มาตรฐานผลิตภัณฑ์อุตสาหกรรม

THAI INDUSTRIAL STANDARD

มอก. 1670 – 2552

IEC 60747 – 2(2000 – 03)

อุปกรณ์สารกึ่งตัวนำ อุปกรณ์ไม่รวมหน่วยและวงจรรวม

เล่ม 2 ไดโอดเรียงกระแส

SEMICONDUCTOR DEVICES-DISCRETE DEVICES AND INTEGRATED CIRCUITS

PART 2: RECTIFIER DIODES

สำนักงานมาตรฐานผลิตภัณฑ์อุตสาหกรรม

กระทรวงอุตสาหกรรม

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มาตรฐานผลิตภัณฑ์อุตสาหกรรม
อุปกรณ์สารกึ่งตัวนำ
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ประกาศในราชกิจจานุเบกษา ฉบับประกาศและงานทั่วไป เล่ม 127 ตอนพิเศษ 92ง
วันที่ 30 กรกฎาคม พุทธศักราช 2554

มาตรฐานผลิตภัณฑ์อุตสาหกรรมอุปกรณ์สารกึ่งตัวนำ อุปกรณ์ไม่รวมหน่วยและวงจรรวม เล่ม 2 ไดโอดเรียงกระแส ได้ประกาศใช้ครั้งแรกโดยรับIEC 747-2(1983) Semiconductor Devices - Discrete devices and integrated circuits - Part 2: Rectifier diodes มาใช้ในระดับเหมือนกันทุกประการ (Identical) โดยใช้ IEC ฉบับภาษาอังกฤษเป็นหลัก โดยประกาศในราชกิจจานุเบกษา ฉบับประกาศทั่วไป เล่มที่117 ตอนที่ 76ง วันที่ 21 กันยายน พุทธศักราช 2543

เนื่องจากIECได้แก้ไขปรับปรุงมาตรฐาน IEC 747-2(1983) เป็น IEC 60747-2 (2000) จึงได้ยกเลิกมาตรฐานเดิม และกำหนดมาตรฐานใหม่โดยรับ IEC 60747-2 (2000) Semiconductor devices- Discrete devices and integrated circuits-Part 2: Rectifier diodes มาใช้ในระดับเหมือนกันทุกประการโดยใช้มาตรฐาน IEC ฉบับภาษาอังกฤษเป็นหลัก

คณะกรรมการมาตรฐานผลิตภัณฑ์อุตสาหกรรมได้พิจารณามาตรฐานนี้แล้ว เห็นสมควรเสนอรัฐมนตรีประกาศตาม มาตรา 15 แห่งพระราชบัญญัติมาตรฐานผลิตภัณฑ์อุตสาหกรรม พ.ศ. 2511

ประกาศกระทรวงอุตสาหกรรม

ฉบับที่ 4205 (พ.ศ. 2553)

ออกตามความในพระราชบัญญัติมาตรฐานผลิตภัณฑ์อุตสาหกรรม

พ.ศ. 2511

เรื่อง ยกเลิกและกำหนดมาตรฐานผลิตภัณฑ์อุตสาหกรรม

อุปกรณ์สารกึ่งตัวนำ อุปกรณ์ไม่รวมหน่วยและวงจรรวม

เล่ม 2 ไดโอดเรียงกระแส

โดยที่เป็นการสมควรปรับปรุงมาตรฐานผลิตภัณฑ์อุตสาหกรรม อุปกรณ์สารกึ่งตัวนำ อุปกรณ์ไม่รวมหน่วยและวงจรรวม เล่ม 2 ไดโอดเรียงกระแส มาตรฐานเลขที่ มอก.1670-2542

อาศัยอำนาจตามความในมาตรา 15 แห่งพระราชบัญญัติมาตรฐานผลิตภัณฑ์อุตสาหกรรม พ.ศ. 2511 รัฐมนตรีว่าการกระทรวงอุตสาหกรรมออกประกาศยกเลิกประกาศกระทรวงอุตสาหกรรม ฉบับที่ 2700 (พ.ศ.2543) ออกตามความในพระราชบัญญัติมาตรฐานผลิตภัณฑ์อุตสาหกรรม พ.ศ.2511 เรื่อง กำหนดมาตรฐานผลิตภัณฑ์อุตสาหกรรม อุปกรณ์สารกึ่งตัวนำ อุปกรณ์ไม่รวมหน่วยและวงจรรวม เล่ม 2 ไดโอดเรียงกระแส ลงวันที่ 12 มิถุนายน พ.ศ.2543 และออกประกาศกำหนดมาตรฐานผลิตภัณฑ์อุตสาหกรรม อุปกรณ์สารกึ่งตัวนำ อุปกรณ์ไม่รวมหน่วยและวงจรรวม เล่ม 2 ไดโอดเรียงกระแส มาตรฐานเลขที่ มอก.1670-2552 ขึ้นใหม่ ดังมีรายละเอียดต่อท้ายประกาศนี้

ทั้งนี้ให้มีผลตั้งแต่วันถัดจากวันที่ประกาศในราชกิจจานุเบกษา เป็นต้นไป

ประกาศ ณ วันที่ 7 เมษายน พ.ศ. 2553

ชาญชัย ชัยรุ่งเรือง

รัฐมนตรีว่าการกระทรวงอุตสาหกรรม

มาตรฐานผลิตภัณฑ์อุตสาหกรรม
อุปกรณ์สารกึ่งตัวนำ อุปกรณ์ไม่รวมหน่วยและวงจรรวม
เล่ม 2 ไดโอดเรียงกระแส

มาตรฐานผลิตภัณฑ์อุตสาหกรรมนี้กำหนดขึ้นโดยรับ IEC 60747-2 (2000) Semiconductor devices-Discrete devices and integrated circuits-Part 2: Rectifier diodes มาใช้ในระดับเหมือนกันทุกประการ (identical) โดยใช้ IEC ฉบับภาษาอังกฤษเป็นหลัก

มาตรฐานนี้ต้องใช้ร่วมกับ IEC 60747-1 โดยเป็นการกำหนดมาตรฐานสำหรับประเภทและประเภทย่อยของอุปกรณ์ไดโอดเรียงกระแสครอบคลุมถึง

- ไดโอดเรียงกระแสแบบพังทลาย
- ไดโอดเรียงกระแสแบบควบคุมการพังทลาย
- ไดโอดเรียงกระแสแบบการสวิตซ์เร็ว

รายละเอียดให้เป็นไปตาม IEC 60747-2 (2000)

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CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

SEMICONDUCTOR DEVICES – DISCRETE DEVICES AND INTEGRATED CIRCUITS –

Part 2: Rectifier diodes

FOREWORD

1) The IEC (International Electrotechnical Commission) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of the IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, the IEC publishes International Standards. Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. The IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
2) The formal decisions or agreements of the IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested National Committees.
3) The documents produced have the form of recommendations for international use and are published in the form of standards, technical specifications, technical reports or guides and they are accepted by the National Committees in that sense.
4) In order to promote international unification, IEC National Committees undertake to apply IEC International Standards transparently to the maximum extent possible in their national and regional standards. Any divergence between the IEC Standard and the corresponding national or regional standard shall be clearly indicated in the latter.
5) The IEC provides no marking procedure to indicate its approval and cannot be rendered responsible for any equipment declared to be in conformity with one of its standards.
6) Attention is drawn to the possibility that some of the elements of this International Standard may be the subject of patent rights. The IEC shall not be held responsible for identifying any or all such patent rights.

International standard IEC 60747-2 has been prepared by subcommittee 47E: Discrete semiconductor devices, of IEC technical committee 47: Semiconductor devices.

This second edition cancels and replaces the first edition published in 1983, its amendments 1 (1992) and 2 (1993). This second edition constitutes a technical revison.

This standard has to be read in conjunction with IEC 60747-1.

The text of this standard is based on the following documents:

FDIS	Report on voting
47E/136/FDIS	47E/143/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 3.

Annex A is for information only.

The committee has decided that the contents of this publication will remain unchanged until 2005. At this date, the publication will be

- reconfirmed;
- withdrawn;
- replaced by a revised edition, or
- amended.

SEMICONDUCTOR DEVICES – DISCRETE DEVICES AND INTEGRATED CIRCUITS –

Part 2: Rectifier diodes

Introductory note

As a rule, it will be necessary to use IEC 60747-1 together with the present publication. In IEC 60747-1, the user will find all basic information on:

– terminology;
– letter symbols;
– essential ratings and characteristics;
– measuring methods;
– acceptance and reliability.

1 Scope

The present publication gives standards for the following categories or sub-categories of devices.

Rectifier diodes, including:

– avalanche rectifier diodes;
– controlled-avalanche rectifier diodes;
– fast-switching rectifier diodes.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 60747-1:1983, *Semiconductor devices – Discrete devices and integrated circuits – Part 1: General*
Amendment 3 (1996).

3 Terms and definitions

According to the ISO/IEC Directives for the drafting and presentation of International Standards this part of IEC 60747 contains only those definitions which are necessary for the understanding of the terms used and of their exact meaning. Further definitions may be found in IEC 60747-1 and in Chapter 521 of the International Electrotechnical Vocabulary (IEC 60050(521)).

3.1 General terms

3.1.1
forward direction
direction of the flow of continuous (direct) current in which a semiconductor diode has the lower resistance

3.1.2
reverse direction
direction of the flow of continuous (direct) current in which a semiconductor diode has the higher resistance

3.1.3
anode terminal (of a semiconductor rectifier diode or rectifier stack)
terminal to which forward current flows from the external circuit

3.1.4
cathode terminal (of a semiconductor rectifier diode or rectifier stack)
terminal from which forward current flows to the external circuit

3.1.5
rectifier stack arm
that portion of a rectifier stack bounded by two circuit terminals which has the characteristic of conducting current substantially in one direction only

NOTE A rectifier stack arm may consist of one rectifier diode or of a number of rectifier diodes connected in either a series, a parallel or a series-parallel arrangement, to operate as a unit. This means that a rectifier stack arm may be the part or the whole of a rectifier stack.

3.2 Terms related to ratings and characteristics: voltages

NOTE When several distinctive forms of a letter symbol exist, the most commonly used form is given (see clause 4).

3.2.1
forward voltage (v_F)
voltage across the terminals which results from the flow of current in the forward direction

3.2.2
threshold voltage ($V_{(TO)}$)
value of the forward voltage obtained at the intersection of the straight line approximation of the forward characteristic with the voltage axis

3.2.3
forward recovery voltage (V_{FR})
varying voltage occurring during the forward recovery time after instantaneous switching from zero or a specified reverse voltage to a specified forward current

3.2.4
continuous (direct) reverse voltage (V_R)
value of the constant voltage applied to a diode in the reverse direction

3.2.5
crest (peak) working reverse voltage (V_{RWM})
highest instantaneous value of the reverse voltage, excluding all repetitive and non-repetitive transient voltages

3.2.6
repetitive peak reverse voltage (V_{RRM})
highest instantaneous value of the reverse voltage, including all repetitive transient voltages, but excluding all non-repetitive transient voltages

3.2.7
non-repetitive peak reverse voltage; peak transient reverse voltage (V_{RSM})
highest instantaneous value of any non-repetitive transient reverse voltage

NOTE 1 Preference should be given to the term "non-repetitive peak reverse voltage".

NOTE 2 The repetitive voltage is usually a function of the circuit and increases the power dissipation of the device. A non-repetitive transient voltage is usually due to an external cause and it is assumed that its effect has completely disappeared before the next transient arrives.

3.2.8
breakdown voltage (V_{BR})
voltage in the region where breakdown occurs.

3.3 Terms related to ratings and characteristics: currents

3.3.1
forward current (I_F)
current flowing through the diode in the direction of lower resistance

3.3.2
mean forward current (I_{FAV})
value of the forward current averaged over the full cycle

3.3.3
r.m.s. forward current (I_{FRMS})
r.m.s value of the forward current over one complete cycle of the operating frequency

3.3.4
repetitive peak forward current (I_{FRM})
peak value of the forward current including all repetitive transient currents

3.3.5
overload forward current ($I_{(OV)}$)
forward current of substantially the same waveshape as the specified normal forward current, but having a greater value, such that its continuous application would cause the rated maximum virtual junction temperature to be exceeded, but that is limited in duration to such an extent 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.

3.3.6
surge forward current (I_{FSM})
forward current pulse of short time duration and specified waveshape, whose application causes or would cause the maximum rated junction temperature to be exceeded, but which is assumed to occur rarely and with a limited number of such occurrences during the service life of the device and to be a consequence of unusual circuit conditions (for example a fault)

3.3.7
reverse current (I_R)
total conductive current flowing through the diode when specified reverse voltage is applied

3.3.8
resistive reverse current (i_{rr})
that part of the steady-state reverse current exclusive of the recovery current, if any

3.3.9
reverse recovery current (i_{RR})
that part of the reverse current which occurs during the reverse recovery time

3.3.10
I^2t value
integral of the square of a surge forward current over the duration of the current surge

3.3.11
peak case non-rupture current (I_{RSMC})
peak value of reverse current that should not be exceeded in order to avoid bursting of the case or the emission of a plasma beam under specified conditions of current, waveshape and time

NOTE This definition implies that a fine crack in the case might be found in a device subjected to the peak case non-rupture current, provided that no plasma beam was emitted. Parts of the case shall not break away, nor shall the device melt externally or burst into flames.

3.3.12
case non-rupture $I^2_{RC}t$
value of $I^2_{RC}t$ that should not be exceeded in order to avoid bursting of the case or the emission of a plasma beam, under specified conditions of current, waveshape and time, and given as follows:

$$I^2_{RC}t = \int_0^{t_w} i^2 \mathrm{d}t$$

where

t_w is the reverse current pulse duration

NOTE This definition implies that a fine crack in the case might be found in a device subjected to the case non-rupture $I^2_{RC}t$ provided that no plasma was emitted. Parts of the case shall not break away, nor shall the device melt externally or burst into flames.

3.4 Terms related to ratings and characteristics: power dissipations

3.4.1
total power dissipation (P_{tot})
sum of the dissipations due to currents in the forward and reverse directions

3.4.2
forward power dissipation (P_F)
power dissipation due to the flow of forward current

3.4.3
mean forward power dissipation (P_{FAV})
mean value of the product of the instantaneous forward voltage and the instantaneous forward current averaged over a full cycle

3.4.4
reverse power dissipation (P_R)
power dissipation resulting from the flow of reverse current

3.4.5
surge reverse power dissipation (of avalanche and controlled-avalanche rectifier diodes) (P_{RSM})
power which is dissipated within the diode resulting from surges occurring when it is operating in the reverse direction

3.4.6
turn-on dissipation (P_{Fon})
power dissipated within the diode during the change between reverse voltage and forward current when the diode is switched from a reverse voltage to a forward current

3.4.7
turn-off dissipation (P_{RR})
power dissipated within the diode during the change between forward current and reverse voltage when the diode is switched from a forward current to a reverse voltage

3.5 Terms related to ratings and characteristics: other characteristics

3.5.1
straight line approximation of the forward characteristic
approximation of the voltage versus current forward characteristic by means of a straight line which crosses this characteristic at two specified points (see figure 5)

3.5.2
forward slope resistance (r_T)
value of the resistance calculated from the slope of the straight line approximation of the forward characteristic (see figure 5)

3.5.3
forward recovery time (t_{fr})
time interval between the instant when the forward voltage rises through a specified first value and the instant when it falls from its peak value V_{FRM} to a specified second value close to the final stable value of forward voltage (as shown in figure 1a), or when the extrapolated forward voltage reaches zero (as shown in figure 1b), upon the application of a specified step of forward current following a zero-voltage or other specified reverse-voltage condition

NOTE 1 Specification method I: The specified first and second values referred to in the definition are usually 10 % and 110 %, respectively, of the final stable value (V^*_F in figures 1a and b).

NOTE 2 Specification method II: The extrapolation is carried out with respect to specified points A and B where A and B are usually 90 % and 50 % of V_{FRM} as shown in generalized form in figure 1b.

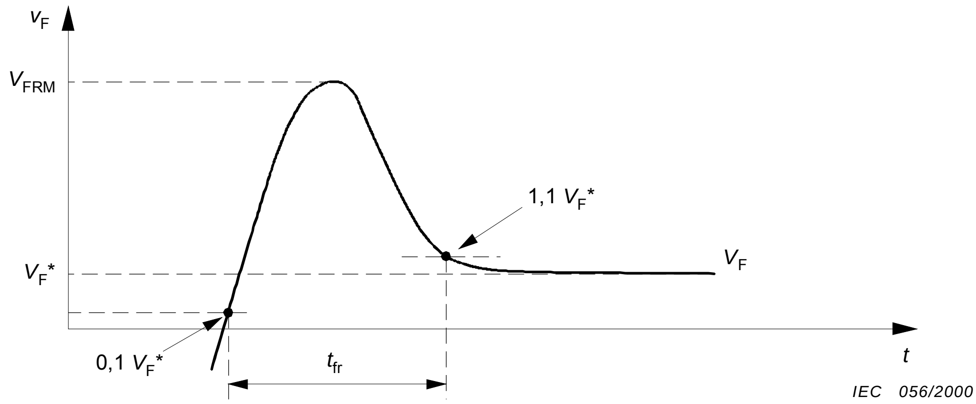


Figure 1a – Specification method I

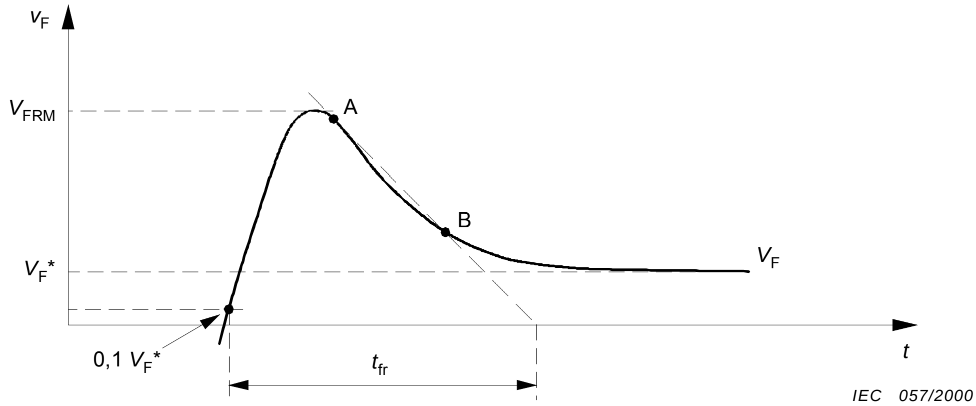


Figure 1b – Specification method II

Figure 1 – Voltage waveform during forward recovery

3.5.4
reverse recovery time (t_{rr})
time interval between the instant when the current passes through zero, when changing from the forward direction to the reverse direction, and the instant when the reverse current is reduced from its peak value I_{RM} to a specified low value (as shown in figure 2a) or when the extrapolated reverse current reaches zero (as shown in figure 2b)

NOTE The extrapolation is carried out with respect to specified points A and B. as shown in generalised form in figure 2b. Although point A is often specified at 90 % of I_{RM}, it may be specified at I_{RM}.

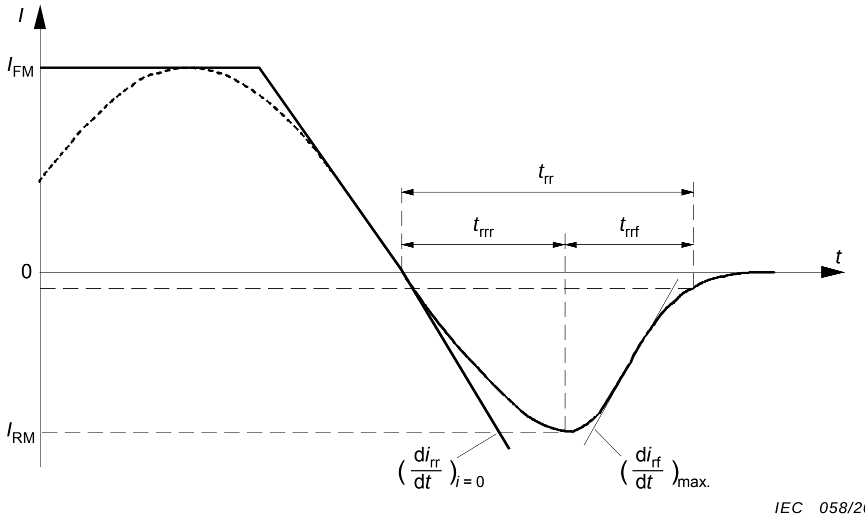


Figure 2a – Specification using low value of I_{rr}

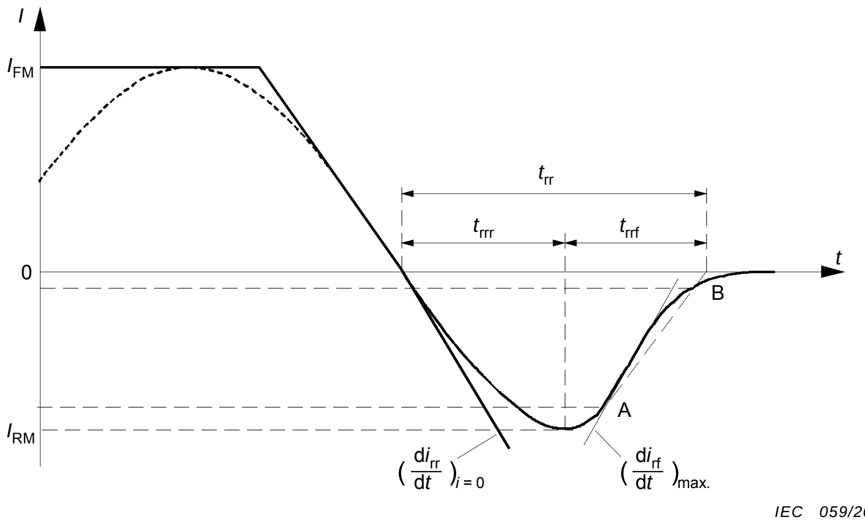


Figure 2b – Specifications using points "A" and "B"

Figure 2 – Current waveform during reverse recovery

3.5.5
recovered charge (Q_r)
total charge recovered from the diode during a specified integration time after switching from a specified forward current condition to a specified reverse condition:

$$Q_r = \int_{t_o}^{t_o+t_i} i_R \cdot dt$$

where

t_o is the instant when the current passes through zero;

t_i is the specified integration time (see figure 3).

NOTE This charge includes components due to both carrier storage and depletion layer capacitance.

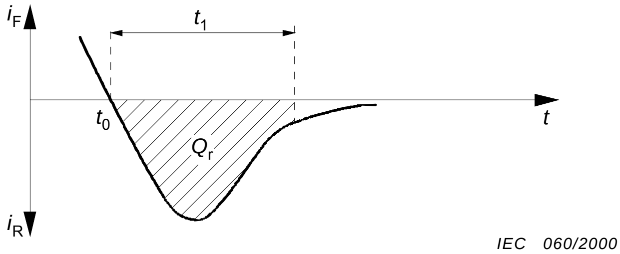


Figure 3 – Recovered charge

3.5.6
reverse recovery current rise time (t_{rrr}, t_a)
time interval between the beginning of the reverse recovery time and the instant when the reverse recovery current reaches its peak value after instantaneous switching from a specified forward current to a specified reverse voltage

NOTE The letter symbol t_a is sometimes used.

3.5.7
reverse recovery current fall time (t_{rrf}, t_b)
time interval between the instant when the reverse recovery current reaches its peak value and the end of reverse recovery time after instantaneous switching from a specified forward current to a specified reverse voltage

NOTE The letter symbol t_b is sometimes used.

3.5.8
rise time charge (Q_{RRR})
part of the recovered charge that is recovered from the diode during the reverse recovery current rise time

3.5.9
fall time charge (Q_{RRF})
that part of the recovered charge that is recovered from the diode during the reverse recovery current fall time

NOTE The time intervals t_{rrr} (3.5.6) and t_{rrf} (3.5.7) are defined so that their sum equals the reverse recovery time t_{rr}, whereas the recovered charge Q_r (3.5.5) is defined for an integration time t_i. As a consequence, the sum of the partial charges Q_{RRR} (3.5.8) and Q_{RRF} (3.5.9) will differ from Q_r unless t_{rr} equals t_i.

3.5.10
(reverse recovery) softness factor (F_{RRS})
absolute value of the ratio of the rate of rise of the reverse recovery current when passing through zero to the maximum rate of fall of the recovery current. See figures 2a and 2b.

$$F_{RRS} = \frac{(\mathrm{d}i_{rr} / \mathrm{d}t)_{i=0}}{(\mathrm{d}i_{rf} / \mathrm{d}t)_{max}}$$

4 Letter symbols

4.1 General

The general rules of IEC 60747-1, Chapter V, are applicable in part.

4.2 Additional general subscripts

In addition to the lists of recommended general subscripts given in IEC 60747-1, Chapter V, the following special subscripts are recommended for the field of rectifier diodes:

4.2.1 For currents, voltages and powers

(See also 2.2.1 of IEC 60747-1, Chapter V):

A, a = anode

K, k = cathode

(TO) = threshold

4.2.2 For electrical parameters

(See also 2.2.2 of IEC 60747-1, Chapter V):

T = slope

4.3 List of letter symbols

The symbols contained in the following lists are recommended for use in the field of rectifier diodes; they have been compiled in accordance with the general rules.

4.3.1 Voltages

Name and designation	Letter symbol	Remarks
Continuous (direct) forward voltage	V_F	
Crest (peak) forward voltage	V_{FM}	
Average forward voltage (with I_O specified)	$V_{F(AV)}$	
Continuous (direct) reverse voltage	V_R	
Crest (peak) working reverse voltage	V_{RWM}	
Repetitive peak reverse voltage (maximum recurrent reverse voltage)	V_{RRM}	
Non-repetitive peak reverse voltage (peak transient reverse voltage)	V_{RSM}	
Breakdown voltage	$V_{(BR)}$	
Forward recovery voltage	V_{FR}	
Peak value of forward recovery voltage	V_{FRM}	

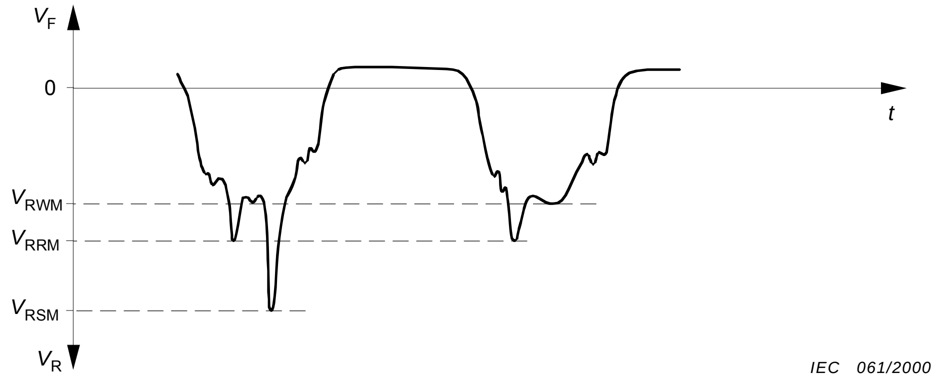
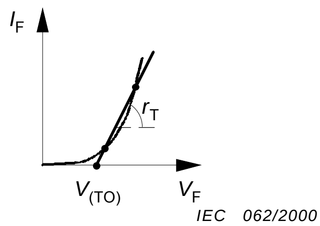


Figure 4 – Reverse voltage ratings

Name and designation	Letter symbol	Remarks
Forward slope resistance Threshold voltage	r_T $V_{(TO)}$	 **Figure 5 – Forward characteristic**

4.3.2 Currents

Name and designation	Letter symbol	Remarks
Continuous (direct) forward current	I_F	
Mean forward current	I_{FAV}	
Repetitive peak forward current	I_{FRM}	
r.m.s forward current	I_{FRMS}	
Overload forward current	$I_{(OV)}$	
Surge (non-repetitive) forward current	I_{FSM}	
Continuous (direct) reverse current	I_R	
Peak reverse recovery current	I_{RM}	
Reverse recovery current	i_{RR}	
Peak case non-rupture current	I_{RSMC}	

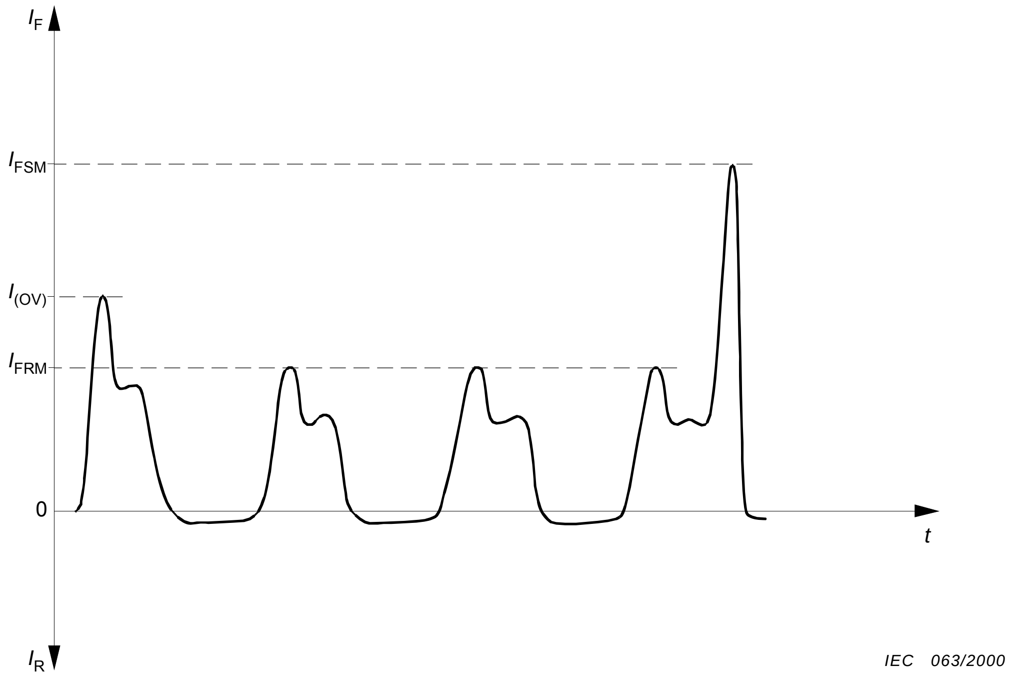


Figure 6 – Forward current ratings

4.3.3 Powers

Name and designation	Letter symbol	Remarks
Forward power dissipation	P_F	
Reverse power dissipation	P_R	
Turn-on dissipation: – average turn-on dissipation – total instantaneous turn-on dissipation – peak turn-on dissipation	 $P_{FT(AV)}$ P_{FT} P_{FTM}	
Turn-off dissipation: – average turn-off dissipation – total instantaneous turn-off dissipation – peak turn-off dissipation	 $P_{RQ(AV)}$ P_{RQ} P_{RQM}	

4.3.4 Switching

Name and designation	Letter symbol	Remarks
Forward recovery time	t_{fr}	
Reverse recovery time	t_{rr}	
Reverse recovery current rise time	t_{rrr}, t_a	
Reverse recovery current fall time	t_{rrf}, t_b	
Recovered charge	Q_r, Q_{RR}	
Rise time charge	Q_{RRR}	
Fall time charge	Q_{RRF}	
(Reverse recovery) softness factor	F_{RRS}	

5 Essential ratings and characteristics

5.1 General

5.1.1 Range of application

This clause gives standards for rectifier diodes including:

– avalanche rectifier diodes;
– controlled-avalanche rectifier diodes;
– fast-switching rectifier diodes.

5.1.2 Rating methods

Rectifier diodes should be specified as ambient-rated or as case-rated devices.

5.1.3 Recommended temperatures

Many of the ratings and characteristics are required to be quoted at a temperature of 25 °C and at one other specified temperature.

Unless otherwise stated, the one other specified temperature should be chosen by the manufacturer from the list in IEC 60747-1; in addition, temperatures of –40 °C and +35 °C may be used.

5.2 Rating conditions

The ratings given in 5.3 should be stated under one or more of the following thermal conditions:

5.2.1 Ambient-rated rectifier diodes

5.2.1.1 Natural convection

At 25 °C and at one higher temperature (see 5.1.3). The cooling fluid and pressure (in the case of a gas) should be specified.

Air pressure should be at least 90 kPa (900 mbar), corresponding to a maximum level of 1 000 m above sea level.

5.2.1.2 Forced circulation

At a temperature taken from the list of recommended temperatures (see 5.1.3). The type, pressure and flow of the cooling fluid should be specified.

5.2.2 Case-rated rectifier diodes

At a reference-point temperature taken from the list of recommended temperatures (see 5.1.3).

NOTE The reference-point temperature is normally the case temperature. For small rectifier diodes, the temperature on one of the terminals may be specified.

5.3 Voltage and current ratings (limiting values)

The following ratings must be valid for the whole range of operating conditions as stated for the particular device.

5.3.1 Non-repetitive peak reverse voltage (V_{RSM})

Maximum value of a pulse of reverse voltage with a half-wave sinusoidal waveform, the duration of which has to be specified.

This duration should be chosen from the following values: 10 ms; 8,3 ms; 1 ms and 0,1 ms.

5.3.2 Repetitive peak reverse voltage (V_{RRM})

Maximum value of repetitive reverse voltage pulses, with half-wave sinusoidal waveform, whose duration and repetition rate have to be specified.

This duration should be chosen from the following values: 10 ms; 8,3 ms; 1 ms and 0,1 ms.

5.3.3 Crest (peak) working reverse voltage (V_{RWM})

Maximum value of a repetitive reverse voltage having a half-wave sinusoidal waveform at mains frequency, usually 50 Hz or 60 Hz (duration: 10 ms or 8,3 ms).

5.3.4 Continuous (direct) reverse voltage (V_R) (where appropriate)

Maximum value.

5.3.5 Mean forward current (I_{FAV})

A curve showing maximum values versus ambient or case temperature for single-phase half-wave circuit with resistive load. In addition, curves for other circuits may be given.

NOTE The rated mean forward current is given on the assumption that no overload occurs.

5.3.6 Repetitive peak forward current (I_{FRM}) (where appropriate), (especially for fast-switching diodes)

Curves showing the maximum (repetitive peak) forward current values as a function of the half-sine wave current duration, with the repetition frequency as a parameter, under the following specified conditions:

– reference-point temperature;
– reverse voltage;
– RC damping network (snubber), where appropriate.

Figure 7 is given as an example and figure 7a is given for explanatory purposes.

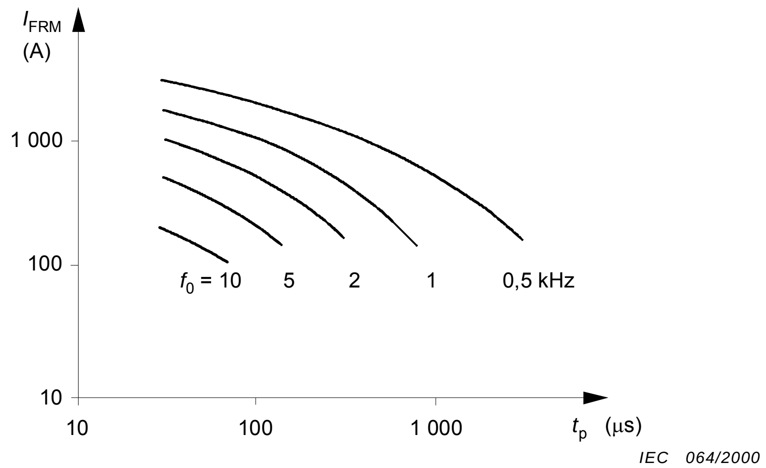


Figure 7 – Maximum peak forward current I_{FRM} as a function of pulse duration t_p
Parameter: repetition frequency f_0

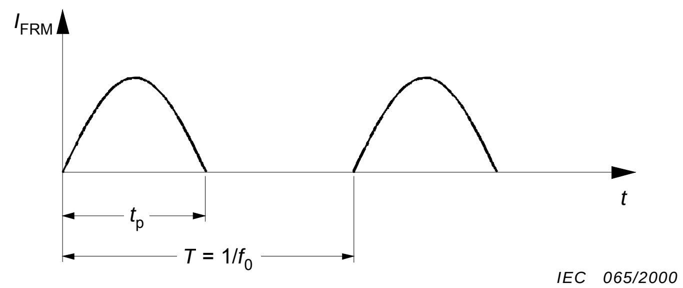


Figure 7a – Definition of pulse time t_p and cycle time T

5.3.7 Overload forward current ($I_{(OV)}$)

Where this rating is appropriate, it should be given by stating the maximum virtual junction temperature and the maximum transient thermal impedance. In addition, overload current ratings may be given by means of diagrams.

5.3.8 Surge (non-repetitive) forward current (I_{FSM})

This rating should be given at initial conditions corresponding to maximum virtual junction temperature. In addition, figures corresponding to lower initial virtual junction temperatures may be given.

Surge current ratings should be given for the following time periods:

a) For times smaller than one half-cycle (at 50 or 60 Hz), but greater than approximately 1 ms, in terms of maximum rated value of

$$\int i^2 \mathrm{d}t$$

These ratings may be given by means of a curve or by specified values. No immediate subsequent application of reverse voltage is assumed.

b) For times equal to, or greater than, one half-cycle and smaller than 15 cycles (at 50 Hz or 60 Hz) in the form of a curve showing the maximum rated surge current versus time.

These ratings should preferably be given for a reverse voltage of 80 % of the maximum repetitive peak reverse voltage. Additional ratings may be given for reverse voltage. Additional ratings may be given for reverse voltages of 50 % or 100 % of the maximum repetitive peak reverse voltage.

c) For a time equal to one cycle with no reverse voltage applied.

5.3.9 Continuous (direct) forward current (I_F)

Maximum value.

5.3.10 Peak case non-rupture current (I_{RSMC})

The limiting value "peak case non-rupture current" should be specified, where appropriate, as the maximum value of a triangular current rising at a specified rate, preferably 25 A/µs, and having a specified pulse duration for a starting case temperature to be specified, preferably 25 °C.

NOTE The limiting value "peak case non-rupture current" is needed for high-current rectifier diodes (mean current ratings of about 1 000 A and higher) that are used in large convertor installations (as a rule, several devices are connected in parallel), where a device failing to block reverse voltage causes a high, steeply rising, short-circuit current that can fracture the case and cause damage to the equipment before a fuse operates.

Therefore, the determination or verification of this limiting value of current needs a high-power testing facility, and the costs of the testing itself and of the samples which are destroyed in the test are considerable and are justified only in cases where the above-mentioned danger really exists.

The value of the peak case non-rupture current depends considerably on the location of the initial breakdown on the silicon chip and is usually lowest if the breakdown occurs near the edge.

5.4 Frequency ratings (limiting values)

Where applicable, maximum and/or minimum frequencies for which the voltage and current ratings (see 5.3) apply.

5.5 Power dissipation ratings (limiting values)

5.5.1 Surge (non-repetitive) reverse power dissipation
(for avalanche and controlled-avalanche rectifier diodes)

Rating curves showing the surge (non-repetitive) reverse power dissipation versus the surge duration, at maximum virtual junction temperature.

The waveform should be selected from 7.3.3.

5.5.2 Repetitive peak reverse power dissipation
(for controlled-avalanche rectifier diodes)

Maximum value at specified ambient or reference-point temperature (see note to 5.5.3).

The waveform should be selected from 7.3.3.

5.5.3 Mean reverse power dissipation
(for controlled-avalanche rectifier diodes)

Maximum value at specified ambient or reference-point temperature (see note below).

NOTE These reverse power dissipation ratings assume zero forward power dissipation. When both forward and reverse power dissipations occur in an application, they must both be derated in accordance with the device manufacturer's application information.

5.6 Temperature ratings (limiting values)

5.6.1 Cooling fluid (T_a) or reference-point temperatures (T_{ref})
(for ambient-rated or case-rated rectifier diodes)

Minimum and maximum values.

5.6.2 Storage temperatures (T_{stg})

Minimum and maximum values.

5.6.3 Virtual junction temperature (T_{vj}) (where appropriate)

Maximum value.

5.7 Electrical characteristics

(At 25 °C cooling fluid or reference-point temperature, unless otherwise stated.)

5.7.1 Forward characteristics (where appropriate)

Curves showing instantaneous values of forward voltage versus forward current up to the peak value of the current corresponding to the rated mean forward current (see 5.3.5), at a temperature of 25 °C and at one other higher temperature, preferably equal to the maximum virtual junction temperature.

5.7.2 Forward voltage (under thermal equilibrium conditions)

5.7.2.1 Continuous (direct) forward voltage (V_F)

Maximum value at the rated continuous (direct) forward current.

5.7.2.2 Crest (peak) forward voltage (V_{FM}) (where appropriate)

Maximum value at a current of π times the rated mean forward current (see 5.3.5).

NOTE π may be taken as equal to 3.

5.7.3 Breakdown voltage ($V_{(BR)}$) (of an avalanche rectifier diode, for non-repetitive use)

Minimum value for a specified pulse current in the low dynamic impedance part of the reverse characteristic.

5.7.4 Repetitive peak reverse current (I_{RM})

Maximum value at the rated repetitive peak reverse voltage; in addition, where appropriate, maximum value at the maximum virtual junction temperature.

5.7.5 Total power dissipation (P_{tot})

For case-rated rectifier diodes only, curves showing the maximum total power dissipation as a function of mean forward current, at a sinusoidal reverse voltage having a peak value equal to half the rated repetitive peak reverse voltage. A curve should be given for each operating condition specified in 5.3.5.

5.7.6 Maximum total energy for one half-sine wave forward current pulse (where appropriate) (especially for fast-switching diodes)

Curves showing the maximum (peak) forward current values as a function of the half-sine wave current pulse duration with the total energy (forward plus reverse recovery energy) as a parameter, under the following specified conditions:

a) reverse voltage;

b) RC damping network (snubber), (where appropriate).

Figure 8 is given as an example.

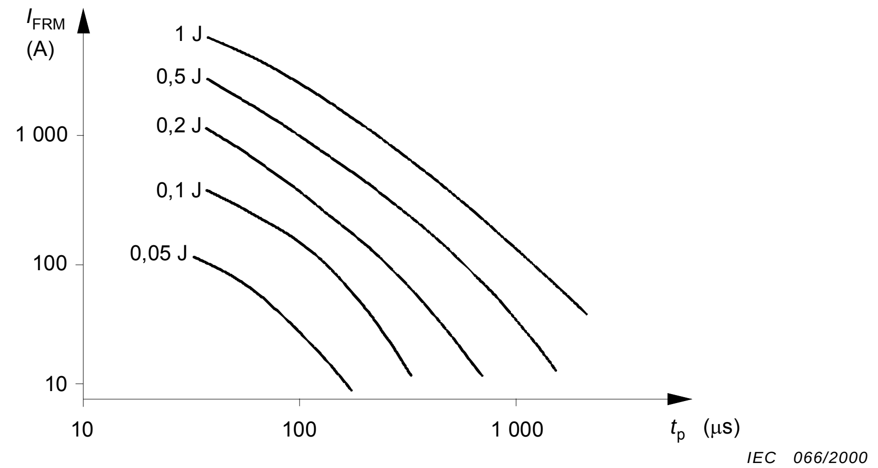


Figure 8 – Maximum total energy of one half-sine wave forward current pulse, for various values of current and pulse duration. Parameter: pulse energy in joules

5.7.7 Recovered charge (Q_r) (where appropriate). See figure 9

Maximum value, or maximum and minimum values, under specified conditions:

a) forward current, preferably equal to the maximum value of 5.3.5;

b) decay rate of forward current d*i*/d*t*;

c) reverse voltage, preferably 50 % of the repetitive peak reverse voltage specified in 5.3.2;

d) ambient or reference-point temperature equal to the highest temperature at which the peak value of the forward current is permitted.

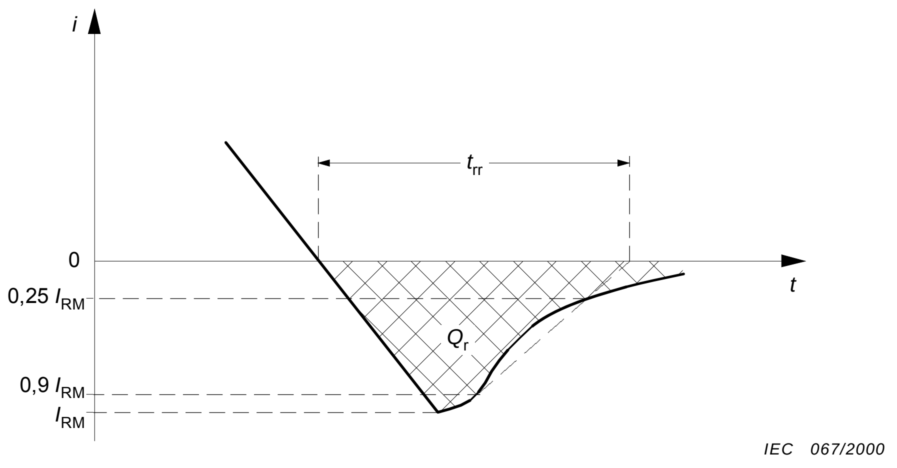


Figure 9 – Recovered charge Q_r, peak reverse recovery current I_{RM}, reverse recovery time t_{rr} (idealized characteristics)

5.7.8 Peak reverse recovery current (I_{RM}) (where appropriate). See figure 9

Maximum value under the specified conditions a) to d) of 5.7.7.

5.7.9 Reverse recovery time (t_{rr}) (where appropriate). See figure 9

Maximum value under the specified conditions a) to d) of 5.7.7.

5.7.10 Forward recovery time (t_{fr}) (where appropriate)

Maximum value, under the following specified conditions (see figures 1a and 1b):

a) virtual junction temperature (T_{vj});

b) peak forward current (I_{FM});

c) rise time of the forward current pulse (t_r), between 10 % and 90 % of I_{FM};

d) voltage defining the beginning of t_{fr}, preferably 10 % of the final stable value of forward voltage (V^*_F);

e) for specification method I: voltage defining the end of t_{fr}, preferably 110 % of V^*_F;

f) for specification method II: voltages defining points A and B for the extrapolation, preferably 90 % and 50 % of V_{FRM}, respectively;

g) reverse voltage (V_R, preferably V_R = 0).

NOTE 1 The minimum compliance (open-circuit) voltage of pulse source should be 3 V_{FRM}.

NOTE 2 Method I is preferred for V_{FRM} values up to about 10 V; method II for values considerably higher (up to several 100 V).

5.7.11 Peak forward recovery voltage (V_{FRM}) (where appropriate)

Maximum value under specified conditions:

a) peak forward current (I_{FM});

b) rise time of the current pulse (t_r) between 10 % and 90 % of I_{FM}, (see figures 1a and 1b) unless specified otherwise;

c) reverse voltage, zero unless specified otherwise;

d) virtual junction temperature

NOTE For short pulses at low duty cycle, the virtual junction temperature may be considered to be equal to the ambient or case temperature.

5.7.12 Reverse recovery softness factor (F_{RRS}) (where appropriate)

Minimum value under following specified conditions:

a) forward current (before switching) at a value of less than 10 % and at 200 % of maximum rated mean forward current of 5.3.5;

b) rate of fall ($-\mathrm{d}i_F/\mathrm{d}t$) of the forward current;

c) reverse voltage, 50 % of the maximum rated repetitive peak reverse voltage of 5.3.2, unless specified otherwise;

d) RC damping network (snubber) including significant parasitic components, where appropriate;

e) virtual junction temperature.

NOTE 1 Usually the softness factor is lower at low forward current.

NOTE 2 The duration of the forward current pulse should be sufficient to ensure carrier density equilibrium is established.

5.8 Thermal characteristics (where appropriate)

5.8.1 Transient thermal impedance ($Z_{th}(t)$)

A curve showing maximum transient thermal impedance versus time, extending from steady-state value down to 1 ms or less, or, alternatively, a mathematical relation.

5.9 Mechanical characteristics and other data

See IEC 60747-1, Chapter VI, clause 7.

5.10 Application data

With series or parallel connection of semiconductor rectifier diodes, it is necessary to consider not only the division of voltage or current in steady-state operation, but also carrier storage effects during commutation.

5.10.1 Steady-state operation (including overload)

5.10.1.1 Series operation

In order to obtain proper division of voltage in a series connection, one or more of the following methods can be used:

1) parallel resistive voltage dividers;
2) parallel capacitive voltage dividers;
3) factory-matched reverse characteristics;
4) multiple transformer windings (not applicable to single-phase half-wave circuits);
5) temperature equalization by mounting on a common heat sink.

The manufacturer should be consulted for detailed information.

5.10.1.2 Parallel operation

In order to obtain proper division of current in a parallel connection, one or more of the following methods can be used:

1) factory-matched forward characteristics;
2) addition of resistance or reactance in series with each diode;
3) balancing transformers or separate transformer windings;
4) temperature equalization by mounting on a common heat sink.

For avalanche rectifier diodes, the surge (non-repetitive) reverse power dissipation of the parallel arrangement is not necessarily increased, and the manufacturer should be consulted for detailed information.

5.10.2 Transient conditions

5.10.2.1 Transient overvoltage due to carrier storage effects

The diode current during commutation may change rapidly due to carrier storage effects and, associated with circuit inductance, can produce an oscillatory voltage. This transient voltage, together with the applied voltage, may often exceed the reverse voltage rating of the diode.

An added shunt capacitance will lengthen the diode recovery time and reduce the transient overvoltage.

The manufacturer should be consulted for detailed information.

5.10.2.2 Voltage division of series connected diodes during commutation

In a series connection of diodes, differences in diode recovery times may produce an unequal voltage division during commutation. Any unbalance may be reduced by a capacitance shunting each diode of the series chain. The capacitors mentioned under 5.10.1.1 may be chosen to meet this purpose.

The manufacturer should be consulted for detailed information.

6 Requirements for type tests and routine tests; marking of rectifier diodes

6.1 Type tests

Type tests are carried out on new products on a sample basis, in order to determine the electrical and thermal ratings (limiting values) and characteristics to be given in the data sheet, and to establish the test limits for future routine tests.

Some or all of the type tests may be repeated from time to time on samples drawn from current production or deliveries, so as to confirm that the quality of the product continuously meets the specified requirements.

The minimum type tests to be carried out on rectifier diodes are listed in table 1.

Some of the type tests are destructive.

6.2 Routine tests

The routine tests are carried out on the current production or deliveries normally on a 100 % basis, in order to verify that the ratings (limiting values) and characteristics specified in the data sheet are met by each specimen.

Routine tests may comprise a selection of the devices into groups.

The minimum routine tests to be carried out on a rectifier diode are listed in table 1.

6.3 Measuring and test methods

The measuring and test methods given in clause 7 shall be applied.

For the endurance tests, the methods given in 7.4, shall be applied.

Table 1 – Minimum type and routine tests for rectifier diodes

	Type test	Routine test
Measurements of characteristics		
Forward voltage	X	X
Additional forward characteristics	X	
Reverse current	X	X
Additional reverse characteristics	X	
Recovered charge, peak reverse recovery current	X [1)]	X [2)]
Thermal resistance and transient thermal impedance	X	
Verification of ratings		
Surge forward current	X	
Peak case non-rupture current	X [1)]	
Endurance test		
High-temperature a.c. reverse bias test	X	
Thermal cycling load test	X	

[1)] Type test only for devices with specified maximum values.

[2)] Routine test only for devices with specified maximum or minimum values.

6.4 Marking of rectifier diodes

Each rectifier diode shall be clearly and indelibly marked with the following information:

– manufacturer's name or identification;
– manufacturer's or supplier's type;
– marking to permit the distinction between anode and cathode terminals.

7 Measuring and test methods

7.1 Measuring methods for electrical characteristics

7.1.1 General precautions

7.1.1.1 General precautions for d.c. measurements

For the measurement of the forward characteristic of a semiconductor rectifier diode, the quality of the source of direct current is not considered to be important, provided that the peak-to-peak ripple is less than 10 %.

For the measurement of the reverse characteristic, the peak-to-peak ripple of the voltage source should not exceed 1 % and particular care should be taken to ensure that the voltage ratings of the rectifier diode are not exceeded due to any voltage transients.

7.1.1.2 General precautions for a.c. measurements

Diodes may be included in source circuits in order to protect the amplifiers in the oscilloscope from unwanted half-cycle pulses.

Where low reverse currents are being measured, it may be necessary to take suitable precautions to avoid pick-up, e.g. a screened transformer and suitable earthing. Care should also be taken to avoid stray capacitances.

In addition, particular care should be taken to keep residual inductance as low as possible, especially for high current devices.

7.1.1.3 Temperature conditions

For all measurements of electrical characteristics described below, the conditions of temperature should be specified.

The measurements should be performed only after thermal equilibrium has been reached.

7.1.2 Forward voltage

7.1.2.1 DC method

The basic circuit for the measurement of the forward voltage is shown in figure 10. The specified forward current is applied through the diode, and the forward voltage drop across the diode terminals is measured under specified conditions.

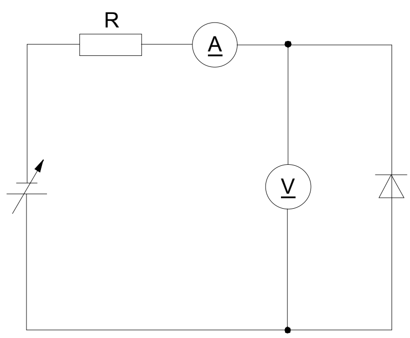
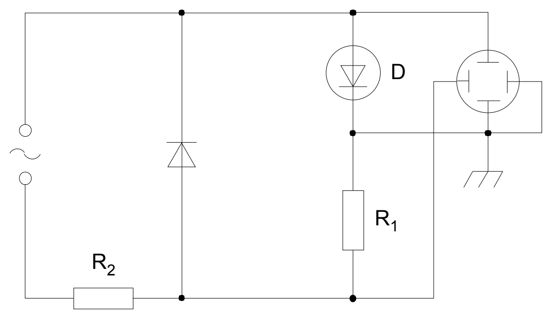


Figure 10 – Circuit for the measurement of forward voltage (d.c. method)

7.1.2.2 Oscilloscope method

The basic circuit for the measurement of instantaneous forward voltage is shown in figure 11. A half-sine wave current is applied to the diode under test in the forward direction, and the voltage-current curve is displayed on an oscilloscope.

Care should be taken to avoid thermal instability.



D = diode under test R_2 = resistor, low resistance

IEC 069/2000

Figure 11 – Circuit for the measurement of forward voltage (oscilloscope method)

7.1.2.3 Pulse method

Purpose

To measure the forward voltage of a rectifier diode under specified conditions, using a pulse method.

Circuit diagram

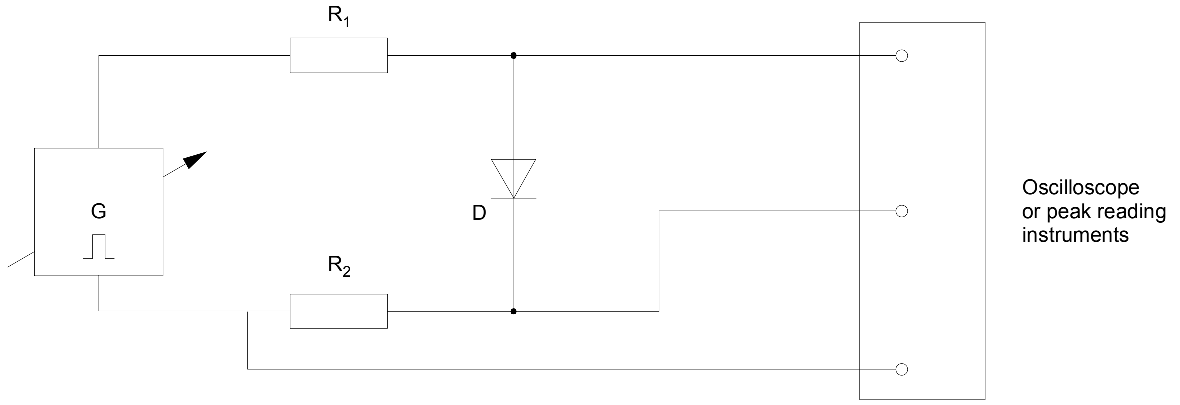


Figure 12 – Circuit diagram

Circuit description and requirements

D = diode being measured
G = pulse generator
R_1 = protective resistor
R_2 = calibrated current sensing resistor
OSC = oscilloscope or peak reading instrument

The pulse width and the repetition rate of the pulse generator should be such that negligible internal heating occurs during the measurement.

The above conditions are usually met with pulse widths of 100 μs to 500 μs. For high-power diodes, sinusoidal pulses with base widths up to 1 ms may be preferable to establish carrier equilibrium.

Measurement procedure

The pulse generator voltage is set initially to zero.

Temperature conditions are set to the specified value.

The specified forward current is then set by increasing the voltage of the pulse generator; the forward voltage is measured on the oscilloscope.

Peak reading instruments may be used instead of the oscilloscope, but they must be instruments that allow measurement of the peak forward voltage at the time the forward current reaches its peak value.

Specified conditions

The values of the following conditions should be stated:

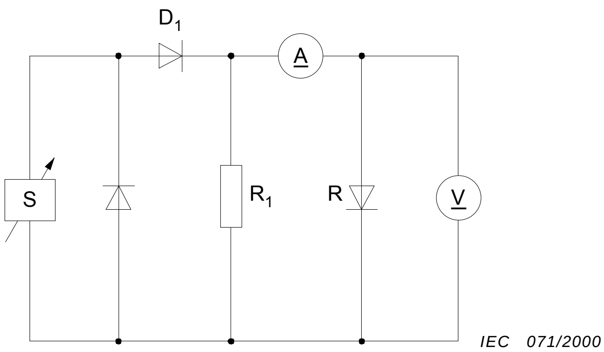
a) peak forward current;
b) ambient, case or reference-point temperature.

7.1.2.4 Average forward voltage

The basic circuit for the measurement of average forward voltage is shown in figure 13.

The impedance of the adjustable current source should be sufficiently high to ensure that half-sine wave forward current flows through the diode under test.

The average forward voltage is indicated by a moving coil meter, the measurement being made under specified conditions.



D = diode under test

S = adjustable high-impedance current source

R_1 and D_1 are chosen to ensure that, when the diode under test and D_1 are reversed biased, nearly all the bias is developed across D_1.

Figure 13 – Circuit for the measurement of average forward voltage

7.1.3 Breakdown voltage ($V_{(BR)}$) of avalanche and controlled-avalanche rectifier diodes

Purpose

To measure the breakdown voltage of an avalanche or controlled-avalanche rectifier diode by a pulse method under specified conditions.

Circuit diagram

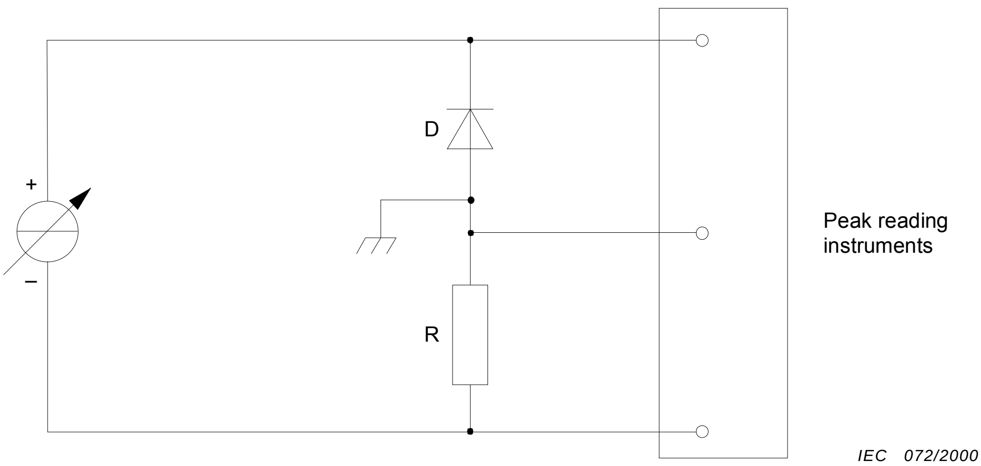


Figure 14 – Circuit diagram

Circuit description and requirements

D is the diode being measured.

R is a non-inductive calibrated resistor.

The pulse length and the duty cycle of the constant current generator should be such that negligible internal heating of the diode occurs.

Measurement procedure

The temperature is set to the specified value.

The generator output is increased to obtain the specified value of reverse current.

The breakdown voltage is read from the peak reading instrument.

Specified conditions

a) Ambient, case or reference-point or virtual junction temperature (T_{amb}, T_{case}, T_{ref}, T_{vj}).

b) Reverse current (I_R).

7.1.4 Reverse current

7.1.4.1 DC method

The basic circuit for the measurement of the reverse current is shown in figure 15.

The specified reverse voltage is applied through a protective resistor and the reverse current is measured under specified conditions.

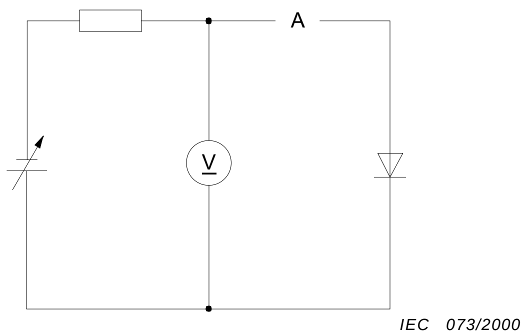


Figure 15 – Circuit for the measurement of reverse current (d.c. method)

7.1.4.2 Oscilloscope method

The basic circuit for the measurement of instantaneous values of reverse current is shown in figure 16. Either a high-impedance or a low-impedance power supply may be used, as shown in figures 16a and 16b respectively. The voltage-current curve is displayed on an oscilloscope.

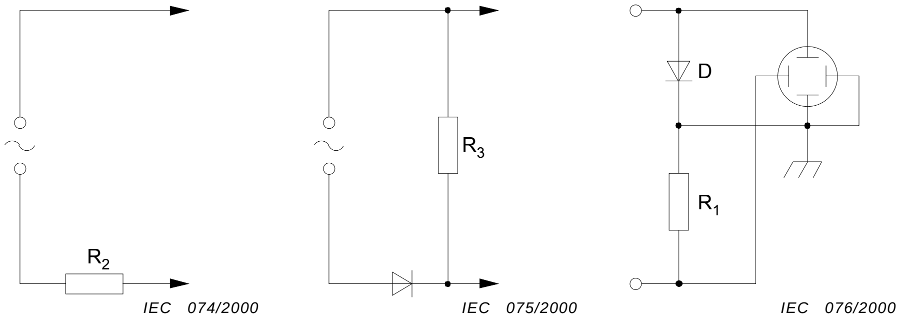


Figure 16a – Variable a.c. voltage source for test

Figure 16b – Half sine wave voltage source for test

Figure 16c – Test circuit using oscilloscope

D = diode under test
R_2 = resistor, high resistance
R_3 = resistor, low resistance

Figure 16 – Circuit for the measurement of reverse current (oscilloscope method)

In figure 16a, a voltage source is connected in series with a limiting resistor R_2 which limits the forward and reverse currents to the same value.

In figure 16b, a voltage source in series with a diode is connected across a shunting resistor R_3.

7.1.4.3 Peak reverse current

Purpose

To measure the peak reverse current of a rectifier diode at a specified value of repetitive peak reverse voltage under specified conditions.

Circuit diagram

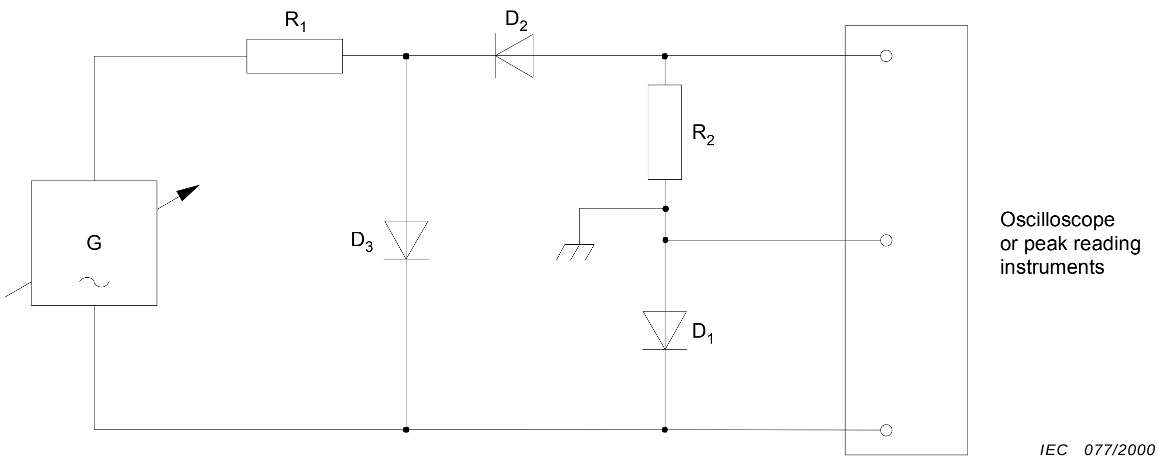


Figure 17 – Circuit diagram

Circuit description and requirements

D_1 = diode being measured
D_2 and D_3 = diodes to provide negative half-cycles, so that only the reverse characteristic of the rectifier diode is measured
G = alternating voltage source
R_1 = protective resistor
R_2 = calibrated current sensing resistor

Measurement procedure

The repetitive peak reverse voltage across the rectifier diode, measured on the oscilloscope, is adjusted by means of the alternating voltage source. The peak value of the reverse current through the rectifier diode is measured on the oscilloscope connected across R_2.

Peak reading instruments may be used instead of the oscilloscope, but they must be instruments that allow measurement of the peak reverse current at the time the reverse voltage reaches its peak value.

Specified conditions

The values of the following conditions should be stated:

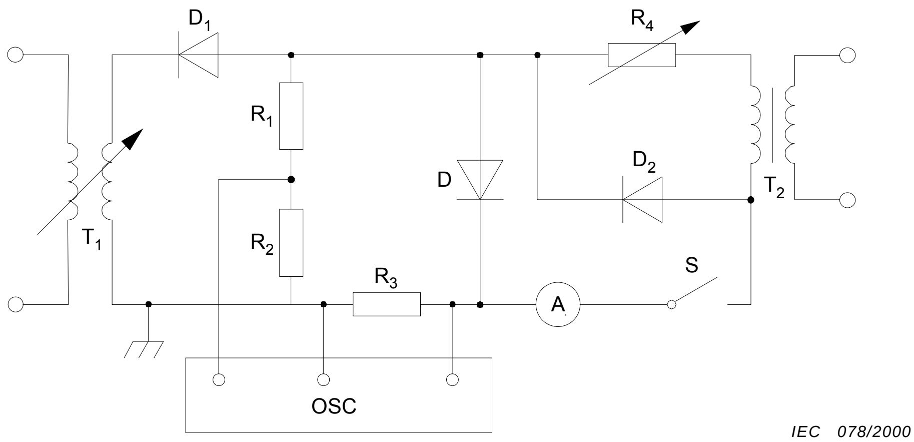
a) repetitive peak reverse voltage;
b) frequency of alternating voltage source;
c) ambient, case, reference-point or virtual junction temperature.

7.1.4.4 Peak reverse current with dissipation due to average forward current

Purpose

To measure the reverse current when the rectifier diode is heated up by forward current. The test circuit is used as a cheater circuit for endurance testing.

Circuit diagram



D = diode being measured

Figure 18 – Circuit diagram

Circuit description and requirements

T_1	=	low-current high-voltage transformer supplying the reverse voltage half-cycle for the diode being measured
T_2	=	high-current low-voltage transformer supplying the forward current half-cycle for the diode being measured
D_1	=	diode to block the forward half-cycle for the diode being measured
D_2	=	balancing diode for T_2
A	=	current meter for average forward current
OSC	=	oscilloscope or peak reading instruments

R_1, R_2 = calibrated voltage divider to suit measuring instrument
R_3 = calibrated current sensing resistor
R_4 = variable resistor to provide the specified forward current
S = electronic or electromechanical switch with conducting angle between 130° and 180° during the forward conducting half cycle of the diode being measured. The leakage current across the open switch must be small in comparison with the reverse current of the diode being measured.

Measurement procedure

The specified forward current is adjusted by means of the resistor R_4.

The output from transformer T_1 is connected for the correct phase and the input voltage is adjusted for the specified peak voltage.

The cooling conditions are adjusted to the specified ambient, case or reference-point temperature. The reverse current is observed on an oscilloscope or a peak-reading instrument.

Specified conditions

a) Ambient, case or reference-point temperature (T_{amb}, T_{case}, T_{ref}).
b) Mean forward current (I_{FAV}).
c) Peak reverse voltage (V_{RM}).

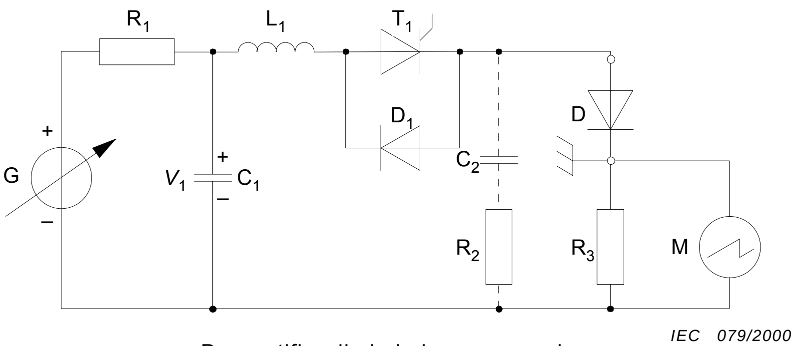
7.1.5 Recovered charge and reverse recovery time (Q_r, t_{rr})

7.1.5.1 Half sinewave method

Purpose

To measure the recovered charge Q_r and the reverse recovery time t_{rr} of a rectifier diode under specified conditions.

Circuit diagram and waveform



D = rectifier diode being measured

Figure 19 – Circuit diagram

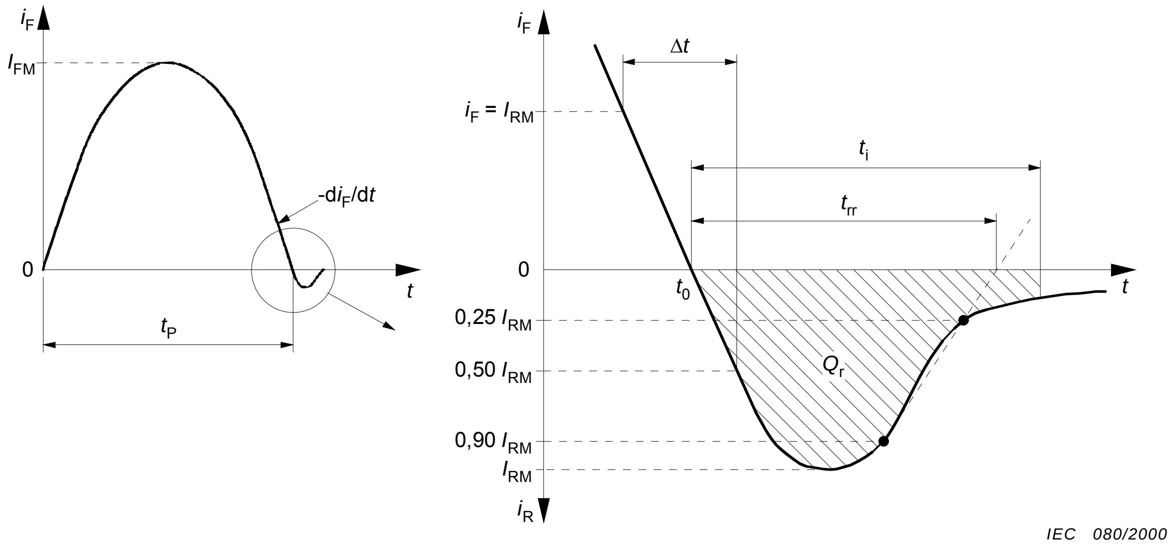


Figure 20 – Current waveform through the diode D

Circuit description and requirements

C_1 = capacitor supplying the forward current (see also L_1)

C_2 = capacitor limiting the high induced reverse voltage

D_1 = antiparallel diode

G = voltage source

L_1 = inductor adjusting the rate of change of forward current $-di_F/dt$ and the pulse duration $\left(t_p \cong \pi\sqrt{L_1C_1}\right)$

M = measuring instrument (for example an oscilloscope)

R_1 = resistor limiting the charge of C_1

R_2 = resistor limiting the high induced reverse voltage

R_3 = calibrated non-inductive current sensing resistor

T_1 = electronic switch (for example a thyristor)

Measurement procedure

Thyristor T_1 is triggered and the voltage source G is adjusted to give the specified value of the peak forward current I_{FM} through the diode D. The pulse duration t_p, the rate of change of forward current $-di_F/dt$ and the voltage V_1 at the C_1 terminals shall be in accordance with the specified conditions.

The recovered charge is measured as:

$$Q_r = \int_{t_0}^{t_0+t_i} i_R \cdot dt$$

where

t_0 is the instant when the current passes through zero;

t_i is the specified integration time, preferably equal to the specified maximum value of t_{rr}.

The reverse recovery time t_{rr} is measured as the time interval between t_0 and the instant when for decreasing values of i_R a line through the points for 0,9 I_{RM} and 0,25 I_{RM} crosses the zero current axis.

Specified conditions

a) Ambient or case temperature.

b) Peak forward current I_{FM}.

c) Voltage V_1 at the C_1 terminals.

d) Pulse duration of forward current t_p.

e) Rate of change of forward current $-di_F/dt$ (see note).

f) Integration time t_i.

g) C_1, C_2, R_2.

NOTE The rate of change of forward current is measured at zero crossing current, for current values between $i_F = I_{RM}$ and $i_R = 0,5\ I_{RM}$:

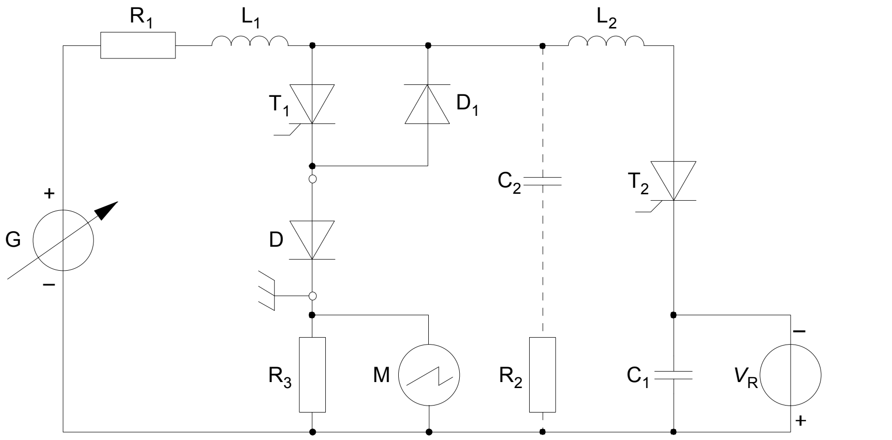
$$-\frac{di_F}{dt} = \frac{3}{2} \cdot \frac{I_{RM}}{\Delta t} \qquad \text{(see figure 20)}$$

7.1.5.2 Rectangular wave method

Purpose

To measure the recovered charge Q_r and the reverse recovery time t_{rr} of a rectifier diode under specified conditions.

Circuit diagram and waveform



D = rectifier diode being measured

Figure 21 – Circuit diagram

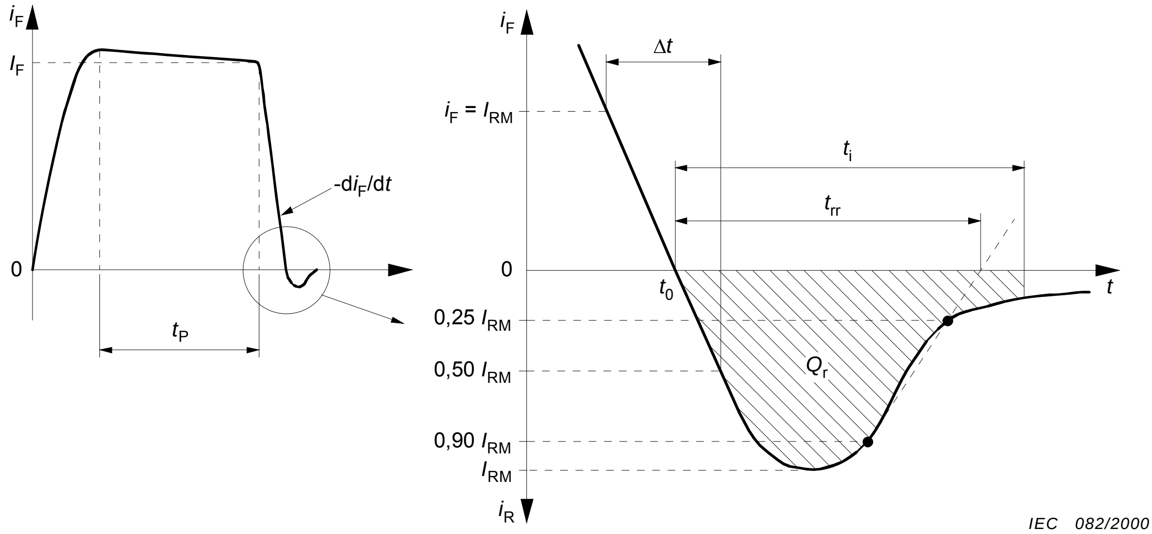


Figure 22 – Current waveform through the diode D

Circuit description and requirements

C_1 = capacitor supplying the reverse recovery current

C_2 = capacitor limiting the high induced reverse voltage

D_1 = antiparallel diode

G = voltage source

L_1 = inductor blocking the reverse voltage (the value of L_1/R_1 is selected to be much smaller than the time t_p)

L_2 = inductor adjusting the rate of change of forward current $-di_F/dt$

M = measuring instrument (for example an oscilloscope)

R_1 = resistor limiting forward current

R_2 = resistor limiting the high induced reverse voltage

R_3 = calibrated non-inductive current sensing resistor

T_1 and T_2 = electronic switches (for example thyristors).

Measurement procedure

Thyristor T_1 is triggered and the voltage source G is adjusted to give the specified value of forward current (I_F) before triggering T_2.

Thyristor T_2 is triggered after the time t_p and the diode current is reversed by means of an externally applied reverse voltage V_R.

The rate of change of forward current is adjusted to the specified value by means of the reverse voltage V_R in association with capacitor C_1 and inductor L_2.

The recovered charge is measured as:

$$Q_r = \int_{t_0}^{t_0+t_i} i_R \cdot dt$$

where

t_0 is the instant when the current passes through zero;

t_i is the specified integration time, preferably equal to the specified maximum value of t_{rr}.

The reverse recovery time t_{rr} is measured as the time interval between t_0 and the instant when for decreasing values of i_R a line through the points for 0,9 I_{RM} and 0,25 I_{RM} crosses the zero current axis.

Specified conditions

a) Ambient or case temperature.

b) Forward current I_F (before triggering T_2).

c) Reverse voltage V_R.

d) Pulse duration of forward current t_p.

e) Rate of change of forward current $-di_F/dt$ (see note).

f) Integration time t_i.

g) L_1, L_2, C_2, R_2.

NOTE The rate of change of forward current is measured at zero crossing current, for current values between $i_F = I_{RM}$ and $i_R = 0,5\ I_{RM}$.

$$-\frac{di_F}{dt} = \frac{3}{2} \cdot \frac{I_{RM}}{\Delta t} \qquad \text{(see figure 22)}$$

7.1.6 Forward recovery time (t_{fr}) and peak forward recovery voltage (V_{FRM})

Purpose

To measure the forward recovery time and the peak forward recovery voltage of a rectifier diode.

Circuit diagram and test waveform

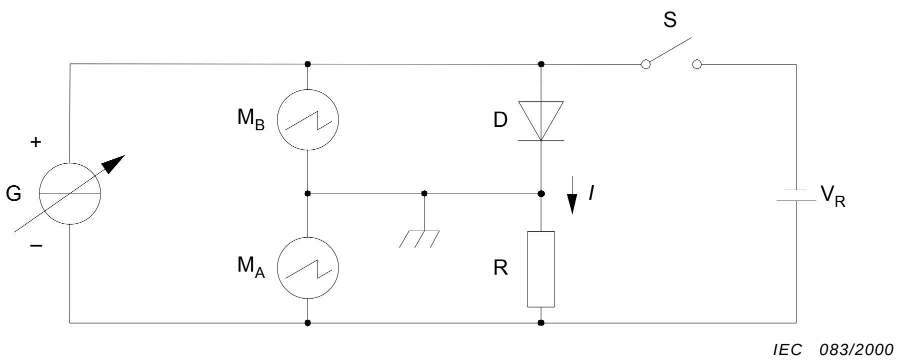


Figure 23 – Circuit diagram

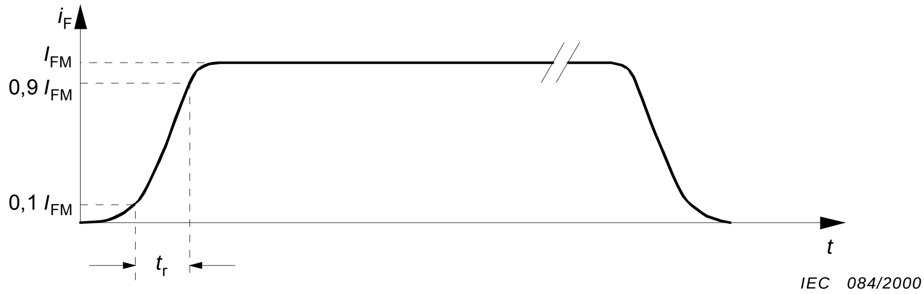


Figure 24a – Current waveform

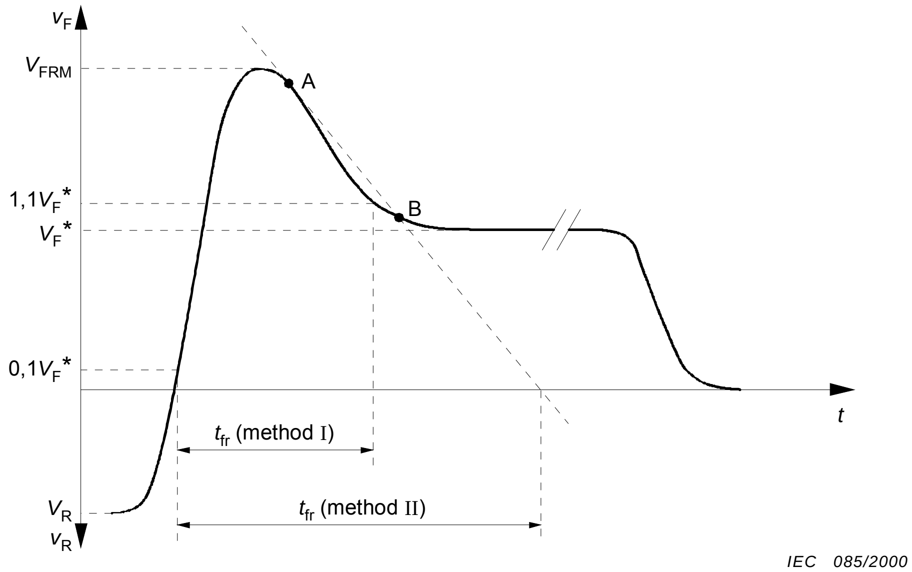


Figure 24b – Voltage waveform

Figure 24 – Current and voltage waveforms

Circuit description and requirements

D = diode being measured

G = current-pulse generator having a compliance voltage (open-circuit output voltage) 50 V minimum or three times V_{FRM}, whichever is greater

R = non-inductive calibrated resistor

S = electronic switch, which is closed except for a period starting just before the current pulse and throughout its duration

M_A and M_B = oscilloscopes or other monitoring instruments

The pulse duration shall be long enough for the forward voltage to have reached the stable value $V*_F$.

The pulse duration and the duty cycle of the current-pulse generator should be such that negligible internal heating of the diode occurs.

Measurement procedure

The temperature is set to the specified value.

While monitoring the current waveform on M_A, the current-pulse source is adjusted to the specified conditions of rise time t_r and forward current I_{FM}.

The reverse voltage V_R is adjusted to the specified value, and switch S is appropriately set.

The peak forward recovery voltage V_{FRM} and the forward recovery time t_{fr} are measured on the waveform of voltage across the diode on M_B in accordance with the specified specification method.

Specified conditions

a) Virtual junction temperature (T_{vj}).
b) Peak forward current (I_{FM}).
c) Rise time of current pulse (t_r) (between 10 % and 90 % of I_{FM}, unless otherwise stated).
d) Specification method I: Voltages defining beginning and end of the forward recovery time, if different from 10 % and 110 %, respectively, of V^*_F.
e) Specification method II: Voltage in points A and B in per cent of V_{FRM}.
f) Reverse voltage (V_R).

7.2 Measuring methods for thermal characteristics

7.2.1 Reference point temperature

7.2.1.1 For devices where a hole has been drilled by the manufacturer for this purpose, the temperature of the case is measured by means of a thermocouple inserted into this hole. The thermocouple should not have a section of a diameter greater than 0,25 mm. The thermocouple bead should be formed by welding rather than by soldering or twisting. The bead is inserted into the hole which is, then, closed over the thermocouple bead by tapping the metal at the edges of the hole (peened closed).

7.2.1.2 For other devices, the temperature at the reference point is measured by means of a temperature-sensitive element having negligible thermal capacitance, which is cemented, soldered, clamped or held rigidly against the case of the device so as to ensure a negligible thermal resistance.

7.2.2 Thermal resistance and transient thermal impedance

7.2.2.1 Introduction

The measurement of thermal resistance and transient thermal impedance is based on the use of a temperature-sensitive parameter as an indicator of virtual junction temperature. The forward voltage of a rectifier diode, at a small percentage of rated current, is normally used as the temperature-sensitive parameter.

The accuracy of this method is not specified. However, adequate precautions should be taken as outlined below.

7.2.2.2 Thermal resistance (R_{th})

Purpose

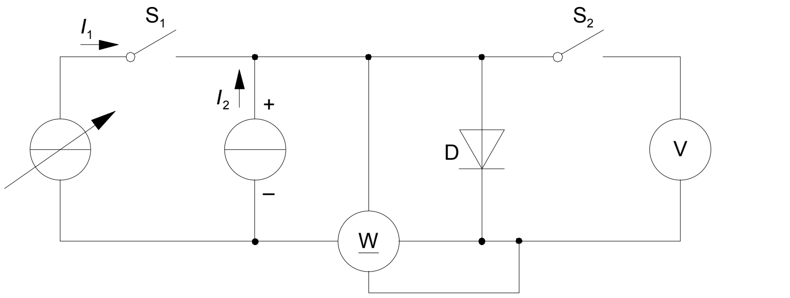
To measure the thermal resistance between the junction and a reference point (preferably at the case) of a rectifier diode.

Principle of the method

The temperatures T_1 and T_2 of the reference point of the device are measured for two different power dissipations P_1 and P_2 and cooling conditions causing the same junction temperature. The forward voltage at a reference current is used to verify that the same junction temperature has been reached.

$$R_{th} = \frac{T_1 - T_2}{P_2 - P_1}$$

Basic circuit diagram



D = diode being measured

Figure 25 – Circuit diagram

Circuit description and requirements

I_1 = load current generating the power dissipation P in the junction, either a d.c. current or an a.c. current

I_2 = reference d.c. current monitored when the load current I_1 is interrupted periodically for short time gaps

W = wattmeter to indicate the power dissipation P in the junction caused by the load current I_1 (for the a.c. method, W measures the average power dissipated in the device being measured)

S_1 = electronic switch to interrupt periodically the load current I_1 (for the d.c. method); for the a.c. method, switch S_1 is not mandatory

S_2 = electronic switch which is closed when the load current I_1 is interrupted

V = null-method voltmeter

Precautions to be observed

Voltage transients occur due to excess charge carriers when switching from the load current I_1 to the reference current I_2.

Additional voltage transients occur, if the case of the device under test contains ferromagnetic material. The switch S_2 should not be closed before these transients have disappeared.

NOTE The load current I_1 listed in d) above can be zero; then the power dissipation P_1 is also zero and the virtual junction temperature is the same as the reference-point temperature T_1.

Measurement procedure

The device being measured is clamped on a heat sink maintained at a fixed temperature. A thermocouple is fixed at the reference point to measure the temperature of the device being measured. The measurement is done in two steps:

1) The heat sink is maintained at an elevated temperature. A low load current I_1, is applied causing the power dissipation P_1. in the junction. After reaching thermal equilibrium, the null-method voltmeter V is adjusted for zero balance.

   The reference-point temperature T_1 is recorded.

2) The heat sink is maintained at a lower temperature. The load current I_1 is raised until the power P_2 warms up the junction to the same temperature as during step 1. This is indicated by zero balance of the null-method voltmeter V.

The reference-point temperature T_2 of the case is recorded.

The thermal resistance R_{th} is calculated using the expression:

$$R_{th} = \frac{T_1 - T_2}{P_2 - P_1}$$

7.2.2.3 Transient thermal impedance ($Z_{th}(t)$)

Purpose

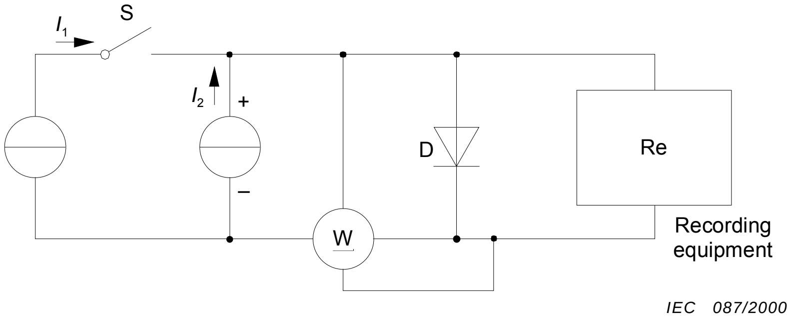
To measure the transient thermal impedance between the junction and a reference point (preferably at the case) of a rectifier diode.

Principle of the method

After applying the heating current and waiting until thermal equilibrium is established, the power dissipated in the device is recorded. The heating current is then interrupted, and the forward voltage at the reference current together with the reference-point temperature are recorded as a function of time.

The virtual junction temperature as a function of time is then calculated by means of the calibration curve obtained for the same reference current.

Basic circuit diagram



D = diode being measured

Figure 26 – Circuit diagram

Circuit description and requirements

I_1 = load current generating the power dissipation P in the junction

I_2 = reference d.c. current

S = switch to interrupt the load current I_1

W = wattmeter to indicate the power dissipation P in the junction caused by the load current I_1

Re = recording equipment, for example, an oscilloscope to record the time variation of the forward voltage caused by I_2

Measurement procedure

1) A calibration curve is prepared by measuring the forward voltage generated by the reference current I_2 as a function of the virtual junction temperature by varying the device temperature externally, for example, by means of an oil bath.
2) The device being measured is clamped on a heat sink maintained at a fixed temperature. A thermocouple is fixed at the reference point to measure the reference-point temperature T_{ref} of the device being measured. The heating current I_1, is applied generating the power dissipation P in the device being measured until thermal equilibrium is established.
3) The heating current I_1, is interrupted by opening the switch S. The forward voltage generated by the reference current I_2 is recorded as a function of the cooling time by the recording equipment Re.

   The reference-point temperature is recorded during this time.
4) The curve of the recorded forward voltage is converted to the virtual junction temperature $T_{(vj)}$ by means of the calibration curve. The transient thermal impedance $Z_{th}(t)$ is calculated using the expression:

$$Z_{th}(t) = \frac{\left[T_{(vj)}(0) - T_{ref}(0)\right] - \left[T_{(vj)}(t) - T_{ref}(t)\right]}{P}$$

where

$T_{(vj)}(0)$, $T_{ref}(0)$ are the temperatures at the time t = 0 when opening S;

$T_{(vj)}(t)$, $T_{ref}(t)$ are the temperatures at the time t.

7.3 Verification test methods for ratings (limiting values)

7.3.1 Surge (non-repetitive) forward current

Purpose

To verify the surge (non-repetitive) forward current rating of a rectifier diode, under specified conditions.

Circuit diagram

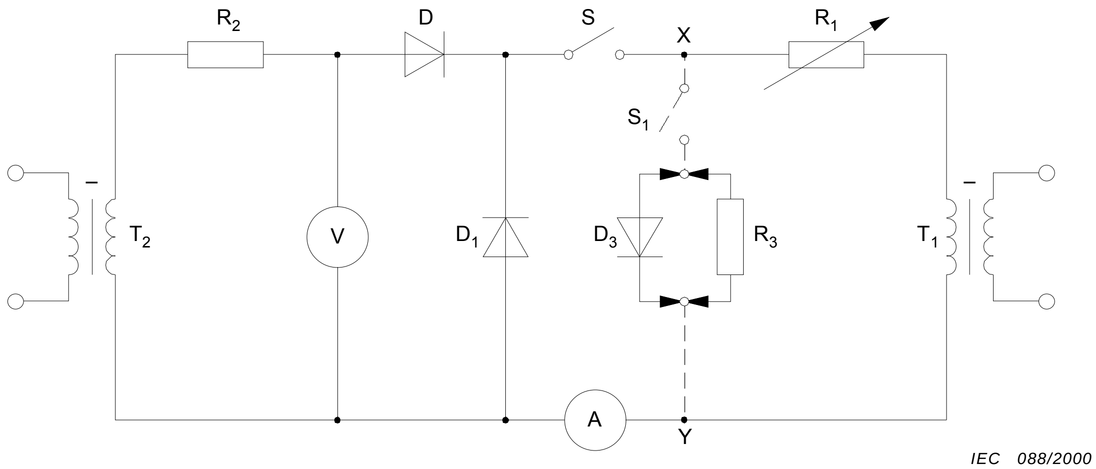


Figure 27 – Circuit diagram

Circuit description and requirements

A = peak reading instrument (e.g. ammeter or oscilloscope)

D_1 = diode under test

D_2 = diode to block the forward voltage supplied by transformer T_2

R_1 = surge current setting resistor which should be large compared with the forward resistance of diode D_3, when present (see note below)

R_2 = protective resistor which should be as small as practicable

S = electromechanical or electronic switch with a conduction angle of approximately 180° during the forward (surge) half-cycle

T_1 = high-current low-voltage transformer supplying through S the forward (surge) half-cycle. The current waveshape should be essentially a half-sine wave of approximately 10 ms (or 8,3 ms) duration, with a repetition rate of approximately 50 (or 60) pulses per second

T_2 = low-current high-voltage transformer supplying through diode D_2 the reverse half-cycle; if fed from a separate source, its phase must be the same as that feeding T_1. The voltage shape should be essentially a half-sine wave

V = peak reading instrument (e.g. voltmeter or oscilloscope).

NOTE If desirable, either a diode D_3 in series with a switch S_1 or a resistor R_3 in series with a switch S_1 may be inserted between points X and Y.

These circuits are not mandatory.

D_3 is a current balancing diode having approximately the same forward resistance as the diode under test.

If a resistor R_3 is used, it should have the same resistance as the forward resistance of the diode under test.

S_1 is an electromechanical or electronic switch with a conduction angle of approximately 180°, during the reverse half-cycle of transformer T_1.

Test procedure

The voltage and current sources are set to zero.

The rectifier diode is inserted into the test socket in accordance with its polarity marking, and the temperature conditions are checked.

The peak reverse voltage, measured on peak-reading instrument V, is adjusted to the specified value.

The surge forward current, measured on peak-reading instrument A, is set to the specified value by adjustment of R_1.

The surge forward current is applied as many times as specified to the rectifier diode under test.

Proof of the ability of the rectifier diode to withstand the surge forward current rating is obtained from the post-test measurements.

Specified conditions

The values of the following conditions should be stated:

a) peak reverse voltage;
b) surge (non-repetitive) forward current;
c) maximum impedance of the reverse voltage source;
d) number of cycles per surge, number of surges and repetition rate;
e) ambient, case or reference-point temperature;
f) post-test measurement limits.

7.3.2 Non-repetitive peak reverse voltage (V_{RSM})

Purpose

To verify the non-repetitive peak reverse voltage rating of a rectifier diode, under specified conditions.

Circuit diagram

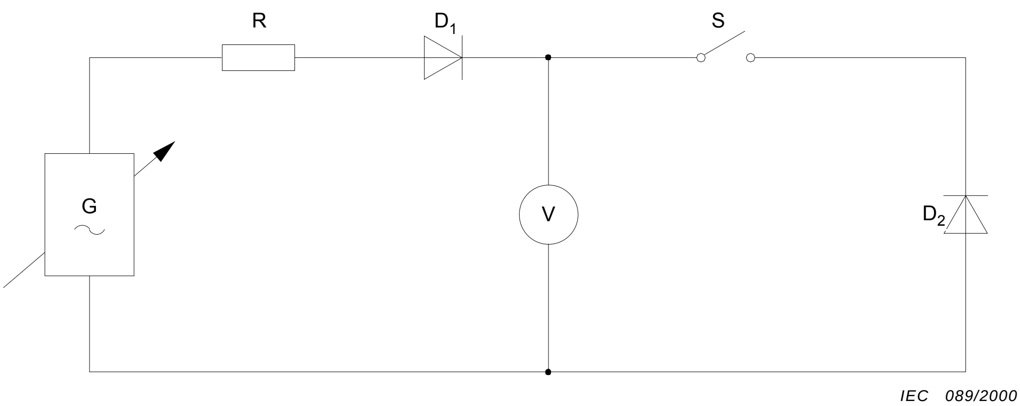


Figure 28 – Circuit diagram

Circuit description and requirements

D_1 = diode to provide negative half-cycles, so that only the reverse characteristic of the diode under test is measured

D_2 = diode under test

G = alternating voltage source

S = electromechanical or electronic switch (with a conduction angle of approximately 180°) which applies the source voltage to the rectifier diode under test for one half-cycle in the reverse direction

V = peak reading instrument

Test procedure

With bias conditions set to zero, the rectifier diode under test is inserted into the test socket.

Switch S is opened and the a.c. 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 closing switch S for approximately 180°.

Proof of the ability of the diode to withstand the non-repetitive peak reverse voltage rating is obtained from the post-test measurements.

Specified conditions

The values of the following conditions should be stated:

a) non-repetitive peak reverse voltage;

b) ambient, case or reference-point temperature;

c) duration of the half-cycle pulse;

d) number of pulses and repetition rate;

NOTE The repetition rate should be such that the thermal effect of one pulse will have completely disappeared before the next pulse arrives.

e) post-test measurement limits.

7.3.3 Peak reverse power (repetitive or non-repetitive) (P_{RRM}, P_{RSM}) of avalanche and controlled-avalanche rectifier diodes

Purpose

To verify the peak reverse power rating of avalanche and controlled-avalanche rectifier diodes under specified conditions.

The following three test methods are described:

A – with a triangular waveform pulse.

B – with a sinusoidal waveform pulse.

C – with a rectangular waveform pulse.

Circuit description and requirements

7.3.3.1 Method A: Triangular waveform pulse method

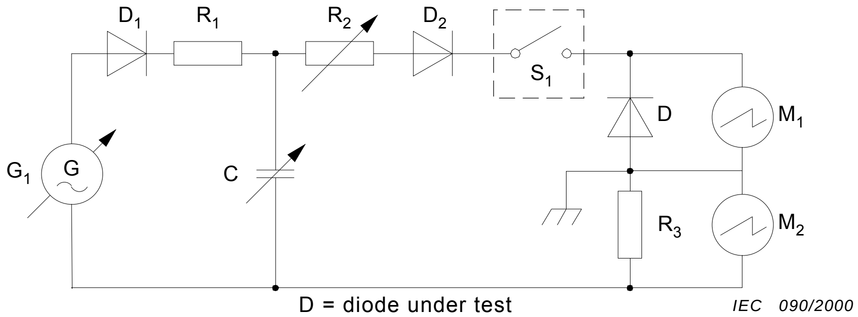


Figure 29 – Circuit for verification of rating of peak reverse power of avalanche and controlled-avalanche rectifier diodes (triangular waveform reverse current method)

G_1 = adjustable a.c. voltage source

D_1 = rectifier diode

R_1 = current limiting resistor

C = variable capacitor for adjusting the pulse duration

R_2 = variable non-inductive resistor for adjusting the peak open-circuit reverse voltage (see 7.3.3.3)

D_2 = blocking diode, if necessary

S_1 = electromechanical or electronic switch to discharge capacitor C (e.g. spark gap or thyristor)

R_3 = non-inductive current sensing resistor

M_1 = instrument (e.g. oscilloscope) for measuring the peak open-circuit reverse voltage (see 7.3.3.3)

M_2 = equipment (e.g. oscilloscope) for measuring the reverse current pulse duration

M_1 and M_2 may be combined (e.g. dual-channel oscilloscope).

The reverse pulse should be as shown in figure 30.

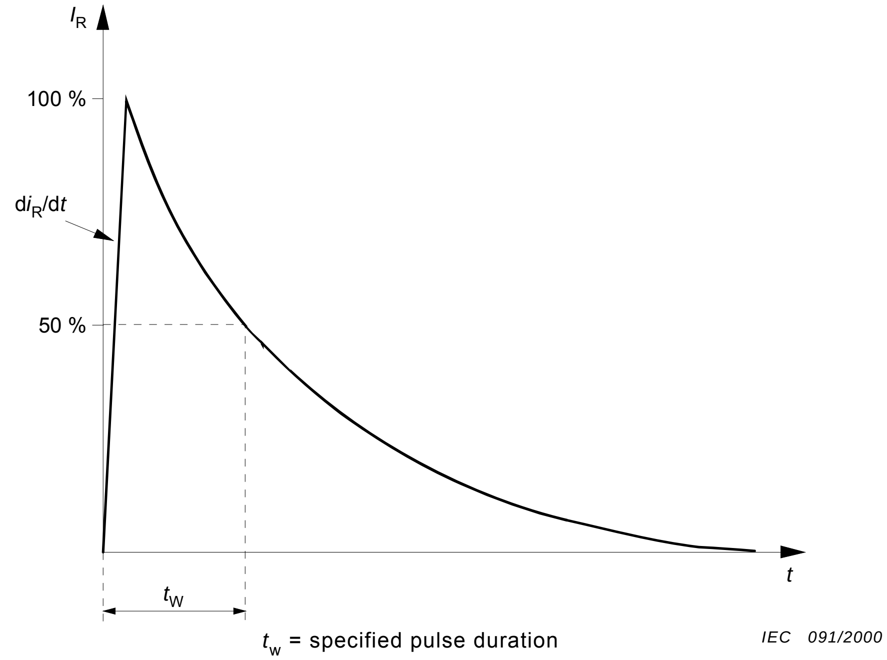


Figure 30 – Reverse current waveform

7.3.3.2 Method B: Sinusoidal waveform pulse method

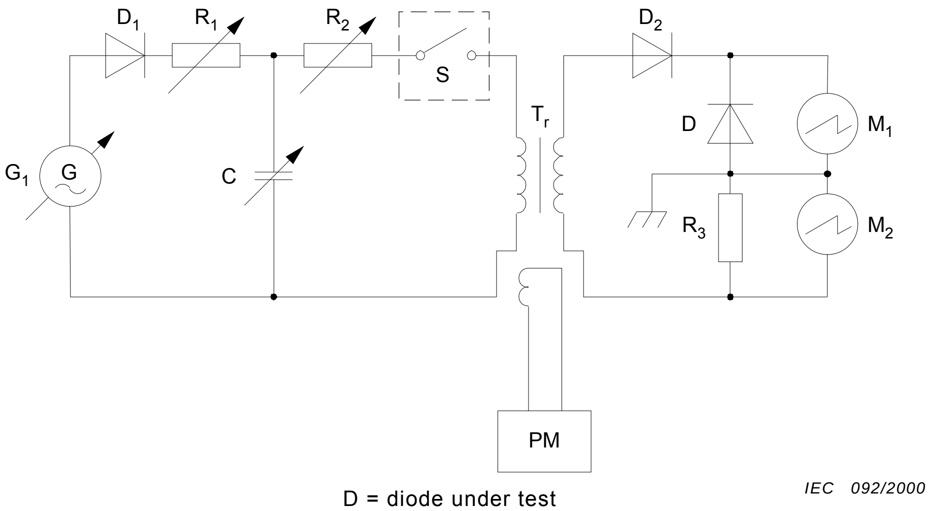


Figure 31 – Circuit for verification of rating of peak reverse power of avalanche and controlled-avalanche rectifier diodes (sinusoidal waveform reverse current method)

G_1 = adjustable a.c. voltage source

D_1 = rectifier diode

R_1 = current limiting resistor

C = variable capacitor for adjusting the pulse duration

R_2 = variable non-inductive resistor for adjusting the peak open-circuit reverse voltage (see 7.3.3.3)

S = electromechanical or electronic switch to discharge capacitor C over the primary winding of transformer T_r (e.g. spark gap or thyristor)

T_r = high-voltage transformer

PM = pre-magnetizing source or other suitable means to prevent saturation of T_r

D_2 = blocking diode, if necessary

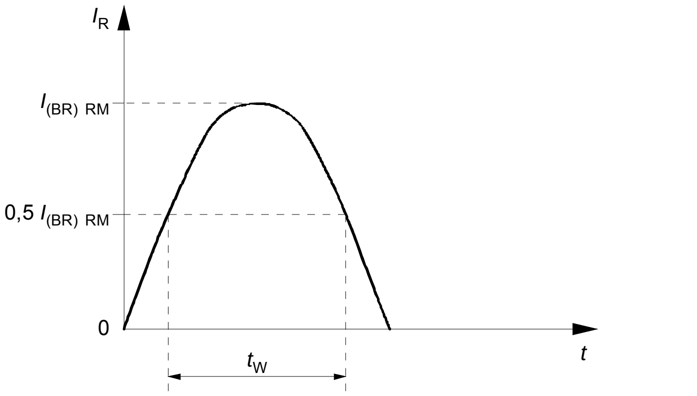
R_3 = non-inductive current sensing resistor

M_1 = instrument (e.g. oscilloscope) for measuring the peak open-circuit reverse voltage (see 7.3.3.3)

M_2 = equipment (e.g. oscilloscope) for measuring the reverse current pulse duration

M_1 and M_2 may be combined (e.g. dual-channel oscilloscope).

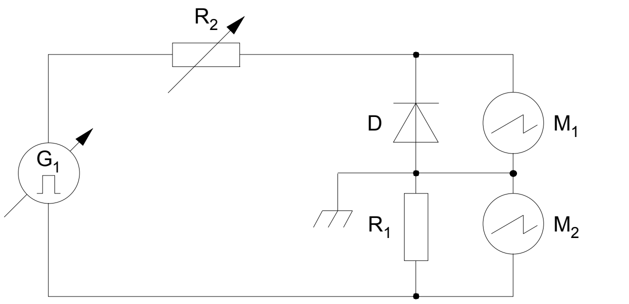
The reverse current pulse should be as shown in figure 32.



t_W = specified pulse duration

Figure 32 – Reverse current waveform

7.3.3.3 Method C: Rectangular waveform pulse method



D = diode under test

Figure 33 – Circuit for verification of rating of peak reverse power of avalanche and controlled-avalanche rectifier diodes (rectangular waveform reverse current method)

G_1 = adjustable pulse generator source capable of providing single or multiple rectangular voltage pulses

R_1 = non-inductive current sensing resistor

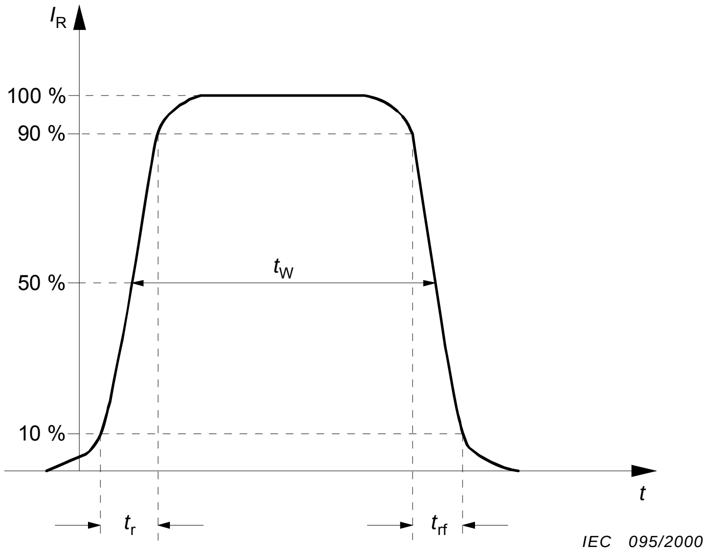
R_2 = variable non-inductive resistor for adjusting the peak open-circuit reverse voltage (see 7.3.4)

M_1 = instrument (e.g. oscilloscope) for measuring the peak open-circuit reverse voltage (see 7.3.4)

M_2 = equipment (e.g. oscilloscope) for measuring the reverse current pulse duration

M_1 and M_2 may be combined (e.g. dual-channel oscilloscope).

The reverse current pulse should be as shown in figure 34.



t_w = specified average pulse duration at 50 % pulse amplitude

$t_r \leq 20\ \%\ t_w$

$t_{rf} \leq 20\ \%\ t_w$

Figure 34 – Reverse current waveform

7.3.3.4 Initial adjustment procedure (for all three methods)

The value of R_2 (including in method C the impedance of the voltage source G_1) is determined from the expression:

$$R_2 = \frac{V_{(BR)}\text{max.} \cdot V_{(BR)}\text{min.}}{P_{RXM}}$$

where

$V_{(BR)}$max. = upper spread limit for $V_{(BR)}$

$V_{(BR)}$min. = lower spread limit for $V_{(BR)}$

$$P_{RXM} = \begin{cases} P_{RSM} \text{ for verification of } P_{RSM} \\ P_{RRM} \text{ for verification of } P_{RRM} \end{cases}$$

With no diode in the socket, the voltage pulse from voltage source G_1 is increased until the peak value of the open-circuit reverse voltage, measured at M_1, is equal to ($V_{(BR)}$max. + $V_{(BR)}$min.) This ensures that the reverse power for any reverse voltage in the range between $V_{(BR)}$ minimum and $V_{(BR)}$maximum will be lower than or at most equal to the rated value P_{RSM} or P_{RRM}, respectively. See figure 35 for P_{RSM}.

The pulse generator is then switched off, but the setting is maintained.

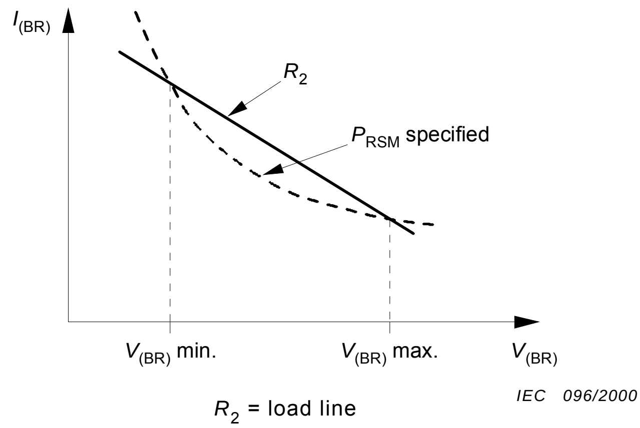


Figure 35 – Verification of P_{RSM} reverse power versus breakdown

Measurement procedure

Insert the diode under test into the test socket in accordance with its polarity marking.

Set the temperature to the specified value.

Apply the specified sequence of pulses.

Proof of the ability of the diode to withstand the peak reverse power rating is obtained from the post-test measurements.

Specified conditions

For all three methods:

a) test method to be used (A, B or C);
b) ambient or case temperature (T_{amb} or T_{case});
c) peak reverse power rating, repetitive (P_{RRM}) or non-repetitive (P_{RSM});
d) for verification of P_{RSM}: duration of the reverse current pulse (t_w);
e) for verification of P_{RRM}:
   - duration of each pulse (t_w),
   - duty factor (δ),
   - number of pulses;
f) post-test measurement limits.

For method A only: minimum rate of rise of reverse current ($\mathrm{d}i_R/\mathrm{d}t$)

7.3.4 Peak case non-rupture current

Purpose

To verify the peak case non-rupture current rating of a rectifier diode under specified conditions.

Circuit diagram and test current waveform

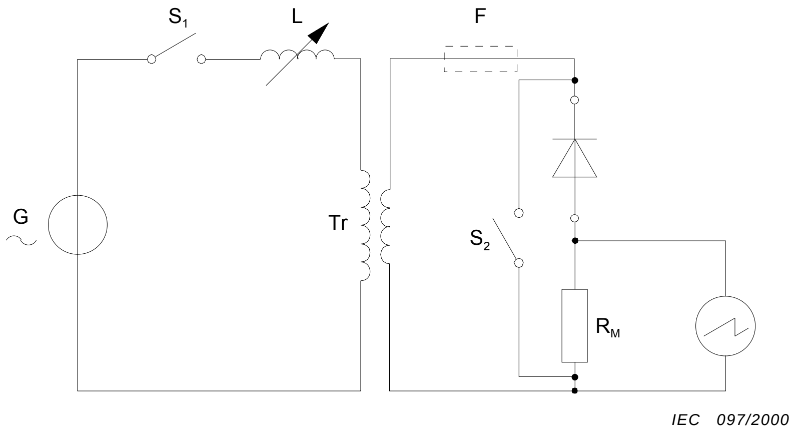


Figure 36 – Circuit diagram

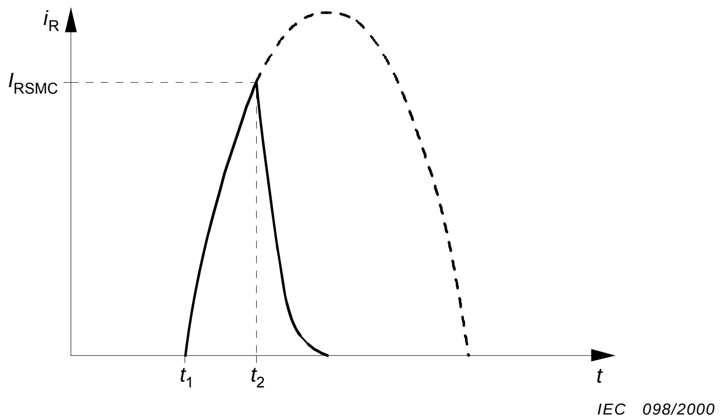


Figure 37 – Waveform of the reverse current i_R through the device under test

Circuit description and requirements

G = a.c. system having appropriate short-circuit capacity

S_1, S_2 = electromechanical or electronic high-power switches that can be operated at defined instants of the line voltage cycle

F = optional fuse in place of S_2 (see test procedure)

L = variable inductor

Tr = high-power transformer

R_M = calibrated non-inductive current sensing resistor

D = rectifier diode under test

Preconditioning and initial measurements

Prior to the test, the device under test should be initially damaged, for example, with a low-energy high-voltage pulse or mechanically, so that the breakdown always occurs at the edge of the silicon chip.

NOTE If required, mechanical damage shall be carried out before the device is encapsulated.

The device under test is subjected to an initial leak test and the leak rate should be lower than 10^{-7} Pa · m^3 s^{-1} (10^{-6} bar cm^3 s^{-1}).

Test procedure

The device under test is inserted in the test apparatus.

The switch S_1 is closed at an instant t_1 such that a voltage is applied to the device under test in the reverse direction causing a breakdown at the previously damaged spot. As a result, the reverse current rises steeply with a rate of rise that may be adjusted (within reasonable limits) by varying the inductance L.

At the instant t_2, the switch S_2 is closed so that the peak current is limited to the specified value I_{RSMC}.

Alternatively, fuse F may be placed in the circuit and the current through the device under test will be interrupted when the fuse operates.

Specified conditions

a) Case or reference-point temperature.

b) Value I_{RSMC} of the peak case non-rupture current.

c) Rate of rise of the reverse current, preferably 25 A/µs.

d) Pulse duration of the test current.

Post-test measurements

The device under test is subjected to leak test and the leak rate should be lower than 10^{-7} Pa · m^3 s^{-1} (10^{-6} bar cm^3 s^{-1}).

Alternatively, a plasma detecting device may be used during the electrical test to make sure that no plasma escapes during the test even if a small crack develops.

Following the electrical test, the device is visually inspected. There should be no sign of particles thrown off nor shall there be evidence that the device has externally melted or burst into flames.

7.4 Endurance test

Clause 2 of IEC 60747-1, chapter VIII, section three, which has the same title, is applicable.

7.4.1 List of endurance tests

For rectifier diodes, a choice of endurance tests is given in table 3.

7.4.2 Conditions for endurance tests

Test conditions and test circuits are listed in table 3. The relevant specification will state which test(s) will apply.

7.4.3 Failure criteria and failure-defining characteristics for acceptance tests

Failure-defining characteristics, their failure criteria and measurement conditions are listed in table 2.

NOTE Characteristics shall be measured in the sequence in which they are listed in this table, because the changes of characteristics caused by some failure mechanisms may be wholly or partially masked by the influence of other measurements.

7.4.4 Failure-defining characteristics and failure criteria for reliability tests

Under consideration.

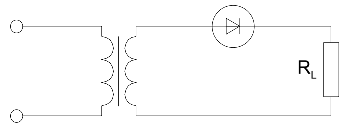
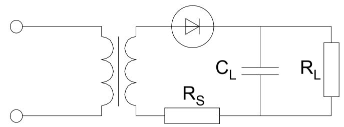
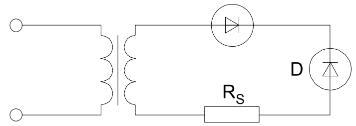
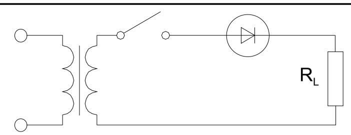
7.4.5 Procedure in case of a testing error

When a device has failed as a result of a testing error (such as a test equipment fault or measurement equipment fault, or an operator error), the failure shall be noted in the data record with an explanation of the cause.

Table 2 – Failure-defining characteristics for acceptance after endurance tests

Failure-defining characteristics	**Failure criteria** (Note)	**Measurement conditions**
I_R	>2 × USL	Highest V_R (= V_{RRM}) and highest temperature specified for I_R
V_F	>1,1 × USL	Highest I_F specified for V_F
NOTE USL = upper specification limit.		

Table 3 – Conditions for the endurance tests

Tests	Operating conditions			Test circuits	Remarks
	Current	Voltage	Temperature		
Operating life (resistive load)	(See 2.1.5 of IEC 60747-1, chapter VIII, section three)	Sine wave 50 Hz or 60 Hz Peak value = 100 % V_{RWM}	(See 2.1.3 of IEC 60747-1, chapter VIII, section three)		R_L = load resistor (Note 1)
Operating life (capacitive load)	Equivalent to the rated mean forward current for capacitive load	Sine wave 50 Hz or 60 Hz Peak value = 100 % V_{RWM}	(See 2.1.3 of IEC 60747-1, Chapter VIII, Section Three)		C_L should have the highest capacitance specified in the relevant specification R_S = current limiting resistor to be specified in the relevant specification (Note 1) R_L = load resistor
High temperature a.c. reverse bias		Sine wave 50 Hz or 60 Hz Peak value = 100 % V_{RWM}	Highest temperature for which V_{RWM} is specified		R_S = current limiting resistor (Note 1) D = blocking diode
Thermal cycling load test	I_F (half-sine wave 50 Hz or 60 Hz) must be high enough to heat the device to T_{vjmax} (Note 2)	Depends on I_F and R_L	T_{case} = 25 °C		R_L should be approximately equal to the effective resistance of the diode under test

NOTE 1 Alternatively, a cheater circuit may be used.

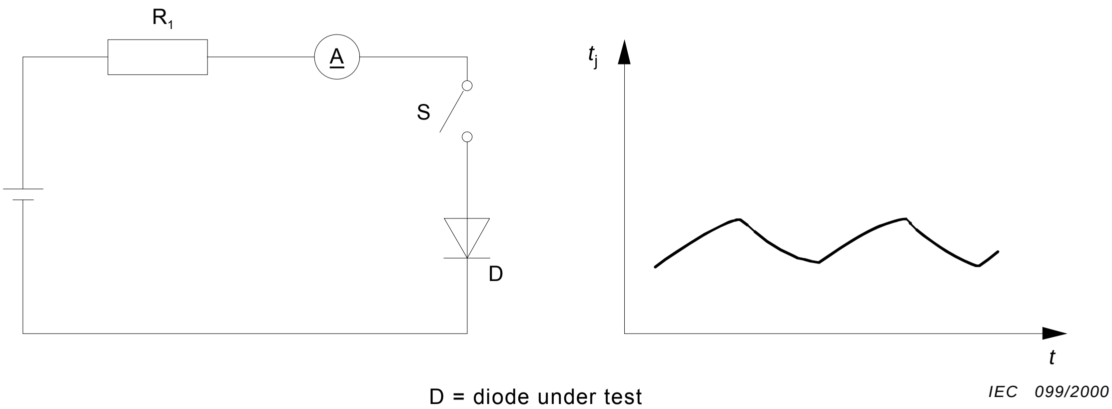
NOTE 2 See 7.4.6.

7.4.6 Thermal cycling load test

Purpose

To confirm by an endurance test that a certain diode type is capable of withstanding fluctuations in junction temperature.

Test circuit and test waveform



D = diode under test

Figure 38 – Test circuit and test waveform

Test procedure

The diode shall be heated by a specified current, preferably nearly equal to the maximum rated mean forward current, until a junction temperature between the maximum rated virtual junction temperature $T_{(vj)max}$ and $T_{(vj)max}$ – 20 °C has been reached.

NOTE When devices are tested in series, the temperature may be between $T_{(vj)max}$ and $T_{(vj)max}$ – 30 °C.

Switch S_1 is then opened, and the diode is cooled to a virtual junction temperature not greater than $40\,^{+10}_{-\ 0}$ °C.

The heating time shall not exceed 6 min and the cooling time shall not exceed 8 min.

The test shall be performed for a specified number of cycles.

The parameters that may be affected by the test shall be measured before and after the test.

Annex A
(informative)

Calculation of the temperature rise under time varying load

NOTE This annex has the status of a report.

The load capability of semiconductor devices depends on the thermal response of the junction temperature. To calculate the rise of the virtual temperature caused by single load pulses or intermittent load, the transient thermal impedance can be used. As the transient thermal impedance:

$$Z_{th}(t) = \frac{\Delta\theta(t)}{P}$$

is defined as the temperature rise $\Delta\theta(t)$ of the virtual temperature caused by a step function change of power dissipation P, the calculations are correct only for a load current which also changes as a step function. If pulses are shaped differently, a staircase approximation can be used as shown in figure A.1 below.

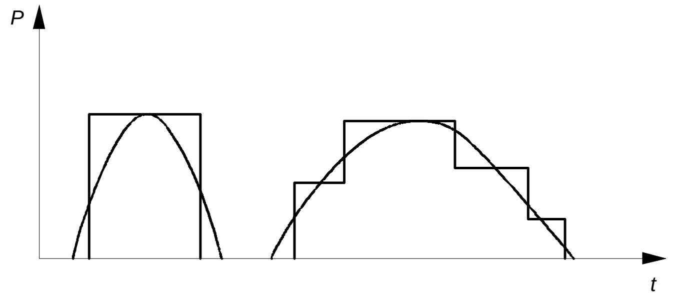


Figure A.1 – Staircase approximation for non-rectangular pulses

For the calculation of the rise of the virtual temperature $\Delta\theta(t)$, the following two methods may be used:

Method A using the transient thermal impedance $Z_{th}(t)$

$$\Delta\theta(t) = P \cdot Z_{th}(t)$$

Method B using an analytical function:

$$\Delta\theta(t) = P\sum_{i=1}^{n} R_i\left[1 - e^{-t/\tau_i}\right]$$

representing the transient thermal impedance by a sum of terms with suitable values for R_i and τ_i.

To represent the transient thermal impedance of a semiconductor device with its cooling attachment, n equals three to six terms may be satisfactory.

As shown in the examples, it is convenient to use method A for the calculation of temperature rise caused by single pulses. For more complicated problems, e.g. in the case of an infinite sequence of pulses and varying parameters or for more precise calculations, method B is more appropriate.

All computations are based on the superposition of thermal responses to single load pulses. An upward step of power loss will be taken as positive, a downward step as negative.

This is shown by the following typical examples:

EXAMPLE 1: Rectangular pulse (see figure A.2 below).

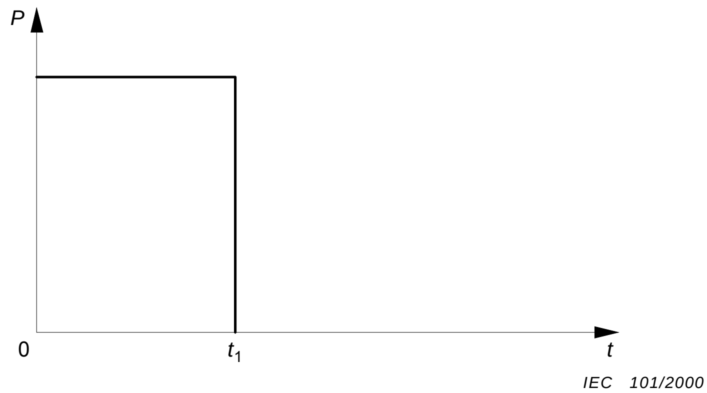


Figure A.2 – Rectangular pulse of duration t_1 producing the power dissipation *P* in the semiconductor device

Method A

Rise of the virtual temperature at time t_1:

$$\Delta\theta(t_1) = P \cdot Z_{th}(t_1)$$

During cooling, at a time $t_2 \geq t_1$:

$$\Delta\theta(t_2) = P\left[Z_{th}(t_2) - Z_{th}(t_2 - t_1)\right]$$

The values of $Z_{th}(t_1)$, $Z_{th}(t_2)$ and $Z_{th}(t_2 - t_1)$ are taken from a curve as shown in figure A.3 below.

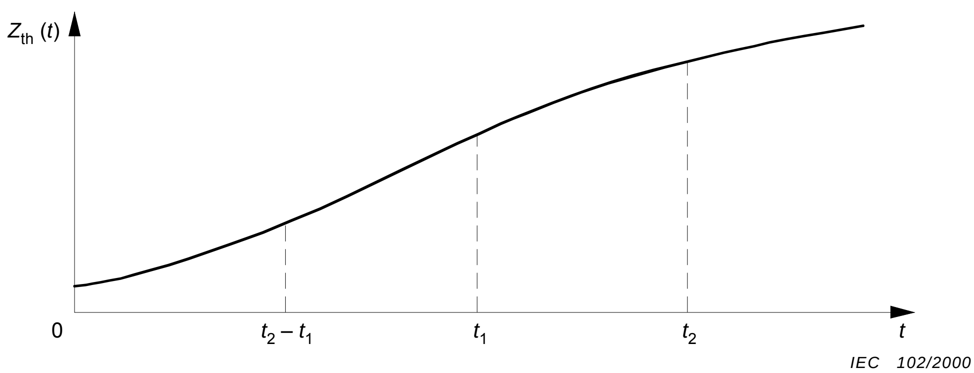


Figure A.3 – Transient thermal impedance $Z_{th}(t)$ versus time

Method B

Rise of the virtual temperature at time t_1:

$$\Delta\theta(t_1) = P\sum_{i=1}^{n} R_i\left[1 - e^{-t_1/\tau_i}\right]$$

During cooling, at a time $t_2 \geq t_1$:

$$\Delta\theta(t_2) = P\sum_{i=1}^{n} R_i\left[1 - e^{-t_1/\tau_i}\right]e^{-(t_2 - t_1)/\tau_i}$$

This expression can be transformed into:

$$\Delta\theta(t_2) = P\left\{\sum_{i=1}^{n} R_i\left[1 - e^{-t_2/\tau_i}\right] - \sum_{i=1}^{n} R_i\left[1 - e^{-(t_2 - t_1)/\tau_i}\right]\right\}$$

This result is identical with that of method A.

EXAMPLE 2: Single sequence of pulses (see figure A.4 below).

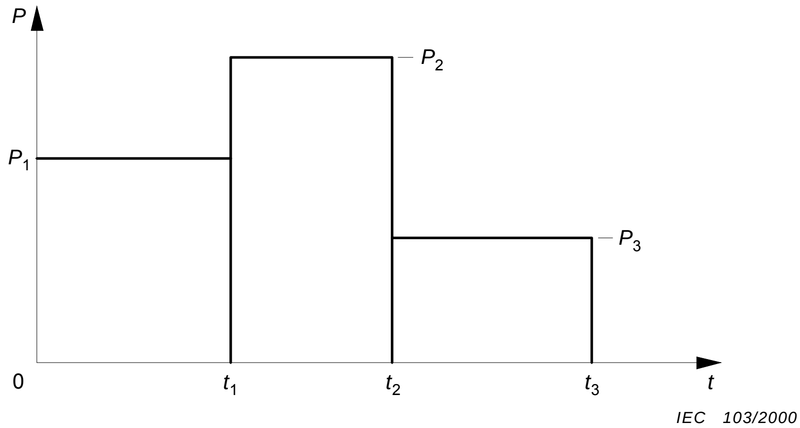


Figure A.4 – Single sequence of three rectangular pulses

From the calculation given in example 1 for the times t_1, t_2 and t_3, we obtain the following results for the virtual temperature:

Method A

$$\Delta\theta(t_1) = P_1 \cdot Z_{th}(t_1)$$

$$\Delta\theta(t_2) = P_1 \cdot Z_{th}(t_2) + (P_2 - P_1)\, Z_{th}(t_2 - t_1)$$

$$\Delta\theta(t_3) = P_1 \cdot Z_{th}(t_3) + (P_2 - P_1) \cdot Z_{th}(t_3 - t_1) + (P_3 - P_2)\, Z_{th}(t_3 - t_2)$$

Method B

$$\Delta\theta(t_1) = P_1\sum_{i=1}^{n} R_i\left[1 - e^{-t_1/\tau_i}\right]$$

$$\Delta\theta(t_2) = P_1\sum_{i=1}^{n} R_i\left[1 - e^{-t_2/\tau_i}\right] + (P_2 - P_1)\sum_{i=1}^{n} R_i\left[1 - e^{-(t_2 - t_1)/\tau_i}\right]$$

$$\Delta\theta(t_3) = P_1\sum_{i=1}^{n} R_i\left[1 - e^{-t_3/\tau_i}\right] + (P_2 - P_1)\sum_{i=1}^{n} R_i\left[1 - e^{-(t_3 - t_1)/\tau_i}\right] + (P_3 - P_2)\sum_{i=1}^{n} R_i\left[1 - e^{-(t_3 - t_2)/\tau_i}\right]$$

Method A and method B give identical results.

The result remains correct, when P_2 = 0 (a no-load interval of duration $t_2 - t_1$ occurs).

For any sequence of Q rectangular pulses (i.e. the sequence of figure A.4, to be continued), we find:

for method A

$$\Delta\theta(t_Q) = \sum_{q=1}^{Q} \left(P_q - P_{q-1}\right) Z_{th}\left(t_Q - t_{q-1}\right)$$

for method B

$$\Delta\theta(t_Q) = \sum_{q=1}^{Q} \left(P_q - P_{q-1}\right) \sum_{i=0}^{n} R_i\left[1 - e^{-\left(t_Q - t_{q-1}\right)/\tau_i}\right]$$

with: P_0 = 0, t_0 = 0

EXAMPLE 3: Periodic sequence of identical pulses (see figure A.5 below).

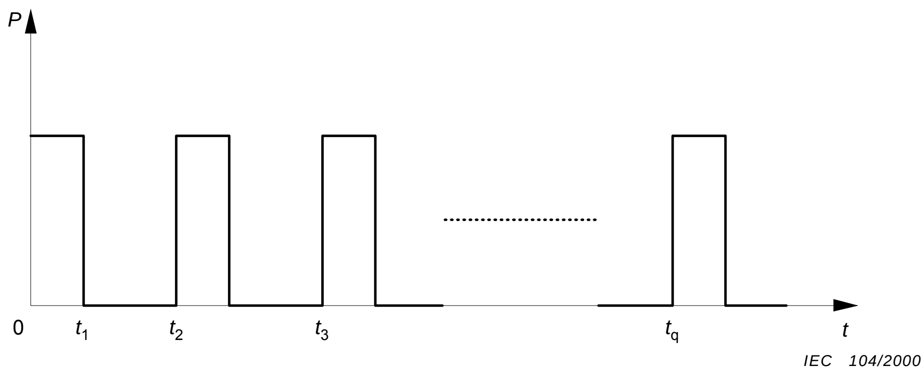


Figure A.5 – Periodic sequence of identical pulses

Method A

An approximation is recommended. Starting from a mean temperature $\Delta\theta_m$ caused by the mean power loss $P \cdot t_1/t_2$:

$$\Delta\theta_1 = \frac{t_1}{t_2} P \cdot Z_{th}(t_\infty)$$

the thermal response of two consecutive pulses $\Delta\theta_1$ is calculated.

$$\Delta\theta_1 = \left[1 - \frac{t_1}{t_2}\right] PZ_{th}(t_2 + t_1) - PZ_{th}(t_2) + PZ_{th}(t_1)$$

The total is: $\Delta\theta = \Delta\theta_m + \Delta\theta_1$

This gives a good approximation, if one of the following conditions is fulfilled:

1) $Z_{th}(t_1) \geq 0{,}5\, Z_{th}(t_\infty)$

2) $Z_{th}(t_2) - Z_{th}(t_1) \leq 0{,}1\, Z_{th}(t_\infty)$

Method B

An exact calculation for the temperature rise at the end of the q^{th} pulse gives:

$$\Delta\theta(t_q) = P\sum_{i=1}^{n} R_i \frac{1-e^{-t_1/\tau_i}}{1-e^{-t_2/\tau_i}}\left[1-e^{-qt_2/\tau_i}\right]$$

For the steady state, i.e. when q goes to infinity (it holds always at the end of the pulses):

$$\Delta\theta = P\sum_{i=1}^{n} R_i \frac{1-e^{-t_1/\tau_i}}{1-e^{-t_2/\tau_i}}$$

EXAMPLE 4: Load by a periodic sequence of various pulses, e.g. according to figure A.6 below.

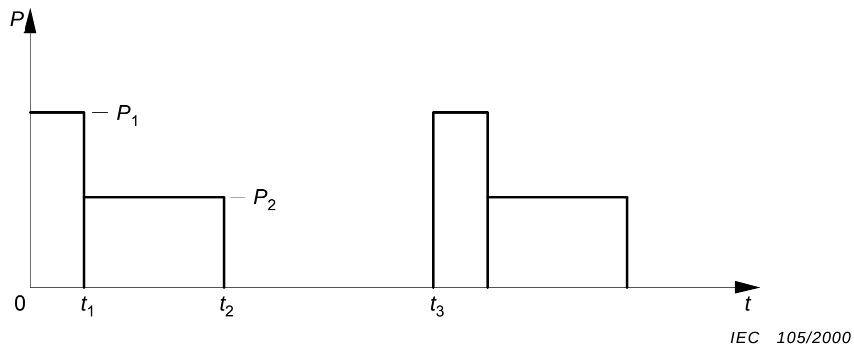


Figure A.6 – Periodic sequence of each two different pulses

Method A

An approximation similar to example 3 is recommended. Starting from the mean temperature rise:

$$\Delta\theta_m = \frac{1}{t_3}\left[t_1 P_1 + (t_2 - t_1) P_2\right] Z_{th}(t_\infty)$$

the thermal response $\Delta\theta_1$ of two consecutive sequences is calculated:

$$\Delta\theta_1 = \left[P_1 - \frac{1}{t_3}\{t_1 P_1 + (t_2 - t_1)P_2\}\right] Z_{th}(t_3 + t_2) - (P_1 - P_2) Z_{th}(t_3 + t_2 - t_1) - P_2 Z_{th}(t_3) +$$

$$+ P_1 Z_{th}(t_2) - (P_1 - P_2) Z_{th}(t_2 - t_1)$$

The total is then: $\Delta\theta = \Delta\theta_m + \Delta\theta_1$

Method B

An exact calculation for the temperature rise in the q^{th} sequence possible:

$$\Delta\theta(qt_3) = P_1 \sum_{i=1}^{n} R_i \frac{\left[1 - e^{-t_1/\tau_i}\right] e^{-(t_2 - t_1)/\tau_i}\left[1 - e^{-qt_3/\tau_i}\right]}{1 - e^{-t_3/\tau_i}} + P_2 \sum_{i=1}^{n} R_i \frac{1 - e^{-(t_2 - t_1)/\tau_i}}{1 - e^{-t_3/\tau_i}} \left[1 - e^{-qt_3/\tau_i}\right]$$

For the steady state, i.e. when q goes to infinity (it holds always at the end of the second pulse):

$$\Delta\theta = P_1 \sum_{i=1}^{n} R_i \frac{\left[1 - e^{t_1/\tau_i}\right] e^{-(t_2 - t_1)/\tau_i}}{1 - e^{-t_3/\tau_i}} + P_2 \sum_{i=1}^{n} R_i \frac{1 - e^{-(t_2 - t_1)/\tau_i}}{1 - e^{-t_3/\tau_i}}$$

NOTE For all examples, additional superpositions are possible:

1) Steady-state load. In this case, the calculated temperature rise $\Delta\theta$ is superimposed to a steady-state temperature rise $\Delta\theta_{st}$:

$$\Delta\theta_{st} = P_{st} \cdot Z_{th}(t_\infty) = P_{st} \cdot \sum_{i=1}^{n} R_i$$

where P_{st} is the steady-state load. The total temperature rise is then:

$$\Delta\theta_{st} + \Delta\theta$$

2) Every load pulse can consist of a pulse sequence of higher frequency, e.g. line frequency. In this case, an additional oscillation of the virtual temperature occurs. To calculate the maximum of this temperature oscillation, an additional term is required. This term can be derived from example 3.

Method A

The required term is formed in the same manner as $\Delta\theta_1$ in example 3.

Method B

The constants R_i can be replaced by R_i'

$$R_i' = R_i \frac{1 - e^{-t_1/\tau_i}}{1 - e^{-t_2/\tau_i}}$$

where t_1 is the pulse duration and t_2 the repetition rate of the higher frequency.

Table A.1 – Equations for calculating the virtual junction temperature rise for some typical load variations

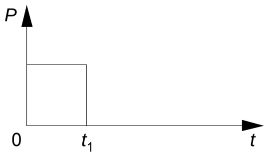
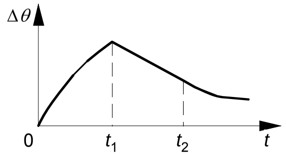
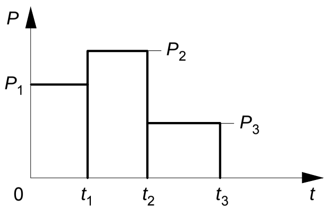
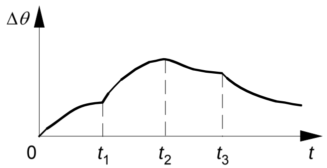
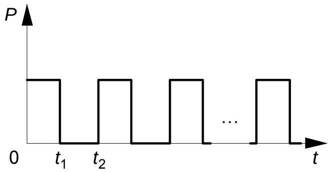
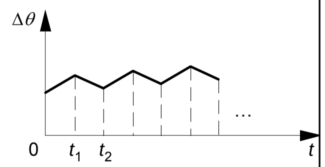
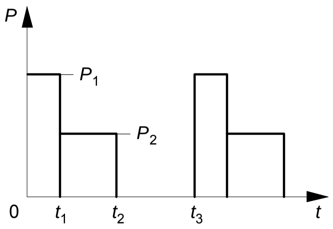
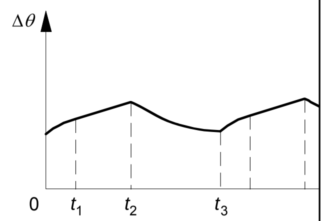
Load condition	Thermal response	Calculation methods	
		Method A	Method B
1 Single pulse  	 	$\Delta\theta(t_1) = P \cdot Z_{th}\ (t_1)$ $\Delta\theta(t_2) = P \cdot Z_{th}\ (t_2)$ $- P \cdot Z_{th}(t_2 - t_1)$	$\Delta\theta(t_1) = P \sum_{i=1}^{n} R_i \left[1 - e^{-t_1/\tau_i}\right]$ $\Delta\theta(t_2) = P \sum_{i=1}^{n} R_i \left[1 - e^{-t_2/\tau_i}\right]$ $- P \sum_{i=1}^{n} R_i \left[1 - e^{-(t_2 - t_1)/\tau_i}\right]$
2 Single sequence of three pulses  Single sequence of Q pulses $P_0 = 0$ $t_0 = 0$	 	$\Delta\theta(t_1) = P_1 \cdot Z_{th}\ (t_1)$ $\Delta\theta(t_2) = P_1 \cdot Z_{th}\ (t_2)$ $+(P_2 - P_1) \cdot Z_{th}(t_2 - t_1)$ $\Delta\theta(t_3) = P_1 \cdot Z_{th}\ (t_3)$ $+(P_2 - P_1) \cdot Z_{th}(t_3 - t_1)$ $+(P_3 - P_2) \cdot Z_{th}(t_3 - t_2)$ $\Delta\theta(t_Q) = \sum_{q=1}^{Q} (P_q - P_{q-1}) Z_{th}(t_Q - t_{q-1})$	$\Delta\theta(t_1) = P_1 \sum_{i=1}^{n} R_i \left[1 - e^{-t_1/\tau_i}\right]$ $\Delta\theta(t_2) = P_1 \sum_{i=1}^{n} R_i \left[1 - e^{-t_2/\tau_i}\right]$ $+(P_2 - P_1) \sum_{i=1}^{n} R_i \left[1 - e^{-(t_2 - t_1)/\tau_i}\right]$ $\Delta\theta(t_3) = P_1 \sum_{i=1}^{n} R_i \left[1 - e^{-t_3/\tau_i}\right]$ $+(P_2 - P_1) \sum_{i=1}^{n} R_i \left[1 - e^{-(t_3 - t_1)/\tau_i}\right]$ $+(P_3 - P_2) \sum_{i=1}^{n} R_i \left[1 - e^{-(t_3 - t_2)/\tau_i}\right]$ $\Delta\theta(t_Q) = \sum_{q=1}^{Q} (P_q - P_{q-1}) \sum_{i=1}^{n} R_i \left[1 - e^{-(t_Q - t_{q-1})/\tau_i}\right]$

Table A.1 *(continued)*

Load condition	Thermal response	Calculation methods	
		Method A	**Method B**
3 Periodical sequence of homogeneous pulses 		$\Delta\theta = \Delta\theta_m + \Delta\theta_1$ $\Delta\theta_m = \frac{t_1}{t_2} P \cdot Z_{th}(t_\infty)$ $\Delta\theta_1 = \left(1 - \frac{t_1}{t_2}\right) P \cdot Z_{th}(t_2 - t_1)$ $-P \cdot Z_{th}(t_2) + P \cdot Z_{th}(t_1)$	$\Delta\theta = P \sum_{i=1}^{n} R_i \frac{1 - e^{-t_1/\tau_i}}{1 - e^{-t_2/\tau_i}}$
4 Periodical sequence each of two different pulses 		$\Delta\theta = \Delta\theta_m + \Delta\theta_1$ $\Delta\theta_m = \frac{t_1}{t_3}\left[(t_1 - t_2) P_1 + t_2 P_2\right] \cdot Z_{th}(t_\infty)$ $\Delta\theta_1 = \left[P_1 - \frac{1}{t_3}\left[(t_2 - t_2) P_1 + t_2 P_2\right]\right] Z_{th}(t_3 + t_2)$ $-(P_1 - P_2) Z_{th}(t_3 + t_2 - t_1)$ $-P_2 Z_{th}(t_3) + P_1 Z_{th}(t_2)$ $+(P_1 - P_2) Z_{th}(t_2 - t_1)$	$\Delta\theta = P_1 \sum_{i=1}^{n} R_i \frac{\left[1 - e^{-t_1/\tau_i}\right] e^{-(t_2 - t_1)/\tau_i}}{1 - e^{-t_3/\tau_i}}$ $+ P_2 \sum_{i=1}^{n} R_i \frac{1 - e^{-(t_2 - t_1)/\tau_i}}{1 - e^{-t_3/\tau_i}}$