device seals. When large quantities of devices are to be used, it may be an advantage to have them taped and reeled per the latest version of EIA Standard, EIA-296, *Lead Taping of Components in Axial Lead Configuration for Automatic Handling*, and the latest revision of EIA-481, *Taping of Surface Mount Components for Automatic Handling*, for handling by automatic equipment.

7.7.4.2 Lead Cutting and Forming

When bending leads, the lead should be held between the bending point and the body of the device to avoid internal damage to the device. This holding point should be designed into lead forming fixtures.

A properly designed fixture may also include lead cutting, thereby eliminating repeated handling of the device. Excessive lead tension should be avoided as this may result in device damage. Repeated lead bending at one point should be avoided, as this will cause lead fatigue and breakage. A slack or expansion elbow should be formed in the lead, if room allows, to prevent excessive tension on leads during mounting and subsequent operations.

7.7.4.3 Methods of Lead Attachment

7.7.4.3.1 Soldering

Care should be exercised in the selection of soldering flux. Rosin or activated rosin type fluxes are preferred. Organic or acid type fluxes should be avoided if possible. The manufacturer's recommendations for maximum soldering temperature, time, and distance from the device body should be observed as excessive heating may damage the device. If possible, a removable heat dissipator may be placed on the lead between the device and soldering point to reduce device heating during soldering.

7.7.4.3.2 Welding

Care should be taken to assure none of the welding current is transmitted through the semiconductor device. The manufacturer should be consulted as to the type of lead material. Weld schedules may be obtained from the American National Standards Institute (ANSI), or the device manufacturer.

7.7.4.3.3 Wire Wrapping

The lead should be restrained between the body of the device and the point of wrapping to avoid excessive lead tension.

7.7.5 Installation of Press-Fit Semiconductor Devices

7.7.5.1 Device Storage and Cleaning – Press-Fit Devices

Storage of devices should be under conditions which minimize mounting surface contamination. Care should be taken to avoid coating mounting surfaces with foreign materials such as oils or grease. Many solvents are available for degreasing or flux removal of the mounting surfaces. Care should be taken to choose a solvent that does not damage the device seals.

7.7.5.2 Selection and Preparation of Heat Dissipator

The heat dissipator material may be copper, aluminum or steel. The heat dissipator thickness should be at least 3.18 mm (1/8 inch).

The diameter of the hole into which the diode is to be pressed must have a dimension that falls within a very tight tolerance (usually ± 0.025 mm (±0.001 inch)) of the diameter recommended by the semiconductor device supplier. A slight chamfer should be given to the hole.

7.7.5.3 Installation of Press-Fit Diode in Heat Dissipator

The entire knurled section of the rectifier diode case should be in contact with the heat dissipator to ensure maximum heat transfer. The diode must not be inserted deeper than the knurl

The diode insertion force must not exceed the maximum value stated by the manufacturer. If the insertion force approaches this value before complete insertion, either the diode is misaligned with the hole or the diode-to-hole interference is excessive. The insertion force must be uniformly applied to the top face (terminal end) of the diode within an annular ring, the dimensions of which should be as given by the diode manufacturer.

7.7.6 Installation of Button-Type Semiconductor Devices

7.7.6.1 Device Handling and Mounting

Handling of button-type devices should be relatively gentle to minimize sharp impact shocks. Care should be taken to avoid nicking the body, especially at the interface to the mounting surface. When mounting button- type devices, the connection to one side should be flexible to allow for stress relief. This stress relief should also be chosen for maximum contact area to afford the best heat transfer.

7.7.6.2 Device Soldering

The manufacturer's recommendations for maximum soldering temperature and time should be observed. Solders available as either preforms or paste may be used. Most solder pastes contain flux. Solder preforms may be obtained with or without internal flux. Solder preforms without flux require the application of a flux to assure good wetting during soldering. Fluxes used may range from a mild rosin to a strong acid type, depending on the materials to be soldered

To prevent poor solder connections, it is suggested that a weight or spring loaded fixture be employed during the soldering operation. This will keep the device from floating on the solder when it becomes liquid.

7.7.6.3 Heating Techniques

Belt furnace, flame soldering, stationary ovens, hot plates, or soldering irons may be used in soldering button- type devices. A soldering profile giving the time-temperature relationship of the chosen method should be obtained to assure good soldering and compliance with manufacturer's recommendations for the device. It is important that severe thermal shock during heating or cooling be avoided, at this may lead to damage of the device die or encapsulation.

7.7.6.4 Post Soldering Considerations

After soldering, the completed assembly should be unloaded, cleaned and inspected. Unloading should be done with care to avoid unnecessary stress. If an acid flux was used, because of its ionic and corrosive nature, the entire assembly should be cleaned. One method is to wash with hot water and detergent. After washing, rinse, blow off excessive water and bake dry to remove trapped moisture. Inspection should be of both the electrical and physical characteristics of the device and its connections.

7.8 Temperature Measurement

Temperature measurements of diodes include direct measurement of ambient and surface temperatures and indirect measurement of internal virtual junction temperature. Since the temperature rise of components above ambient temperature will depend on parameters such as dissipated power, air velocity, altitude and ambient temperature, an arbitrary choice of these parameters may be made to provide the necessary standardization between the user's and the semiconductor or heat dissipator manufacturer's testing procedures. Correlation between these tests and specific equipment tests is the responsibility of the user.

Acceptable methods of temperature measurement such as thermocouples, thermometers, pyrometers, temperature-sensitive resistors and temperature-sensitive paints may be used. Where specific temperatures may be measured accurately only with specific methods (such as virtual junction temperature), the methods used must be specified in sufficient detail to permit duplication. For further details covering procedures and instruments for temperature measurements, refer to clause 6.5.6.

The following clauses outline methods of determining diode junction and case temperatures, heat sink temperature and air ambient temperature which are of particular value to the equipment manufacturer.

7.8.1 Diode Junction Temperature

Diode junction temperature is usually calculated rather than measured in operating equipment. In most applications the forward current of the diode is pulsating, causing the junction temperature to fluctuate as shown in Figure 66. Calculation of peak or some instantaneous junction temperature requires the use of transient thermal impedance. The procedure may be somewhat involved and is covered in the literature. The average junction temperature rise is shown in Figure 66 and may be calculated by multiplying average power loss by the value of thermal resistance. (See clause 7.4.3) Both transient thermal impedance and thermal resistance are required on current JEDEC registration formats for rectifier diodes.

If the apparent transient thermal impedance or apparent thermal resistance for some other specified waveform (single phase, three phase, etc.) is given, the product of this value and the average power loss for the particular current waveform will give the peak junction temperature. (See clause 7.4.3.)

7.8.1 Diode Junction Temperature (cont'd)

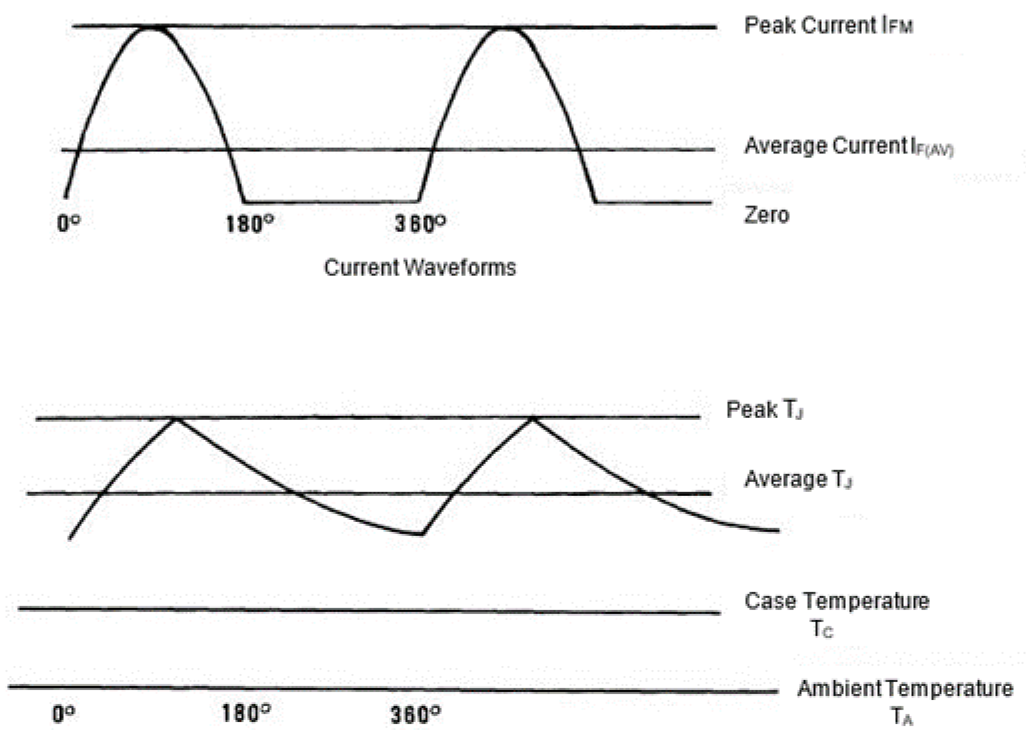


Figure 66 — Typical On-State Current and Corresponding Junction and Case Temperature in a Half-Wave AC Circuit

7.8.2 Case Temperature

The case temperature of a stud-mounted, hexagonal base diode is measured at the center of any flat on the hex. For disk-type devices, the case temperature should be measured at a point on the cylindrical surface of a designated mounting pole. 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 thermocouples and is defined as follows:

a. **Type of Thermocouple:** The thermocouple material shall be copper-constantan (Type-T) as recommended by the Standards Handbook for Electrical Engineers (latest edition) for the range of -183 °C to 371 °C. The wire size shall be no larger than #30 AWG. The junction of the thermocouple shall be welded together to form a bead rather than soldered or twisted. (See latest edition Annual Book of ASTM Standards - Part 30, Method E220, for Calibration of Thermocouples by Comparison Techniques and for information on construction and usage of thermocouples.)

b. **Mounting Method:** A small hole, just large enough to insert the thermocouple, shall be drilled approximately 1/32 inch deep in the flat of the case hex at the point specified by the manufacturer. The edge of the hole should then be peened with a small center punch to force a rigid mechanical contact with the welded bead of the thermocouple. If forced-air cooling is used, the thermocouple shall be mounted away from the air stream, and the thermocouple leads close to the junction shall be shielded.

7.8.2 Case Temperature (cont'd)

c. **Accuracy:** An accuracy of plus or minus 1/2 °C should be expected of the thermocouple. Under load conditions, slight variations in the temperature of different points on the case may reduce this accuracy to plus or minus 1 °C for free convection cooling, and plus or minus 2 °C for forced air-cooling.

d. **Other Methods of Mounting:** Methods of mounting thermocouples other than by soldering or welding them directly to the case, will result in temperature readings lower than the actual temperature. These deviations will result, for example, from inadequate contact with the case when using cemented thermocouples.

7.8.3 Mounting Surface Temperature

The mounting surface temperature is measured using a thermocouple imbedded in a washer. The mounting surface technique for measuring the reference point temperature is nondestructive and is generally as repeatable as the case temperature measuring technique. The mounting surface technique is "application oriented" in that it takes into account the mounting surface interface. However, it may introduce a significant error into transient thermal impedance measurements made using the cooling technique. The thermocouple characteristics and details of the washer design are given below. It should be noted that case temperature and mounting surface temperature are sometimes used interchangeably.

7.8.3.1 Type of Thermocouple

The thermocouple material shall be copper-constantan (Type T). Its useful temperature range for standard temperature measurements is from -180 °C to +371 °C. The wire size shall be no larger than #30 AWG. The junction of the thermocouple shall be formed by welding the wires together to form a bead rather than soldered or twisted.

7.8.3.2 Mounting Washer Construction

The following general rules apply:

a. The base material of the washer shall be copper (half hard or softer is preferred).

b. The thickness of the washer shall be 3.18 mm ± 0.13 (0.125 ± 0.005 inch).

c. The outline of the washer shall be larger by 0.76 to 1.52 mm (0.03 to 0.06 inch) than the outline of the seating surface of the package for which the washer is intended.

d. Clearance holes shall be 0.41 to 0.79 mm (0.016 to 0.031 inch) larger than the maximum outside diameter of the studs or screws intended to pass through the holes.

e. The surface of the washer shall be flat within 1 µm per mm (1 mil per inch) and parallel within 3 µm per mm (3 mils per inch) and shall be nickel plated to a thickness of 1.3 µm to 2.6 µm.

f. (50 µ-inches to 100 µ-inches). (See ANSI B46.1 - 1995, Surface Texture, for further details.).

g. The surface of the washer shall be free from burrs, but the maximum chamfering of edges or holes shall not exceed 0.41 mm (0.016 inch) by 45 degrees so as not to effectively reduce the contact area of the washer.

h. Both surfaces of the washer shall have a 1.6 µm (63 microinch) finish or better and be free of oxides. (See ANSI B46.1 - 1995, Surface Texture, for further details.)

i. The thermocouple hole shall be drilled into the washer midway between and parallel to the top and bottom surfaces. The size of the thermocouple hole shall be no greater than 1.52 mm (0.06 inch) in diameter, but it is recommended that it be no larger than necessary to accept the thermocouple.

7.8.3.2 Mounting Washer Construction (cont'd)

j. For flat-type packages the bottom of the thermocouple hole shall extend approximately 0.76 mm (0.03 inch) beyond the geometric center of the washer. The radial orientation of the thermocouple hole is arbitrary.

k. For stud-type packages the bottom of the thermocouple hole shall be approximately 0.76 mm (0.03 inch) from the inside hole of the washer.

l. For tab-type packages, the bottom of the thermocouple hole shall extend approximately 0.76 mm (0.03 inch) beyond geometric center of the seating surface.

m. It is recommended that the thermocouple be secured into the washer with a thermal conducting adhesive and that particular attention be paid to minimizing air voids around the bead of the thermocouple. (The thermocouple bead should be in direct contact with the copper washer.)

n. Clearance holes for device leads should allow suitable clearance to prevent electrical shorting to the washer. It is recommended that the clearance holes be approximately 1.52 mm (0.06 inch) larger in diameter than the leads to allow clearance for insulating sleeving which should be used on the leads.

o. Device mounting torque should comply with the manufacturer's recommendations.

p. A thermally conducting compound should be used on both sides of the washer to interface with the device case and the heat dissipator.

q. Special care must be taken so that only the bead of the thermocouple is allowed to come into mechanical contact with the washer.

7.8.4 Lead Temperature

The lead temperature of a lead-mounted diode is measured on the specified lead(s) at a specified point from the body of the device or its tubulation(s). For thermally unsymmetrical double-side cooled devices in which the anode or cathode can be connected to either device terminal, the specified lead temperature shall be the higher of the two lead temperatures measured with both leads terminated thermally in the same manner. The lead temperatures are to be measured by means of a copper-constantan thermocouple containing a maximum wire size of #36 AWG. The thermocouple(s) are to be welded or soldered to the specified lead contact point(s) with the weld or solder material kept to an absolute minimum.

7.8.5 Free-Air Convection Measurements of Assemblies

The heat dissipator should be suspended vertically in a cubic enclosure whose dimensions are a minimum of four times the dissipator height. The enclosure should be so designed that the inside walls are insulated from ambient, i.e., they are substantially at the inside ambient temperature. See Figure 67.

The ambient temperature should be measured by means of a thermocouple mounted at a distance 1/4 the dissipator height directly below the center of the bottom of the heat dissipator.

The heat dissipator temperature should be measured by means of a thermocouple attached to the dissipator by peening at a radius of 6.35 mm (1/4 inch) greater than the maximum diode base radius.

The case temperature of the diode should be measured as described in clause 7.8.2.

7.8.5 Free-Air Convection Measurements of Assemblies (cont'd)

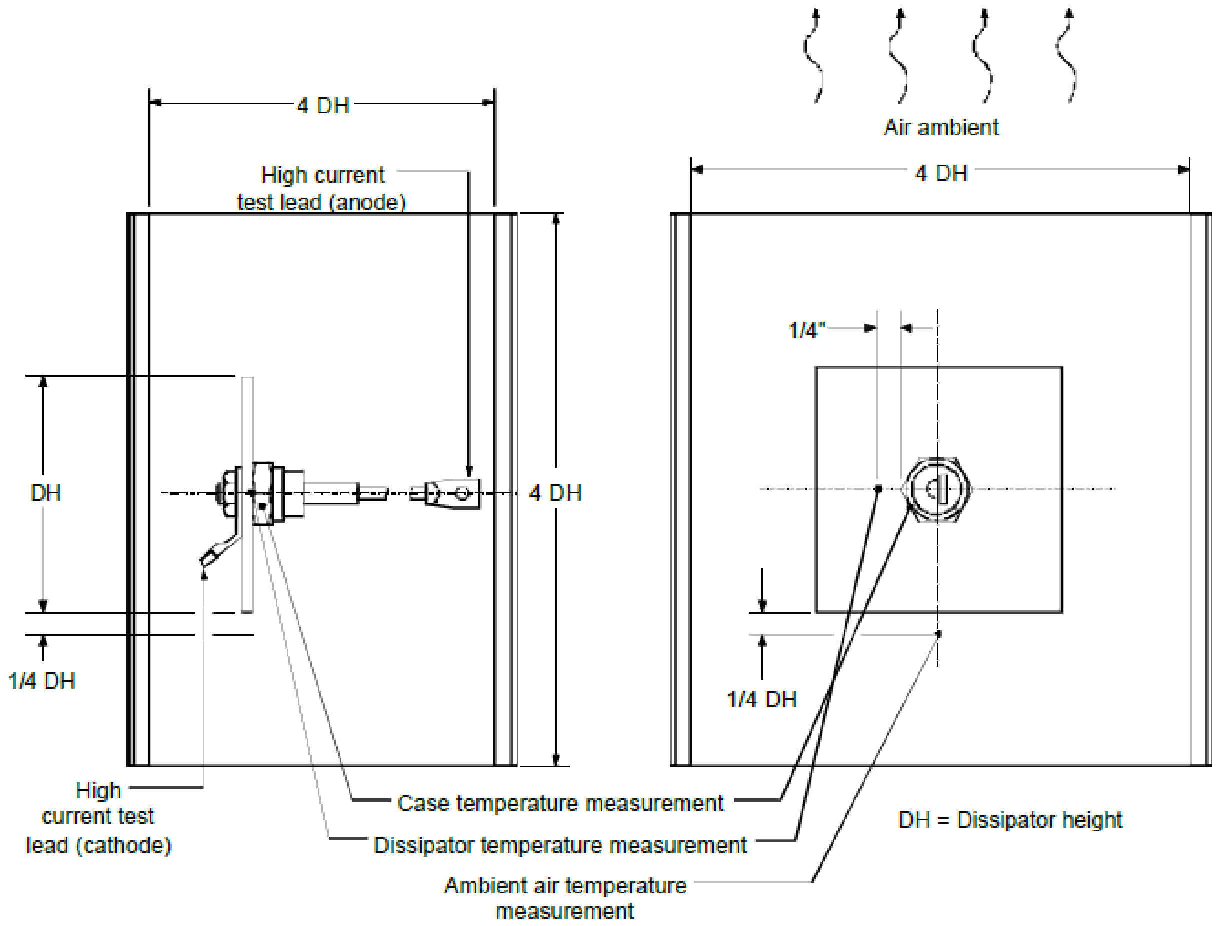


Figure 67 — Free-Air Convection Measurement

7.8.6 Forced-Air Convection Measurements of Assemblies

The heat dissipator, oriented parallel to the air stream, should be rigidly fastened inside a rectangular duct whose width and height exceed the corresponding dimensions of the dissipator by 25.4 mm (1 inch) or 25% (whichever is smaller). Any additional parts of the diode and/or test lead may protrude through a sealed hole in the duct or out of the duct as shown on Figure 68. The dissipator should be supported by mounting brackets, using insulating material. Mounting brackets and high current leads should not cover more than 2% of the duct cross-section area. The length of the duct, from air input end to air exhaust end, should be seven times the dissipator length. The inside duct walls should have a smooth surface. The dissipator should be located so that its leading edge is four fin lengths downstream from the air input end of the duct.

The air velocity should be measured one dissipator width upstream from the leading edge of the dissipator. The recommended test air velocity will be considered the average of all point velocities over the air stream cross-section. The dissipator air pressure drop should be measured between one dissipator length upstream from the leading edge of the dissipator and one dissipator length downstream from its trailing edge.

7.8.6 Forced-Air Convection Measurements of Assemblies (cont'd)

The ambient temperature should be measured one dissipator length upstream from the leading edge of the dissipator by means of a thermometer or thermocouple.

The dissipator temperature should be measured by means of a thermocouple attached by peening to the dissipator at a radius of 6.35 mm (1/4 inch) greater than the maximum diode base radius. This measurement point should also be located on the dissipator centerline parallel to the air flow and on the downstream of the diode.

The case temperature of the diode should be measured as described in clause 7.8.2.

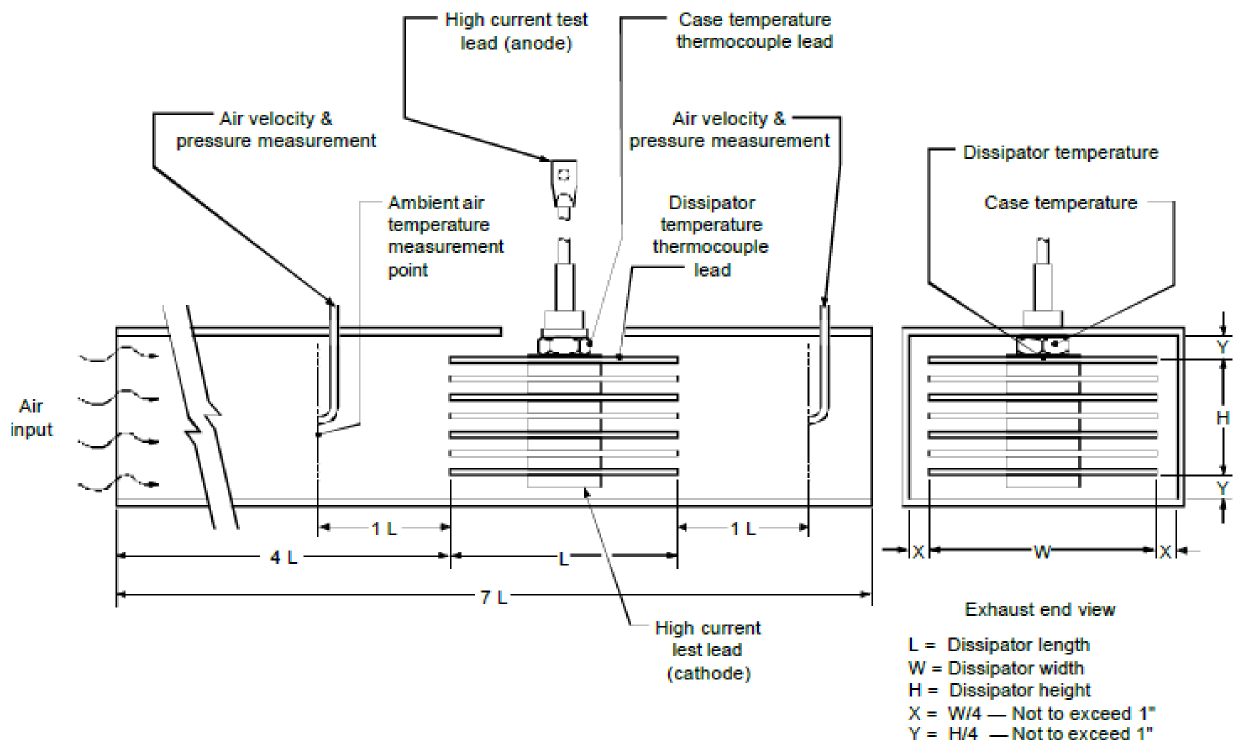


Figure 68 — Forced Convection Measurement

7.9 Diode Failure Modes

Diode failures may be broadly classified as either catastrophic or degradation failures. Catastrophic failure occurs when a device exhibits a sudden change in characteristic that renders it inoperable. A degradation failure is generally defined as a failure because some characteristics change more than a specific amount. The device may still function satisfactorily in the circuit.

7.9.1 Catastrophic Failure

Catastrophic failure can occur whenever the diode is operated beyond its published ratings or it contains an unknown fabrication defect. This type of failure generally results in an electrical short circuit between anode and cathode terminals. However, if the resulting short circuit current is high enough, device internal parts may melt and thus render the device an open circuit.

7.9.1 Catastrophic failure (cont'd)

Generally, it is over-voltage or over-current operation that produces catastrophic failures. Over-voltage failures may be due to excessive circuit transient voltages that were not accounted for in the circuit design. Voltage failures may also occur if inadequate device cooling raises the operating junction temperature above rated value and thereby invalidates the steady-state voltage rating of the diode. Over-current catastrophic failures are generally caused by improper fusing or poor circuit protection coordination in the event of a circuit fault condition. Of course, improper handling or mounting during the installation of diodes in equipment can mechanically damage the devices to the extent that they fail catastrophically as soon as electric power is applied. Excessive device mounting torque and excessive force applied to insulating terminals or the lead are two common causes of physical damage to diodes.

7.9.2 Degradation Failure

Any significant degradation of the diode forward or switching characteristics is quite rare. The characteristic most vulnerable to degradation is the reverse blocking voltage characteristic. This effect is outside the control of the user, assuming that the device is operated at all times within all of its maximum ratings. It should be pointed out, however, that the occurrence of this type of degradation increases with increasing operating voltage and temperature levels. Hence, the user can reduce the possibility of blocking voltage degradation by operating below the maximum temperature and/or voltage ratings of the device. Thus, the probability of long diode operating life can be increased simply by using heat dissipators which are somewhat oversized and selecting diodes of a voltage grade somewhat in excess of the actual maximum circuit voltage.

7.10 Simple Measurements in Troubleshooting

An ohmmeter may be used to determine whether a diode is shorted in the reverse direction. Disconnect one terminal from the circuit and then measure the device resistance in the reverse direction. Use the highest resistance range of the ohmmeter to assure that the driving voltage is several volts. Resistance readings will range upward from 10 kilohms depending upon the particular device reverse characteristics. Very high reverse resistance may indicate that the diode is open. In this case, the forward direction should be checked by reversing the ohmmeter leads. Forward resistance readings are usually a few ohms.

The ohmmeter test will not determine whether the diode reverse characteristics have degraded. When it is believed that the diode has been overstressed and there is some doubt as to whether it will block rated voltage, dc voltage should be gradually applied to the device through a suitable resistor and dc milliammeter. The diode specification sheets should be consulted for typical values of room temperature reverse current at rated voltage. The supply voltage used in this test and the series resistor and ammeter should be chosen so that if the diode breaks down during the reverse voltage test, the resistor will limit the current to the full scale value of the milliammeter. Thus, reverse current will be read low on the milliammeter scale, but no particular accuracy is required in this test. The dc supply should be free of voltage transients.

The simple test mentioned above will generally determine whether a diode is operational. If precise device rating or characteristic information is required, refer to the test information given in chapter 5 and chapter 6 of this standard.

7.11 Surface Mounting

This is an approach for reducing size and often reducing the overall cost in the application of the smaller components typically assembled on printed circuit boards.

Surface mounting involves soldering parts onto the surface of a printed circuit board rather than inserting pins or leads through holes in the board and soldering them on the underside. Surface-mount component packages are much smaller than those typically used in through-hole mounting, and the leads are short or folded under the package. The result is a much higher packing density with potential improvements in reliability.

The technique lends itself to automation. A drawback is the potentially closer proximity of the chip, to the molten solder during the soldering process, thus subjecting the surface-mounted devices to an abnormally high temperature. Therefore, the package and internal construction undergo a greater thermal shock. On the other hand, the available soldering equipment for this type of component can be effectively controlled to create optimum conditions, which hand soldering may not be capable of doing.

It is imperative that the component manufacturer clearly define the mounting procedures and that the user follow them; these include, but are not limited to, a profile of the recommended time and temperature steps.

Annex A (Informative) Differences Between JESD282B.02 and its Predecessors

This annex briefly summarizes changes in this standard, JESD282B.02, compared to its predecessors. If the change to a concept involves any words added or deleted (excluding deletion of accidentally repeated words), it is included. Punctuation changes (e.g., spaces, commas, semicolons, and hyphens added or deleted) may not be included.

Differences between JESD282B.02 and JESD282B.01 (November 2002):

Clause	Item and description of change
Chapter 1	Added Scope.
General	Editorial revision that updates the formatting to JEDEC standard. Updated JEDEC logo and back pages to standard format Equation numbering deleted, replaced by equation identification by clause. Consolidation of several clauses for streamlining. Replace the terms Section and Paragraph with Chapter and Clause. Changes to sensitive terminology (specifically, the following three line items).
3.4.3	2nd paragraph;
7.7.1.1	Last sentence; sensitive terminology replaced with "inhibiting".
7.8	2nd paragraph; the cited IEEE reference with sensitive terminology removed (The reference is no longer available from IEEE).

Differences between JESD282B.01 and JESD282-B (April 2000):

Page	Item and description of change
13	**Revision to Figure 1.8(c):** Replaced figure.
93	**Revision to Figure 5.15:** Corrected missing letters in the label 'Diode Response Measured at E'.
111	**Revision to Figure 5.25:** The vertical axis label 'OG $Z_{th(t)}$' was missing the 'L', changed to 'LOG $Z_{th(t)}$'.
149	**6.5.2 Reverse Recovery,** 3rd paragraph: Made minor editorial change in last sentence.
150	**Revision to Title of Figure 6.1:** Changed 't' to 'various types'.
152	**Revision to Figure 6.2a:** Changed Output wave value for E_a under Full-wave bridge from '0.707' to '1.00'.
152	**Revision to Figure 6.2a:** Changed Output wave value for F.F. (now E_a/E_d) under Full-wave bridge from '1.57' to '1.11'.
153	**Revision to Figure 6.2b:** Changed Rectifier diode wave values 'I_t' to $I_{F(RMS)}$'.
153	**Revision to Figure 6.2b:** Changed Voltage Factor (V.F.) under Six phase from '0.406' to '0.408'.
154	**Revision to Figure 6.3a:** Made minor line adjustment to the table header.

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Standard Improvement Form — JEDEC JESD282B.02

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

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1. I recommend changes to the following:
   - ☐ Requirement, clause number __________
   - ☐ Test method number __________ Clause number __________

   The referenced clause number has proven to be:
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   - ☐ Other __________

2. Recommendations for correction:

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