# JEDEC STANDARD

## Terms, Definitions, and Letter Symbols for Discrete Semiconductor and Optoelectronic Devices

## JESD77D

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**JEDEC SOLID STATE TECHNOLOGY ASSOCIATION**

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# TERMS, DEFINITIONS, AND LETTER SYMBOLS FOR DISCRETE SEMICONDUCTOR AND OPTOELECTRONIC DEVICES

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**CONTENTS (cont'd)**



**TABLES**

## Foreword

The purpose of this standard is to promote the uniform use of symbols, abbreviations, terms, and definitions throughout the semiconductor industry.

Originally developed to assist the writers and users of specifications and to facilitate the use of JEDEC registration formats, the material has received widespread industry acceptance.

Where applicable, reference is made to standardization documents of the following organizations:

American National Standards Institute, Inc. (ANSI)
Electronic Industries Association (EIA)
Institute of Electrical and Electronics Engineers (IEEE)
International Electrotechnical Commission (IEC)
National Institute of Standards and Technology (NIST)

and to Military Specification MIL-S-19500.

The material contained in this standard was formulated under the cognizance of JEDEC Committee JC-10 on Terms and Definitions and approved by the JEDEC Board of Directors.

JEDEC Standard No. 77D incorporates all previously issued supplements and new material. In order that a correct and up-to-date document be maintained, it is the responsibility of the user to collate subsequent supplements. To assist the user, the table of contents of each succeeding supplement will cover all sections. It should be used as the basic reference when looking up each term, definition, or symbol.

The text of this standard is based on JESD77C, which it replaces, and JEDEC Board of Directors ballot JCB-11-56.

# SECTION 1 LETTER SYMBOLS AND ABREVIATIONS

## 1.1 Definitions of letter symbols and abbreviations

**abbreviation:** A shortened form of a word or expression.

**letter symbol (for a quantity** or **a unit):** One or more letters written successively and without spacing, in a specified style and often provided with additional marks, by convention representing a quantity or a unit. (Ref. ANSI Y10.1 and IEC 27-1.)

NOTE In a few special cases, nonalphanumerical signs are considered as letters in this connection, e.g., the sign ° (degree), which is used as a letter symbol for a unit of angle and in the letter symbol °C for a unit of temperature.

**quantity symbol:** A letter symbol that is used to represent a physical quantity or a relationship between quantities.

**unit symbol:** A letter symbol that is used in place of the name of a unit.

## 1.2 Criteria and conventions for letter symbols and abbreviations

### 1.2.1 Primary (quantity) symbols

The letter symbol used to designate a quantity or parameter shall be a single letter. This single letter, referred to as the primary symbol, may be modified by subscripts or superscripts. See "secondary (quantity) symbols".

Table 1-1 illustrates primary symbols and unit symbols. Tables 1-3 and 1-4 illustrate principles of application when combined with secondary symbols.

NOTE The terms "primary" and "secondary" are used as synonyms for "kernel" and "additional marks", respectively, as defined in ANSI Y10.1 and IEC 21-1 and used in the definition of "letter symbol" in 1.1; they are not to be confused with the terms "chief" and "reserve".

**1.1 Definitions of letter symbols and abbreviations (cont'd)**

**1.2.1 Primary (quantity) symbols (cont'd)**

**Table 1-1 — Primary symbols**

| Primary symbol | Term | Unit of measurement | Unit symbol[1)] |
|---|---|---|---|
| *b* | susceptance | siemens† or mho | S or mho |
| *C* | capacitance | farad† | F |
| *E* | energy | joule† | J |
| *f* | frequency | hertz† | Hz |
| *G* | gain (power) | decibel†[2)] | dB[2)] |
| *g* | conductance | siemens† or mho | S or mho |
| *h* | maxtrix parameter | — | — |
| *I*, *i* | current | ampere† | A |
| *L* | inductance | henry† | H |
| *P*, *p* | power | watt† | W |
| *Q*, *q* | electric charge | coulomb† | C |
| *R*, *r* | resistance | ohm† | Ω |
| *T* | temperature | kelvin† or degree Celsius† | K or °C |
| *t* | time | second† | s |
| *V*, *v* | voltage | volt† | V |
| *Y*, *y* | admittance | siemens† or mho | S or mho |
| *Z*, *z* | impedance | ohm† | Ω |

† International System (SI) unit
1) The unit symbols are often used with the SI (metric) system multiplier prefixes, for example, µA for microampere.
2) Alternatively, power gain may be expressed as a dimensionless ratio.

## 1.2 Criteria and conventions for letter symbols and abbreviations (cont'd)

### 1.2.2 Secondary (quantity) symbols

A subscript or superscript, referred to as a secondary symbol, may be used to modify the primary symbol. The secondary symbol is used to designate special values of state, points, parts, times, etc. An abbreviation may be used as a subscript (secondary symbol).

Symbol subscripts shall be written on one line only. If there is more than one secondary symbol modifying the primary symbol, all such symbols shall be placed on the same (subscripted) line.

Terminal and value abbreviations shall be as shown in table 1-2.

For currents and voltages, the first subscript designates the terminal at which the current is measured, or the terminal where the potential is measured with respect to the reference terminal, which is sometimes designated by the second subscript. Conventional current into the terminal is positive.

NOTE — The term “primary” and “secondary” are used as synonyms for “kernel” and “additional marks”, respectively, as defined in ANSI Y10.1 and IEC 21-1 and used in the definition of “letter symbol” in 1.1; they are not to be confused with the terms “chief” and “reserve”.

### 1.2.3 Primary and secondary symbols combined

A letter symbol containing both primary and secondary letters has a unique meaning. This meaning cannot necessarily be inferred from the meanings of the individual primary and secondary symbols forming the combination.

Tables 1-3 and 1-4 show the significance of uppercase and lowercase letters. Figure 1-1 illustrates the meaning of the various combinations using, as an example, output voltage with a dc and an ac component.

### 1.2.4 Descriptive information

Descriptive information concerning a letter symbol may be added in parentheses after the secondary symbol. It is recommended that subscripts attached to subscripts and all secondary symbols with parenthetical expressions be in line. The abbreviations “max” and “min” are excluded from this rule. When these designate limit values, they are not considered to be part of the symbol itself.

EXAMPLES — $I_{\mathrm{F(AV)}}$, $h_{\mathrm{ie(imag)}}$, $I_{\mathrm{EC(ofs)}}$, $I_{\mathrm{CBO}}$ max

Refer to 1.2.12.(4) for uppercase or lowercase letters.

## 1.2 Criteria and conventions for letter symbols and abbreviations (cont'd)

### 1.2.4 Descriptive information (cont'd)

**Table 1-2 — Secondary symbols**

| Secondary symbol | Description |
|---|---|
| A, a | anode terminal |
| A | ambient (temperature), free-air temperature |
| (AV) | average |
| B, b | base terminal |
| (BO) | breakover |
| (BR) | breakdown |
| C, c | collector terminal |
| C | case |
| D,d | drain terminal, off-state (nontrigger) |
| d | delay (time) |
| E, e | emitter terminal |
| F, f | forward direction, forward tansfer |
| f | fall (time) |
| fr | forward recovery (time) |
| G, g | gate terminal |
| H, h | holding |
| I, i | input |
| J, j | general terminal |
| J | junction (temperature) |
| K, k | cathode terminal |
| M, m | maximum value (waveform peak) |
| (ofs) | offset |
| O, o | output, open circuit |
| (OV) | overload |
| P | peak point |
| p | pulse (time) |
| (PP) | peak-to-peak |
| Q, q | turn-off, recovery (time) |
| R, r | reverse direction , reverse transfer, repetitive (as 2nd or 3rd subscript), resistive termination |
| r | rise (time) |
| (REC) | recovery |
| (RMS) | root-mean-square |
| rr | reverse recovery (time) |
| S, s | source terminal, stored (charge), short circuit, nonrepetitive (as 2nd or 3rd subscript) |
| T, t | on-state, trigger |
| U, u | bulk (substrate) |
| V | voltage termination, valley point |
| W | working |
| w | duration (width) of pulse |
| X | specified circuit termination |

## 1.2 Criteria and conventions for letter symbols and abbreviations (cont'd)

### 1.2.4 Descriptive information (cont'd)

**Table 1-3 — Symbol capitalization for current, voltage, and power**

| | | **Primary symbol** | |
|---|---|---|---|
| | | **Lowercase (*i*, *v*, *p*)** | **Uppercase (*I*, *V*, *P*)** |
| **Secondary symbols (terminal subscripts)** | **Lowercase** | Instantaneous value of alternating component | With no additional subscript: root-mean-square value of alternating component |
| | | | With additional subscript m: peak value of alternating component |
| | **Uppercase** | Instantaneous total value | With no additional subscript: direct current value |
| | | | With additional subscript M: peak total value |
| | | | With additional subscript (AV): average value |
| | | | With additional subscript (RMS): total value |
| | | | With additional subscript (PP): peak-to-peak value |

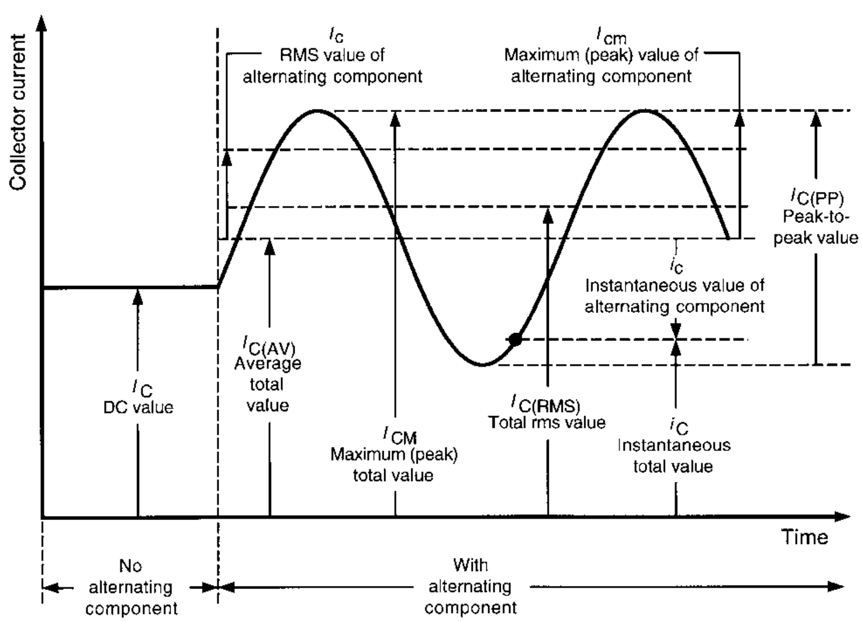



**Figure 1-1 — Proper use of symbols**

## 1.2 Criteria and conventions for letter symbols and abbreviations (cont'd)

### 1.2.4 Descriptive information (cont'd)

**Table 1-4 — Symbol capitalization for capacitance and four-pole matrix parameters**

| | | **Primary symbol** | |
|---|---|---|---|
| | | **Lowercase (*g, h, r, s, z*, etc.)** | **Uppercase (*A, C, G, R, Z*, etc.)** |
| **Secondary symbols (subscripts)** | Lowercase | Small-signal values of resistance and impedance inherent within the device (e.g., $r_i$, $z_o$), and s parameters (e.g., $s_i$, $s_o$) | Small-signal values of amplification, capacitance, and gain (e.g., $A_{vd}$, $C_o$, $G_{pe}$) |
| | Uppercase | Large-signal and static values of conductance, resistance, and impedance inherent within the device (e.g., $g_{FS}$, $r_I$, $z_O$), and s parameters (e.g., $s_I$, $s_O$) | Large-signal and static values of amplification, capacitance, and gain (e.g., $A_{VD}$, $C_O$, $G_{PE}$), and resistance and impedance in external circuits (e.g., $R_I$, $Z_O$) |

NOTE The first subscript, or subscript pair in matrix notation, identifies the element of the four-pole matrix:

— i or 11 = input,
— o or 22 = output,
— f or 21 = forward transfer, and
— r or 12 = reverse transfer.

The second subscript, or the subscript following the numeric pair, identifies the circuit configuration. For example,

— e = common emitter,
— b = common base,
— c = common collector, and
— j = common terminal, general.

## 1.2 Criteria and conventions for letter symbols and abbreviations (cont'd)

### 1.2.5 Subscript sequence

The first subscript designates the terminal at which the current is measured, or the terminal where the potential is measured with respect to the reference terminal designated by the second subscript. (Conventional current flow into the terminal from the external circuit is positive.)

### 1.2.6 Supply voltage

The supply voltage to a terminal shall be indicated by repeating the terminal subscript, such as $V_{BB}$, $V_{CC}$, $V_{EE}$.

### 1.2.7 Multiple-unit devices

In multiple-unit devices, terminals that are not common to all the units shall be identified by adding the unit number preceding and in line with each terminal letter designation in accordance with terminal numbering in EIA-321. Example of use in a quantity letter symbol: $V_{1B2B}$.

### 1.2.8 Multiple electrodes of the same type

Multiple terminals connected to electrodes of the same type shall be identified by adding a number following and in line with each terminal designation in accordance with terminal numbering in EIA-321. Example of use in a quantity letter symbol: $V_{B1B2}$.

### 1.2.9 Multiple-unit devices with multiple electrodes of the same type

Combinations of 1.2.7 and 1.2.8 may be applied. Example of use in a quantity letter symbol: $V_{1G2,\ 2G2}$.

### 1.2.10 Multiple subscripts

For the sake of clarity, the different parts of a multiple subscript may be separated by small spaces. Hyphens and commas should be avoided between parts of a subscript unless necessary to avoid ambiguity. For the same purpose, part of a subscript may be put within parentheses. No general rule for the order between parts of a subscript can be given, but for guidance, a part indicating the kind of quantity should be placed first and a part indicating special circumstances last. Examples of use in quantity letter symbols: $R_{\theta JC}$, $V_{CE(sat)}$, $V_{1E1,1E2,}$ $\alpha_{vs}$.

### 1.2 Criteria and conventions for letter symbols and abbreviations (cont'd)

#### 1.2.11 Unit symbols

The letter symbol used in place of a unit name shall be taken from a recognized standard such as ANSI/IEEE Std 260.1, ANSI/IEEE Std 268, NIST Special Publication 330, or IEC 27 and shall be used in accordance with the rules given therein. Some of the most important rules are:

1) Do not use an attachment to a unit symbol (e.g., a subscript or postscript) as a means of giving information about the special nature of the quantity under consideration. Such information should be conveyed instead by the quantity symbol.

2) Unit symbols are to be in lowercase letters (e.g., cd) unless the unit name has been derived from a proper name, in which case the first letter of the symbol is capitalized (e.g., W, Hz). International (SI) prefix symbols representing multipliers of $10^6$ or greater are uppercase, those representing 1000 or less are lowercase. Symbols retain their prescribed case regardless of surrounding typography.

3) Always leave a space between numerical values and unit symbols (e.g., 10 V, 5 mA, 50 kΩ, 25 $^{o}$C) except when used as an adjective modifier to a noun, in which case a hyphen should be inserted between the number and the symbol (e.g., a 12-V battery). However, no space is used between a number and the symbols for degree, minute, and second of plane angle (e.g., 12º45´10″).

4) Do not use compound prefixes formed by juxtaposition of two or more SI prefixes. For example, use 1 pF, not 1 μμF. If outside the range covered by SI prefixes, which extend from yocto ($10^{-24}$) to yotta ($10^{24}$), use powers of ten applied to the base unit.

5) Division may be indicated using a slash (e.g., V/Ω), and this procedure may be extended to cases where the numerator and/or denominator are themselves products or quotients; but in such a combination, a slash should not be followed by a multiplication sign or a division sign on the same line unless parentheses are inserted to avoid ambiguity. For example, write $W/(sr{\cdot}m^2)$ or $W{\cdot}sr^{-1}{\cdot}m^{-2}$ or $(W/sr)/m^2$, but not $W/sr/m^2$ or $W/sr{\cdot}m^2$.

6) Multiplication may be indicated using either a raised dot or a space between pairs of symbols (e.g., N·m, N m). In systems with limited character sets, a period may be used in place of the raised dot. The space may be omitted provided that special care is taken when the symbol for one of the units is the same as the symbol for a prefix; e.g., mN means millinewton and therefore must not be used for meter newton.

## 1.2 Criteria and conventions for letter symbols and abbreviations (cont'd)

### 1.2.12 Abbreviations

1) Short words are not usually abbreviated unless their abbreviation has been established by long practice.

2) An abbreviation is usually written with no spaces between the letters of the abbreviation. The use of hyphens and slashes is avoided where practicable.

3) Periods are used after technical abbreviations only when necessary to avoid misinterpretation of the abbreviation or at the end of a sentence.

4) Uppercase or lowercase letters may be used as appropriate except where the use of a particular case has been established by long practice. When used as secondary symbols, the parts of a multiletter abbreviation shall not be a mixture of uppercase and lowercase letters.

5) Subscripts and superscripts are not used in abbreviations.

6) Abbreviations shall be used only when their meanings are unquestionably clear. When in doubt, spell it out.

7) Abbreviations for word combinations shall be used as such and shall not be separated for use singly.

8) The same abbreviation shall be used for all tenses and the singular and plural forms of a given word.

### 1.2.13 Typefaces

In textbooks and technical publications, in both text and equations, the use of italic type is recommended for quantity symbols, whether uppercase or lowercase, Greek or Latin. Numerals, abbreviations, operators (e.g., +, –, /, exp, ( ), Δ), and unit symbols shall be in roman (upright) type. Characters used as subscripts should be in the same type style as they would be if they were not subscripts; i.e., use roman type unless the subscript represents a quantity symbol. In subscripts, quantity symbols often refer not to a specific quantity but to the concept in the abstract. Examples include $G_{\mathrm{PE}}$, $\alpha_C$, $\alpha_{V(\mathrm{BR})}$.

For data sheets, specifications, and technical reports prepared on a typewriter, the use of conventional typewriter typefaces is acceptable for symbols that are ordinarily italicized.

# SECTION 2 GENERAL

## 2.1 General terms and definitions

**absolute maximum rating:** Synonym for "maximum rating".

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

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

**anode current:** Synonym for "forward current".

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

NOTE 1 See note to "anode".

NOTE 2 This definition does not apply to current-regulator diodes.

NOTE 3 For voltage-reference diodes, any temperature-compensating diodes that may be included shall be ignored in the determination of the anode terminal.

NOTE 4 For unidirectional blocking or low-capacitance ABDs, any rectifier diode(s) that may be included shall be ignored in the determination of the anode terminal.


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

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

**bipolar technology:** A technology for producing devices in which electrical conduction depends on the flow of both majority and minority carriers.

**blocking:** A term describing the state of a semiconductor device or junction that imposes high resistance to the passage of current. (Ref. JESD282B.)

**body (of a semiconductor device):** The semiconductor portion of a device limited by the physical extent of the semiconductor material and including any associated oxide layers and metallization.

**breakdown:** The phenomenon, occurring in a reverse-biased semiconductor junction, whose initiation is observed as a transition from a region of high small-signal resistance to a region of substantially lower small-signal resistance for an increasing magnitude of reverse current. (Ref. JESD282B.)

**breakdown current:** A current in the breakdown region.

**2.1 General terms and definitions (cont'd)**

**breakdown region:** The portion of the voltage-current characteristic beyond the initiation of breakdown for an increasing magnitude of reverse current. (Ref. JESD282B.)

**breakdown voltage:** A voltage in a breakdown region.

**built-in electric field (in a transition region):** The internal electric field in the absence of bias.

**bulk characteristics (of a semiconductor material):** The characteristics of a piece of semiconductor material that has uniform properties throughout the whole piece, as measured in those parts of the piece in which the measured value of a characteristic is not modified by the proximity of the boundaries of the piece.

NOTE Bulk characteristics for pieces smaller than required by the definition are those that would be measured for a sufficiently large piece having the same technological properties.

**carrier, (charge) (in a semiconductor):** A mobile (i.e., free) conduction electron or mobile hole. (Ref. IEC 747-1.)

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

NOTE See note to "anode".

**cathode current:** Synonym for “reverse current”.

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

NOTE 1 See note to "anode".

NOTE 2 This definition does not apply to current-regulator diodes.

NOTE 3 For voltage-reference diodes, any temperature-compensating diodes that may be included shall be ignored in the determination of the cathode terminal.

NOTE 4 For unidirectional blocking or low-capacitance ABDs, any rectifier diode(s) that may be included shall be ignored in the determination of the cathode terminal.

**characteristic:** An inherent and measurable property of a device.

NOTE Such a property may be electrical, mechanical, thermal, hydraulic, electromagnetic, or nuclear and can be expressed as a value for stated or recognized conditions. A characteristic may also be a set of related values, usually shown in graphical form. (Ref. IEC 134.)

**chip:** A separated part of a wafer (or, in some cases, a whole wafer) intended to perform a function or functions in a device.

### 2.1 General terms and definitions (cont'd)

**component (general):** A constituent part.

NOTE 1 Examples include source and drain regions as components of transistors, lead frames and dice/dies as components of packaged integrated circuits, resistors and integrated circuits as components of printed circuit boards, motherboards as components of computers, LCD screens as components of monitors, ac and dc components of complex waveforms, and loops and algorithms as components of software programs.

NOTE 2 Unless the context identifies the thing of which a component is a part, a descriptive prepositional phrase identifying the thing should follow the word “component”.

**collecting junction:** A semiconductor junction in an operating condition in which the net flow of charge carriers of each type across the junction is in the direction from the region where they are minority carriers to the region where they are majority carriers, i.e., in the direction of the force resulting from the internal electric field.

**collection region (within a semiconductor device):** A functional region that receives the principal current leaving the control region.

**control-charge region (within a semiconductor device):** A functional region that contains the controlling charge and that may or may not be the path for the principal current.

**control region (within a semiconductor device):** A functional region through which the principal-current charge carriers flow and are controlled in the manner for which the device is intended.

**device:** A piece of equipment, a mechanism, or another entity designed to serve a special purpose or perform a special function.

NOTE 1 In JEDEC documents, the word “device” is often used as an abbreviated reference to the type or types of solid-state devices that are within the scope of those documents. Context could indicate otherwise; e.g., in the phrase “the device used to hold the device under test”, the first usage of the word “device” refers to a mechanism; the second to a solid-state device.

NOTE 2 Contrast with “component (general)”.

**dice; dies:** Plural of “die”.

**die:** Synonym for “chip”.

**diffusion (of charge carriers):** The movement of charge carriers caused only by a charge carrier concentration gradient.

NOTE In the case of transfer across a p-n junction, the amount of transfer depends on the internal electric field resulting from the built-in electric field and applied bias.

**2.1 General terms and definitions (cont'd)**

**discrete semiconductor device:** A semiconductor device that is specified to perform an elementary electronic function and is not divisible into separate components functional in themselves.

NOTE 1 Diodes, transistors, rectifiers, thyristors, and multiple versions of these devices are examples. Other semiconductor structures having the physical complexity of integrated circuits but performing elementary electronic functions (e.g., complex Darlington transistors) are usually considered to be discrete semiconductor devices.

NOTE 2 If a semiconductor device is not considered to be an integrated circuit in both complexity and functionality, it is considered to be a discrete device.

**electrical connection (within a semiconductor device):** An electrically conducting element that is intended to function as a pathway between other elements, including terminals, and whose primary purpose is to conduct electric current in a confined manner.

NOTE The connection may consist of a separate conductive entity such as a wire or metallic film or be an integral part of the body.

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

**electrostatic-discharge-sensitive device:** A discrete device or integrated circuit that may be permanently damaged by electrostatic potentials encountered in routine handling, testing, and shipping.

NOTE In documents of the IEC and CENELEC, the abbreviation ESDS stands for “electrostatic-discharge-sensitive device”; in the USA, ESDS stands merely for “electrostatic discharge sensitive” or “electrostatic discharge sensitivity”, and “ESDS device” is not further abbreviated. The abbreviation ESD stands for “electrostatic discharge”.

**element (of a discrete device):** Any constituent part of the discrete device that contributes directly to its operation and performs a definable function.

NOTE The definition includes electrical interconnections between elements or between elements and terminals.

**emitting junction:** A semiconductor junction in an operating condition in which the net flow of charge carriers of each type across the junction is in the direction from the region where they are majority carriers to the region where they are minority carriers, i.e., in the direction opposite to the force resulting from the internal electric field.

**extrinsic semiconductor:** A semiconductor with charge-carrier concentration dependent upon impurities or other imperfections. (Ref. IEC 747-1.)

**forward bias:** The bias that tends to produce forward current.

**2.1 General terms and definitions (cont'd)**

**forward current (in a p-n junction):** The current flowing from the p-type region to the n-type region.

**forward current (in a semiconductor diode):** The current flowing from the external circuit into the anode terminal.

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

**forward voltage (across a p-n junction):** The voltage between the p-type region and the n-type region when the p-type region is at a positive voltage relative to the n-type region.

**forward voltage (across a semiconductor diode):** A positive anode-cathode voltage.

**functional region (within a semiconductor material):** An identifiable volume whose boundaries depend on operating conditions.

EXAMPLES space-charge region, channel region.

**heterojunction:** A region of transition between two different semiconductor materials, usually with a negligible discontinuity in the crystalline structure.

NOTE A heterojunction can be between materials of the same conductivity type (isotype heterojunction) or of the opposite conductivity type (anisotype heterojunction).

**inherent electric field (in a transition region):** Synonym for “built-in electric field”.

**internal electric field (in a transition region):** The electric field due to the presence of space charges in the transition region.

NOTE This field is dependent on the impurity profile of the transition region and on the bias applied between the two adjacent neutral regions.

**i-type (intrinsic) semiconductor:** A nearly pure and ideal semiconductor in which the electron and hole densities are nearly equal under conditions of thermal equilibrium. (Ref. IEC 747-1.)

**junction diode:** A semiconductor diode consisting of two physical regions of opposite conductivity type separated by a p-n transition region.

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

**majority carrier:** The type of carrier constituting more than half of the total charge-carrier concentration.

**2.1 General terms and definitions (cont'd)**

**maximum rating:** A rating that establishes either a limiting capability or a limiting condition beyond which damage to the device may occur. (Ref. IEC 747-1.)

NOTE 1 A limiting condition may be either a maximum or a minimum.

NOTE 2 IEC 747-1 refers to such a limiting condition as a “rating (limiting value)”.

**minority carrier:** The type of carrier constituting less than half of the total charge-carrier concentration.

**no (internal) connection (NC):** A terminal that has no internal connection and that can be used as a support for external wiring without disturbing the function of the device if the voltage applied to this terminal (by means of the wiring) does not exceed the highest supply voltage rating of the circuit.

NOTE 1 If higher voltages are acceptable, this should be stated.

NOTE 2 The IEC equivalent term is “blank terminal”; nevertheless, the IEC abbreviation is “NC”.

**nonusable terminal (NU):** A terminal that shall not be used in normal applications and that may or may not have an internal connection.

**n-type semiconductor:** An extrinsic semiconductor in which the conduction-electron density exceeds the mobile-hole density. (Ref. IEC 747-1.)

**open circuit:** A circuit having a terminating impedance sufficiently high that halving its magnitude does not produce a change in the parameter being measured that is greater than the required accuracy of the measurement.

**physical region (within a semiconductor material):** An identifiable volume material whose technological boundaries are fixed by the manufacturing process and independent of operating conditions.

EXAMPLES Transition region, buried layer, substrate.

**p-n boundary:** An interface in the transition region between p-type and n-type materials at which the donor and acceptor concentrations are equal.

**p-n junction; p-n transition region:** A junction between p-type and n-type semiconductor regions.

**principal-current charge carriers (within the body of a device):** The charge carriers that compose the principal current.

NOTE The definition excludes charge carriers that are present for control purpose only.

**principal current (in a semiconductor device):** The current that is controlled by the semiconductor device.

**2.1 General terms and definitions (cont'd)**

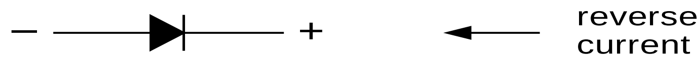
**p-type semiconductor:** An extrinsic semiconductor in which the mobile-hole density exceeds the conduction-electron density. (Ref. IEC 747-1.)

**rating:** The nominal value of any electrical, thermal, mechanical, or environmental quantity assigned to define the operating conditions under which a component, machine, apparatus, electronic device, etc., is expected to give satisfactory service. (Ref. IEC 747-1.)

NOTE "Rating" is a generic term, but also see "maximum rating".

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

**reverse bias:** The bias that tends to produce reverse current.




**reverse current (in a p-n junction):** The current flowing from the n-type region to the p-type region.

**reverse current (in a semiconductor diode):** The current flowing from the external circuit into the cathode terminal.

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

**reverse voltage (across a p-n junction):** The voltage between the n-type region and the p-type region when the n-type region is at a positive voltage relative to the p-type region.

**reverse voltage (across a semiconductor diode):** A positive cathode-anode voltage.

**semiconductor (**nonspecific**):** A substance whose conductivity due to the charge carriers of both signs is normally in the range between that of metals and that of insulators and in which the charge carrier density can be changed by external means.

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

NOTE For specification purposes, a semiconductor device must be considered to be either a discrete semiconductor device or an integrated circuit.

**semiconductor diode:** A semiconductor device having two electrodes and exhibiting a nonlinear voltage-current characteristic; in more restricted usage, a semiconductor device that has the asymmetrical voltage-current characteristic exemplified by a single p-n junction. (Ref. IEEE Std 100.)

**semiconductor (material) (within a semiconductor device):** A material in which the electric current is made up of both negative and positive mobile charge carriers (i.e., conduction electrons and holes, respectively).

**2.1 General terms and definitions (cont'd)**

**short circuit:** A circuit having a terminating impedance sufficiently low that doubling its magnitude does not produce a change in the parameter being measured that is greater than the required accuracy of the measurement.

**small signal:** A signal that when doubled in magnitude does not produce a change in the parameter being measured that is greater than the required accuracy of the measurement.

**solid-state (within the scope of JEDEC):** Relating to, or utilizing, those electrical, magnetic, optical, thermal, and/or chemical properties of semiconductors that are based on the arrangement or behavior of atoms, ions, molecules, nucleons, electrons, holes, and/or imperfections.

**solid-state component:** A solid-state device that is, or is intended to be, a constituent part of a higher order assembly.

**solid-state device:** An electronic device whose operation depends on the properties of the integral solid semiconductor materials.

**solid-state industry:** Those companies and organizations whose primary function is associated with design, fabrication, assembly, test, inspection, and/or distribution of solid-state devices.

**solid-state physics:** The study of the physical properties of solids, with special emphasis on the electrical, magnetic, optical, thermal, and chemical properties of semiconducting materials in relation to their electronic structure.

**solid-state technology:** The applied sciences and skills of developing and manufacturing solid-state devices.

**space-charge region (of a semiconductor device):** A functional region in which the net charge density is significantly different from zero.

NOTE 1 The net charge is caused by electrons, holes, and ionized acceptors and donors.

NOTE 2 The space-charge regions of a semiconductor device include accumulation (enhancement), depletion, and inversion layers.

**space-charge region (of a p-n junction):** A space-charge region contained between two neutral regions of types p and n.

**static value:** (1) A nonvarying value or quantity of measurement at a specified fixed point.

(2) The slope of the line from the origin to the operating point on the appropriate characteristic curve.

**2.1 General terms and definitions (cont'd)**

**substrate (of a semiconductor device):** (1) The part of the original material that remains essentially unchanged when the device elements are formed upon or within the original material.

NOTE The original material may be a layer of semiconductor material cut from a single crystal, a layer of semiconductor material deposited on a supporting base, or the supporting base itself.

(2) The original semiconductor material being processed.

NOTE The intended meaning will usually be clear from the context in which the term is used. If necessary, distinction can be made between the “original substrate” and the “remaining substrate”.

**supply region (within a semiconductor device):** A functional region that delivers principal-current charge carriers to the control region of the device.

**surge protective device (SPD):** Synonym for “transient voltage suppressor”.

**temperature coefficient:** The change in a parameter divided by the change in temperature that caused it.

NOTE This quotient is the average value over the total temperature change. The specific term should be “temperature coefficient of (parameter)”. The change in the parameter may or may not be normalized to the initial value of the parameter.

**temperature derating:** A specification showing how a rating stated at a particular temperature is reduced at higher temperatures.

NOTE 1 Derating is usually expressed graphically or in terms of derating factors (e.g., mA/°C or mW/°C).

NOTE 2 Average power ratings are derated to zero at the maximum-rated junction temperature. Peak pulse power ratings may exceed zero at the maximum-rated junction temperature.

**terminal (of a semiconductor device):** An externally available point of connection.

NOTE The use of the term “termination” as a synonym is deprecated because that term denotes the external elements connected to the terminal.

**thermal impedance, (transient):** The change in temperature difference between two specified points or regions that occurs during a time interval divided by the step-function change in power dissipation that occurred at the beginning of the interval and caused the change in temperature difference. (Ref. JESD282B.)

**thermal resistance, (steady-state):** The temperature difference between two specified points or regions divided by the power dissipation under conditions of thermal equilibrium.

**transient voltage suppressor (TVS):** A semiconductor device that is intended to limit voltage transients by conducting surge currents.

**2.1 General terms and definitions (cont'd)**

**transistor (general):** A semiconductor device, capable of providing power amplification, whose basic functional structure includes the series connection of a supply region, a control region, and a collection region, and whose output is a simple, continuous function of the input.

**transition region, (physical) (within a semiconductor material):** The physical region between two homogeneous semiconductor regions that have different electrical properties.

**unipolar technology:** A technology for producing devices in which electrical conduction is due entirely to the flow of majority carriers.

**2.2 General letter symbols, terms, and definitions**

| | |
|---|---|
| $F$ or NF* | **spot noise figure† ; spot noise factor†:** The ratio of (1) the total output noise power per unit bandwidth (spectral density) at a single output frequency when the noise temperature of all input terminations is at the reference noise temperature, $T_0$, at all frequencies that contribute to the output noise to (2) that part of (1) caused by the noise of the signal-input termination at the signal-input frequency. |
| $\overline{F}$ or $\overline{\text{NF}}$* | **average noise figure†; average noise factor†:** The ratio of (1) the total output noise power within an output frequency band when the noise temperature of all input terminations is at the reference noise temperature, $T_0$, at all frequencies that contribute to the output noise to (2) that part of (1) caused by the noise of the signal-input termination within the signal-input frequency band. |
| $I_F$ | **forward current, dc:** The dc current flowing from the external circuit into the anode terminal. |
| $I_n$ | **noise current, equivalent input (of a two-port device):** The current of an ideal current source (having an internal impedance equal to infinity) in parallel with the input terminals of the device that represents the part of the internally generated noise that can properly be represented by a current source.<br><br>NOTE In the definition, the equivalent input noise voltage, which would be needed for a complete and precise description of the device noise, is neglected. If the external source impedance is infinite, the noise current represents the total noise. |
| $I_R$ | **reverse current, dc:** The dc current flowing from the external circuit into the cathode terminal. |
| $R_\theta$ or $R_{th}$ (formerly $\theta$) | **thermal resistance:** Synonym for "thermal resistance, (steady-state)" in 2.1. |

* NF and $\overline{\text{NF}}$ abbreviations are often used for symbols $F$ and $\overline{F}$; however, symbols $F$ and $\overline{F}$ are preferred.
† These quantities may be expressed logarithmically in decibels (dB).

**2.2 General letter symbols, terms, and definitions (cont'd)**

$R_{\theta CA}$ or $R_{thCA}$ **case-to-ambient thermal resistance:** The thermal resistance from the device case to the ambient.

$R_{\theta JA}$ or $R_{thJA}$ (formerly $\theta_{J\text{-}A}$) **junction-to-ambient thermal resistance:** The thermal resistance from the semiconductor junction(s) to the ambient.

$R_{\theta JC}$ or $R_{thJC}$ (formerly $\theta_{J\text{-}C}$) **junction-to-case thermal resistance:** The thermal resistance from the semiconductor junction(s) to a stated location on the case.

$R_{\theta JL}$ or $R_{thJL}$ **junction-to-lead thermal resistance:** The thermal resistance from the semiconductor junction(s) to a stated location on a lead.

$R_{\theta JM}$ or $R_{thJM}$ **junction-to-mounting-surface thermal resistance:** The thermal resistance from the semiconductor junction(s) to a stated location on the mounting surface.

**All temperature symbols are shown together, followed by all time symbols.**

$T_A$ **ambient temperature; free-air temperature:** The air temperature measured below a device, in an environment of substantially uniform temperature, cooled only by natural air convection and not materially affected by reflective and radiant surfaces.

$T_C$ **case temperature:** The temperature measured at a specified location on the case of a device.

$T_J$ **junction temperature:** The temperature of a semiconductor junction.

NOTE In data sheets it is common practice to use this term to mean virtual-junction temperature.

$T_J$ or $T_{VJ}$ **virtual-junction temperature:** A temperature representing the temperature of the junction(s) calculated on the basis of a simplified model of the thermal and electrical behavior of the semiconductor device.

NOTE The term “virtual-junction temperature” is taken from IEC standards. It is particularly applicable to multijunction semiconductors and is used in this standard to denote the temperature of the active semiconductor element when required in specifications and test methods. The term “virtual-junction temperature” is used interchangeably with the term “junction temperature” in this standard.

$T_n$ **noise temperature:** The uniform physical absolute temperature at which a network (and all its sources, if it is a multiport network) would have to be maintained, if it (and its sources) were passive, in order to make available (or deliver) the same random noise power per unit bandwidth (spectral density) at a given frequency as is actually available (or delivered) from the network.

## 2.2 General letter symbols, terms, and definitions (cont'd)

$T_{stg}$ **storage temperature:** The temperature at which the device, without any power applied, is stored.

$T_0$ **reference noise temperature:** A specified absolute temperature to be assumed as a noise temperature at the input ports of a network when calculating certain noise parameters and for normalizing purposes.

NOTE When the reference noise temperature is 290 K, it is considered to be the standard reference noise temperature.

**All time symbols are shown together; preceding lines and pages show temperature symbols. For illustration of pulse times, see figure 2-1.**

$t_d$ **delay time** (general)**:** The time interval between a reference point on one waveform and a reference point on another waveform.

**delay time (between input and output):** The time interval between a transition at an input and a resultant change at an output. (See also $t_d$, $t_{di}$, and $t_{dv}$ in 4.1.2.)

$t_f$ **fall time** (general)**:** The time interval between one reference point on a waveform and a second reference point of smaller magnitude on the same waveform. (See also $t_f$, $t_{fi}$, and $t_{fv}$ in 4.1.2 and 4.3.2.)

NOTE The first and second reference points are usually 90% and 10%, respectively, of the steady-state amplitude of the waveform existing before the transition, measured with respect to the steady-state amplitude existing after the transition.

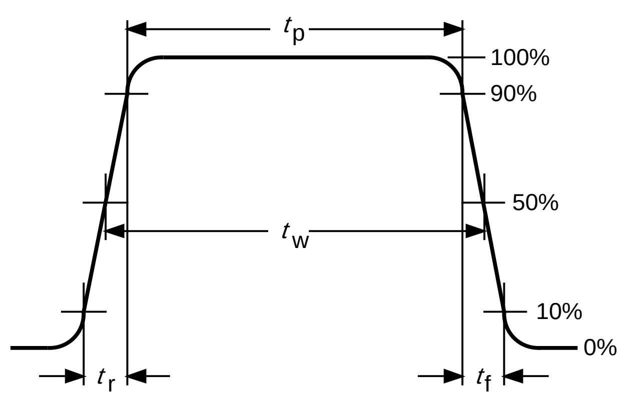



**Figure 2-1 — Pulse time symbology**

**2.2 General letter symbols, terms, and definitions (cont'd)**

$t_p$ **pulse duration (**formerly **pulse time):** The time interval between a reference point on the leading edge of a pulse waveform and a reference point on the trailing edge of the same waveform.

NOTE The two reference points are usually 90% of the steady-state amplitude of the waveform existing after the leading edge, measured with respect to the steady-state amplitude existing before the leading edge. If the reference points are 50% points, the symbol tw and the term "average pulse duration" should be used.

$t_r$ **rise time** (general)**:** The time interval between one reference point on a waveform and a second reference point of greater magnitude on the same waveform. (See also $t_r$, $t_{ri}$, and $t_{rv}$ in 4.1.2 and 4.3.2.)

NOTE The first and second reference points are usually 10% and 90%, respectively, of the steady-state amplitude of the waveform existing after the transition, measured with respect to the steady-state amplitude existing before the transition.

$t_w$ **average pulse duration (**formerly **pulse average time):** The time interval between a reference point on the leading edge of a pulse waveform and a reference point on the trailing edge of the same waveform, with both reference points being 50% of the steady-state amplitude of the waveform existing after the leading edge, measured with respect to the steady-state amplitude existing before the leading edge.

NOTE If the reference points are not 50% points, the symbol tp and the term "pulse duration" should be used.

$V_F$ **forward voltage, dc:** A positive dc anode-cathode voltage.

$V_n$ **noise voltage, equivalent input (of a two-port device):** The voltage of an ideal voltage source (having an internal impedance equal to zero) in series with the input terminals of the device that represents the part of the internally generated noise that can properly be represented by a voltage source.

NOTE In the definition, the equivalent input noise current, which would be needed for a complete and precise description of the device noise, is neglected. If the external source impedance is zero, the noise voltage represents the total noise.

$V_R$ **reverse voltage, dc:** A positive dc cathode-anode voltage.

$Z_\theta$ or $Z_{th}$ (formerly $\theta_{(t)}$) **(transient) thermal impedance:** See "thermal impedance, (transient)" in 2.1.

$Z_{\theta JA}$ or $Z_{thJA}$ (formerly $\theta_{J\text{-}A(t)}$) **junction-to-ambient (transient) thermal impedance:** The transient thermal impedance from the semiconductor junction(s) to the ambient.

**2.2 General letter symbols, terms, and definitions (cont'd)**

$Z_{\theta JC}$ or $Z_{thJC}$ (formerly $\theta_{J\text{-}C(t)}$) **junction-to-case (transient) thermal impedance:** The transient thermal impedance from semiconductor junction(s) to a stated location on the case.

$Z_{\theta JL}$ or $Z_{thJL}$ **junction-to-lead (transient) thermal impedance:** The transient thermal impedance from the semiconductor junction(s) to a stated location on a lead.

$Z_{\theta JM}$ or $Z_{thJM}$ **junction-to-mounting-surface (transient) thermal impedance** The transient thermal impedance from the semiconductor junction(s) to a stated location on the mounting surface.

## SECTION 3 DIODES AND RECTIFIERS

For the definition of “semiconductor diode”, see 2.1.

### 3.1 Signal diodes and rectifier diodes

#### 3.1.1 General terms and definitions

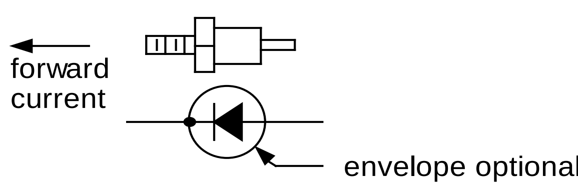
**bridge rectifier circuit:** A double-way rectifier circuit in which (1) each terminal of the alternating-voltage circuit is connected to the anode of one rectifier element in a set of elements whose cathodes are all connected to the positive output of the circuit, (2) each terminal of the alternating-voltage circuit is also connected to the cathode of one rectifier element in another set of elements whose anodes are all connected to the negative output, and (3) the load is connected between the positive and negative outputs.

NOTE The term is derived from the similarity in layout of a single-phase four-element bridge rectifier to that of a Wheatstone bridge.

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

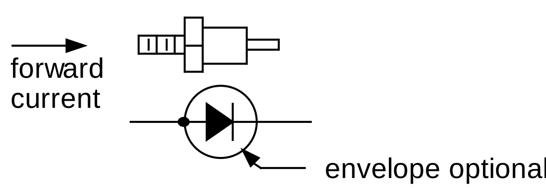
NOTE The terms “single-way” and “double-way” provide a means for describing the effect of the rectifier circuit on current in the transformer windings connected to the rectifier circuits. Most rectifier circuits may be classified into these two general types. Many double-way circuits are also referred to as bridge circuits.

**forward-polarity rectifier diode with heat sink:** A rectifier diode whose cathode is connected to the mounting stud or heat sink.




**rectifier stack:** An integral assembly of two or more rectifier diodes, including its associated housing, and any integral mounting and cooling attachments.

**reverse-polarity rectifier diode with heat sink:** A rectifier diode whose anode is connected to the mounting stud or heat sink.



### 3.1 Signal diodes and rectifier diodes (cont'd)

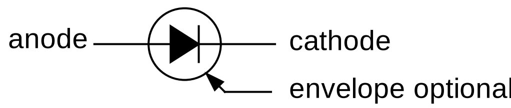
#### 3.1.1 General terms and definitions (cont'd)

**semiconductor rectifier diode:** A semiconductor diode intended to be used for current and voltage rectification.

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

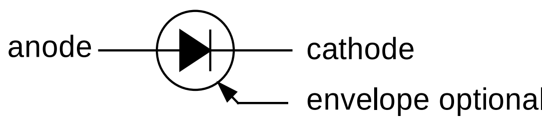
NOTE 2 The term “rectifier cell” is sometimes used as a synonym for “rectifier diode” when the diode is an element of a rectifier stack.

Graphic symbol (ref. IEEE Std 315):




**semiconductor signal diode:** A semiconductor diode intended to be used for signal processing.

Graphic symbol (ref. IEEE Std 315):



### 3.1.2 Letter symbols, terms, and definitions

**For illustration of currents, see Figure 3-1.**

| | |
|---|---|
| $I_{F(RMS)}$, $I_f$, $I_F$, $I_{F(AV)}$, $i_F$, $I_{FM}$ | **forward current*:** The current flowing from the external circuit into the anode terminal. |
| $I_{FM(OV)}$ | **overload forward current:** A current whose continuous application would cause the maximum-rated virtual junction temperature to be exceeded, but that is limited in duration such that this temperature is not exceeded.<br><br>NOTE Devices may be subjected to overload currents as frequently as called for by the application while being subjected to normal operating voltages. (Ref. IEC 747-2.) |
| $I_{FRM}$ | **repetitive peak forward current:** The peak forward current including all repetitive transient currents but excluding all nonrepetitive transient currents. (Ref. JESD282B.) |
| $I_{FSM}$ | **surge peak forward current:** The peak forward current including all nonrepetitive transient currents but excluding all repetitive transient currents. (Ref. JESD282B.) |
| $I_O$ | **average rectified output current, 50-Hz or 60-Hz sine-wave input, 180$^o$ conduction angle:** The output current averaged over a full cycle from a rectifier with a 50-Hz or 60-Hz sine-wave input and a 180$^o$ conduction angle. (Ref. JESD282B.) |
| $I_{(OV)}$ | Alternative symbol for $I_{FM(OV)}$. |
| $I_{R(RMS)}$, $I_r$, $I_R$, $I_{R(AV)}$, $i_R$, $I_{RM}$ | **reverse current*:** The current flowing from the external circuit into the cathode terminal. |
| $i_{R(REC)}$, $I_{RM(REC)}$ | **reverse recovery current*:** The transient reverse current associated with a change from forward current to a reverse condition. (Ref. JESD282B.) |

* See Table 3-1 for detailed meaning of symbols.

**3.1 Signal diodes and rectifier diodes (cont'd)**

**3.1.2 Letter symbols, terms, and definitions (cont'd)**

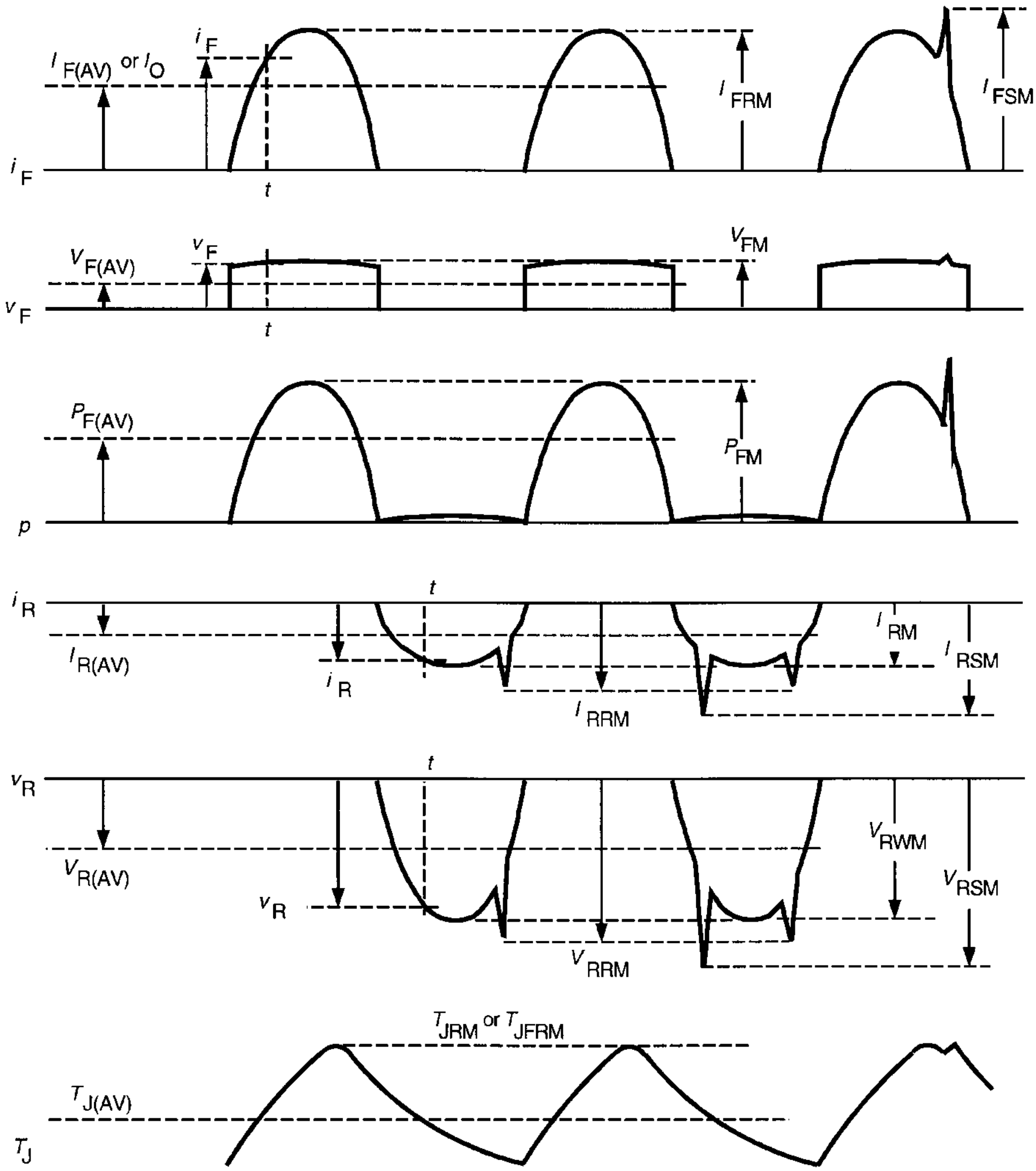



**Figure 3-1 — Symbols for rectifier diode current, voltage, power dissipation, and the resulting junction temperature**

## 3.1 Signal diodes and rectifier diodes (cont'd)

### 3.1.2 Letter symbols, terms, and definitions (cont'd)

**Table 3-1 — Current**

| Quantity | Total rms value | RMS value of alternating component | DC value with no alternating component | Mean value averaged over full cycle | Instantaneous total value | Maximum (peak) total value |
|---|---|---|---|---|---|---|
| Forward current | $I_{F(RMS)}$ | $I_f$ | $I_F$ | $I_{F(AV)}$ | $i_F$ | $I_{FM}$ |
| Forward current, overload | – | – | – | – | – | $I_{FM(OV)}$, $I_{(OV)}$ |
| Forward current, repetitive peak | – | – | – | – | – | $I_{FRM}$ |
| Forward current, surge peak | – | – | – | – | – | $I_{FSM}$ |
| Average rectified current, 50-Hz or 60-Hz sine-wave input, 180$^{o}$ conduction angle | – | – | – | $I_O$ | – | – |
| Reverse current | $I_{R(RMS)}$ | $I_r$ | $I_R$ | $I_{R(AV)}$ | $i_R$ | $I_{RM}$ |
| Reverse recovery current | – | – | – | – | $i_{R(REC)}$ | $I_{RM(REC)}$ |
| Reverse current, repetitive peak | – | – | – | – | – | $I_{RRM}$ |
| Reverse current surge peak | – | – | – | – | – | $I_{RSM}$ |

$I_{RRM}$ **repetitive peak reverse current:** The peak reverse current including all repetitive transient currents but excluding all nonrepetitive transient currents. (Ref. JESD282B.)

$I_{RSM}$ **surge peak reverse current:** The peak reverse current including all nonrepetitive transient currents but excluding all repetitive transient currents.

**3.1 Signal diodes and rectifier diodes (cont'd)**

**3.1.2 Letter symbols, terms, and definitions (cont'd)**

$P_F$, $P_{F(AV)}$, $p_F$, $P_{FM}$ — **forward power dissipation*:** The power dissipation resulting from the respective forward current. (Ref. JESD282B.)

$P_R$, $P_{R(AV)}$, $p_R$, $P_{RM}$ — **reverse power dissipation*:** The power dissipation resulting from the respective reverse current. (Ref. JESD282B.)

$P_T$, $P_{T(AV)}$, $P_{TM}$ — **total power dissipation*:** The sum of the respective forward and reverse power dissipations. (Ref. JESD282B.)

$Q_{rr}$ — **recovered charge:** The total amount of charge recovered from a diode, including the capacitive component of charge, when the diode is switched from a specified conductive condition to 1) a specified nonconductive condition, or 2) an unspecified nonconductive condition with the measurement ending after a specified integration time, $t_{i,}$, with other circuit conditions as specified. (Ref. JESD282B.)

$Q_{rrf}$ — **fall time charge:** That part of the recovered charge that is recovered from the diode during the reverse recovery fall time. (Ref. JESD282B.)

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

$Q_{rrr}$ — **rise time charge:** That part of the recovered charge that is recovered from the diode during the reverse recovery rise time. (Ref. JESD282B.)

NOTE See note to $Q_{rrf}$.

$Q_s$ — **stored charge:** The total amount of charge recovered from a diode minus the capacitive component of charge when the diode is switched from a specified conductive condition to a specified nonconductive condition with other circuit conditions specified. (Ref. JESD282B.)

RRSF — **reverse recovery softness factor:** The absolute value of the ratio of (1) $di_{RR}/dt$ (the rate of rise of the reverse recovery current) when the current is passing through zero at the beginning of the reverse recovery time, to (2) $di_{RF}/dt$ (the maximum value of the rate of fall of the reverse recovery current) after the current has passed through its peak value, $I_{RM}$. (Ref. JESD282B.)

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

RSF — **recovery softness factor:** See “RRSF” (reverse recovery softness factor).

* See Table 3-2 for detailed meaning of symbols.

## 3.1 Signal diodes and rectifier diodes (cont'd)

### 3.1.2 Letter symbols, terms, and definitions (cont'd)

**Table 3-2 — Power and temperature**

| Quantity | Total rms value | RMS value of alternating component | DC value with no alternating component | Mean value averaged over full cycle | Instantaneous total value | Maximum (peak) total value |
|---|---|---|---|---|---|---|
| Forward power dissipation | – | – | $P_F$ | $P_{F(AV)}$ | $P_F$ | $P_{FM}$ |
| Reverse power dissipation | – | – | $P_R$ | $P_{R(AV)}$ | $P_R$ | $P_{RM}$ |
| Total power dissipation | – | – | $P_T$ | $P_{T(AV)}$ | – | $P_{TM}$ |
| (Virtual) junction temperature | – | – | $T_J$ | $T_{J(AV)}$ | $T_J$ | $T_{JM}$ |
| (Virtual) junction temperature, repetitive peak [1)] | – | – | – | – | – | $T_{JFRM}$ |
| (Virtual) junction temperature, surge peak [1)] | – | – | – | – | – | $T_{JFSM}$ |
| (Virtual) junction temperature, repetitive peak | – | – | – | – | – | $T_{JRM}$ |
| (Virtual) junction temperature, repetitive peak [2)] | – | – | – | – | – | $T_{JRRM}$, $T_{JRWM}$ |
| 1) With forward current flowing | | | | | | |
| 2) With reverse voltage applied | | | | | | |

**All temperature symbols are shown together, followed by time symbols.**

**For illustration of temperatures, see Figure 3-1.**

$T_J$, $T_{J(AV)}$, $T_{JM}$ **(virtual) junction temperature*:** See “$T_J$, junction temperature” and “$T_J$, $T_{VJ}$, virtual junction temperature” in 2.2.

$T_{JFRM}$ **repetitive peak (virtual) junction temperature (with forward current flowing):** The peak (virtual) junction temperature resulting from repetitive peak forward current.

$T_{JFSM}$ **surge peak (virtual) junction temperature (with forward current flowing):** The peak (virtual) junction temperature resulting from surge peak forward current.

* See Table 3-2 for detailed meaning of symbols.

### 3.1 Signal diodes and rectifier diodes (cont'd)

#### 3.1.2 Letter symbols, terms, and definitions (cont'd)

$T_{JRM}$ **repetitive peak (virtual) junction temperature:** The peak (virtual) junction temperature resulting from repetitive peak forward current alternating with repetitive peak reverse voltage.

$T_{JRRM}$ **repetitive peak (virtual) junction temperature (with reverse voltage applied):** The peak (virtual) junction temperature resulting from repetitive peak reverse voltage.

$T_{JRWM}$ **working peak (virtual) junction temperature (with reverse voltage applied):** The peak (virtual) junction temperature resulting from working peak reverse voltage.

**All time symbols are shown together; preceding pages show temperature symbols.**

$t_a$ **reverse recovery current rise time:** The portion of the reverse recovery time interval prior to the instant when the reverse recovery current reaches its maximum (peak) value. (See Figure 3-2.) (Ref. JESD282B.)

$t_b$ **reverse recovery current fall time:** The portion of the reverse recovery time interval after the reverse recovery current has reached its maximum (peak) value.
(See Figure 3-2.) (Ref. JESD282B.)

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

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

1) the reverse current first intersects the zero-current axis as shown in Figure 3-2a, or

2) the extrapolated reverse current reaches zero, as shown in Figure 3-2b, or

3) the reverse current reaches a specified low value $i_{R(REC)}$, as shown in Figure 3-2c.

NOTE 1 In 2), the extrapolation is carried out with respect to specified points “A” and “B”, as shown in generalized form in Figure 3-2b. Point “A” may be specified at other than $I_{RM(REC)}$.

NOTE 2 JESD282B includes definitions 1), 2), and 3).

NOTE 3 IEC 747-2 includes definitions 2) and 3) only.

**3.1 Signal diodes and rectifier diodes (cont'd)**

**3.1.2 Letter symbols, terms, and definitions (cont'd)**

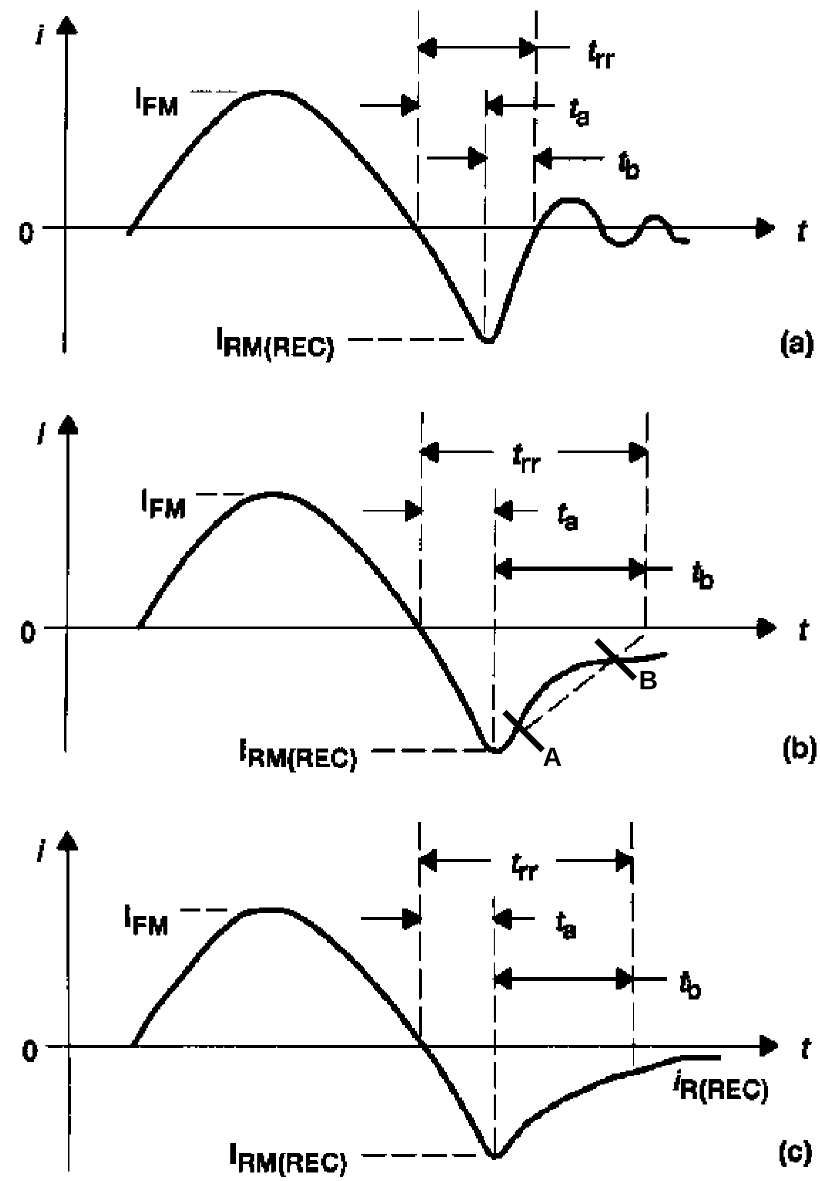



**Figure 3-2 — Current waveforms during rectifier diode reverse recovery**

### 3.1 Signal diodes and rectifier diodes (cont'd)

#### 3.1.2 Letter symbols, terms, and definitions (cont'd)

**For illustration of voltages, see Figure 3-1.**

| | |
|---|---|
| $V_{(BR)}$, $v_{(BR)}$ | **breakdown voltage* :** A voltage in a breakdown region. |
| $V_{F(RMS)}$, $V_f$, $V_F$, $V_{F(AV)}$, $v_F$, $V_{FM}$ | **forward voltage*:** A positive anode-cathode voltage. |
| $V_{R(RMS)}$, $V_r$, $V_R$, $V_{R(AV)}$, $v_R$, $V_{RM}$ | **reverse voltage*:** A positive cathode-anode voltage. |
| $V_{RRM}$ | **repetitive peak reverse voltage:** The peak reverse voltage including all repetitive transient voltages but excluding all nonrepetitive transient voltages. (Ref. JESD282B.) |
| $V_{RSM}$ | **nonrepetitive peak reverse voltage:** The peak reverse voltage including all nonrepetitive transient voltages but excluding all repetitive transient voltages. (Ref. JESD282B.) |
| $V_{RWM}$ | **working peak reverse voltage:** The peak reverse voltage excluding all transient voltages. (Ref. JESD282B.) |
| $V_{(TO)}$, $v_{(TO)}$ | **threshold voltage*:** The forward voltage at which the device conducts forward current of a specified low value. |

* See Table 3-3 for detailed meaning of symbols.

## 3.1 Signal diodes and rectifier diodes (cont'd)

### 3.1.2 Letter symbols, terms, and definitions (cont'd)

**Table 3-3 — Voltage**

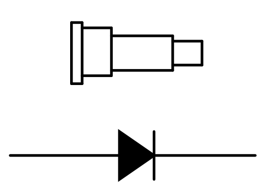
| Quantity | Total rms value | RMS value of alternating component | DC value with no alternating component | Mean value averaged over full cycle | Instantaneous total value | Maximum (peak) total value |
|---|---|---|---|---|---|---|
| Breakdown voltage | – | – | $V_{(BR)}$ | – | $v_{(BR)}$ | – |
| Forward voltage | $V_{F(RMS)}$ | $V_f$ | $V_F$ | $V_{F(AV)}$ | $v_F$ | $V_{FM}$ |
| Reverse voltage | $V_{R(RMS)}$ | $V_r$ | $V_R$ | $V_{R(AV)}$ | $v_R$ | $V_{RM}$ |
| Reverse voltage, working peak | – | – | – | – | – | $V_{RWM}$ |
| Reverse voltage, repetitive peak | – | – | – | – | – | $V_{RRM}$ |
| Reverse voltage, nonrepetitive peak | – | – | – | – | – | $V_{RSM}$ |
| Threshold voltage | – | – | $V_{(TO)}$ | – | $v_{(TO)}$ | – |

## 3.2 Microwave diodes

### 3.2.1 General terms and definitions

**detector diode:** A diode, often associated with microwave circuits, that converts rf energy into dc or video output.

**forward-polarity (microwave) diode:** A microwave diode in which the anode is connected to the base (i.e., the larger-diameter terminal) of the package.



**Gunn diode:** A transferred-electron diode intended to operate at a frequency determined by the transit time of charge packets or “domains” that are formed due to the transferred-electron effect.

**3.2 Microwave diodes (cont'd)**

**3.2.1 General terms and definitions (cont'd)**

**IMPATT [impact avalanche and transit-time] diode; avalanche diode operating in the IMPATT mode:** A semiconductor microwave diode that, when its junction is biased into avalanche, exhibits a negative resistance over a frequency range determined by the transit time of charge carriers through the depletion region.

**LSA [limited space-charge accumulation] diode:** A transferred-electron diode similar to the Gunn diode except that it is intended to operate at frequencies that are determined by the microwave cavity in which the diode is mounted and that are several times higher than the transit-time frequency so that the formation of charge packets (or domains) is limited.

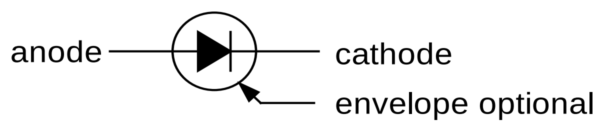
NOTE Compared to the Gunn diode, higher output power at higher frequency is achievable.

**matched pair (of microwave diodes):** A pair of microwave diodes identical in outline dimensions and with matched electrical characteristics as described in EIA-370.

NOTE The two diodes may both be forward polarity, or one forward and one reverse polarity, or both reverse polarity.

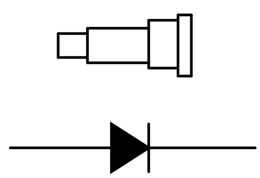
**microwave diode:** A two-terminal device that is responsive in the microwave region of the electromagnetic spectrum, commonly regarded as extending from 1 GHz to 300 GHz.

Graphic symbol (ref. IEEE Std 315):




**mixer diode:** A diode, often associated with microwave circuits, that combines rf signals at two frequencies to generate an rf signal at a third frequency.

**reverse-polarity (microwave) diode:** A microwave diode in which the cathode is connected to the base (i.e., the larger-diameter terminal) of the package.



### 3.2 Microwave diodes (cont'd)

#### 3.2.1 General terms and definitions (cont'd)

**transferred-electron diode:** A semiconductor microwave diode that exhibits negative resistance arising from the transferred-electron effect.

NOTE 1 The transferred-electron effect is the generation of bulk negative differential conductivity in compound semiconductor devices that have multiple energy valleys when the applied electrical field is greater than the critical value at which electrons transfer from (1) a lower energy valley in which they have greater mobility and smaller effective mass to (2) a higher energy valley in which they have smaller mobility and greater effective mass.

NOTE 2 The term "energy valley" refers to a valley in an energy-versus-momentum profile.

**TRAPATT [trapped plasma avalanche transit-time] diode; avalanche diode operating in TRAPATT mode:** A semiconductor microwave diode that, when its junction is biased into avalanche, exhibits a negative resistance at frequencies below the transit-time frequency range of the diode due to generation and dissipation of trapped electron-hole plasma resulting from the intimate interaction between the diode and a multiresonant microwave cavity.

#### 3.2.2 Letter symbols, terms, and definitions

$\overline{F}_{o}$ **overall average noise figure (of a mixer diode):** The average noise figure of the cascaded combination of a mixer and IF amplifier.

$\overline{F}_{os}$ **standard overall average noise figure (of a mixer diode):** The overall average noise figure when the average noise figure of the IF amplifier is a specified standard value (usually 1.5 dB) and the passband of the IF amplifier is sufficiently narrower than that of the mixer so that the mixer conversion loss and output noise temperature are essentially constant over the IF passband.

$L_c$ **conversion loss:** The ratio of available input power at a single signal frequency to the available single signal frequency output power, not including intrinsic mixer noise or power converted from other than the single-input frequency.

NOTE Delivered signal output power may be used, in which case the loss is referred to as "conversion insertion loss".

$M$ **figure of merit (of a detector diode):** The quantitative excellence of the detector in terms of current sensitivity and video impedance; i.e., that part of the signal-to-noise ratio equation that pertains to the crystal parameters and the equivalent noise resistance of the video amplifier.

$N_r$ **output noise ratio:** The ratio of the noise temperature of an output port to the reference noise temperature, $T_0$, when the noise temperature of all input terminations is at $T_0$ at all frequencies that contribute to the output noise.

TSS **tangential signal sensitivity:** The signal power below a 1-milliwatt reference level required to produce an output pulse whose amplitude is sufficient to raise the noise fluctuation by an amount equal to the average noise level.

### 3.2 Microwave diodes (cont'd)

#### 3.2.2 Letter symbols, terms, and definitions (cont'd)

VSWR **voltage-standing-wave ratio:** The ratio of the sum of the amplitudes of the incident and reflected voltages to their difference.

$z_{if}$ **intermediate-frequency impedance:** The impedance at the intermediate frequency of a mixer semiconductor diode as presented at the output terminals of the mixer when the device is driven by the local oscillator under the specified conditions.

$z_m$ **modulator-frequency load impedance:** The ac load impedance presented to the diode at the output terminals.

$z_{rf}$ **radio-frequency impedance:** The radio-frequency impedance of a mixer as measured at the local-oscillator terminals of the mixer.

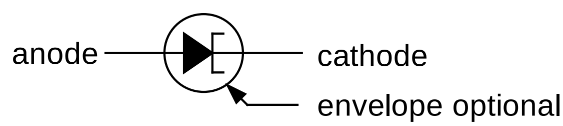
$z_v$ **video impedance:** The impedance at the specified frequency presented at the output terminals of the diode.

### 3.3 Tunnel diodes and backward diodes

#### 3.3.1 General terms and definitions

**backward diode:** A semiconductor diode in which quantum-mechanical tunneling leads to a current-voltage characteristic with a reverse current greater than the forward current, for equal and opposite applied voltages, in some voltage range centered about the origin.

Graphic symbol (ref. IEEE Std 315):

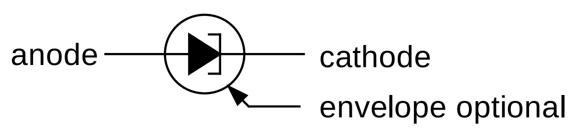



**tunnel diode:** A semiconductor diode in which quantum-mechanical tunneling leads to a region of negative slope in the forward direction of the current-voltage characteristic.

NOTE 1 The current is typically a single-valued function of voltage.

NOTE 2 In practice, the distinction between tunnel diodes and backward diodes is based on circuit application emphasis of the negative-resistance property (tunnel diode) or the low-level rectification property (backward diode).

Graphic symbol (ref. IEEE Std 315):



**3.3 Tunnel diodes and backward diodes (cont'd)**

**3.3.2 Letter symbols, terms, and definitions**

**For illustration of these parameters, see Figure 3-3.**

$I_I$ **inflection-point current:** The current at that point on the forward current-voltage characteristic at which the slope of the characteristic reaches its most negative value.

$I_P$ **peak-point current:** The current at that point on the forward current-voltage characteristic corresponding to the lowest positive (forward) voltage at which $di/dv = 0$.

$I_V$ **valley-point current:** The current at that point on the forward current-voltage characteristic corresponding to the second-lowest positive (forward) voltage at which $di/dv = 0$.

$r_i$ **dynamic resistance at inflection point:** The small-signal incremental terminal resistance at that point on the forward current-voltage characteristic at which the slope of the characteristic reaches its most negative value.

$V_I$ **inflection-point voltage:** The voltage at that point on the forward current-voltage characteristic at which the slope of the characteristic reaches its most negative value.

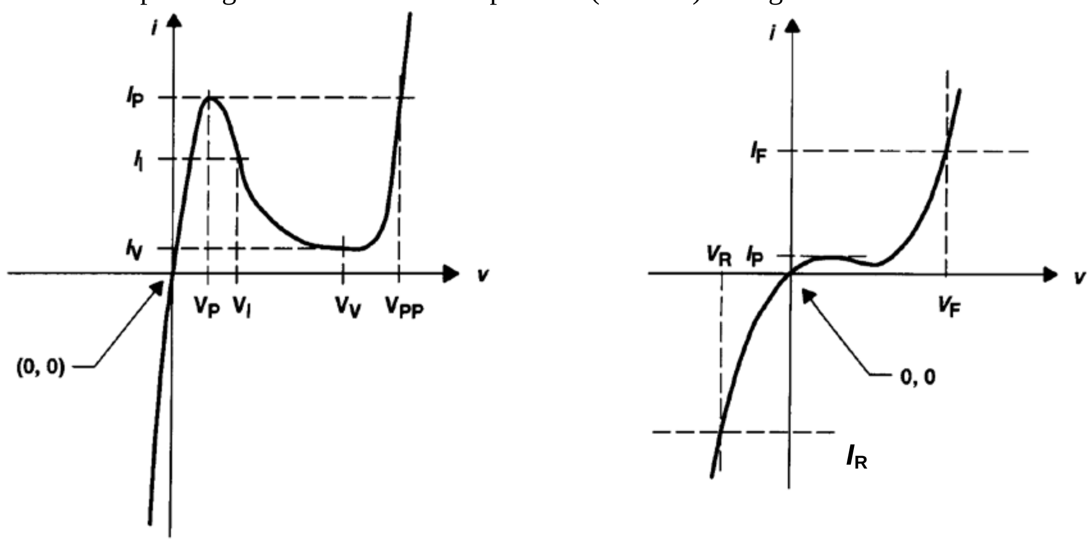
$V_P$ **peak-point voltage:** The voltage at that point on the forward current-voltage characteristic corresponding to the lowest positive (forward) voltage at which $di/dv = 0$.

$V_{PP}$ **projected peak-point voltage:** The voltage at that point on the forward current-voltage characteristic where the current is equal to the peak-point current and where the voltage is greater than the valley-point voltage.

### 3.3 Tunnel diodes and backward diodes (cont'd)

#### 3.3.2 Letter symbols, terms, and definitions (cont'd)

$V_V$ **valley-point voltage:** The voltage at that point on the forward current-voltage characteristic corresponding to the second lowest positive (forward) voltage at which d*i*/d*v* = 0.




**(a) — Typical tunnel-diode characteristic** **(b) — Typical backward-diode characteristic**

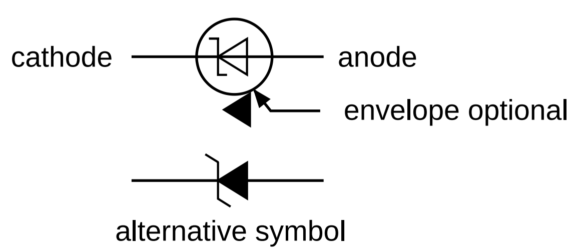
**Figure 3-3 — Current-voltage characteristics**

### 3.4 Voltage-regulator and voltage-reference diodes

#### 3.4.1 General terms and definitions

**voltage-reference diode:** A diode that is normally biased to operate in the breakdown region of its voltage-current characteristic and that develops across its terminals a reference voltage of specified accuracy when biased to operate throughout a specified current and temperature range. (Ref. IEC 747-1.)

Graphic symbol (ref. IEEE Std 315):



### 3.4 Voltage-regulator and voltage-reference diodes (cont'd)

#### 3.4.1 General terms and definitions (cont'd)

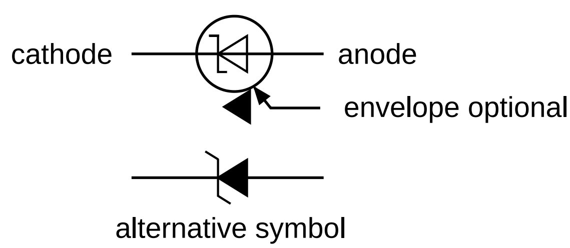
**voltage-regulator diode:** A semiconductor diode with a single p-n junction (or with multiple p-n junctions, none of which interact) that is normally biased in the breakdown region of its voltage-current characteristic and limits variation in voltage across its terminals over a specified current range.
(Ref. JESD211.)

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

NOTE 2 When forward-biased, a voltage-regulator diode has a voltage-current characteristic similar to that of a rectifier diode.

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

Graphic symbol (ref. IEEE Std 315):




**Zener diode:** A semiconductor diode with a single p-n junction whose breakdown characteristics are due to the Zener effect. (Ref. JESD211.)

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

**temperature-compensated voltage-reference diode:** A voltage-regulator diode that is designed to have minimal changes in the regulated voltage over a broad temperature range. (Ref. JESD211.)

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

## 3.4 Voltage-regulator and voltage-reference diodes (cont'd)

### 3.4.2 Letter symbols, terms, and definitions

$I_Z$ **regulator [reference] current, dc:**
$I_{ZK}$ **regulator [reference] current, dc near breakdown knee:**
$I_{ZM}$ **regulator [reference] current, dc maximum-rated:**
$I_{ZT}$ **regulator [reference] current, dc at specified test point:** The dc reverse current through the diode when it is biased to operate in its breakdown region at, respectively,

— an operating point between $I_{ZK}$ and $I_{ZM}$,
— a specified current near the breakdown knee,
— a specified current based on the maximum-rated power, or
— a specified current between $I_{ZK}$ and $I_{ZM}$ for the purpose of specifying $V_Z$.

$I_{zk}$, $I_{zt}$ **regulator [reference] current, rms components:** A specified rms current for measuring regulator impedance.

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

$I_{ZRM}$ **reverse surge current, repetitive peak:** The peak reverse current in the breakdown region including all repetitive transient currents but excluding all nonrepetitive transient currents.

$I_{ZSM}$ **reverse surge current, nonrepetitive peak:** The peak reverse current in the breakdown region including all nonrepetitive transient currents but excluding all repetitive transient currents.

$V_Z$ **regulator [reference] voltage, dc:**
$V_{ZM}$ **regulator [reference] voltage, dc at maximum-rated current:** The dc voltage across the diode when it is biased to operate in its breakdown region at $I_{ZT}$ or $I_{ZM}$, respectively.

$z_z$ **regulator [reference] impedance, small-signal at $I_{ZT}$:**
$z_{zk}$ **regulator [reference] impedance, small-signal at $I_{ZK}$:** The small-signal impedance of the diode when it is biased to operate in its breakdown region with $I_{zt}$ applied at $I_Z$ or $I_{ZK}$, respectively.

$\alpha_{VZ}$ **temperature coefficient of regulator voltage:** The change in regulator voltage, divided by the change in temperature that caused it.

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

**3.4 Voltage-regulator and voltage-reference diodes (cont'd)**

**3.4.2 Letter symbols, terms, and definitions (cont'd)**

$\Delta V_{Z(temp)}$ **reference-voltage variation with temperature:** The difference between the highest and the lowest values of reference voltage corresponding to specified temperatures over a temperature range.

NOTE Use of a temperature coefficient in units of %/°C or mV/°C is not recommended for reference diodes due to the nonlinearity of the voltage variation.

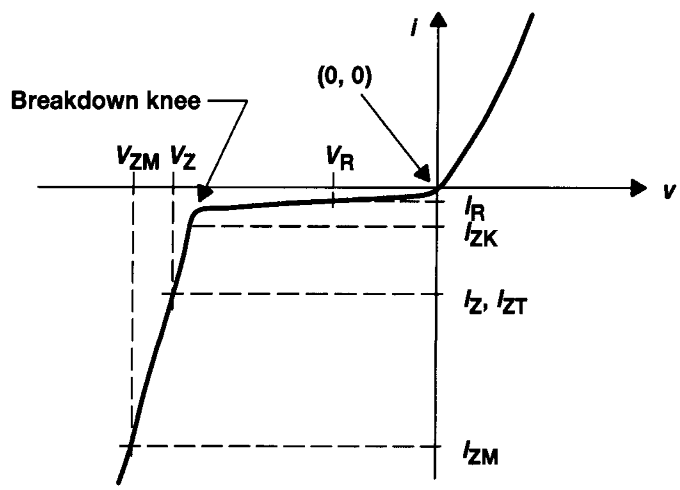



**Figure 3-4 — Symbols for currents and voltages**

**3.5 Current-regulator diodes**

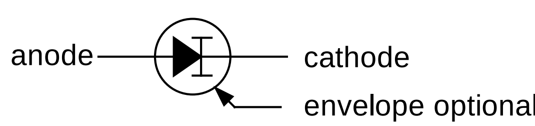
**3.5.1 General terms and definitions**

**anode (of a current-regulator diode):** The terminal to which current flows from the external circuit when the diode is biased to operate as a current regulator.

**cathode (of a current-regulator diode):** The terminal from which current flows into the external circuit when the diode is biased to operate as a current regulator.

**current-regulator diode:** A diode that limits current to an essentially constant value over a specified voltage range.

Graphic symbol (ref. IEEE Std 315):



### 3.5 Current-regulator diodes (cont'd)

#### 3.5.2 Letter symbols, terms, and definitions

$I_L$ **limiting current:** A specified current below the lower knee of the current-regulating characteristic.

$I_S$ **regulator current:** A current within the regulating range of a current-regulator diode.

$V_K$ **knee voltage:** A specified regulator voltage near the lower knee of the current-regulating characteristic.

$V_L$ **limiting voltage:** The voltage at point $I_L$ on the current-voltage characteristic.

$V_S$ **regulator voltage:** A voltage within the regulating range of a current-regulator diode.

$z_k$ **knee impedance:** The small-signal impedance at operating point $V_K$ on the current-voltage characteristic.

$z_s$ **regulator impedance:** The small-signal impedance within the regulating range of a current-regulator diode.

$\alpha_{IS}$ **temperature coefficient of regulator current:** The change in regulator current, usually expressed as a percentage of regulator current, divided by the change in temperature that caused it.

NOTE This quotient is the average value over the total temperature change.

$\Delta I_S$ **regulator-current variation:** The difference between the regulator current at $V_S$ and at some lower regulator voltage.

NOTE In JEDEC registration format JC-22 RDF-11, the lower regulator voltage is 50% of $V_S$.

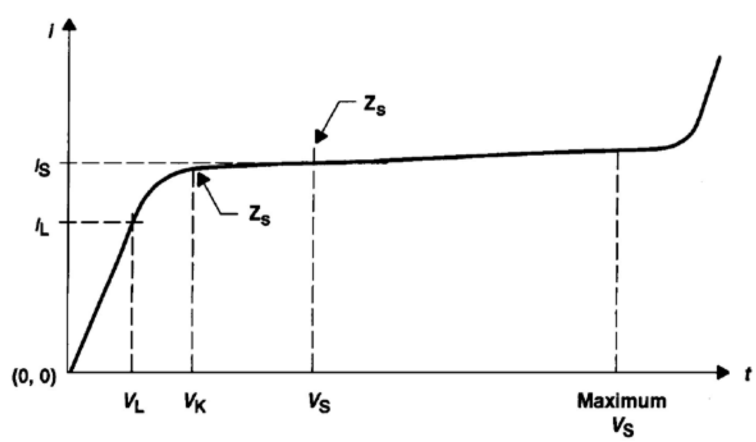



**Figure 3-5 — Current-regulator diode characteristic**

### 3.6 Varactor diodes (voltage-variable-capacitance diodes)

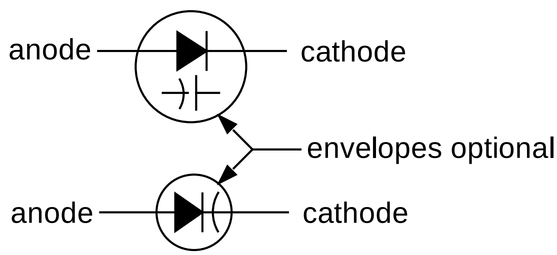
#### 3.6.1 General terms and definitions

**tuning diode:** A varactor diode used for rf tuning.

NOTE This includes functions such as automatic frequency control (AFC) and automatic fine tuning (AFT).

**varactor diode:** A two-terminal semiconductor device in which use is made of the property that its capacitance varies with the applied voltage.

Graphic symbols (ref. IEEE Std 315):




**voltage-variable-capacitance diode (VVC** or **VVCD):** Synonym for “varactor diode”.

### 3.6 Varactor diodes (voltage-variable-capacitance diodes) (cont'd)

#### 3.6.2 Letter symbols, terms, and definitions

$C_c$ **case capacitance:** The capacitance between the diode terminals of the case with the semiconductor die not installed or with the semiconductor die installed but not connected.

$C_j$ **junction capacitance:** The small-signal capacitance between the contacts of the uninstalled semiconductor die.

$C_t$ **total capacitance:** The total small-signal capacitance between the diode terminals of a complete device.

NOTE $C_t . C_c + C_j$

$C_{t1}/C_{t2}$ **capacitance ratio:** The ratio of total capacitance at one voltage to total capacitance at another voltage.

$f_{co}$ **cutoff frequency:** The frequency at which the figure of merit ($Q$) is equal to unity.

$L_s$ **series inductance:** The inductance between specified points on the diode terminals.

$Q$ **figure of merit:** Two pi (2B) times the ratio of the energy stored per cycle to the energy dissipated per cycle.

$r_s$ **series resistance, small-signal:** The total small-signal resistance between the diode terminals.

$\alpha_C$ **temperature coefficient of capacitance:** The change in capacitance divided by the change in temperature that caused it.

NOTE This quotient is the average value over the total temperature change.

$\eta$ **efficiency:** The ratio of output power to input power, i.e., $\eta = P_{out}/P_{in}$.

# SECTION 4 TRANSISTORS

For the definition of "transistor", see 2.1.

## 4.1 Junction transistors, multijunction types

### 4.1.1 General terms and definitions

**base** (nonspecific)**:** The overall combination of base region, base terminal, and the interface between them.

NOTE This term should be used in this manner only when no confusion is likely to occur.

**base region, functional:** A control region through which the principal current passes and in which the concentration of principal-current charge carriers is the result of an applied base current.

NOTE 1 The principal current is the result of diffusion and impurity concentration gradient drift.

NOTE 2 This definition applies for the actual operating mode of the device regardless of the name of any associated terminal.

**base region, (physical):** The physical region that is located between the collector junction and the emitter junction and contains the control region.

**base terminal (B, b):** The specified externally available point of connection to the base region.

**bipolar transistor** (general)**:** A transistor in which, in the operating mode, the controlling input consists of charge carriers that are injected into the control region and are of a polarity that is opposite to the polarity of the principal-current charge carriers, and in which the magnitude of the principal current depends on the magnitude of the control current.

**collector** (nonspecific)**:** The overall combination of collector transition region, collector region, collector terminal, and the interface between them.

NOTE This term should be used in this manner only when no confusion is likely to occur.

**collector region, functional:** A collection region that acquires principal-current charge carriers from a controlling base region through an associated collecting junction.

NOTE This definition applies for the actual operating mode of the device regardless of the name of any associated terminal. In the normal operating mode, this functional region is located in the collector region; in the inverse operating mode, it is located in the emitter region.

**collector region, (physical):** The physical region that is designed by the manufacturer to contain the collection region in the normal operating mode and, in a simple discrete transistor, is externally accessible by the designated collector terminal.

### 4.1 Junction transistors, multijunction types (cont'd)

#### 4.1.1 General terms and definitions (cont'd)

**collector terminal (C, c):** The specified externally available point of connection to the collector region.

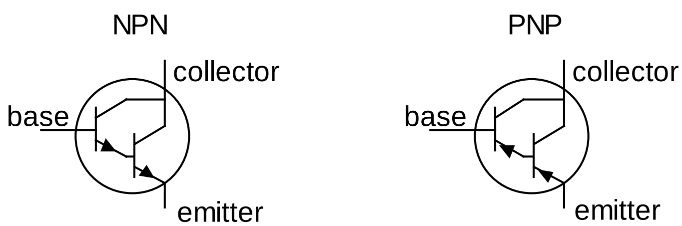
**Darlington transistor:** A compound semiconductor device consisting of two transistors in which the collectors are connected together and the emitter of the first transistor is connected to the base of the second transistor.

NOTE 1 The two transistors connected in this manner may be regarded as a compound transistor with three terminals.

NOTE 2 The circuit may include a biasing network.

NOTE 3 The presence of a terminal to provide direct access to the base of the second transistor is optional.

Graphic symbols (ref. IEEE Std 315):




NOTE In the graphic symbols, the envelope is optional if no element is shown connected to the envelope.

**depletion layer, collector(-base):** Synonym for “space-charge region, collector(-base)”

**depletion layer, emitter(-base):** Synonym for “space-charge region, emitter(-base)”.

**emitter (nonspecific):** The overall combination of emitter transition region, emitter region, emitter terminal, and the interface between them.

NOTE This term should be used in this manner only when no confusion is likely to occur.

**emitter region, functional:** A supply region that delivers principal-current charge carriers into a controlling base region through an associated emitting junction.

NOTE This definition applies for the actual operating mode of the device regardless of the name of any associated terminal. In the normal operating mode, this functional region is located in the emitter region; in the inverse operating mode, it is located in the collector region.

**emitter region, (physical):** The physical region that is designed by the manufacturer to contain the supply region in the normal operating mode and, in a simple discrete transistor, is externally accessible by the designated emitter terminal.

**4.1 Junction transistors, multijunction types (cont'd)**

**4.1.1 General terms and definitions (cont'd)**

**emitter terminal (E, e):** The specified externally available point of connection to the emitter region.

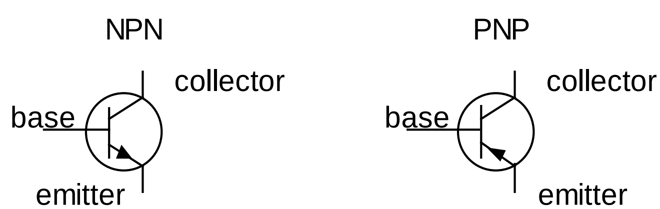
**junction, collector(-base):** The transition region between the collector region and the base region.

**junction, emitter(-base):** The transition region between the emitter region and the base region.

**junction transistor, (bipolar):** A bipolar transistor consisting of three succeeding physical regions of alternating conductivity type (npn or pnp) that include the supply region, control region, and collection region and that are separated from each other by two transition regions.

**multijunction transistor:** A transistor having a base and two or more junctions.

Graphic symbols for triode transistors (ref. IEEE Std 315):




NOTE In the graphic symbols, the envelope is optional if no element is shown connected to the envelope.

**programmable unijunction transistor:** See 6.2.1.

**saturation:** A base-current and a collector-current condition resulting in a forward-biased collector junction.

**space-charge region, collector(-base):** The space-charge region between the functional collector region and the functional base region.

**space-charge region, emitter(-base):** The space-charge region between the functional emitter region and the functional base region.

### 4.1 Junction transistors, multijunction types (cont'd)

#### 4.1.2 Letter symbols, terms, and definitions

$C_{cb}$ or $C_{cb(dir)}$ **collector-base interterminal capacitance:**

$C_{ce}$ or $C_{ce(dir)}$ **collector-emitter interterminal capacitance:**

$C_{eb}$ or $C_{eb(dir)}$ **emitter-base interterminal capacitance:** The direct interterminal capacitance between the terminal indicated by the first subscript and the terminal indicated by the second subscript, with the junction (collector-base, collector-emitter, emitter-base, respectively) reverse-biased and with the remaining terminal (emitter, base, collector, respectively) open-circuited to dc but ac connected to the guard terminal of a three-terminal bridge.

NOTE This capacitance includes the interelement capacitance plus capacitance to the shield if the shield is connected to one of the terminals under measurement.

$C_{ibo}$ **common-base open-circuit input capacitance:**

$C_{ieo}$ **common-emitter open-circuit input capacitance:** The capacitance measured across the input terminals (emitter and base in both cases) with the collector terminal ac open-circuited.

$C_{ibs}$ **common-base short-circuit input capacitance:**

$C_{ies}$ **common-emitter short-circuit input capacitance:** The capacitance measured across the input terminals (emitter and base in both cases) with the collector terminal ac short-circuited to the reference terminal.

$C_{obo}$ **common-base open-circuit output capacitance:**

$C_{oeo}$ **common-emitter open-circuit output capacitance:** The capacitance measured across the output terminals (collector and base, collector and emitter, respectively) with the input ac open-circuited.

$C_{obs}$ **common-base short-circuit output capacitance:**

$C_{oes}$ **common-emitter short-circuit output capacitance:** The capacitance measured across the output terminals (collector and base, collector and emitter, respectively) with the third terminal ac short-circuited to the reference terminal.

$C_{rbs}$ **common-base short-circuit reverse transfer capacitance:**

$C_{rcs}$ **common-collector short-circuit reverse transfer capacitance:**

$C_{res}$ **common-emitter short-circuit reverse transfer capacitance:** The capacitance measured from the output terminal to the input terminal with the reference terminal (base, collector, emitter, respectively) and the case, if a case terminal is provided, connected to the guard terminal of a three-terminal bridge and with the device biased in the active region.

## 4.1 Junction transistors, multijunction types (cont'd)

### 4.1.2 Letter symbols, terms, and definitions (cont'd)

$C_{tc}$ **collector depletion-layer capacitance:**

$C_{te}$ **emitter depletion-layer capacitance:** The part of the capacitance across the junction (collector-base, emitter-base, respectively) that is associated with its depletion layer.

NOTE This capacitance is a function of the total potential difference across the depletion layer. (Ref. IEC 747-7.)

$f_{hfb}$ **common-base small-signal short-circuit forward current transfer ratio cutoff frequency:**

$f_{hfc}$ **common-collector small-signal short-circuit forward current transfer ratio cutoff frequency:**

$f_{hfe}$ **common-emitter small-signal short-circuit forward current transfer ratio cutoff frequency:** The lowest frequency at which the magnitude of the small-signal short-circuit forward current cutoff frequency transfer ratio is 0.707 times its value at a specified low frequency (usually 1 kHz or lower).

$f_{max}$ **maximum frequency of oscillation:** The maximum frequency at which a transistor can be made to oscillate under specified conditions. (Ref. IEC 747-7.)

NOTE This approximates the frequency at which the maximum available power gain has decreased to unity.

$f_{sb}$ **common-base frequency of unity forward transmission coefficient:**

$f_{sc}$ **common-collector frequency of unity forward transmission coefficient:**

$f_{se}$ **common-emitter frequency of unity forward transmission coefficient:** The frequency at which the modulus of the forward transmission coefficient 0$s_{21}$0 has decreased to unity. (Ref. IEC 747-7.)

$f_T$ **transition frequency; frequency at which common-emitter small-signal forward current transfer ratio extrapolates to unity:** The product of the modulus (magnitude) of the common-emitter small-signal short-circuit forward current transfer ratio, $h_{fe}$, and the frequency of measurement when this frequency is sufficiently high that the modulus (magnitude) of $h_{fe}$ is decreasing with a slope of approximately 6 decibels per octave. (Also, see $f_1$.) (Ref. IEC 747-7.)

$f_1$ **frequency of unity current transfer ratio:** The frequency at which the modulus of the common-emitter small-signal short-circuit forward current transfer ratio 0$h_{fe}$0 has decreased to unity. (Ref. IEC 747-7.)

NOTE This frequency must be determined by direct measurement, not by extrapolation. See $f_T$.

**4.1 Junction transistors, multijunction types (cont'd)**

**4.1.2 Letter symbols, terms, and definitions (cont'd)**

$g_{MB}$ **common-base static transconductance:**
$g_{MC}$ **common-collector static transconductance:**
$g_{ME}$ **common-emitter static transconductance:** The dc output current divided by the dc input voltage with the output voltage held constant.

$g_{mb}$* **common-base small-signal transconductance:**
$g_{mc}$* **common-collector small-signal transconductance:**
$g_{me}$* **common-emitter small-signal transconductance:** The ac rms output current divided by the ac rms input voltage with the output voltage held constant.

NOTE The fact that the output voltage is held constant implies that the output terminal is ac short-circuited to the common terminal.

$G_{PB}$ **common-base large-signal insertion power gain:**
$G_{PC}$ **common-collector large-signal insertion power gain:**
$G_{PE}$ **common-emitter large-signal insertion power gain:** The ratio, usually expressed in decibels, of (1) the signal power delivered to the load after insertion of a transducer between the source and the load to (2) the signal power that was delivered to the load when the load was connected directly to the source, under large-signal conditions.

$G_{pb}$ **common-base small-signal insertion power gain:**
$G_{pc}$ **common-collector small-signal insertion power gain:**
$G_{pe}$ **common-emitter small-signal insertion power gain:** The ratio, usually expressed in decibels, of (1) the signal power delivered to the load after insertion of a transducer between the source and the load to (2) the signal power that was delivered to the load when the load was connected directly to the source, under small-signal conditions.

$G_{TB}$ **common-base large-signal tranducer power gain:**
$G_{TC}$ **common-collector large-signal tranducer power gain:**
$G_{TE}$ **common-emitter large-signal tranducer power gain:** The ratio, usually expressed in decibels, of the signal power delivered to the load to the maximum signal power available from the source, under large-signal conditions.

$G_{tb}$ **common-base small-signal transducer power gain:**
$G_{tc}$ **common-collector small-signal transducer power gain:**
$G_{te}$ **common-emitter small-signal transducer power gain:** The ratio, usually expressed in decibels, of the signal power delivered to the load to the maximum signal power available from the source, under small-signal conditions.

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* The symbols $y_{fb}$, $y_{fc}$, and $y_{fe}$ and their corresponding terms are preferred.

**4.1 Junction transistors, multijunction types (cont'd)**

**4.1.2 Letter symbols, terms, and definitions (cont'd)**

$h_{FB}$ **common-base static forward current transfer ratio:**
$h_{FC}$ **common-collector static forward current transfer ratio:**
$h_{FE}$ **common-emitter static forward current transfer ratio:** The ratio of the dc output current to the dc input current with the output voltage held constant. (Ref. IEC 747-7.)

$h_{fb}$ **common-base small-signal short-circuit forward current transfer ratio:**
$h_{fc}$ **common-collector small-signal short-circuit forward current transfer ratio:**
$h_{fe}$ **common-emitter small-signal short-circuit forward current transfer ratio:** The ratio of the ac rms output current to the small-signal ac rms input current with the output voltage held constant. (Ref. IEC 747-7.)

NOTE The fact that the output voltage is held constant implies that the output terminal is ac short-circuited to the common terminal.

$h_{IB}$ **common-base static input resistance:**
$h_{IC}$ **common-collector static input resistance:**
$h_{IE}$ **common-emitter static input resistance:** The dc input voltage divided by the dc input current.

$h_{ib}$ **common-base small-signal short-circuit input impedance:**
$h_{ic}$ **common-collector small-signal short-circuit input impedance:**
$h_{ie}$ **common-emitter small-signal short-circuit input impedance:** The small-signal ac rms input voltage divided by the ac rms input current with the output voltage held constant.

NOTE The fact that the output voltage is held constant implies that the output terminal is ac short-circuited to the common terminal.

$h_{ie(imag)}$ **imaginary part of the common-emitter small-signal short-circuit input impedance:** The rms out-of-phase (imaginary) component of the small-signal ac rms base-emitter voltage divided by the ac rms base current with the collector-emitter voltage held constant.

NOTE The fact that the collector-emitter voltage is held constant implies that the collector terminal is ac short-circuited to the emitter terminal.

$h_{ie(real)}$ **real part of the common-emitter small-signal short-circuit input impedance:** The in-phase (real) component of the small-signal ac rms base-emitter voltage divided by the ac rms base current with the collector-emitter voltage held constant.

NOTE The fact that the collector-emitter voltage is held constant implies that the collector terminal is ac short-circuited to the emitter terminal.

**4.1 Junction transistors, multijunction types (cont'd)**

**4.1.2 Letter symbols, terms, and definitions (cont'd)**

$h_{ob}$ **common-base small-signal open-circuit output admittance:**

$h_{oc}$ **common-collector small-signal open-circuit output admittance:**

$h_{oe}$ **common-emitter small-signal open-circuit output admittance:** The ac rms output current divided by the small-signal ac rms output voltage applied to the output terminal with the input ac open-circuited.

$h_{oe(imag)}$ **imaginary part of the common-emitter small-signal open-circuit output admittance:** The ac rms collector current divided by the out-of-phase (imaginary) component of the small-signal ac rms collector-emitter voltage with the base terminal ac open-circuited.

$h_{oe(real)}$ **real part of the common-emitter small-signal open-circuit output admittance:** The ac rms collector current divided by the in-phase (real) component of the small-signal ac rms collector-emitter voltage with the base terminal ac open-circuited.

$h_{rb}$ **common-base small-signal open-circuit reverse voltage transfer ratio:**

$h_{rc}$ **common-collector small-signal open-circuit reverse voltage transfer ratio:**

$h_{re}$ **common-emitter small-signal open-circuit reverse voltage transfer ratio:** The ratio of the ac rms input voltage to the small-signal ac rms output voltage with the input ac open-circuited. (Ref. IEC 747-7.)

**For illustration of the proper use of these symbols, see Figure 4-1.**

$I_B$ **base current, dc:**

$I_C$ **collector current, dc:**

$I_E$ **emitter current, dc:** The value of the dc current into the terminal indicated by the subscript.

$I_b$ **base current, rms value of alternating component:**

$I_c$ **collector current, rms value of alternating component:**

$I_e$ **emitter current, rms value of alternating component:** The root-mean-square value of alternating current into the terminal indicated by the subscript.

$i_B$ **base current, instantaneous total value:**

$i_C$ **collector current, instantaneous total value:**

$i_E$ **emitter current, instantaneous total value:** The instantaneous total value of alternating current into the terminal indicated by the subscript.

**4.1 Junction transistors, multijunction types (cont'd)**

**4.1.2 Letter symbols, terms, and definitions (cont'd)**

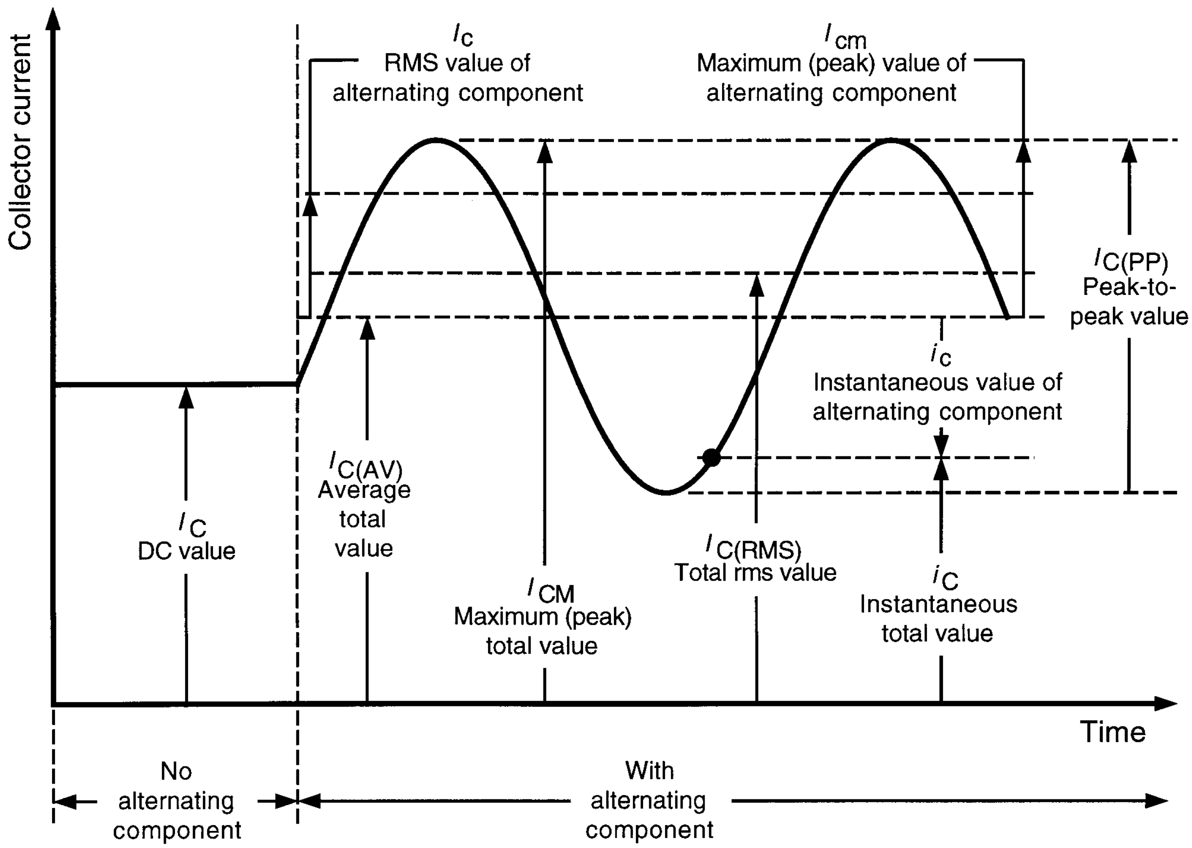


**Figure 4-1 — Proper use of symbols**

$I_{BEV}$ **base cutoff current:** The current into the base terminal when it is biased in the reverse direction with respect to the emitter terminal and there is a specified voltage between the collector and emitter terminals.

$I_{CBO}$ **collector cutoff current, emitter open:** The current into the collector terminal when it is biased in the reverse direction with respect to the base terminal and the emitter terminal is open-circuited.

**4.1 Junction transistors, multijunction types (cont'd)**

**4.1.2 Letter symbols, terms, and definitions (cont'd)**

$I_{CEO}$ **collector cutoff current, base open:**
$I_{CER}$ **collector cutoff current, resistance between base and emitter:**
$I_{CES}$ **collector cutoff current, base short-circuited to emitter:**
$I_{CEV}$ **collector cutoff current, voltage between base and emitter:**
$I_{CEX}$ **collector cutoff current, circuit between base and emitter:** The current into the collector terminal when it is biased in the reverse direction* with respect to the emitter terminal, and the base terminal is, respectively,

— open-circuited.
— returned to the emitter terminal through a specified resistance.
— short-circuited to the emitter terminal.
— returned to the emitter terminal through a specified voltage.
— returned to the emitter terminal through a specified circuit.

$I_{E1E2(off)}$ **emitter cutoff current:** The current into the emitter-1 terminal of a double-emitter transistor when the emitter-1 terminal is biased with respect to the emitter-2 terminal and the transistor is in the off state (the collector-base diode is not forward-biased) with specified termination of the collector and base terminals.

$I_{EBO}$ **emitter cutoff current, collector open:** The current into the emitter terminal when it is biased in the reverse direction with respect to the base terminal and the collector terminal is open-circuited.

$I_{EC(ofs)}$ **emitter-collector offset current:** The external short-circuit current between the emitter and collector when the base-collector diode is reverse-biased.

$I_{ECS}$ **emitter cutoff current, base short-circuited to collector:** The current into the emitter terminal when it is biased in the reverse direction* with respect to the collector terminal and the base terminal is short-circuited to the collector terminal.

Im($h_{ie}$) See preferred symbol $h_{ie(imag)}$.
Im($h_{oe}$) See preferred symbol $h_{oe(imag)}$.
Im($y_{ie}$) See preferred symbol $y_{ie(imag)}$.
Im($y_{oe}$) See preferred symbol $y_{oe(imag)}$.

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* For these parameters, the collector or emitter terminal is considered to be biased in the reverse direction when it is made positive for npn transistors, or negative for pnp transistors, with respect to the emitter terminal.

**4.1 Junction transistors, multijunction types (cont'd)**

**4.1.2 Letter symbols, terms, and definitions (cont'd)**

$P_{BE}$ **common-emitter input power to the base, dc:**
$P_{CB}$ **common-base input power to the collector, dc:**
$P_{CE}$ **common-emitter input power to the collector, dc:**
$P_{EB}$ **common-base input power to the emitter, dc:** The product of the dc input current and voltage with the common-reference-terminal circuit configuration.

$p_{BE}$ **common-emitter input power to the base, instantaneous total:**
$p_{CB}$ **common-base input power to the collector, instantaneous total:**
$p_{CE}$ **common-emitter input power to the collector, instantaneous total:**
$p_{EB}$ **common-base input power to the emitter, instantaneous total:** The product of the instantaneous input current and voltage with the common-reference-terminal circuit configuration.

$P_{IB}$ **common-base large-signal input power:**
$P_{IC}$ **common-collector large-signal input power:**
$P_{IE}$ **common-emitter large-signal input power:** The product of the large-signal ac rms input current and ac rms voltage with the common-reference-terminal circuit configuration.

$p_{ib}$ **common-base small-signal input power:**
$p_{ic}$ **common-collector small-signal input power:**
$p_{ie}$ **common-emitter small-signal input power:** The product of the small-signal ac rms input current and ac rms voltage with the common-reference-terminal circuit configuration.

$P_{OB}$ **common-base large-signal output power:**
$P_{OC}$ **common-collector large-signal output power:**
$P_{OE}$ **common-emitter large-signal output power:** The product of the large-signal ac rms output current and ac rms voltage in the common-reference-terminal circuit configuration.

$P_{ob}$ **common-base small-signal output power:**
$P_{oc}$ **common-collector small-signal output power:**
$P_{oe}$ **common-emitter small-signal output power:** The product of the small-signal ac rms output current and ac rms voltage in the common-reference-terminal circuit configuration.

**4.1 Junction transistors, multijunction types (cont'd)**

**4.1.2 Letter symbols, terms, and definitions (cont'd)**

| | |
|---|---|
| $P_T$ | **total dc power input to all terminals:** The sum of the products of the dc input currents and voltages, i.e., $P_T = V_{BE}$ @ $I_B + V_{CE}$ @ $I_C$, or $P_T = V_{EB}$ @ $I_E + V_{CB}$ @ $I_C$ . |
| $p_T$ | **total instantaneous power input to all terminals:** The sum of the products of the instantaneous input currents and voltages. |
| $r_b{'}C_c$ | **collector-base time constant:** The product of the intrinsic base resistance and collector capacitance under specified small-signal conditions. |
| $r_{CE(sat)}$ | **collector-emitter saturation resistance:** The resistance between the collector and emitter terminals for the saturation conditions specified. |
| Re($h_{ie}$) | See preferred symbol $h_{ie(real)}$. |
| Re($h_{oe}$) | See preferred symbol $h_{oe(real)}$. |
| Re($y_{ie}$) | See preferred symbol $y_{ie(real)}$. |
| Re($y_{oe}$) | See preferred symbol $y_{oe(real)}$. |
| $r_{ele2(on)}$ | **small-signal emitter-emitter on-state resistance:** The small-signal resistance between the emitter terminals of a double-emitter transistor when the base-collector diode is forward-biased. |
| $s_{fb}$ or $s_{21b}$ | **common-base forward transmission coefficient:** |
| $s_{fc}$ or $s_{21c}$ | **common-collector forward transmission coefficient:** |
| $s_{fe}$ or $s_{21e}$ | **common-emiiter forward transmission coefficient:** The complex ratio of the voltage at the output port to the voltage incident on the input port under small-signal conditions, the output-port terminating impedance and the impedance of the source of the incident voltage being equal and purely resistive. (Ref. IEC 747-7.) |
| $s_{ib}$ or $s_{11b}$ | **common-base input reflection coefficient:** |
| $s_{ic}$ or $s_{11c}$ | **common-collector input reflection coefficient:** |
| $s_{ie}$ or $s_{11e}$ | **common-emitter input reflection coefficient:** The complex ratio of the voltage reflected from the input port to the voltage incident on the input port under small-signal conditions, the output-port terminating impedance and the impedance of the source of the incident voltage being equal and purely resistive. (Ref. IEC 747-7.) |

## 4.1 Junction transistors, multijunction types (cont'd)

### 4.1.2 Letter symbols, terms, and definitions (cont'd)

$s_{ob}$ or $s_{22b}$ **common-base output reflection coefficient:**
$s_{oc}$ or $s_{22c}$ **common-collector output reflection coefficient:**
$s_{oe}$ or $s_{22e}$ **common-emitter output reflection coefficient:** The complex ratio of the voltage reflected from the output port to the voltage incident on the output port under small-signal conditions, the input-port terminating impedance and the impedance of the source of the incident voltage being equal and purely resistive. (Ref. IEC 747-7.)

$s_{rb}$ or $s_{12b}$ **common-base reverse transmission coefficient:**
$s_{rc}$ or $s_{12c}$ **common-collector reverse transmission coefficient:**
$s_{re}$ or $s_{12e}$ **common-emitter reverse transmission coefficient:** The complex ratio of the voltage at the input port to the voltage incident on the output port under small-signal conditions, the input-port terminating impedance and the impedance of the source of the incident voltage being equal and purely resistive. (Ref. IEC 747-7.)

**For illustrations of times, see Figures 4-2 and 4-3**.

$t_c$ **turn-off crossover time:** The time interval during which the collector voltage rises from 10% of its peak off-state value and the collector current falls to 10% of its peak on-state value, in both cases ignoring spikes caused by interaction with other components or parasitics, e.g., freewheeling-diode recovery current and parasitic inductance.

NOTE For reserve symbol, see $t_{xo}$.

$t_d$ **delay time:** Synonym for “current delay time, $t_{di}$”.*

$t_{di}$ **current delay time:** The time interval during which an input pulse that is switching the transistor from a nonconducting to a conducting state rises from 10% of its peak amplitude and the collector current waveform rises to 10% of its on-state amplitude, ignoring spikes caused by interaction with other components or parasitics, e.g., freewheeling-diode recovery current and parasitic inductance.

$t_{dv}$ **voltage delay time:** The time interval during which an input pulse that is switching the transistor from a nonconducting to a conducting state rises from 10% of its peak amplitude and the collector voltage waveform falls to 90% of its on-state amplitude, ignoring spikes caused by interaction with other components or parasitics, e.g., freewheeling-diode recovery current and parasitic inductance.

$t_f$ **fall time:** Synonym for “current fall time, $t_{fi}$”.*

---

* See note following $t_{xo}$.

* See note following $t_{xo}$.

### 4.1 Junction transistors, multijunction types (cont'd)

#### 4.1.2 Letter symbols, terms, and definitions (cont'd)

$t_{fi}$ **current fall time:** The time interval during which the collector current changes from 90% to 10% of its peak on-state value, ignoring spikes caused by interaction with other components or parasitics, e.g., freewheeling-diode recovery current and parasitic inductance.

$t_{fv}$ **voltage fall time:** The time interval during which the collector voltage changes from 90% to 10% of its peak off-state value, ignoring spikes caused by interaction with other components or parasitics, e.g., freewheeling-diode recovery current and parasitic inductance.

$t_{off}$ **turn-off time:** Synonym for "current turn-off time, $t_{off(i)}$".*

$t_{off(i)}$ **current turn-off time:** The sum of current storage time and current fall time, i.e., $t_{off(i)} = t_{si} + t_{fi}$.

$t_{off(v)}$ **voltage turn-off time:** The sum of voltage storage time and voltage rise time, i.e., $t_{off(v)} = t_{sv} + t_{rv}$.

$t_{on}$ **turn-on time:** Synonym for "current turn-on time, $t_{on(i)}$".*

$t_{on(i)}$ **current turn-on time:** The sum of current delay time and current rise time, i.e., $t_{on(i)} = t_{di} + t_{ri}$.

$t_{on(v)}$ **voltage turn-on time:** The sum of voltage delay time and voltage fall time, i.e., $t_{on(v)} = t_{dv} + t_{fv}$.

$t_r$ **rise time:** Synonym for "current rise time, $t_{ri}$".*

$t_{ri}$ **current rise time:** The time interval during which the collector current changes from 10% to 90% of its peak off-state value, ignoring spikes caused by interaction with other components or parasitics, e.g., freewheeling-diode recovery current and parasitic inductance.

$t_{rv}$ **voltage rise time:** The time interval during which the collector voltage changes from 10% to 90% of its peak on-state value, ignoring spikes caused by interaction with other components or parasitics, e.g., freewheeling-diode recovery current and parasitic inductance.

**4.1 Junction transistors, multijunction types (cont'd)**

**4.1.2 Letter symbols, terms, and definitions (cont'd)**

$t_s$ **storage time:** Synonym for "current storage time, $t_{si}$".*

$t_{si}$ **current storage time:** The time interval during which an input pulse that is switching the transistor from a conducting to a nonconducting state falls from 90% of its peak amplitude and the collector current waveform falls to 90% of its on-state amplitude, ignoring spikes caused by interaction with other components or parasitics, e.g., freewheeling-diode recovery current and parasitic inductance.

$t_{sv}$ **voltage storage time:** The time interval during which an input pulse that is switching the transistor from a conducting to a nonconducting state falls from 90% of its peak amplitude and the collector voltage waveform rises to 10% of its off-state amplitude, ignoring spikes caused by interaction with other components or parasitics, e.g., freewheeling-diode recovery current and parasitic inductance.

$t_{ti}$ **current tail time:** The time interval following current fall time during which the collector current changes from 10% to 2% of its peak on-state value, ignoring spikes caused by interaction with other components or parasitics, e.g., freewheeling-diode recovery current and parasitic inductance.

$t_{xo}$ **turn-off crossover time:** For definition, see $t_c$. The symbol $t_{xo}$ is a reserve symbol to be used if use of $t_c$ is likely to cause confusion.

NOTE As names of time intervals for characterizing switching transistors, the terms "fall time" and "rise time" always refer to the change that is taking place in the magnitude of the output current even though measurements may be made using voltage waveforms. In a purely resistive circuit, the (current) rise time may be considered equal and coincident to the voltage fall time and the (current) fall time may be considered equal and coincident to the voltage rise time. The delay times for current and voltage will be equal and coincident, as will the storage times. When significant amounts of inductance or capacitance are present in a circuit, these equalities and coincidences no longer exist, and use of the unmodified terms delay time, fall time, turn-off time, turn-on time, rise time, and storage time must be avoided.

* See note following $t_{xo}$.

**4.1 Junction transistors, multijunction types (cont'd)**

**4.1.2 Letter symbols, terms, and definitions (cont'd)**

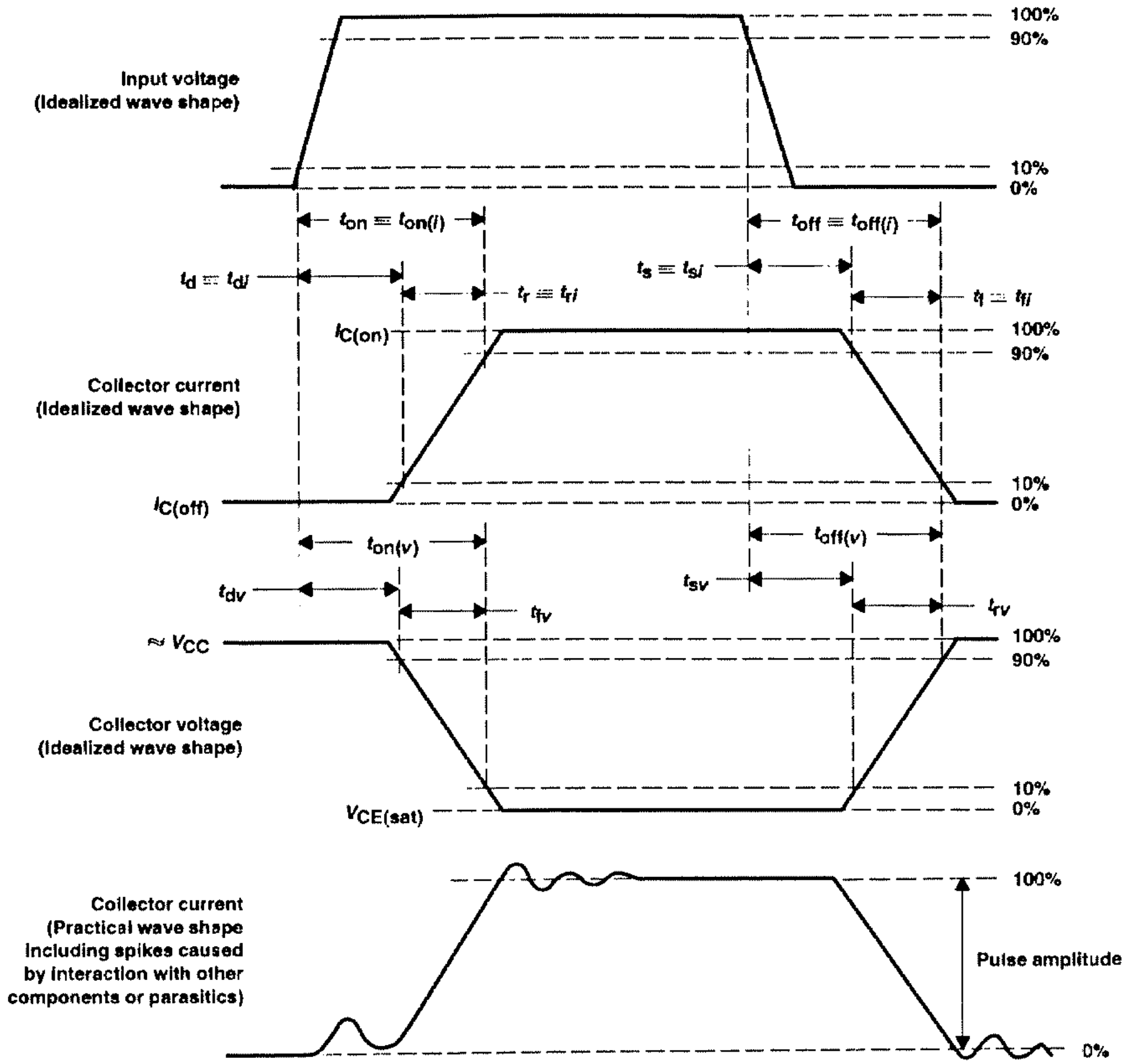
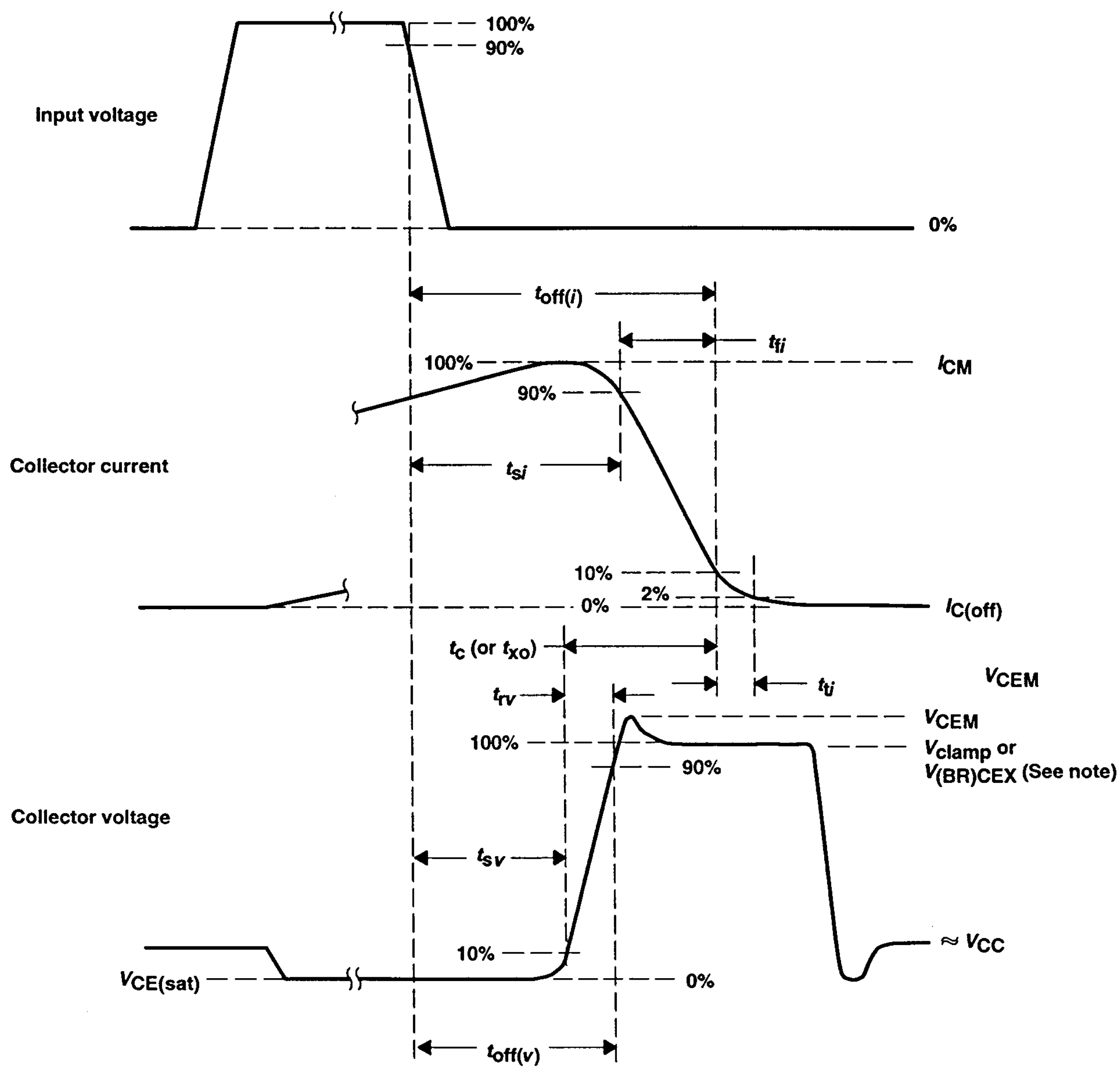



**Figure 4-2 — Waveforms for resistive-load switching**

**4.1 Junction transistors, multijunction types (cont'd)**

**4.1.2 Letter symbols, terms, and definitions (cont'd)**




NOTE $V_{clamp}$ (in a clamped inductive-load switching circuit) or $V_{(BR)CEX}$ (in an unclamped circuit) is the peak off-state voltage excluding spikes.

**Figure 4-3 — Waveforms for inductive-load switching, turn-off**

**4.1 Junction transistors, multijunction types (cont'd)**

**4.1.2 Letter symbols, terms, and definitions (cont'd)**

| | |
|---|---|
| $V_{BB}$ | **base supply voltage, dc:** |
| $V_{CC}$ | **collector supply voltage, dc:** |
| $V_{EE}$ | **emitter supply voltage, dc:** The dc supply voltage applied to a circuit connected to the base, collector, or emitter, respectively. |
| $V_{BC}$ | **base-collector voltage, dc:** |
| $V_{BE}$ | **base-emitter voltage, dc:** |
| $V_{CB}$ | **collector-base voltage, dc:** |
| $V_{CE}$ | **collector-emitter voltage, dc:** |
| $V_{EB}$ | **emitter-base voltage, dc:** |
| $V_{EC}$ | **emitter-collector voltage, dc:** The dc voltage between the terminal indicated by the first subscript and the reference terminal (stated in terms of the polarity at the terminal indicated by the first subscript). |
| $v_{bc}$ | **base-collector voltage, instantaneous value of alternating component:** |
| $v_{be}$ | **base-emitter voltage, instantaneous value alternating component:** |
| $v_{cb}$ | **collector-base voltage, instantaneous value of alternating component:** |
| $v_{ce}$ | **collector-emitter voltage, instantaneous value of alternating component:** |
| $v_{eb}$ | **emitter-base voltage, instantaneous value of alternating component:** |
| $v_{ec}$ | **emitter-collector voltage, instantaneous value of alternating component:** The instantaneous value of ac voltage between the terminal indicated by the first subscript and the reference terminal. |
| $V_{BE(sat)}$ | **base-emitter saturation voltage:** The voltage between the base and emitter terminals for specified base-current and collector-current conditions that are intended to ensure that the collector junction is forward-biased. |
| $V_{(BR)CBO}$ (formerly $BV_{CBO}$) | **collector-base breakdown voltage, emitter open:** The breakdown between the collector and base terminals when the collector terminal is biased in the reverse direction with respect to the base terminal and the emitter terminal is open-circuited. |

**4.1 Junction transistors, multijunction types (cont'd)**

**4.1.2 Letter symbols, terms, and definitions (cont'd)**

$V_{(BR)CEO}$ (formerly $BV_{CEO}$) **collector-emitter breakdown voltage, base open:**

$V_{(BR)CER}$ (formerly $BV_{CER}$) **collector-emitter breakdown voltage, resistance between base and emitter:**

$V_{(BR)CES}$ (formerly $BV_{CES}$) **collector-emitter breakdown voltage, base short-circuited to emitter:**

$V_{(BR)CEV}$ (formerly $BV_{CEV}$) **collector-emitter breakdown voltage, voltage between base and emitter:**

$V_{(BR)CEX}$ (formerly $BV_{CEX}$) **collector-emitter breakdown voltage, circuit between base and emitter:** The breakdown voltage between the collector and emitter terminals when the collector terminal is biased in the reverse direction* with respect to the emitter terminal, and the base terminal is, respectively,

— open-circuited.
— returned to the emitter terminal through a specified resistance.
— short-circuited to the emitter terminal.
— returned to the emitter terminal through a specified voltage.
— returned to the emitter terminal through a specified circuit.

$V_{(BR)E1E2}$ **emitter-emitter breakdown voltage:** The breakdown voltage between the emitter terminals of a double-emitter transistor with specified termination between collector and base.

$V_{(BR)EBO}$ (formerly $BV_{EBO}$) **emitter-base breakdown voltage, collector open:** The breakdown voltage between the emitter and base terminals when the emitter terminal is biased in the reverse direction* with respect to the base terminal and the collector terminal is open-circuited.

$V_{(BR)ECO}$ (formerly $BV_{ECO}$) **emitter-collector breakdown voltage, base open:** The breakdown voltage between the emitter and collector terminals when the emitter terminal is biased in the reverse direction* with respect to the collector terminal and the base terminal is open-circuited.

---

* For these parameters, the collector terminal or emitter terminal is considered to be biased in the reverse direction when it is made positive for npn transistors, or negative for pnp transistors, with respect to the emitter terminal or collector terminal, respectively.

**4.1 Junction transistors, multijunction types (cont'd)**

**4.1.2 Letter symbols, terms, and definitions (cont'd)**

$V_{CB(fl)}$ **collector-base open-circuit voltage (floating potential):**
$V_{CE(fl)}$ **collector-emitter open-circuit voltage (floating potential):**
$V_{EB(fl)}$ **emitter-base open-circuit voltage (floating potential):**
$V_{EC(fl)}$ **emitter-collector open-circuit voltage (floating potential):** The open-circuit voltage (floating potential) between the terminal indicated by the first subscript and the reference terminal when the remaining terminal is biased in the reverse direction* with respect to the reference terminal.

$V_{CBO}$ **collector-base voltage, emitter open:** The voltage between the collector and base terminals when the emitter terminal is open-circuited.

$V_{CE(ofs)}$ **collector-emitter offset voltage:** The open-circuit voltage between the collector and emitter terminals when the base-emitter diode is forward-biased.

$V_{CE(sat)}$ **collector-emitter saturation voltage:** The voltage between the collector and emitter terminals under conditions of base current or base-emitter voltage beyond which the collector current remains essentially constant as the base current or voltage is increased. (Ref. IEC 747-7.)

NOTE This is the voltage between the collector and emitter terminals when both the base-emitter and base-collector junctions are forward-biased.

$V_{CEO}$ **collector-emitter voltage, base open:**
$V_{CER}$ **collector-emitter voltage , resistance between base and emitter:**
$V_{CES}$ **collector-emitter voltage, base short-circuited to emitter:**
$V_{CEV}$ **collector-emitter voltage**, **voltage between base and emitter:**
$V_{CEX}$ **collector-emitter voltage, circuit between base and emitter:** The voltage between the collector and emitter terminals when the base terminal is, respectively,

— open-circuited.
— returned to the emitter terminal through a specified resistance.
— short-circuited to the emitter terminal.
— returned to the emitter terminal through a specified voltage.
— returned to the emitter terminal through a specified circuit.

* For these parameters, the collector terminal or emitter terminal is considered to be biased in the reverse direction when it is made positive for npn transistors, or negative for pnp transistors, with respect to the emitter terminal or collector terminal, respectively.

**4.1 Junction transistors, multijunction types (cont'd)**

**4.1.2 Letter symbols, terms, and definitions (cont'd)**

$V_{CEO(sus)}$ **collector-emitter sustaining voltage, base open:**

$V_{CER(sus)}$ **collector-emitter sustaining voltage, resistance between base and emitter:**

$V_{CES(sus)}$ **collector-emitter sustaining voltage, base short-circuited to emitter:**

$V_{CEV(sus)}$ **collector-emitter sustaining voltage, voltage between base and emitter:**

$V_{CEX(sus)}$ **collector-emitter sustaining voltage, circuit between base and emitter:** The collector-emitter breakdown voltage at relatively high values of collector current at which the breakdown voltage is relatively insensitive to changes in collector current, when the base terminal is, respectively,

— open-circuited.
— returned to the emitter terminal through a specified resistance.
— short-circuited to the emitter terminal.
— returned to the emitter terminal through a specified voltage.
— returned to the emitter terminal through a specified circuit.

NOTE This is the transient voltage between the collector and emitter terminals during switching with an inductive load from a forward-biased base-emitter to the external condition identified by the third subscript letter.

$V_{EBO}$ **emitter-base voltage, collector open:** The voltage between the emitter and base terminals with the collector terminal open-circuited.

$V_{EC(ofs)}$ **emitter-collector offset voltage:** The open-circuit voltage between the emitter and collector terminals when the base-collector diode is forward-biased.

$|V_{E1E2(ofs)}|$ **emitter-emitter offset voltage, (magnitude of the):** The absolute value of the open-circuit voltage between the two emitter terminals of a double-emitter transistor, when the base-collector diode is forward-biased.

$|\Delta V_{E1E2(ofs)}|\Delta I_B$ **change in offset voltage with base current, (magnitude of the):** The absolute value of the algebraic difference between the emitter-emitter offset voltages of a double-emitter transistor at two specified base currents.

$|\Delta V_{E1E2(ofs)}|\Delta T_A$ **change in offset voltage with temperature, (magnitude of the):** The absolute value of the algebraic difference between the emitter-emitter offset voltages of a double-emitter transistor at two specified ambient temperatures.

$V_{RT}$ **reach-through voltage:** That value of reverse collector-to-base voltage at which the space charge region of the collector-base junction extends to the space-charge region of the emitter-base junction.

### 4.1 Junction transistors, multijunction types (cont'd)

#### 4.1.2 Letter symbols, terms, and definitions (cont'd)

$y_{fb}$ **common-base small-signal short-circuit forward transfer admittance:**

$y_{fc}$ **common-collector small-signal short-circuit forward transfer admittance:**

$y_{fe}$ **common-emitter small-signal short-circuit forward transfer admittance:** The ac rms output current divided by the ac rms input voltage with the output voltage held constant.

NOTE The fact that the output voltage is held constant implies that the output terminal is ac short-circuited to the common terminal.

$y_{ib}$ **common-base small-signal short-circuit input admittance:**

$y_{ic}$ **common-collector small-signal short-circuit input admittance:**

$y_{ie}$ **common-emitter small-signal short-circuit input admittance:** The ac rms input current divided by the ac rms input voltage with the output voltage held constant.

NOTE The fact that the output voltage is held constant implies that the output terminal is ac short-circuited to the common terminal.

$y_{ie(imag)}$ **imaginary part of the common-emitter small-signal short-circuit input admittance:** The ac rms base current divided by the ac rms out-of-phase (imaginary) component of the base-emitter voltage with the collector-emitter voltage held constant.

NOTE The fact that the collector-emitter voltage is held constant implies that the collector terminal is ac short-circuited to the emitter terminal.

$y_{ie(real)}$ **real part of the common-emitter small-signal short-circuit input admittance:** The ac rms base current divided by the ac rms in-phase (real) component of the base-emitter voltage with the collector-emitter voltage held constant.

NOTE The fact that the collector-emitter voltage is held constant implies that the collector terminal is ac short-circuited to the emitter terminal.

$y_{ob}$ **common-base small-signal short-circuit output admittance:**

$y_{oc}$ **common-collector small-signal short-circuit output admittance:**

$y_{oe}$ **common-emitter small-signal short-circuit output admittance:** The ac rms output current divided by the ac rms output voltage with the input voltage held constant.

NOTE The fact that the input voltage is held constant implies that the input terminal is ac short-circuited to the common terminal.

### 4.1 Junction transistors, multijunction types (cont'd)

#### 4.1.2 Letter symbols, terms, and definitions (cont'd)

$y_{oe(imag)}$ **imaginary part of the common-emitter small-signal short-circuit output admittance:** The ac rms collector current divided by the out-of-phase (imaginary) component of the ac rms collector voltage with the base-emitter voltage held constant.

NOTE The fact that the base-emitter voltage is held constant implies that the base terminal is ac short-circuited to the emitter terminal.

$y_{oe(real)}$ **real part of the common-emitter small-signal short-circuit output admittance:** The ac rms collector current divided by the in-phase (real) component of the ac rms collector voltage with the base-emitter voltage held constant.

NOTE The fact that the base-emitter voltage is held constant implies that the base terminal is ac short-circuited to the emitter terminal.

$y_{rb}$ **common-base small-signal short-circuit reverse transfer admittance:**
$y_{rc}$ **common-collector small-signal short-circuit reverse transfer admittance:**
$y_{re}$ **common-emitter small-signal short-circuit reverse transfer admittance:** The ac rms input current divided by the ac rms output voltage with the input voltage held constant.

NOTE The fact that the input voltage is held constant implies that the input terminal is ac short-circuited to the common terminal.

### 4.2 Unijunction transistors

#### 4.2.1 General terms and definitions

**base region:** A region of a semiconductor device into which majority carriers are injected.

**base terminal (B):** The specified externally available point of connection to a base region.

**emitter region:** A region of a semiconductor device from which charge carriers that are minority carriers in a base region are injected into a base region.

**emitter terminal (E):** The specified externally available point of connection to the emitter region.

**junction, emitter(-base):** The space-charge region between the emitter region and a base region.

NOTE See also “emitting junction” in 2.1.

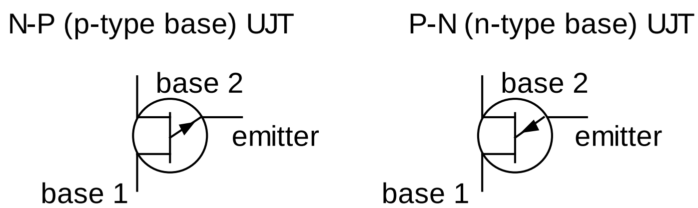
**peak point**: The point on the emitter current-voltage characteristic corresponding to the lowest current at which $dv_{EB1}/di_E = 0$.

**4.2 Unijunction transistors (cont'd)**

**4.2.1 General terms and definitions (cont'd)**

**unijunction transistor (UJT):** A three-terminal semiconductor device having one junction and a stable negative-resistance characteristic over a wide temperature range.

Graphic symbols (ref. IEEE Std 315):




NOTE In the graphic symbols, the envelope is optional if no element is shown connected to the envelope.

**valley point:** The point on the emitter current-voltage characteristic corresponding to the second lowest current at which $dv_{EB1}/di_E = 0$.

**4.2.2 Letter symbols, terms, and definitions**

**For illustration of current-voltage characteristics, see Figure 4-4.**

| | |
|---|---|
| $I_{B2(mod)}$ | **interbase modulated current:** The current into the base-2 terminal when the emitter current is greater than the valley-point current. |
| $I_{EB20}$ | **emitter reverse current:** The current into the emitter terminal when it is biased in the reverse direction with respect to the base-2 terminal and the base-1 terminal is open-circuited. |
| $I_P$ | **peak-point current:** The emitter current at the peak point. |
| $I_V$ | **valley-point current:** The emitter current at the valley point. |
| $r_{BB}$ | **interbase resistance:** The resistance between the two bases with the emitter current equal to zero. |
| $V_{B2B1}$ | **interbase voltage:** The voltage between base 2 and base 1. |
| $V_{EB1(sat)}$ | **emitter saturation voltage:** The forward voltage between the emitter and base 1 at an emitter current greater than the valley-point current. |
| $V_{OB1}$ | **base-1 peak voltage:** The peak voltage measured across the resistor in series with base 1 when the device is operated as a relaxation oscillator in a specified circuit. |

**4.2 Unijunction transistors (cont'd)**

**4.2.2 Letter symbols, terms, and definitions (cont'd)**

$V_P$ **peak-point voltage:** The voltage between the emitter and base 1 at the peak point.

$V_V$ **valley-point voltage:** The voltage between the emitter and base 1 at the valley point.

$\eta$ **intrinsic standoff ratio:** The ratio $\frac{V_P - V_F}{V_{B2B1}}$,

where $V_F$ is the forward voltage drop of the emitter junction.

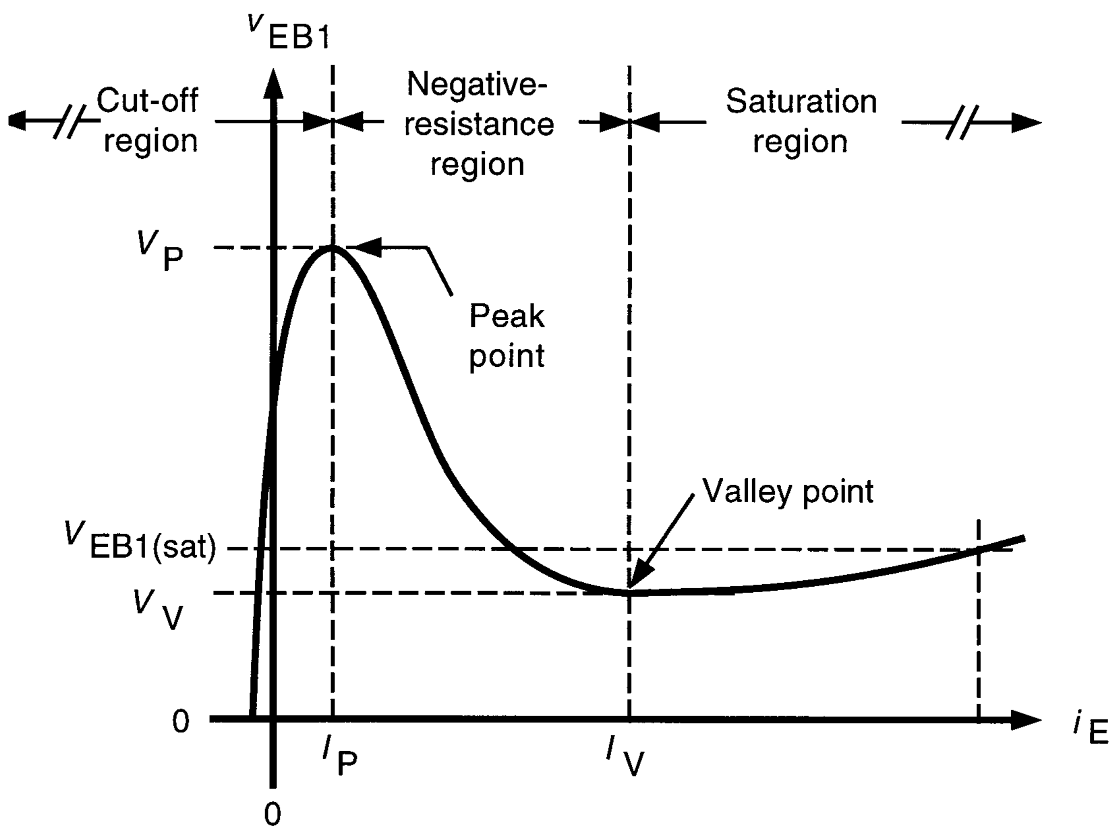



**Figure 4-4 — Current-voltage characteristic**

## 4.3 Field-effect transistors

### 4.3.1 General terms and definitions

**channel region (of a JFET):** A control region through which the principal-current charge carriers pass and whose cross-section is determined by the voltage applied to a gate, the principal current being the result of an applied drift field.

NOTE This definition applies for the actual operating mode of the device regardless of the name of any associated terminal.

**channel region (of an IGFET):** A control region through which the principal current passes and in which the concentration of principal-current charge carriers is determined by voltage applied to a gate, the principal current being the result of an applied drift field.

NOTE This definition applies for the actual operating mode of the device regardless of the name of any associated terminal.

**depletion-mode operation:** The operation of a field-effect transistor such that changing the gate-source voltage from zero to a finite value decreases the magnitude of the drain current. (Ref. IEC 747-8.)

**depletion-type field-effect transistor:** A field-effect transistor having appreciable channel conductance for zero gate-source voltage; the channel conductance may be increased or decreased according to the polarity of the applied gate-source voltage. (Ref. IEC 747-8.)

**drain region:** A collection region that acquires principal-current charge carriers from a channel, the current being due to a voltage applied to the drain.

NOTE This definition applies for the actual operating mode of the device regardless of the name of any associated terminal.

**drain terminal (D, d):** The specified externally available point of connection to the drain region.

**dual-gate field-effect transistor:** Synonym for “tetrode field-effect transistor”.

**enhancement-mode operation:** The operation of a field-effect transistor such that changing the gate-source voltage from zero to a finite value increases the magnitude of the drain current. (Ref. IEC 747-8.)

**enhancement-type field-effect transistor:** A field-effect transistor having substantially zero channel conductance for zero gate-source voltage; the channel conductance may be increased by the application of a gate-source voltage of appropriate polarity. (Ref. IEC 747-8.)

**field-effect transistor (FET):** A transistor in which the conduction is due entirely to the flow of majority carriers through a conduction channel controlled by an electric field arising from a voltage applied between the gate and the source.

**For graphic symbols, see Figure 4-5.**

## 4.3 Field-effect transistors (cont'd)

### 4.3.1 General terms and definitions (cont'd)

**gate region (of a JFET):** A control region that determines the cross-sectional area of the channel region as a function of the gate voltage.

NOTE This definition applies for the actual operating mode of the device regardless of the name of any associated terminal.

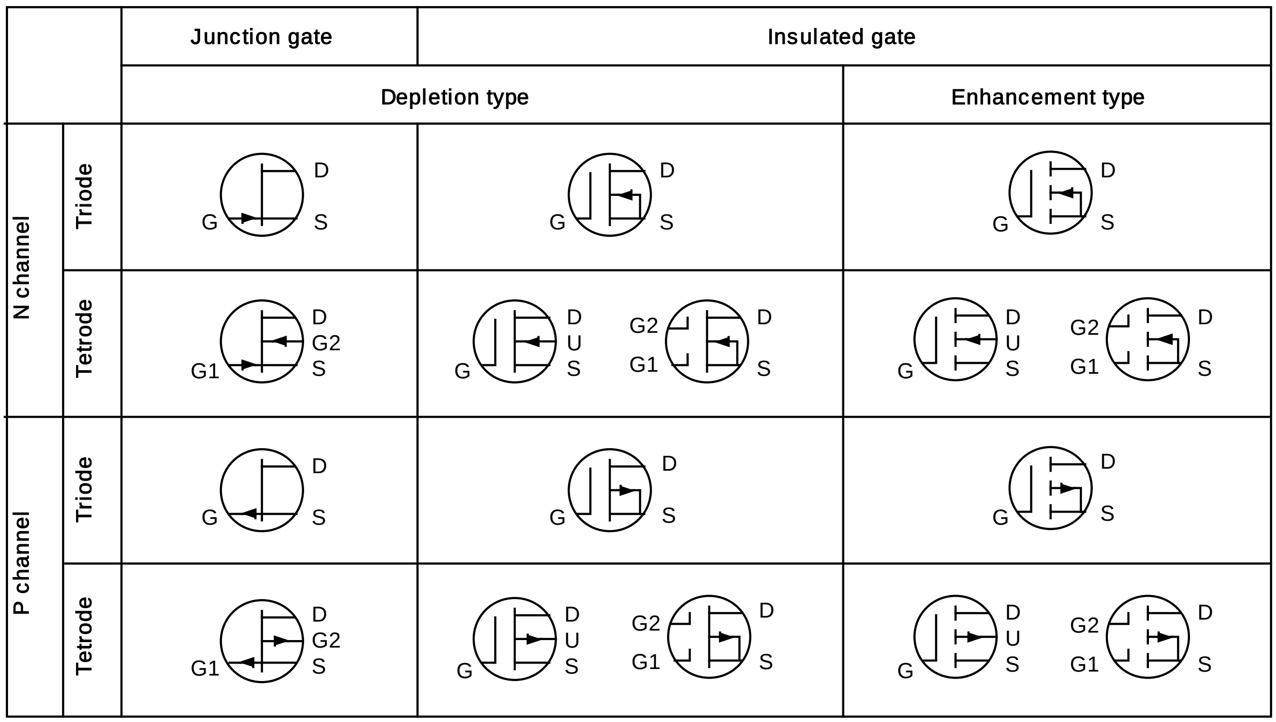



**Figure 4-5 — Graphic symbols for field-effect transistors**

**gate region (of an IGFET):** A control region that determines the surface charge-carrier concentration in the channel region as a function of the gate voltage.

NOTE This definition applies for the actual operating mode of the device regardless of the name of any associated terminal.

**gate terminal (G, g):** The specified externally available point of connection to the gate region.

**insulated-gate field-effect transistor (IGFET):** A field-effect transistor having one or more gate electrodes that are electrically insulated from the channel. (Ref. IEC 747-8.)

**junction-gate field-effect transistor (JFET):** A field-effect transistor whose gate regions form p-n junctions with the channel.

### 4.3 Field-effect transistors (cont'd)

#### 4.3.1 General terms and definitions (cont'd)

**metal-oxide-semiconductor field-effect transistor (MOSFET):** An insulated-gate field-effect transistor in which the insulating layer between each gate electrode and the channel is oxide material and the gate is metal or another highly conductive material. (Ref. IEC 747-8.)

**metal-semiconductor field-effect transistor (MESFET):** A field-effect transistor in which a metal-semiconductor rectifying contact is used for the gate electrode.

NOTE 1 Typically the structure is fabricated in gallium arsenide and the term GaAs MESFET may be used.

NOTE 2 Both depletion-type and enhancement-type devices have been manufactured. The acronyms are D-MESFET and E-MESFET, respectively.

**modulation-doped field-effect transistor (MODFET):** A metal-semiconductor field-effect transistor in which a doped material forms a heterojunction with an undoped channel; the doped material supplies electrons to the undoped channel whose high electron mobility results in enhanced channel conductance.

NOTE 1 Typically an aluminum gallium arsenide layer is grown on an undoped gallium arsenide layer by an epitaxial growth technique.

NOTE 2 Other popularly used acronyms for this device are HEMT for high-electron-mobility transistor, SDHT for selectively doped heterostructure transistor, and TEGFET for two-dimensional electron-gas field-effect transistor.

**n-channel field-effect transistor:** A field-effect transistor that has an n-type conduction channel. (Ref. IEC 747-8.)

**ohmic region:** The region of the drain voltage-current characteristic curve in which a change in drain-source voltage causes a proportional change in drain current.

**p-channel field-effect transistor:** A field-effect transistor that has a p-type conduction channel. (Ref. IEC 747-8.)

**saturation region:** The region of the drain voltage-current characteristic curve in which a change in drain-source voltage causes a relatively small change in drain current.

**source region:** A supply region that supplies principal-current charge carriers into a controlled channel.

NOTE This definition applies for the actual operating mode of the device regardless of the name of any associated terminal.

**source terminal (S, s):** The externally available point of connection to the source region.

### 4.3 Field-effect transistors (cont'd)

#### 4.3.1 General terms and definitions (cont'd)

**subchannel region (of an IGFET):** A control region within which the channel is formed and in which control charge determines threshold voltage, the control charge being the result of an applied subchannel voltage.

NOTE This definition applies for the actual operating mode of the device regardless of the name of any associated terminal.

**tetrode field-effect transistor:** A field-effect transistor having two independent gate regions, a source region, and a drain region. (Ref. IEC 747-8.)

NOTE 1 A substrate terminated externally and independently of other elements is considered a gate for the purposes of this definition.

NOTE 2 If no confusion is likely, the term may be abbreviated to “field-effect tetrode.”

**triode field-effect transistor:** A field-effect transistor having a gate, a source, and a drain. (Ref. IEC 747-8.)

NOTE If no confusion is likely, the term may be abbreviated to “field-effect triode”.

**vertical field-effect transistor:** A field-effect transistor in which the current between the source and drain regions is primarily normal to the top surface of the die.

#### 4.3.2 Letter symbols, terms, and definitions

$b_{fs}$ **common-source small-signal forward transfer susceptance:**
$b_{is}$ **common-source small-signal input susceptance:**
$b_{os}$ **common-source small-signal output susceptance:**
$b_{rs}$ **common-source small-signal reverse transfer susceptance:** The imaginary part of the corresponding admittance: $y_{fs}$, $y_{is}$, $y_{os}$, or $y_{rs}$.

NOTE Symbols in the forms $b_{xx}$ and $y_{xx(imag)}$ are equivalent.

$C_{ds}$ **drain-source capacitance:** The capacitance between the drain and source terminals with the gate terminal connected to the guard terminal of a three-terminal bridge.

$C_{du}$ **drain-substrate capacitance:** The capacitance between the drain and substrate terminals with the gate and source terminals connected to the guard terminal of a three-terminal bridge.

$C_{gs}$ **gate-source capacitance:** The capacitance between the gate and source terminals with the drain terminal connected to the guard terminal of a three-terminal bridge.

## 4.3 Field-effect transistors (cont'd)

### 4.3.2 Letter symbols, terms, and definitions (cont'd)

$C_{iss}$ **common-source short-circuit input capacitance:** The capacitance between the input terminals (gate and source) with the drain terminal ac short-circuited to the source terminal.

$C_{oss}$ **common-source short-circuit output capacitance:** The capacitance between the output terminals (drain and source) with the gate terminal ac short-circuited to the source terminal.

$C_{rss}$ **common-source short-circuit reverse transfer capacitance:** The capacitance between the drain and gate terminals with the source terminal connected to the guard terminal of a three-terminal bridge.

$f_{sd}$ **common-drain frequency of unity forward transmission coefficient:**
$f_{sg}$ **common-gate frequency of unity forward transmission coefficient:**
$f_{ss}$ **common-source frequency of unity forward transmission coefficient:** The frequency at which the modulus of the forward transmission coefficient $|s_{21}|$ has decreased to unity.

$g_{fs}$ **common-source small-signal forward transfer conductance:**
$g_{is}$ **common-source small-signal input conductance:**
$g_{os}$ **common-source small-signal output conductance:**
$g_{rs}$ **common-source small-signal reverse transfer conductance:** The real part of the corresponding admittance: $y_{fs}$, $y_{is}$, $y_{os}$, or $y_{rs}$.

NOTE Symbols in the forms $g_{xx}$ and $y_{xx(real)}$ are equivalent.

$G_{pg}$ **common-gate small-signal insertion power gain:**
$G_{ps}$ **common-source small-signal insertion power gain:** The ratio, usually expressed in decibels, of (1) the signal power delivered to the load after insertion of a transducer between the source and the load to (2) the signal power that was delivered to the load when the load was connected directly to the source, under small-signal conditions.

$G_{tg}$ **common-gate small-signal transducer power gain:**
$G_{ts}$ **common-source small-signal transducer power gain:** The ratio, usually expressed in decibels, of the signal power delivered to the load to the maximum signal power available from the source, under small-signal conditions.

$I_D$ **drain current, dc:** The direct current into the drain terminal.

**4.3 Field-effect transistors (cont'd)**

**4.3.2 Letter symbols, terms, and definitions (cont'd)**

| | |
|---|---|
| $I_{D(off)}$ | **drain cutoff current:** The direct current into the drain terminal of a depletion-type transistor with a specified reverse gate-source voltage applied to bias the device to the off state. |
| $I_{D(on)}$ | **on-state drain current:** The direct current into the drain terminal with a specified forward gate-source voltage applied to bias the device to the on state. |
| $I_{DSS}$ | **zero-gate-voltage drain current:** The direct current into the gate terminal when the gate-source voltage is zero.<br><br>NOTE This is an on-state current in a depletion-type device, an off-state current in an enhancement-type device. |
| $I_G$ | **gate current, dc:** The direct current into the gate terminal. |
| $I_{GF}$ | **forward gate current:** The direct current into the gate terminal with a forward gate-source voltage applied. |
| $I_{GR}$ | **reverse gate current:** The direct current into the gate terminal with a reverse gate-source voltage applied. |
| $I_{GSS}$ | **reverse gate current, drain short-circuited to source:** The direct current into the gate terminal of a junction-gate field-effect transistor with the gate terminal reverse-biased with respect to the source terminal and the drain terminal short-circuited to the source terminal. |
| $I_{GSSF}$ | **forward gate current, drain short-circuited to source:** The direct current into the gate terminal of an insulated-gate field-effect transistor with a forward gate-source voltage applied and the drain terminal short-circuited to the source terminal. |
| $I_{GSSR}$ | **reverse gate current, drain short-circuited to source:** The direct current into the gate terminal of an insulated-gate field-effect transistor with a reverse gate-source voltage applied and the drain terminal short-circuited to the source terminal. |
| $\mathrm{Im}(y_{fs})$ | See preferred symbols $b_{fs}$ or $y_{fs(imag)}$. |
| $\mathrm{Im}(y_{is})$ | See preferred symbols $b_{is}$ or $y_{is(imag)}$. |
| $\mathrm{Im}(y_{os})$ | See preferred symbols $b_{os}$ or $y_{os(imag)}$. |
| $\mathrm{Im}(y_{rs})$ | See preferred symbols $b_{rs}$ or $y_{rs(imag)}$. |
| $I_S$ | **source current, dc:** The direct current into the source terminal. |

**4.3 Field-effect transistors (cont'd)**

**4.3.2 Letter symbols, terms, and definitions (cont'd)**

$I_{SDS}$ **zero-gate-voltage source current:** The direct current into the source terminal when the gate-drain voltage is zero.

NOTE This is an on-state current in a depletion-type device, an off-state current in an enhancement-type device.

$I_{S(off)}$ **source cutoff current:** The direct current into the source terminal of a depletion-type transistor with a specified gate-drain voltage applied to bias the device to the off state.

$P_T$ **total dc power input to all terminals:** The sum of the products of the dc input currents and voltages, i.e.,

$$P_T = V_{GS} \bullet I_G + V_{DS} \bullet I_D$$

or

$$P_T = V_{SG} \bullet I_S + V_{DG} \bullet I_D \ .$$

$p_T$ **total instantaneous power input to all terminals:** The sum of the products of the instantaneous input currents and voltages.

$r_{ds(on)}$ **small-signal drain-source on-state resistance:** The small-signal resistance between the drain and source terminals with a specified gate-source voltage applied to bias the device to the on state.

NOTE For a depletion-type device, this gate-source voltage may be zero.

$r_{DS(on)}$ **static drain-source on-state resistance:** The dc resistance between the drain and source terminals with a specified gate-source voltage applied to bias the device to the on state.

NOTE For a depletion-type device, this gate-source voltage may be zero.

$\mathrm{Re}(y_{fs})$ See preferred symbols $g_{fs}$ or $y_{fs(real)}$.
$\mathrm{Re}(y_{is})$ See preferred symbols $g_{is}$ or $y_{is(real)}$.
$\mathrm{Re}(y_{os})$ See preferred symbols $g_{os}$ or $y_{os(real)}$.
$\mathrm{Re}(y_{rs})$ See preferred symbols $g_{rs}$ or $y_{rs(real)}$.

$s_{fd}$ or $s_{21d}$ **common-drain forward transmission coefficient:**
$s_{fg}$ or $s_{21g}$ **common-gate forward transmission coefficient:**
$s_{fs}$ or $s_{21s}$ **common-source forward transmission coefficient:** The complex ratio of the voltage at the output port to the voltage incident on the input port under small-signal conditions, the output-port terminating impedance and the impedance of the source of the incident voltage being equal and purely resistive.

## 4.3 Field-effect transistors (cont'd)

### 4.3.2 Letter symbols, terms, and definitions (cont'd)

$s_{id}$ or $s_{11d}$ **common-drain input reflection coefficient:**

$s_{ig}$ or $s_{11g}$ **common-gate input reflection coefficient:**

$s_{is}$ or $s_{11s}$ **common-source input reflection coefficient:** The complex ratio of the voltage reflected from the input port to the voltage incident on the input port under small-signal conditions, the output-port terminating impedance and the impedance of the source of the incident voltage being equal and purely resistive.

$s_{od}$ or $s_{22d}$ **common-drain output reflection coefficient:**

$s_{og}$ or $s_{22g}$ **common-gate output reflection coefficient:**

$s_{os}$ or $s_{22s}$ **common-source output reflection coefficient:** The complex ratio of the voltage reflected from the output port to the voltage incident on the output port under small-signal conditions, the input-port terminating impedance and the impedance of the source of the incident voltage being equal and purely resistive.

$s_{rd}$ or $s_{12d}$ **common-drain reverse transmission coefficient:**

$s_{rg}$ or $s_{12g}$ **common-gate reverse transmission coefficient:**

$s_{rs}$ or $s_{12s}$ **common-source reverse transmission coefficient:** The complex ratio of the voltage at the input-port to the voltage incident on the output port under small-signal conditions, the input-port terminating impedance and the impedance of the source of the incident voltage being equal and purely resistive.

**For illustrations of times, see Figures 4-6 and 4-7.**

$t_c$ **turn-off crossover time:** The time interval during which the drain voltage rises from 10% of its peak off-state value and the drain current falls to 10% of its peak on-state value, in both cases ignoring spikes caused by interaction with other components or parasitics, e.g., freewheeling-diode recovery current and parasitic inductance.

NOTE For reserve symbol, see $t_{xo}$.

$t_{d(off)}$ **turn-off delay time:** Synonym for “current turn-off delay time, $t_{d(off)i}$”.*

$t_{d(off)i}$ **current turn-off delay time:** The time interval during which an input pulse that is switching the transistor from a conducting to a nonconducting state falls from 90% of its peak amplitude and the drain current waveform falls to 90% of its on-state amplitude, ignoring spikes caused by interaction with other components or parasitics, e.g., freewheeling-diode recovery current and parasitic inductance.

---

* See note following $t_{xo}$.

**4.3 Field-effect transistors (cont'd)**

**4.3.2 Letter symbols, terms, and definitions (cont'd)**

$t_{d(off)v}$ **voltage turn-off delay time:** The time interval during which an input pulse that is switching the transistor from a conducting to a nonconducting state falls from 90% of its peak amplitude and the drain voltage waveform rises to 10% of its off-state amplitude, ignoring spikes caused by interaction with other components or parasitics, e.g., freewheeling-diode recovery current and parasitic inductance.

$t_{d(on)}$ **turn-on delay time**: Synonym for "current turn-on delay time, $t_{d(on)i}$".*

$t_{d(on)i}$ **current turn-on delay time:** The time interval during which an input pulse that is switching the transistor from a nonconducting to a conducting state rises from 10% of its peak amplitude and the drain current waveform rises to 10% of its on-state amplitude, ignoring spikes caused by interaction with other components or parasitics, e.g., freewheeling-diode recovery current and parasitic inductance.

$t_{d(on)v}$ **voltage turn-on delay time:** The time interval during which an input pulse that is switching the transistor from a nonconducting to a conducting state rises from 10% of its peak amplitude and the drain voltage waveform falls to 90% of its off-state amplitude, ignoring spikes caused by interaction with other components or parasitics, e.g., freewheeling-diode recovery current and parasitic inductance.

$t_f$ **fall time:** Synonym for "current fall time, $t_{fi}$".*

$t_{fi}$ **current fall time:** The time interval during which the drain current changes from 90% to 10% of its peak on-state value, ignoring spikes caused by interaction with other components or parasitics, e.g., freewheeling-diode recovery current and parasitic inductance.

$t_{fv}$ **voltage fall time:** The time interval during which the drain voltage changes from 90% to 10% of its peak off-state value, ignoring spikes caused by interaction with other components or parasitics, e.g., freewheeling-diode recovery current and parasitic inductance.

$t_{off}$ **turn-off time:** Synonym for "current turn-off time, $t_{off(i)}$".*

$t_{off(i)}$ **current turn-off time:** The sum of current turn-off delay time and current fall time, i.e., $t_{off(i)} = t_{d(off)i} + t_{fi}$.

$t_{off(v)}$ **voltage turn-off time:** The sum of voltage turn-off delay time and voltage rise time, i.e., $t_{off(v)} = t_{d(off)v} + t_{rv}$.

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* See note following $t_{xo}$.

**4.3 Field-effect transistors (cont'd)**

**4.3.2 Letter symbols, terms, and definitions (cont'd)**

$t_{on}$ **turn-on time:** Synonym for "current turn-on time, $t_{on(i)}$".*

$t_{on(i)}$ **current turn-on time:** The sum of current turn-on delay time and current rise time, i.e., $t_{on(i)} = t_{d(on)i} + t_{ri}$.

$t_{on(v)}$ **voltage turn-on time:** The sum of voltage turn-on delay time and voltage fall time, i.e., $t_{on(v)} = t_{d(on)v} + t_{fv}$.

$t_r$ **rise time:** Synonym for "current rise time, $t_{ri}$".*

$t_{ri}$ **current rise time:** The time interval during which the drain current changes form 10% to 90% of its peak on-state value, ignoring spikes caused by interaction with other components or parasitics, e.g., freewheeling-diode recovery current and parasitic inductance.

$t_{rv}$ **voltage rise time:** The time interval during which the drain voltage changes from 10% to 90% of its peak off-state value, ignoring spikes caused by interaction with other components or parasitics, e.g., freewheeling-diode recovery current and parasitic inductance.

$t_{ti}$ **current tail time:** The time interval following current fall time during which the drain current changes from 10% to 2% of its peak on-state value, ignoring spikes caused by interaction with other components or parasitics, e.g., freewheeling-diode recovery current and parasitic inductance.

$t_{xo}$ **turn-off crossover time:** For definition, see $t_c$. The symbol $t_{xo}$ is a reserve symbol to be used if use of $t_c$ is likely to cause confusion.

NOTE As names of time intervals for characterizing switching transistors, the terms "fall time" and "rise time" always refer to the change that is taking place in the magnitude of the output current even though measurements may be made using voltage waveforms. In a purely resistive circuit, the (current) rise time may be considered equal and coincident to the voltage fall time. The delay times for current and voltage will be equal and coincident. When significant amounts of inductance or capacitance are present in a circuit, these equalities and coincidences no longer exist, and use of the unmodified terms delay time, fall time, turn-off time, turn-on time, and rise time must be avoided.

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* See note following $t_{xo}$.

**4.3 Field-effect transistors (cont'd)**

**4.3.2 Letter symbols, terms, and definitions (cont'd)**

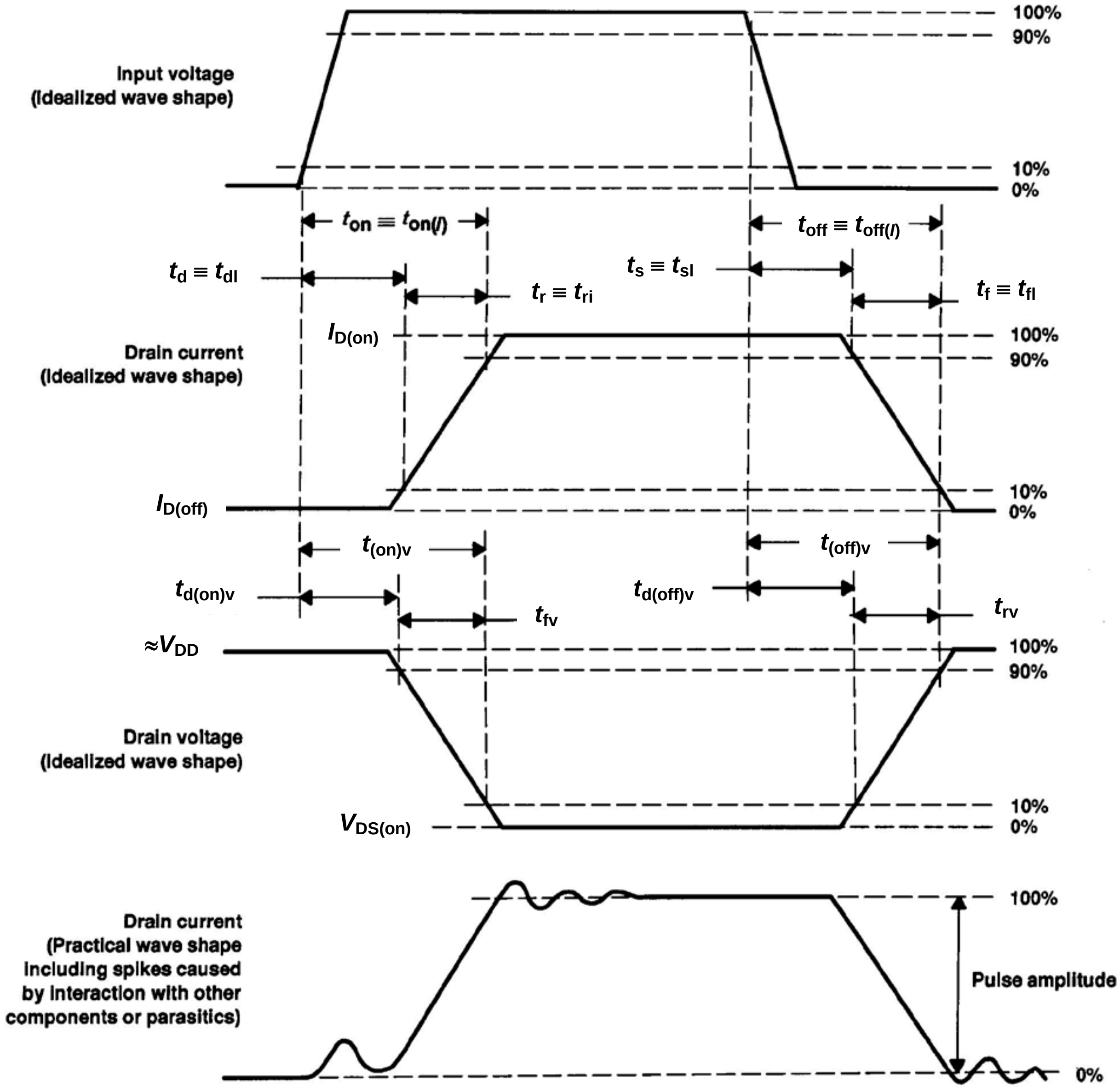
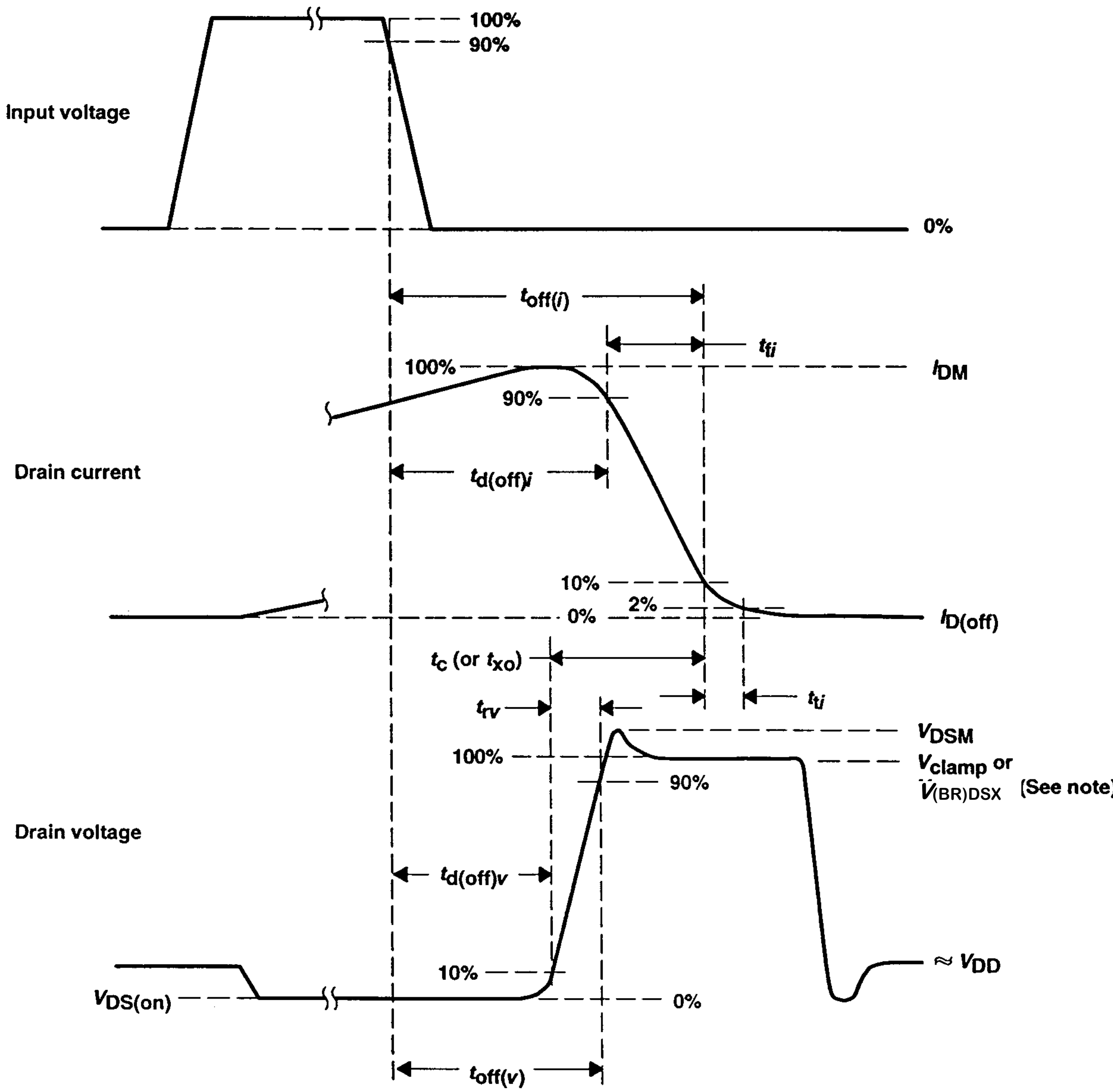



**Figure 4-6 — Waveforms for resistive-load switching**

**4.3 Field-effect transistors (cont'd)**

**4.3.2 Letter symbols, terms, and definitions (cont'd)**




NOTE $V_{clamp}$ (in a clamped inductive-load switching circuit) or $V_{(BR)DSX}$ (in an unclamped circuit) is the peak off-state voltage excluding spikes.

**Figure 4-7 — Waveforms for inductive-load switching, turn-off**

**4.3 Field-effect transistors (cont'd)**

**4.3.2 Letter symbols, terms, and definitions (cont'd)**

$V_{(BR)DSR}$ **drain-source breakdown voltage, resistance between gate and source:**
$V_{(BR)DSS}$ **drain-source breakdown voltage, gate short-circuited to source:**
$V_{(BR)DSV}$ **drain-source breakdown voltage, voltage between gate and source:**
$V_{(BR)DSX}$ **drain-source breakdown voltage, circuit between gate and source:** The breakdown voltage between the drain and the source terminals when the gate terminal is, respectively,

— returned to the source terminal through a specified resistance.
— short-circuited to the source terminal.
— returned to the source terminal through a specified voltage.
— returned to the source terminal through a specified circuit.

$V_{(BR)GSS}$ **gate-source breakdown voltage:** The breakdown voltage between the gate and source terminals with the drain terminal short-circuited to the source terminal.

NOTE The symbol $V_{(BR)GSS}$ is primarily used with junction-gate field-effect transistors. The symbols $V_{(BR)GSSF}$ or $V_{(BR)GSSR}$ should be used with insulated-gate transistors having shunting diodes or similar voltage-limiting devices.

$V_{(BR)GSSF}$ **forward gate-source breakdown voltage:** The breakdown voltage between the gate and source terminals with a forward gate-source voltage applied and the drain terminal short-circuited to the source terminal.

$V_{(BR)GSSR}$ **reverse gate-source breakdown voltage:** The breakdown voltage between the gate and source terminals with a reverse gate-source voltage applied and the drain terminal short-circuited to the source terminal.

$V_{DD}$ **drain supply voltage, dc:**
$V_{GG}$ **gate supply voltage, dc:**
$V_{SS}$ **source supply voltage, dc:** The dc supply voltage applied to a circuit connected to the drain, gate, or source terminal, respectively.

$V_{DG}$ **drain-gate voltage, dc:** The dc voltage between the drain and gate terminals.

$V_{DS}$ **drain-source voltage, dc:** The dc voltage between the drain and source terminals.

$V_{DS(on)}$ **drain-source on-state voltage:** The voltage between the drain and source terminals with a specified forward gate-source voltage applied to bias the device to the on state.

$V_{DU}$ **drain-substrate voltage, dc:** The dc voltage between the drain and substrate terminals.

**4.3 Field-effect transistors (cont'd)**

**4.3.2 Letter symbols, terms, and definitions (cont'd)**

$V_{GS}$ — **gate-source voltage, dc:** The dc voltage between the gate and source terminals.

$V_{GSF}$ — **forward gate-source voltage:** The voltage between the gate and source terminals of such polarity that an increase in its magnitude causes the channel resistance to decrease.

$V_{GSR}$ — **reverse gate-source voltage:** The voltage between the gate and source terminals of such polarity that an increase in its magnitude causes the channel resistance to increase.

$V_{GS(off)}$ — **gate-source cutoff voltage (of a depletion-type FET):** The gate-source voltage at which the magnitude of the drain current reaches a specified low value.
(Ref. IEC 747-8.)

$V_{GS(th)}$ — **gate-source threshold voltage (of an enhancement-type FET):** The gate-source voltage at which the magnitude of the drain current reaches a specified low value.
(Ref. IEC 747-8.)

$V_{GU}$ — **gate-substrate voltage, dc:** The dc voltage between the gate and substrate terminals.

$V_{SU}$ — **source-substrate voltage, dc:** The dc voltage between the source and substrate terminals.

$y_{fs}$ — **common-source small-signal short-circuit forward transfer admittance:** The ac rms drain current divided by the ac rms gate-source voltage with the drain-source voltage held constant.

NOTE The fact that the drain-source voltage is held constant implies that the drain terminal is ac short-circuited to the source terminal.

$y_{is}$ — **common-source small-signal short-circuit input admittance:** The ac rms gate current divided by the ac rms gate-source voltage with the drain-source voltage held constant.

NOTE The fact that the drain-source voltage is held constant implies that the drain terminal is ac short-circuited to the source terminal.

$y_{os}$ — **common-source small-signal short-circuit output admittance:** The ac rms drain current divided by the ac rms drain-source voltage with the gate-source voltage held constant.

NOTE The fact that the gate-source voltage is held constant implies that the gate terminal is ac short-circuited to the source terminal.

### 4.3 Field-effect transistors (cont'd)

#### 4.3.2 Letter symbols, terms, and definitions (cont'd)

$y_{rs}$ **common-source small-signal short-circuit reverse transfer admittance:** The ac rms gate current divided by the ac rms drain-source voltage with the gate-source voltage held constant.

NOTE The fact that the gate-source voltage is held constant implies that the gate terminal is ac short-circuited to the source terminal.

$y_{fs(imag)}$ **common-source small-signal forward transfer susceptance:**
$y_{is(imag)}$ **common-source small-signal input susceptance:**
$y_{os(imag)}$ **common-source small-signal output susceptance:**
$y_{rs(imag)}$ **common-source small-signal reverse transfer susceptance:** The imaginary part of the corresponding admittance: $y_{fs}$, $y_{is}$, $y_{os}$, or $y_{rs}$.

NOTE Symbols in the forms $y_{xx(imag)}$ and $b_{xx}$ are equivalent.

$y_{fs(real)}$ **common-source small-signal forward transfer conductance:**
$y_{is(real)}$ **common-source small-signal input conductance:**
$y_{os(real)}$ **common-source small-signal output conductance:**
$y_{rs(real)}$ **common-source small-signal reverse transfer conductance:** The real part of the corresponding admittance: $y_{fs}$, $y_{is}$, $y_{os}$, or $y_{rs}$.

NOTE Symbols in the forms $y_{xx(real)}$ and $g_{xx}$ are equivalent.

## 4.4 Insulated-gate bipolar transistors

### 4.4.1 General terms and definitions

**insulated-gate bipolar transistor (IGBT):** A three-terminal (collector, emitter, and gate), four-layer (pnpn/npnp) semiconductor device with an MOS-gated channel connecting the two n-type regions (for n-channel types), or the two p-type regions (for p-channel types), and in which the conductance of the high-resistance collector region is modulated (enhanced) by the injection of minority carriers from an opposite-polarity semiconductor region adjacent to the collector and opposite the channel region.

NOTE 1 The IGBT is a compound semiconductor structure with input characteristics similar to those of a vertical power MOSFET, but containing an additional bipolar component that conductivity-modulates the drain region of the MOSFET section.

NOTE 2 The conductivity modulation of the vertical DMOS power MOSFET drain region substantially reduces the inherent rise in collector-emitter resistance that results with increasing collector-emitter voltage capability.

NOTE 3 The IGBT is similar in basic structure to an MOS-gated thyristor but exhibits a fundamental operational difference in that it maintains gate control, i.e., it does not latch, over a wide range of collector current and collector-emitter voltage.

NOTE 4 The term “insulated-gate bipolar transistor” (IGBT) is the generic name for the entire class of conductivity-enhanced MOS-gated pnpn/npnp devices. Other names used to identify these types of devices include conductivity-modulated field-effect transistor (COMFET), gain-enhanced MOS field-effect transistor (GEMFET), insulated-gate transistor (IGT), and insulated-gate rectifier (IGR).

**short-circuit safe operating area (SCSOA):** All combinations of collector current and collector-emitter voltage that are permitted to occur during nonrepetitive turn-off of short-circuit current in the transistor without endangering its survival.

NOTE 1 This information is normally presented graphically.

NOTE 2 The SCSOA is defined for nonrepetitive operation. This means that it applies for a limited number of occurrences in the life of a device and all equilibrium conditions must be reestablished before a second occurrence.

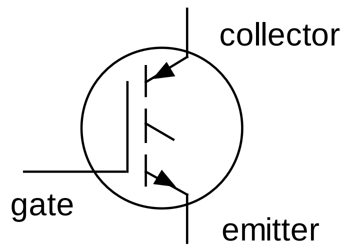
**switching safe operating area (SwSOA):** All combinations of collector current and collector-emitter voltage that are permitted to occur during turn-off of the transistor without endangering its survival.

NOTE This information is normally presented graphically.

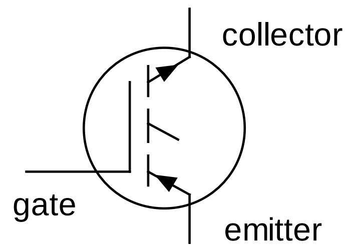
**4.4 Insulated-gate bipolar transistors (cont'd)**

**4.4.1 General terms and definitions (cont'd)**

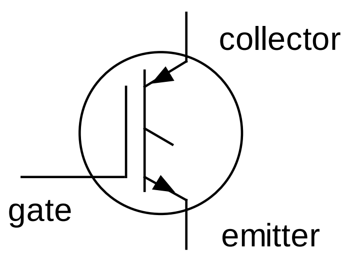
Graphic symbols (ref. IEC 617-5):



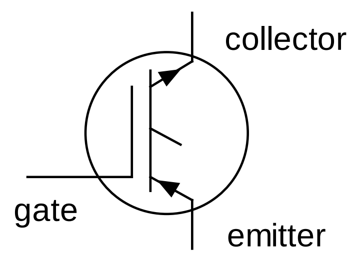

N-channel
enhancement type




P-channel
enhancement type




N-channel
depletion type




P-channel
depletion type

NOTE In the graphic symbols, the envelope is optional if no element is shown connected to the envelope.

## 4.4 Insulated-gate bipolar transistors (cont'd)

### 4.4.2 Letter symbols, terms, and definitions

$C_{ies}$ **common-emitter short-circuit input capacitance:** The capacitance between the gate and emitter terminals with the collector terminal ac short-circuited to the emitter terminal.

$C_{oes}$ **common-emitter short-circuit output capacitance:** The capacitance between the collector and emitter terminals with the gate terminal ac short-circuited to the emitter terminal.

$C_{re}$ **common-emitter reverse transfer capacitance:** The capacitance measured from the collector terminal to the gate terminal with the emitter terminal (and the case, if a case terminal is provided) connected to the guard terminal of a three-terminal bridge and with the device biased in the active region.

NOTE Some data sheets refer to this parameter as $C_{res}$; however, this is deprecated because “s” as the third subscript implies shorted terminals.

$E_{off}$ **turn-off switching loss:** The total energy converted to heat within the device during the turn-off interval.

$E_{on}$ **turn-on switching loss:** The total energy converted to heat within the device during the turn-on interval.

$E_{TS}$ **total switching loss:** The sum of turn-off switching loss and turn-on switching loss.

$g_{me}$ **common-emitter small-signal transconductance:** The ac rms collector current divided by the ac rms gate voltage with the collector-emitter voltage held constant.

NOTE 1 The use of the symbol “g” and the term “conductance” for a quantity that is actually an admittance can be justified only at low frequencies where the magnitude and the real part of the admittance are essentially equal.

NOTE 2 The fact that the collector-emitter voltage is held constant implies that the collector terminal is ac short-circuited to the emitter terminal.

$I_C$ **collector current, dc:** The value of the dc current into the collector terminal.

$I_{CES}$ **collector cutoff current, gate short-circuited to emitter:** The current into the collector terminal when the collector-emitter voltage polarity is as required for normal operation and the gate terminal is short-circuited to the emitter terminal.

NOTE In normal operation, the collector-emitter voltage is positive for n-channel IGBTs or negative for p-channel IGBTs.

**4.4 Insulated-gate bipolar transistors (cont'd)**

**4.4.2 Letter symbols, terms, and definitions (cont'd)**

$I_{CM}$ **peak collector current:** The peak value of the current into the collector terminal.

$I_E$ **emitter current, dc:** The value of the dc current into the emitter terminal.

$I_G$ **gate current, dc:** The value of the dc current into the gate terminal.

$I_{GESF}$ **forward gate current, collector short-circuited to emitter:** The direct current into the gate terminal with a forward gate-emitter voltage* applied and the collector terminal short-circuited to the emitter terminal.

$I_{GESR}$ **reverse gate current, collector short-circuited to emitter:** The direct current into the gate terminal with a reverse gate-emitter voltage* applied and the collector terminal short-circuited to the emitter terminal.

$I_{GF}$ **forward gate current:** The direct current into the gate terminal with a forward gate-emitter voltage* applied.

$I_{GR}$ **reverse gate current:** The direct current into the gate terminal with a reverse gate-emitter voltage* applied.

$Q_g$ **gate charge:** A commonly used synonym for “turn-on gate charge”.

$Q_{g(on)}$ **turn-on gate charge:** The total gate charge required to turn on the device.

SCWT **short-circuit withstand time:** The maximum-rated value of short-circuit pulse duration, $t_{sc}$.

$t_{c(off)}$ **(turn-off) crossover time** (for reserve symbol, see $t_{xo(off)}$): The time interval during which collector voltage rises from 10% of its peak off-state value and collector current falls to 10% of its peak on-state value, in both cases ignoring spikes caused by interaction with other components or parasitics, e.g., freewheeling-diode recovery current and parasitic inductance.

NOTE The subscript “(off)” may be omitted from the symbol and the adjective “turn-off” may be omitted from the term if the turn-on crossover time is not also specified and no confusion is likely.

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* For the definitions of forward and reverse gate-emitter voltages, see $V_{GEF}$ and $V_{GER}$.
* For the definitions of forward and reverse gate-emitter voltages, see $V_{GEF}$ and $V_{GER}$.

## 4.4 Insulated-gate bipolar transistors (cont'd)

### 4.4.2 Letter symbols, terms, and definitions (cont'd)

$t_{c(on)}$ **turn-on crossover time** (for reserve symbol, see $t_{xo(on)}$): The time interval during which collector current rises from 10% of its peak on-state value and collector voltage falls to 10% of its peak off-state value, in both cases ignoring spikes caused by interaction with other components or parasitics, e.g., freewheeling-diode recovery current and parasitic inductance.

$t_{d(off)i}$ **(current) turn-off delay time:** The time interval during which the forward gate-emitter voltage falls from 90% of its peak amplitude and the collector current falls to 90% of its on-state amplitude, ignoring spikes caused by interaction with other components or parasitics, e.g., freewheeling-diode recovery current and parasitic inductance.

NOTE The subscript “ *i*” may be omitted from the symbol and the adjective “current” may be omitted from the term if no confusion with the voltage turn-off delay time is likely.

$t_{d(off)v}$ **voltage turn-off delay time:** The time interval during which the forward gate-emitter voltage falls from 90% of its peak amplitude and the collector voltage rises to 10% of its off-state amplitude, ignoring spikes caused by interaction with other components or parasitics, e.g., freewheeling-diode recovery current and parasitic inductance.

$t_{d(on)i}$ **(current) turn-on delay time:** The time interval during which the forward gate-emitter voltage rises from 10% of its peak amplitude and the collector current rises to 10% of its on-state amplitude, ignoring spikes caused by interaction with other components or parasitics, e.g., freewheeling-diode recovery current and parasitic inductance.

NOTE The subscript “*i*” may be omitted from the symbol and the adjective “current” may be omitted from the term if no confusion with the voltage turn-on delay time is likely.

$t_{d(on)v}$ **voltage turn-on delay time:** The time interval during which the forward gate-emitter voltage rises from 10% of its peak amplitude and the collector voltage falls to 90% of its off-state amplitude, ignoring spikes caused by interaction with other components or parasitics, e.g., freewheeling-diode recovery current and parasitic inductance.

$t_{fi}$ **(current) fall time:** The time interval during which the collector current changes from 90% to 10% of its peak on-state value, ignoring spikes caused by interaction with other components or parasitics, e.g., freewheeling-diode recovery current and parasitic inductance.

NOTE The subscript “*i*” may be omitted from the symbol and the adjective “current” may be omitted from the term if no confusion with the voltage fall time is likely.

**4.4 Insulated-gate bipolar transistors (cont'd)**

**4.4.2 Letter symbols, terms, and definitions (cont'd)**

$t_{fv}$ **voltage fall time:** The time interval during which the collector voltage changes from 90% to 10% of its peak off-state value, ignoring spikes caused by interaction with other components or parasitics, e.g., freewheeling-diode recovery current and parasitic inductance.

$t_{off(i)}$ **(current) turn-off time:** The sum of the current turn-off delay time and the current fall time; i.e., $t_{off(i)} = t_{d(off)i} + t_{fi}$.

NOTE The subscript "*i*" may be omitted from the symbol and the adjective "current" may be omitted from the term if no confusion with the voltage turn-off time is likely.

$t_{off(v)}$ **voltage turn-off time:** The sum of the voltage turn-off delay time and the voltage rise time; i.e., $t_{off(v)} = t_{d(off)v} + t_{rv}$.

$t_{on(i)}$ **(current) turn-on time:** The sum of the current turn-on delay time and the current rise time; i.e., $t_{on(i)} = t_{d(on)i} + t_{ri}$.

NOTE The subscript "*i*" may be omitted from the symbol and the adjective "current" may be omitted from the term if no confusion with the voltage turn-on time is likely.

$t_{on(v)}$ **voltage turn-on time:** The sum of the voltage turn-on delay time and the voltage fall time; i.e., $t_{on(v)} = t_{d(on)v} + t_{fv}$.

$t_{ri}$ **(current) rise time:** The time interval during which the collector current changes from 10% to 90% of its peak on-state value, ignoring spikes caused by interaction with other components or parasitics, e.g., freewheeling-diode recovery current and parasitic inductance.

NOTE The subscript "*i*" may be omitted from the symbol and the adjective "current" may be omitted from the term if no confusion with the voltage rise time is likely.

$t_{rv}$ **voltage rise time:** The time interval during which the collector voltage changes from 10% to 90% of its peak off-state value, ignoring spikes caused by interaction with other components or parasitics, e.g., freewheeling-diode recovery current and parasitic inductance.

$t_{sc}$ **short-circuit pulse duration:** The time duration of a turn-on pulse applied to the gate while the IGBT operates into a short circuit.

NOTE A rated value may be specified that is the longest duration for which survival is to be expected. This rated value is sometimes referred to as the "short-circuit withstand time, SCWT".

**4.4 Insulated-gate bipolar transistors (cont'd)**

**4.4.2 Letter symbols, terms, and definitions (cont'd)**

$t_{xo(off)}$ **turn-off crossover time:** For definition, see $t_{c(off)}$. (The symbol $t_{xo(off)}$ is a reserve symbol to be used if the use of $t_{c(off)}$ is likely to cause confusion).

$t_{xo(on)}$ **turn-on crossover time:** For definition, see $t_{c(on)}$. (The symbol $t_{xo(on)}$ is a reserve symbol to be used if the use of $t_{c(on)}$ is likely to cause confusion).

$t_z$ **current tail time:** The time interval following the turn-off time during which the collector current falls from 10% to 1% of its peak on-state value.

$V_{(BR)CES}$ **collector-emitter breakdown voltage, gate short-circuited to emitter:** The breakdown voltage between the collector and emitter terminals when the collector-emitter voltage polarity is as required for normal operation and the gate terminal is short-circuited to the emitter terminal.

NOTE In normal operation, the collector-emitter voltage is positive for n-channel IGBTs or negative for p-channel IGBTs.

$V_{(BR)CESR}$ **collector-emitter breakdown voltage, gate short-circuited to emitter, reverse condition:** The breakdown voltage between the collector and emitter terminals when the collector-emitter voltage polarity is a reverse condition (i.e, opposite to the polarity required for normal operation) and the gate terminal is short-circuited to the emitter terminal.

NOTE In a reverse condition, the collector-emitter voltage is negative for n-channel IGBTs or positive for p-channel IGBTs.

$V_{CE}$ **collector-emitter voltage, dc:** The dc voltage between the collector and emitter terminals.

$V_{CE(on)}$ **collector-emitter on-state voltage:** A synonym for “collector-emitter saturation voltage”.

$V_{CE(sat)}$ **collector-emitter saturation voltage:** The voltage between the collector and emitter terminals under conditions of forward gate-emitter voltage beyond which the collector current remains essentially constant as the gate-emitter voltage is increased.

$V_{CG}$ **collector-gate voltage, dc:** The dc voltage between the collector and gate terminals.

$V_{GE}$ **gate-emitter voltage, dc:** The dc voltage between the gate and emitter terminals.

**4.4 Insulated-gate bipolar transistors (cont'd)**

**4.4.2 Letter symbols, terms, and definitions (cont'd)**

$V_{\mathrm{GEF}}$ **forward gate-emitter voltage:** The voltage between the gate and emitter terminals of such polarity that an increase in its magnitude causes the resistance between the collector and emitter terminals to decrease.

$V_{\mathrm{GER}}$ **reverse gate-emitter voltage:** The voltage between the gate and emitter terminals of such polarity that an increase in its magnitude causes the resistance between the collector and emitter terminals to increase.

$V_{\mathrm{GE(th)}}$ **gate-emitter threshold voltage (of an enhancement-type IGBT):** The forward gate-emitter voltage at which the magnitude of the collector current reaches a specified low value.

Θ

# SECTION 5 OPTOELECTRONIC DEVICES

## 5.1 Optoelectronic devices, general

### 5.1.1 General terms and definitions

**blackbody:** Ideally, a body that would absorb all and reflect none of the radiant energy falling upon it; its reflectivity would be zero and its absorptivity (and consequently, its emissivity) would be 100%. In practice, a radiator of uniform temperature whose radiant emittance in all parts of the spectrum is the maximum obtainable from any radiator at the same temperature, or a radiator whose spectral radiant emittance conforms with Planck's law of radiation.

**color temperature:** The temperature of a blackbody having the same visible color as that of a given non-blackbody radiator.

**flux density, luminous:** The luminous flux at a surface divided by the area of the surface. (See also illuminance [illumination] ($E_v$) in 5.2.2 and luminous exitance ($M_v$) in 5.3.2.)

**flux density, radiant:** The radiant flux at a surface divided by the area of the surface. (See also irradiance ($E_e$) in 5.2.2 and radiant exitance ($M_e$) in 5.3.2.)

**light:** Radiant energy within the limits of the visible spectrum.

**optical axis:** A line about which the radiant-energy or sensitivity pattern is centered. (Ref. IEC 747-5.)

NOTE 1 The radiant-energy or sensitivity pattern may be nonsymmetrical.

NOTE 2 The optical axis may deviate from the mechanical axis.

**optoelectronic device:** (1) A device that is responsive to or that emits or modifies electromagnetic radiation in the visible, infrared, and/or ultraviolet spectral regions.
(2) A device that utilizes electromagnetic radiation in the visible, infrared, and/or ultraviolet spectral regions for its internal operation. (Ref. IEC 747-5.)

### 5.1.2 Letter symbols, terms, and definitions

| | |
|---|---|
| $Q$, $Q_e$ | **radiant energy:** Energy traveling in the form of electromagnetic waves. (Ref. ANSI/IEEE Std 100.) |
| $Q$, $Q_v$ | **luminous energy:** Energy traveling in the form of visible radiation. |
| $\tau$ | **time constant:** The reciprocal of the angular modulation frequency of the incident or emitted radiation at which the response has dropped 3 dB from the zero-frequency level. |
| $\Phi$, $\Phi_e$ | **radiant flux:** The time rate of flow of radiant energy. |
| $\Phi$, $\Phi_v$ | **luminous flux:** The time rate of flow of luminous energy. |

## 5.1 Optoelectronic devices, general (cont'd)

### 5.1.2 Letter symbols, terms, and definitions (cont'd)

**Table 5-1 — Conversion factors for optoelectronics**

| To convert from | | To | | Multiply by |
|---|---|---|---|---|
| **Length and area** | | | | |
| angstrom | (Å) | meter* | (m) | $1.000\ 000 \times 10^{-10}$† |
| angstrom | (Å) | micrometer* | (µm) | $1.000\ 000 \times 10^{-4}$† |
| foot | (ft) | meter* | (m) | $3.048\ 000 \times 10^{-1}$† |
| inch | (in) | meter* | (m) | $2.540\ 000 \times 10^{-2}$† |
| micron | (µ) | micrometer* | (µm) | 1.000 000† |
| square foot | ($ft^2$) | square meter* | ($m^2$) | $9.290\ 304 \times 10^{-2}$† |
| **Photometry** | | | | |
| apostilb | (asb) | candela per square meter* | ($cd/m^2$) | $3.183\ 099 \times 10^{-1}$ |
| candela* | (cd) | lumen per steradian | (lm/sr) | 1.000 000† |
| candela per square foot | ($cd/ft^2$) | candela per square meter* | ($cd/m^2$) | 1.076 391 x 10 |
| footcandle ($lm/ft^2$) | (fc) | lux* | (lx) | 1.076 391 x 10 |
| footlambert | (fL) | candela per square foot | ($cd/ft^2$) | $3.183\ 099 \times 10^{-1}$ |
| footlambert | (fL) | candela per square meter* | ($cd/m^2$) | 3.426 259 |
| lambert | (L) | candela per square meter* | ($cd/m^2$) | $3.183\ 099 \times 10^{3}$ |
| lux* | (lx) | lumen per square meter* | ($lm/m^2$) | 1.000 000† |
| nit | (nt) | candela per square meter* | ($cd/m^2$) | 1.000 000† |
| phot ($lm/cm^2$) | (ph) | lux* | (lx) | $1.000\ 000 \times 10^{4}$† |
| stilb | (sb) | candela per square meter* | ($cd/m^2$) | $1.000\ 000 \times 10^{4}$† |

* International System (SI) unit.
† This is an exact conversion.

## 5.2 Photosensitive devices

### 5.2.1 General terms and definitions

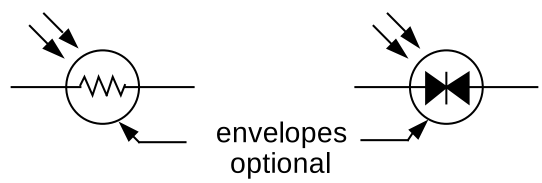
**conversion efficiency (of a photovoltaic diode):** The maximum available power output resulting from photovoltaic operation divided by the total incident radiant flux.

**dark condition:** The condition attained when the electrical parameter under consideration approaches a value that cannot be altered by further irradiation shielding.

**photoconductive diode:** A photodiode that is intended to be used as a photoconductive transducer.

**photoconductive transducer:** A device that is intended to change its conductance as a function of incident radiant flux.

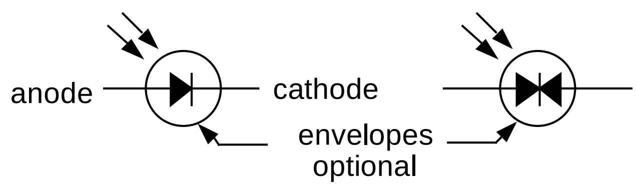
Graphic symbols:




**photocurrent:** The difference between the light current and the dark current.

**photodiode:** A diode that is intended to be responsive to radiant energy.

Graphic symbols (ref. IEEE Std 315):




**photodiode, avalanche:** A photodiode that is intended to take advantage of avalanche multiplication of photocurrent.

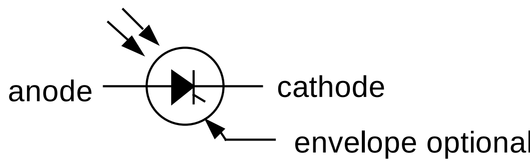
**photosensitive device:** A device that is responsive to electromagnetic radiation in the visible, infrared, and/or ultraviolet spectral regions.

**5.2 Photosensitive devices (cont'd)**

**5.2.1 General terms and definitions (cont'd)**

**photothyristor:** A thyristor that is intended to be responsive to radiant energy for controlling its operation as a thyristor.

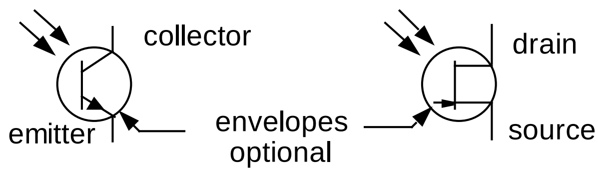
Graphic symbol:




NOTE A gate terminal may or may not be provided.

**phototransistor:** A transistor that is intended to be responsive to radiant energy.

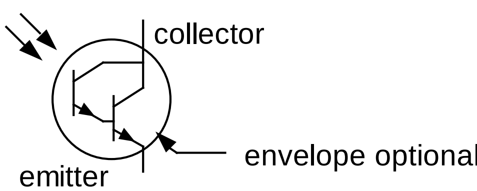
Graphic symbols (ref. IEEE Std 315):




NOTE A base or gate terminal may or may not be provided.

**phototransistor, Darlington:** A phototransistor whose collector and emitter are connected to the collector and base, respectively, of a second transistor.

Graphic symbol:




NOTE Base terminals may or may not be provided.

**photovoltaic diode:** A photodiode that is intended to generate a terminal voltage in response to radiant energy.

## 5.2 Photosensitive devices (cont'd)

### 5.2.1 General terms and definitions (cont'd)

**quantum efficiency:** The ratio of the number of effective electron-hole pairs produced within the device to the number of incident photons.

NOTE For devices that internally amplify or multiply the electron-hole pairs (such as phototransistors or avalanche photodiodes), the effect of the gain is to be excluded from quantum efficiency.

### 5.2.2 Letter symbols, terms, and definitions

**For symbols, defining equations, and standard units associated with photosensitive devices, see table 5-2.**

| | |
|---|---|
| $A_D$ | **detector area:** The photosensitive area in a device. |
| $B_n$ (formerly $\Delta f$) | **noise equivalent bandwidth:** The bandwidth of a flat (white) noise spectrum having sharp cutoffs and the same maximum value and the same noise power as the actual broadband output noise power of the device or circuit. |
| $D^*$ | **detectivity, *D*-star:** A measure of low-level detector performance determined by dividing the square root of the detector area by the noise equivalent power spectral density a “gain over noise” figure of merit. |
| $D^{**}$ | **detectivity, normalized:** The *D*-star detectivity that is normalized to account for the detector field of view, Ω. |
| $E$, $E_e$ | **irradiance:** The density of the radiant flux incident on a surface, i.e., the radiant flux at a surface divided by the area of the irradiated surface. |
| $E$, $E_v$ | **illuminance; illumination:** The density of the luminous flux incident on a surface, i.e., the luminous flux at a surface divided by the area of the illuminated surface. |
| $f_{mod}$ | **modulation frequency:** The frequency of modulation of the luminous or radiant flux. |
| $I_D$ | **dark current:** The current through a photosensitive device under dark conditions. |
| $I_L$ | **light current:** The current through a photosensitive device when it is exposed to radiant energy. |
| $I_n$ | **detector noise current:** The broadband output noise current. |
| $I_S$ | **detector signal current, dc:** The information component of the dc output current. |

**5.2 Photosensitive devices (cont'd)**

**5.2.2 Letter symbols, terms, and definitions (cont'd)**

| | |
|---|---|
| $I_S$ | **detector signal current, rms value of ac component:** The rms value of the ac information component of the output current. |
| $N$, $N_e$ | **responsivity, irradiance:** The rms value of the fundamental component of the electrical output divided by the rms value of the fundamental component of the irradiance of a specified spectral distribution. |
| $N$, $N_v$ | **responsivity, illuminance:** The rms value of the fundamental component of the electrical output divided by the rms value of the fundamental component of the input illuminance of a specified spectral distribution. |
| $P_n$ or NEP† | **noise equivalent power:** The rms value of the fundamental component of a modulated radiant flux incident on the detector area that will produce a signal (voltage or current) at the detector output that is equal to the broadband rms noise (voltage or current).<br>NOTE The noise equivalent power equals the broadband output noise (voltage or current) divided by the responsivity (in volts per watt or amperes per watt). |
| $P_n$ or NEP† | **noise equivalent power spectral density:** The noise equivalent power in a one-hertz bandwidth at the detector output.<br>NOTE The noise equivalent power spectral density equals the noise equivalent power divided by the square root of the noise bandwidth. |
| $R$, $R_e$ | **responsivity, radiant:** The rms value of the fundamental component of the electrical output divided by the rms value of the fundamental component of the radiant flux of a specified spectral distribution. |
| $R$, $R_v$ | **responsivity, luminous:** The rms value of the fundamental component of the electrical output divided by the rms value of the fundamental component of the luminous flux of a specified spectral distribution. |
| $S$, $S_e$ | **sensitivity, irradiance:** The electrical output divided by the unmodulated uniform normal irradiance of a specified spectral distribution. |
| $S$, $S_e$ | **sensitivity, radiant:** The electrical output divided by the incident radiant flux of a specified spectral distribution. |
| $S$, $S_v$ | **sensitivity, illuminance:** The electrical output divided by the unmodulated uniform normal illuminance of a specified spectral distribution. |

† The abbreviation NEP is often used for $P_n$; however, the symbol $P_n$ is preferred.

**5.2 Photosensitive devices (cont'd)**

**5.2.2 Letter symbols, terms, and definitions (cont'd)**

| | |
|---|---|
| $S$, $S_V$ | **sensitivity, luminous:** The electrical output divided by the unmodulated incident luminous flux of a specified spectral distribution. |
| $t_d$ | **delay time:** |
| $t_f$ | **fall time:** |
| $t_{off}$ | **turn-off time:** |
| $t_{on}$ | **turn-on time:** |
| $t_r$ | **rise time:** |
| $t_s$ | **storage time:** For phototransistors, the definitions of the corresponding terms in 4.1.2 apply with the understanding that the input pulse is radiant flux. |
| $V_n$ | **detector noise voltage:** The broadband output noise voltage. |
| $V_S$ | **detector signal voltage, dc:** The information component of the dc output voltage. |
| $V_s$ | **detector signal voltage, rms value of ac component:** The rms value of the ac information component of the output voltage. |

## 5.2 Photosensitive devices (cont'd)

### 5.2.2 Letter symbols, terms, and definitions (cont'd)

**Table 5-2 — Symbols, defining equations, and standard units associated with photosensitive devices**

| Quantity† | Quantity symbol† | Defining equation | Unit symbol‡ |
|---|---|---|---|
| Detectivity,<br>D-Star | $D^*$ | $D^* = RA_D^{1/2}\Delta f^{1/2}/I_n$<br>or $RA_D^{1/}2\Delta^{f1/2}/V_n$<br>or $A_D^{1/2}/P_{n,}P_n$ in W/Hz$^{1/2}$<br>or $A_D^{1/2}\Delta f^{1/2}/P_n$, $P_n$ in W | m·Hz$^{1/2}$/W |
| Detectivity,<br>normalized | $D^{**}$ | $D^{**} = (\Omega/\pi)^{1/2}D^*$ | m·Hz$^{1/2}$sr$^{1/2}$/W |
| Irradiance | $E$, $E_e$ | $E = \mathrm{d}\Phi/\mathrm{d}A$ | W/m$^2$ |
| Illuminance;illumination | $E$, $E_v$ | | lx |
| Responsivity,<br>irradiance | $N$, $N_e$ | $N = V_s/E$<br>or $I_s/E$ | V·m$^2$/W§<br>A·m$^2$/W¶ |
| Responsivity,<br>illuminance | $N$, $N_v$ | | V/lx<br>A/lx |
| Noise equivalent power | $P_n$ | $P_{ns} = I_n/R$<br>or $V_n$/R | W |
| Noise equivalent power<br>spectral density | | $P_n = I_n/R\Delta f^{1/2}$<br>or $V_n/R\Delta f^{1/2}$ | W/Hz$^{1/2}$ |
| Responsivity,<br>radiant | $R$, $R_e$ | $R = V_s/\Phi$<br>or $I_s/\Phi$ | V/W<br>A/W |
| Responsivity,<br>luminous | $R$, $R_v$ | | V/lm<br>A/lm |
| Sensitivity,<br>irradiance | $S$, $S_e$ | $S = V_S/E$<br>or $I_S/E$ | V·m$^2$/W#<br>A·m$^2$/W†† |
| Sensitivity,<br>illuminance | $S$, $S_v$ | | V/lx<br>A/lx |
| Sensitivity,<br>radiant | $S$, $S_e$ | $S = V_S/\Phi$<br>or $I_S/\Phi$ | V/W<br>A/W |
| Sensitivity,<br>luminous | $S$, $S_v$ | | V/lm<br>A/lm |

† If quantities are restricted to a narrow wavelength band, the word "spectral" is included in the term and the wavelength is specified. The corresponding symbols are changed by adding the subscript $\lambda$ for a spectral concentration (e.g., N$\lambda$ or $N_{v\lambda}$) or a $\lambda$ in parentheses for a function of wavelength (e.g., N($\lambda$) or $N_v(\lambda)$).

‡ International System (SI) units. For other commonly used units, see table 5-1.

§ Although ambiguous, a commonly used unit is “volt (rms) per watt per square meter”.

¶ Although ambiguous, a commonly used unit is “ampere (rms) per watt per square meter”.

# Although ambiguous, a commonly used unit is “volt per watt per square meter”.

†† Although ambiguous, a commonly used unit is “ampere per watt per square meter”.

## 5.3 Photoemitters

### 5.3.1 General terms and definitions

**avalanche luminescent diode:** A light-emitting diode that emits luminous energy when a controlled reverse current in the breakdown region is applied.

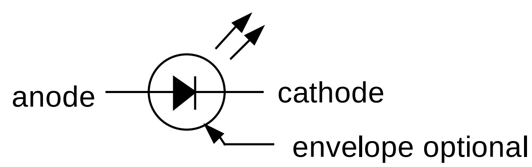
**axis of measurement:** The direction from the source of radiant energy, relative to the optical axis, in which the measurement of radiometric and/or spectroradiometric characteristics is performed.

**conversion efficiency (of a photon-emitting device):** The maximum available luminous or radiant flux output divided by the total input power.

**infrared-emitting diode (IRED):** A diode capable of emitting radiant energy in the infrared region of the spectrum as a result of the recombination of electrons and holes.
(Ref. IEC 747-5.)

**light-emitting diode (LED):** A diode capable of emitting luminous energy resulting from the recombination of electrons and holes. (Ref. IEC 747-5.)

Graphic symbol (ref. IEEE Std 315):




**photoemissive device:** Deprecated as a synonym for “photoemitter”.

**photoemitter:** A device that emits electromagnetic radiation in the visible, infrared, and/or ultraviolet spectral regions.

**quantum efficiency, internal:** The ratio of the number of photons internally produced to the number of electrons flowing into the radiation source.

**quantum efficiency, external:** The ratio of the number of photons radiated to the number of electrons flowing into the radiation source.

**radiant efficiency:** The total radiant flux emitted divided by the total input power.

**visible-light-emitting diode (VLED):** Deprecated synonym for “light-emitting diode”.

**5.3 Photoemitters (cont'd)**

**5.3.2 Letter symbols, terms, and definitions**

**For symbols, defining equations, and standard units associated with photometric quantities, see table 5-3, and for those associated with radiometric quantities, see Table 5-4.**

| | |
|---|---|
| $I$, $I_e$ | **radiant intensity:** The radiant flux per unit solid angle in a given direction. |
| $I$, $I_v$ | **luminous intensity:** The luminous flux per unit solid angle in a given direction. |
| | **luminous intensity, angular:** The luminous flux per unit solid angle if the given direction is at a specified angle from the optical axis. |
| | **luminous intensity, axial:** The luminous flux per unit solid angle if the given direction is the optical axis. |
| $K$ | **luminous efficacy:** The total luminous flux divided by the total radiant flux. (Ref. ANSI/IEEE Std 100.) |
| $K(\lambda)$ | **spectral luminous efficacy:** The luminous flux at a given wavelength divided by the radiant flux at that wavelength. (Ref. ANSI/IEEE Std 100.) |
| $L$, $L_e$ | **radiance:** The radiant intensity of any surface in a given direction per unit of projected area of the surface as viewed from that direction. |
| $L$, $L_v$ | **luminance:** The luminous intensity of any surface in a given direction per unit of projected area of the surface as viewed from that direction. |
| $M$, $M_e$ | **radiant exitance:** The density of the radiant flux leaving an emitter surface, i.e., the radiant flux divided by the area of emitting surface. |
| $M$, $M_v$ | **luminous exitance:** The density of the luminous flux leaving an emitter surface, i.e., the luminous flux divided by the area of emitting surface. |
| $M_{bb}$ | **total blackbody exitance:** The total radiant exitance of a blackbody at all wavelengths. |
| $M_{\lambda p}$, $M_{e\lambda p}$ | **peak spectral radiant exitance:** The radiant exitance at the wavelength at which its spectral exitance is at the peak value. |
| $M_{\lambda p}$, $M_{v\lambda p}$ | **peak spectral luminous exitance:** The luminous exitance at the wavelength at which its spectral exitance is at the peak value. |

**5.3 Photoemitters (cont'd)**

**5.3.2 Letter symbols, terms, and definitions (cont'd)**

$t_f$ **radiant-pulse fall time:** The time interval during which the radiant flux changes from 90% to 10% of its peak on-state value.

$t_{off}$ **turn-off time:** The time interval between a step change in input current that is switching the diode from its emitting to its nonemitting state and the instant at which the radiant flux reaches 10% of its peak on-state value.

$t_{on}$ **turn-on time:** The time interval between a step change in input current that is switching the diode from its nonemitting to its emitting state and the instant at which the radiant flux reaches 90% of its peak on-state value.

$t_r$ **radiant-pulse rise time:** The time interval during which the radiant flux changes from 10% to 90% of its peak on-state value.

$V(\lambda)$ **spectral luminous efficiency:** The ratio of the luminous efficacy for a given wavelength to the luminous efficacy at the wavelength of maximum luminous efficacy. (Ref. ANSI/IEEE Std 100.)

$w$, $w_e$ **radiant density:** The radiant energy per unit volume.

$w$, $w_v$ **luminous density:** The luminous energy per unit volume.

$\Delta\lambda$ **spectral bandwidth:** The wavelength interval in which a photometric or radiometric quantity is at least half of its maximum value. (Ref. IEC 747-5.)

$\varepsilon$ **emissivity:** The ratio of the radiant exitance of the measured specimen to that of a blackbody at the same temperature.

$\theta_{HI}$ **half-intensity beam angle:** The full-cone angle within which the radiant intensity is at least half of the maximum intensity. (Ref. IEC 747-5.)

$\lambda_p$ **peak-emission wavelength:** The wavelength at which the spectral radiant intensity is maximum. (Ref. IEC 747-5.)

**5.3 Photoemitters (cont'd)**

**5.3.2 Letter symbols, terms, and definitions (cont'd)**

**Table 5-3 — Symbols, defining equations, and standard units for fundamental photometric quantities**

| Quantity† | Quantity symbol† | Defining equation‡ | Unit symbol§ |
|---|---|---|---|
| Luminous energy (quantity of light) | $Q$, $Q_v$ | $Q_v = \int_{380}^{780} K(\lambda) Q_{e\lambda}\, d\lambda$ | lm·s |
| Luminous density | $w$, $w_v$ | $w = dQ/dV$ | lm·s/m$^3$ |
| Luminous flux | $\Phi$, $\Phi_v$ | $\Phi = dQ/dt$ | lm |
| Luminous exitance | $M$, $M_v$ | $M = d\Phi/dA$ | lm/m$^2$ |
| Luminous intensity (candlepower) | $I$, $I_v$ | $I = d\Phi/d\omega$ (ω = the solid angle through which flux from a point source is radiated) | cd |
| Luminance (photometric brightness) | $L$, $L_v$ | $L = d^2\Phi/d\omega\,(dA \cos\theta)$ or $L = dI/(dA \cos\theta)$ ($\theta$ = the angle between the line of sight and the normal to the surface being considered) | nt |
| Luminous efficacy | $K$ | $K = \Phi_v/\Phi_e$ | lm/W |
| Luminous efficiency, spectral | $V(\lambda)$ | $V(\lambda) = K(\lambda)/K(\lambda)_{max}$ | — |

† If quantities are restricted to a narrow wavelength band, the word "spectral" is included in the term and the wavelength is specified. The corresponding symbols are changed by adding the subscript $\lambda$ for a spectral concentration (e.g., $Q_\lambda$ or $Q_{v\lambda}$) or a $\lambda$ in parentheses for a function of wavelength (e.g., $K(\lambda)$).

‡ The equations in this column are given merely for identification.

§ International System (SI) unit. For other commonly used units, see table 5-1.

NOTE The primary symbols for radiometric quantities (see table 5-4) are the same as those for the corresponding photometric quantities (see above). When it is necessary to differentiate them, the subscripts e and v, respectively, should be used, e.g., $Q_e$ and $Q_v$.

**5.3 Photoemitters (cont'd)**

**5.3.2 Letter symbols, terms, and definitions (cont'd)**

**Table 5-4 — Symbols, defining equations, and standard units for fundamental radiometric quantities**

| Quantity† | Quantity symbol† | Defining equation‡ | Unit symbol§ |
|---|---|---|---|
| Radiant energy | $Q$, $Q_e$ | | J |
| Radiant density | $w$, $w_e$ | $w = dQ/dV$ | $J/m^3$ |
| Radiant flux | $\Phi$, $\Phi_e$ | $\Phi = dQ/dt$ | W |
| Radiant exitance | $M$, $M_e$ | $M = d\Phi/dA$ | $W/m^2$ |
| Radiant intensity | $I$, $I_e$ | $I = d\Phi/d\omega$ (ω = the solid angle through which flux from a point source is radiated) | W/sr |
| Radiance | $L$, $L_e$ | $L = d^2\Phi/d\omega\,(dA \cos\theta)$ or $L = dI/(dA \cos\theta)$ ($\theta$ = the angle between the line of sight and the normal to the surface being considered) | $W/(sr \cdot m^2)$ |
| Emissivity | $\varepsilon$ | $\varepsilon = M/M_{bb}$ ($M$ and $M_{bb}$ are, respectively, the radiant exitance of the measured specimen and that of a blackbody at the same temperature as the specimen) | — |

**†** If quantities are restricted to a narrow wavelength band, the word "spectral" is included in the term and the wavelength is specified. The corresponding symbols are changed by adding the subscript $\lambda$ for a spectral concentration (e.g., $Q_\lambda$ or $Q_{v\lambda}$) or a $\lambda$ in parentheses for a function of wavelength (e.g., $L(\lambda)$).

‡ The equations in this column are given merely for identification.

§ International System (SI) unit. For other commonly used units, see table 5-1.

NOTE The primary symbols for photometric quantities (see table 5-3) are the same as those for the corresponding radiometric quantities (see above). When it is necessary to differentiate them, the subscripts v and e, respectively, should be used, e.g., $Q_v$ and $Q_e$.

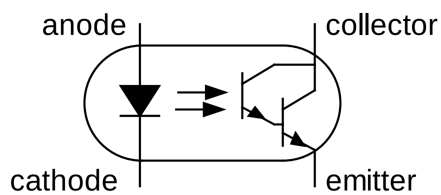
## 5.4 Optocouplers (photocouplers, optoisolators)

### 5.4.1 General terms and definitions

**optocoupler; photocoupler; optoisolator:** An optoelectronic device designed for the transformation of electrical signals by utilizing optical radiant energy to provide coupling with electrical isolation between the input and the output. (Ref. IEC 747-5.)

**photodarlington coupler:** An optocoupler whose photosensitive element is a Darlington phototransistor.

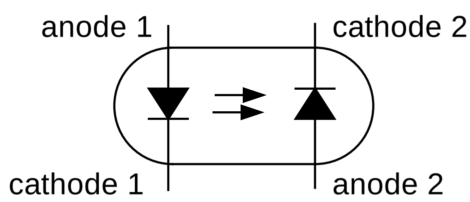
Graphic symbol:




NOTE The base regions may or may not be brought out as electrical terminals.

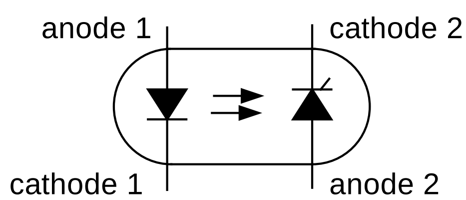
**photodiode coupler:** An optocoupler whose photosensitive element is a photodiode.

Graphic symbol:




**photothyristor coupler:** An optocoupler whose photosensitive element is a photothyristor.

Graphic symbol:



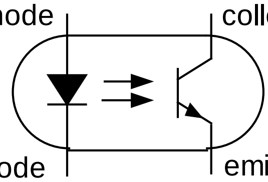

NOTE A gate terminal may or may not be provided.

### 5.4 Optocouplers (photocouplers, optoisolators) (cont'd)

#### 5.4.1 General terms and definitions (cont'd)

**phototransistor coupler:** An optocoupler whose photosensitive element is a phototransistor.

Graphic symbol:




NOTE A base terminal may or may not be provided.

#### 5.4.2 Letter symbols, terms, and definitions

NOTE The terminology for currents, voltages, and other parameters of the photoemitter element and of the photosensitive element should reflect the usage for the individual elements (diode, transistor, thyristor, etc.).

$C_{io}$ **input-to-output internal capacitance; transcapacitance:** The capacitance between the output of the photosensitive element and the input of the photoemitter element.

$h_F$ or CTR† **current transfer ratio:** The ratio of the output current of the photosensitive element to the input current of the photoemitter element. (Ref. IEC 747-5.)

$I_{IO}$ **dc input-to-output current; isolation current:** The dc current between any input terminal and any output terminal.

$r_{IO}$ **isolation resistance:** The dc resistance between the photoemitter element input and the photosensitive element output.

$t_d$ **delay time:**
$t_f$ **fall time:**
$t_{off}$ **turn-off time:**
$t_{on}$ **turn-on time:**
$t_r$ **rise time:**
$t_s$ **storage time:** For optocouplers with transistor outputs, the definitions of the corresponding terms in 4.1.2 apply.

$V_{IO}$ **dc input-to-output voltage; isolation voltage**: The dc voltage between any input terminal and any output terminal. (Ref. IEC 747-5.)

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† The abbreviation CTR is often used for $h_F$; however, the symbol $h_F$ is preferred.

# SECTION 6 THYRISTORS AND PROGRAMMABLE UNIJUNCTION TRANSISTORS

## 6.1 Thyristors

### 6.1.1 General terms and definitions

**anode-cathode voltage; anode voltage (of a unidirectional diode thyristor):** The voltage between the anode and cathode terminals.

NOTE The anode-cathode voltage is called positive when the anode potential is higher than the cathode potential and called negative when the anode potential is lower than the cathode potential.

**anode-cathode voltage; anode voltage (of a unidirectional triode thyristor):** The voltage between the anode and the cathode terminals.

**anode terminal (A) (of a unidirectional diode thyristor):** The terminal to which the current flows from the external circuit when the thyristor is in the on state.

**anode terminal (A) (of a unidirectional triode thyristor):** The main terminal to which the principal current flows from the circuit being controlled when the thyristor is in the on state.

NOTE A second anode terminal may be provided for connecting to the control circuit of an n-gate thyristor.

**breakdown region, (reverse):** The portion of the voltage-current characteristic beyond the initiation of breakdown for an increasing magnitude of reverse current. (See Figure 6-3.)

**breakover point:** In a quadrant in which switching can occur, the point for which the differential resistance is zero and the off-state voltage reaches a maximum value. (See Figures 6-1 through 6-4.)

**cathode terminal (K) (of a unidirectional diode thyristor):** The terminal from which the current flows to the external circuit when the thyristor is in the on state.

**cathode terminal (K) (of a unidirectional triode thyristor):** The main terminal from which the principal current flows to the circuit being controlled when the thyristor is in the on state.

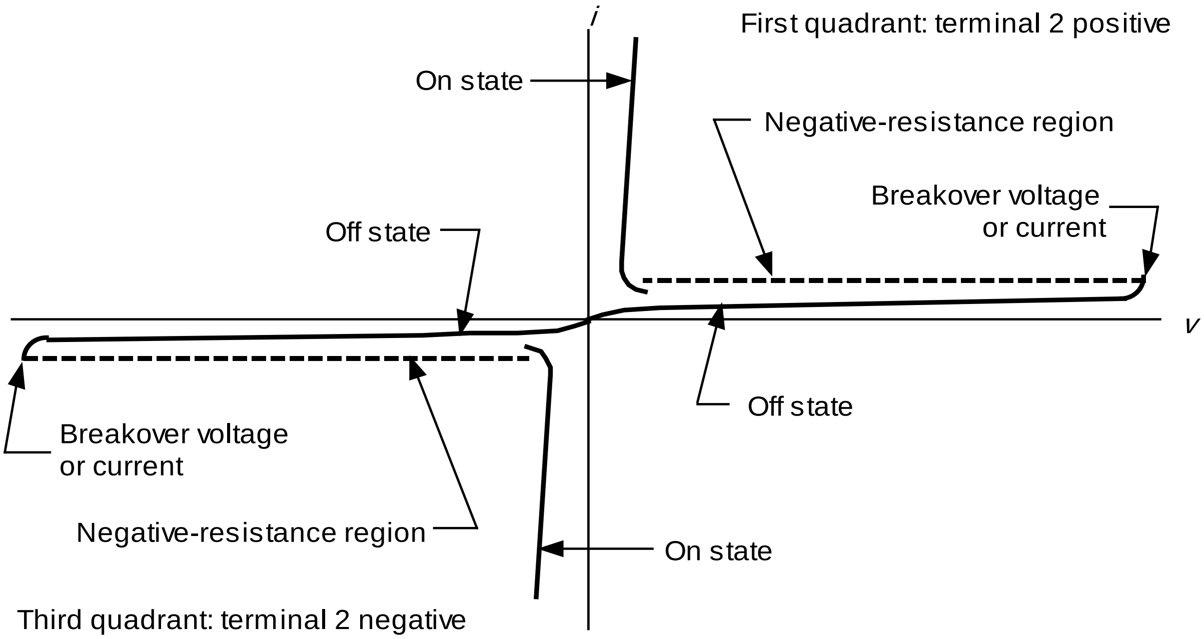
NOTE A second cathode terminal may be provided for connecting to the control circuit of a p-gate thyristor.

**characteristic, (static) (of a bidirectional diode thyristor):** A function, usually represented graphically, relating the thyristor voltage to the thyristor current for a specified virtual junction temperature, under conditions of internal electrical and thermal equilibrium. (See Figure 6-1.)

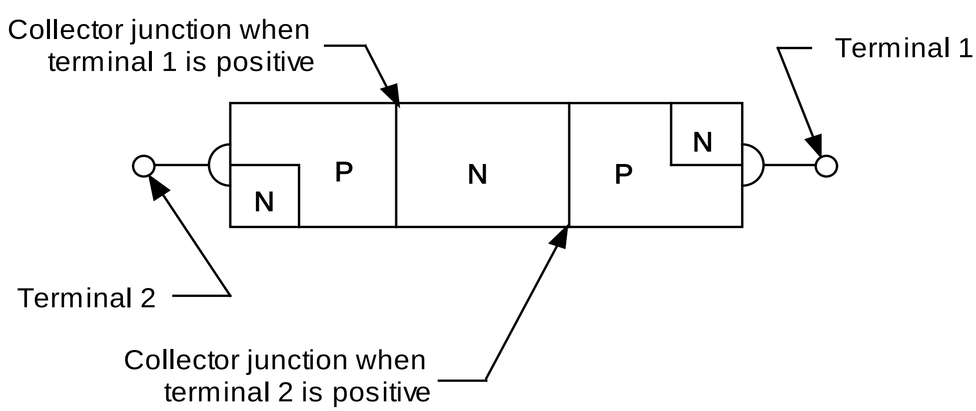
NOTE The word “static” is usually omitted except when a distinction between static and dynamic characteristics is necessary.

**6.1 Thyristors (cont'd)**

**6.1.1 General terms and definitions (cont'd)**




**(a) Principal voltage-current characteristics**

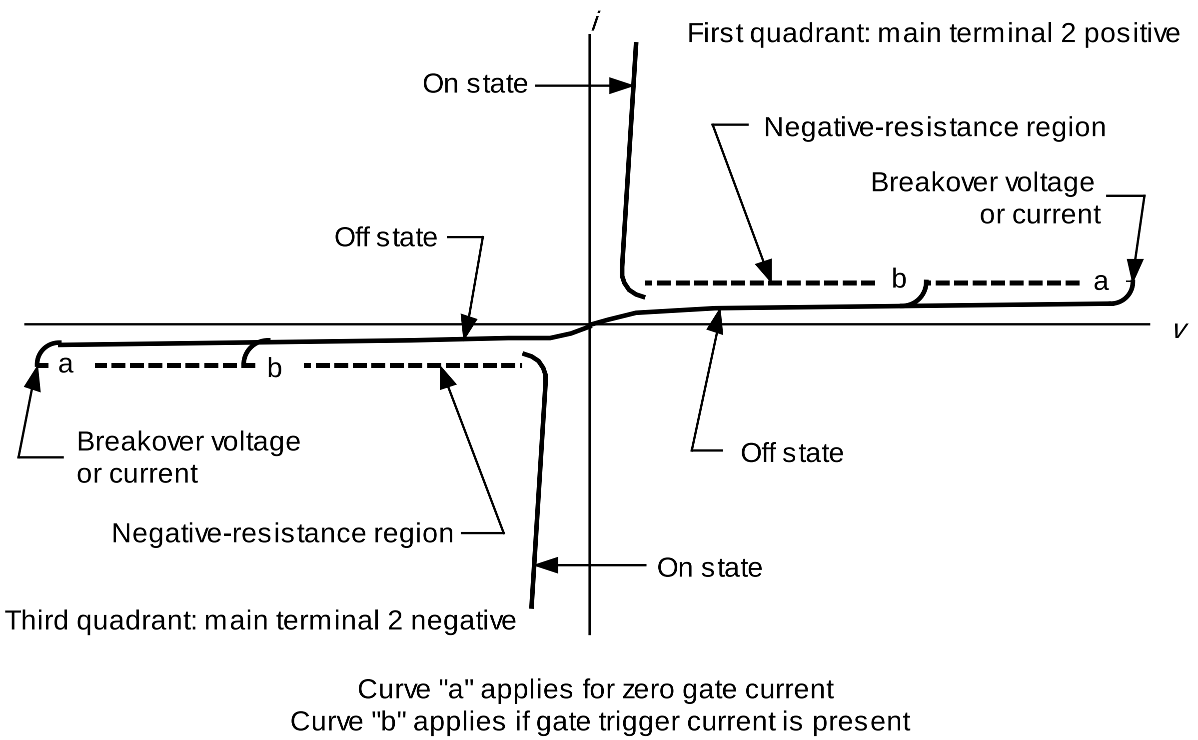



**(b) Schematic representation**

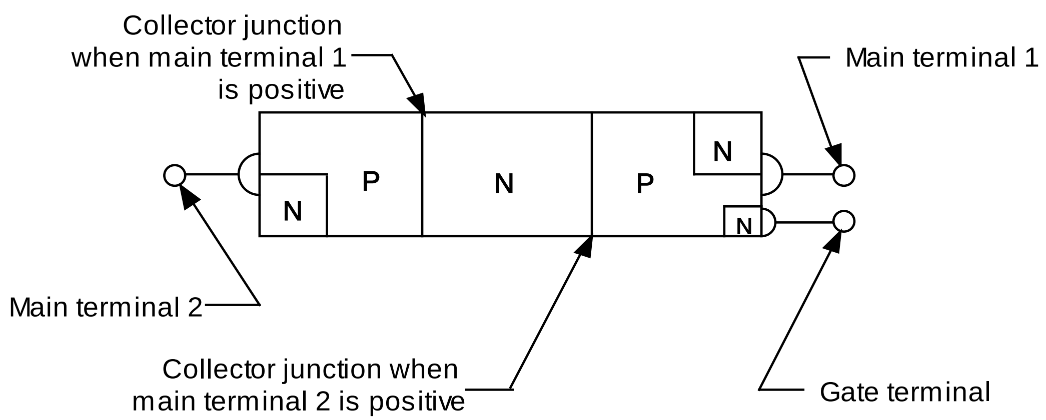
**Figure 6-1 — Bidirectional diode thyristor**

**6.1 Thyristors (cont'd)**

**6.1.1 General terms and definitions (cont'd)**




**(a) Principal voltage-current characteristics**

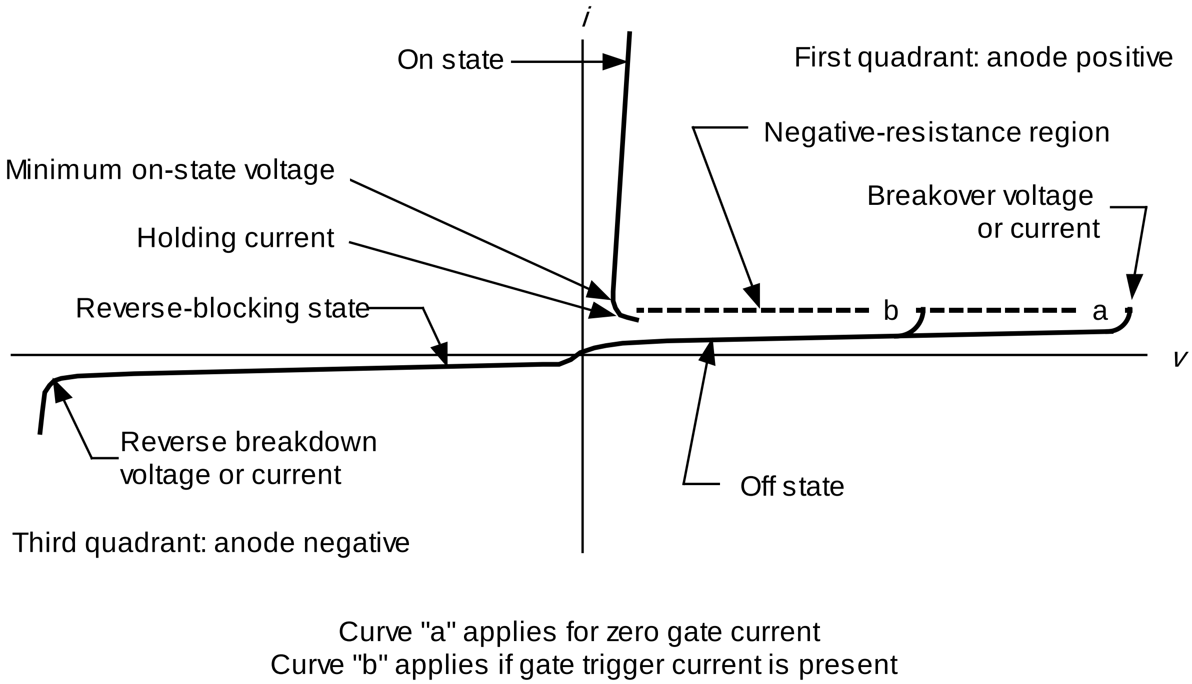



**(b) Schematic representation**

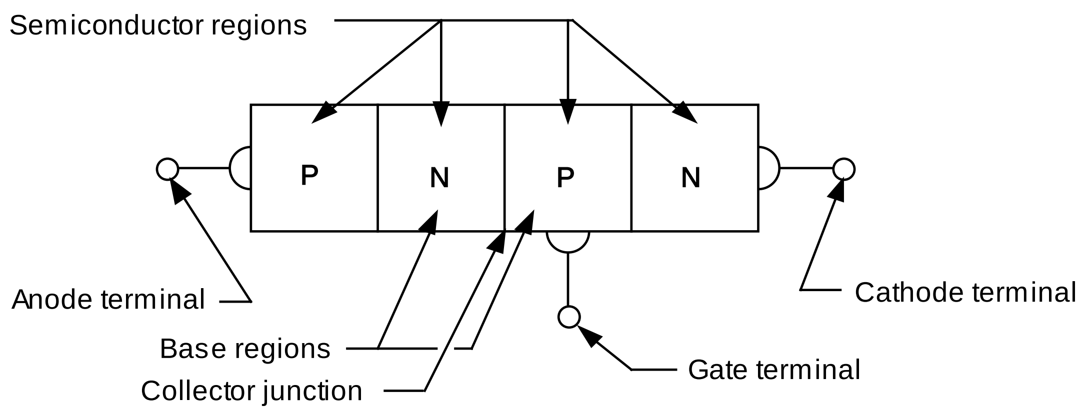
**Figure 6-2 — Bidirectional triode thyristor (triac)**

**6.1 Thyristors (cont'd)**

**6.1.1 General terms and definitions (cont'd)**




**(a) Principal voltage-current characteristics**

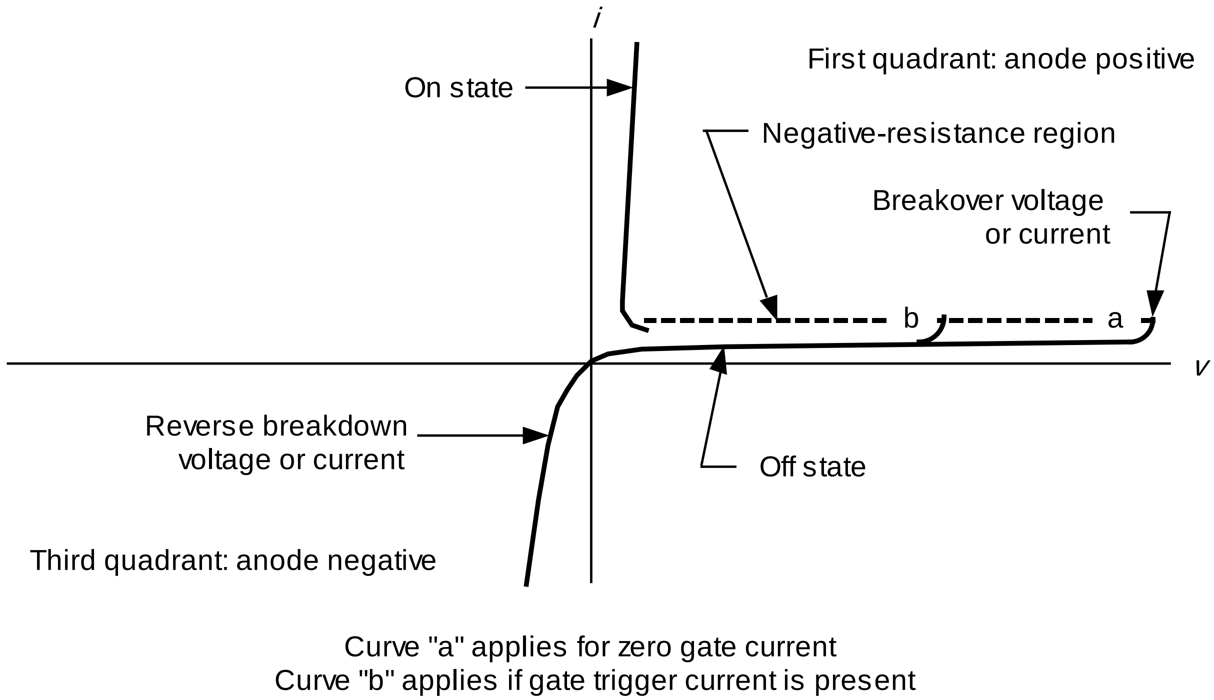



**(b) P-gate thyristor schematic representation**

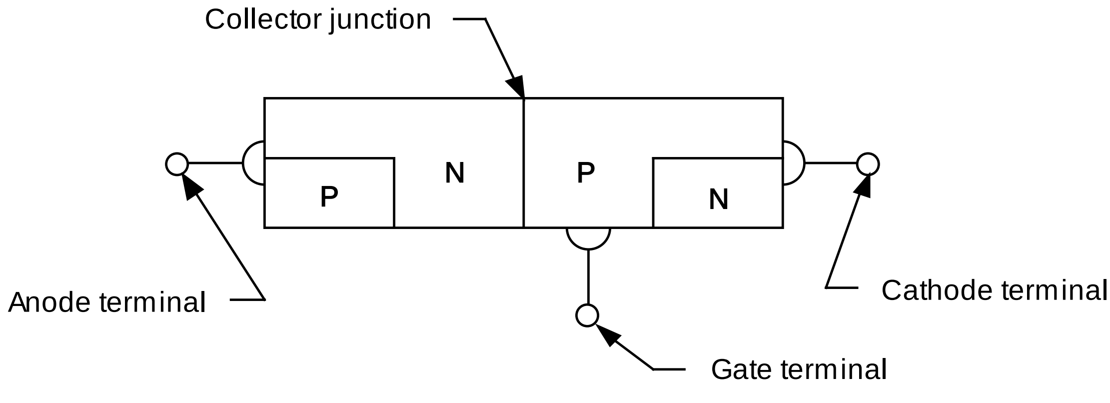
**Figure 6-3 — Reverse-blocking thyristor**

**6.1 Thyristors (cont'd)**

**6.1.1 General terms and definitions (cont'd)**




**(a) Principal voltage-current characteristics**




**(b) P-gate thyristor schematic representation**

**Figure 6-4 — Reverse-conducting thyristor**

### 6.1 Thyristors (cont'd)

#### 6.1.1 General terms and definitions (cont'd)

**characteristic, (static) (of a unidirectional diode thyristor):** A function, usually represented graphically, relating the anode voltage to the anode current for a specified virtual junction temperature, under conditions of internal electrical and thermal equilibrium. (See Figures 6-3 and 6-4.)

NOTE The word "static" is usually omitted except when a distinction between static and dynamic characteristics is necessary.

**collector junction:** The junction across which the polarity of the voltage reverses when switching occurs. (See Figures 6-1 through 6-4.) (Ref. EIA-397.)

**dc trigger point (on the gate characteristic):** The point on the gate characteristic $V_{FG}$ = f($I_{FG}$) at which, for continuously rising gate current or gate voltage, the thyristor switches from the off state to the on state.

**diac:** An alternative term for "thyristor, bidirectional diode".

NOTE Most devices designated as "diac" have been three-layer devices (npn or pnp), but others have had five layers. Some early versions were unidirectional, and a 1975 IEEE definition included them as well as bidirectional types.

**gate current:** The (control) current into the gate terminal.

**gate region:** A control region in which a momentary injection of controlling charge causes a regenerative turn-on action.

NOTE This definition applies for the actual operating mode of the device regardless of the name of any associated terminal.

**gate terminal (G):** The terminal unique to the control circuit.

**main terminal 1 (MT1) (of a bidirectional triode thyristor):** The main terminal intended by the thyristor manufacturer to conduct the control current in addition to the principal current.

NOTE Some bidirectional triode thyristors are completely symmetrical, e.g., SBS thyristors. For these, the choice for the manufacturer is arbitrary, and the user can return the control circuit to whichever main terminal will provide the required polarity of gate current.

**main terminal 2 (MT2) (of a bidirectional triode thyristor):** The other main terminal after main terminal 1 has been designated by the thyristor manufacturer.

**main terminals:** The two terminals through which the principal current flows.

## 6.1 Thyristors (cont'd)

### 6.1.1 General terms and definitions (cont'd)

**mean partial power loss:** The mean value of the instantaneous power loss in a particular period of the cycle, averaged over the full cycle.

NOTE 1 The term “power dissipation” has been used in the past as a true synonym for “power loss”. This is no longer recommended. The term “loss” should be related to the electrical loss ($V \cdot I$) at the place of its origin, and the term “dissipation” should be related to the heat that is dissipated from the surface of the device into the environment. Different terms must be provided for the two quantities because, due to internal storage of heat, the two differ with time.

NOTE 2 As an exception, “mean power dissipation” may still be used as a synonym for “mean power loss”, but only when appropriate, i.e., if the differences with time have no influence on the mean values of the two. This is the case for mean values that are averaged over a cycle. In the latter case, the subscript “(AV)” is usually omitted from the letter symbols.

**negative differential-resistance region:** Any portion of the characteristic within which the differential resistance is negative. (See Figures 6-1 through 6-4.)

**off impedance:** The small-signal impedance between the terminals through which the principal current flows when the thyristor is in the off state. (Ref. EIA-397.)

**off state:** The state of a thyristor, in a quadrant in which switching can occur, that corresponds to the portion of the characteristic between the origin and the breakover point. (See Figures 6-1 through 6-4.)

**on impedance:** The small-signal impedance between the terminals through which the principal current flows when the thyristor is in the on state. (Ref. EIA-397.)

**on state:** The state of a thyristor, in a quadrant in which switching can occur, that corresponds to the low-resistance, low-voltage portion of the characteristic. (See Figures 6-1 through 6-4.)

**principal current:** The current that is switched (controlled) by the thyristor.

**principal voltage:** The voltage (potential difference) between the main terminals.

NOTE 1 In the case of unidirectional triode thyristors, the principal voltage is called positive when the anode potential is more positive than the cathode potential and called negative when the anode potential is less positive than the cathode potential. Thus, for these thyristors, “principal voltage” and “anode-cathode voltage” are synonymous.

NOTE 2 In the case of bidirectional thyristors, the principal voltage is called positive when the potential of main terminal 2 is more positive than the potential of main terminal 1.

## 6.1 Thyristors (cont'd)

### 6.1.1 General terms and definitions (cont'd)

**principal (voltage-current) characteristic, (static) (of a bidirectional triode thyristor):** A function, usually represented graphically, relating the principal voltage to the principal current for a specified virtual junction temperature, under conditions of internal electrical and thermal equilibrium. (See Figure 6-2.)

NOTE 1 Where applicable, the characteristic may be given with the gate current as a parameter.

NOTE 2 The word "static" is usually omitted except when a distinction between static and dynamic characteristics is necessary.

**principal (voltage-current) characteristic, (static) (of a unidirectional triode thyristor):** A function, usually represented graphically, relating the anode voltage to the anode current for a specified virtual junction temperature, under conditions of internal electrical and thermal equilibrium. (See Figures 6-3 and 6-4.)

NOTE 1 Where applicable, the characteristic may be given with the gate current as a parameter.

NOTE 2 The word "static" is usually omitted except when a distinction between static and dynamic characteristics is necessary.

**prospective triggering area:** In a graphical presentation $V_{FG} = f(I_{FG})$, the area enclosed between the lines for the specified values of upper-limit and lower-limit gate trigger current and gate trigger voltage. (See Figure 6-5.)

**reverse-blocking state:** The state of a reverse-blocking or asymmetrical thyristor that corresponds to a reverse voltage between the origin and the beginning of the reverse breakdown region. (See Figure 6-3.)

**reverse-conducting state:** The state of a reverse-conducting triode thyristor that corresponds to the third quadrant of the characteristic. (See Figure 6-4.)

**semiconductor controlled rectifier (SCR); silicon controlled rectifier (SCR):** Synonyms for "thyristor, reverse blocking triode".

**straight-line approximation of the on-state characteristic:** An approximation of the current versus voltage on-state characteristic by means of a straight line that crosses this characteristic at two specified points. (See Figure 6-6a.)

**straight-line approximation of the reverse-conducting characteristic:** An approximation of the current versus voltage reverse-conducting characteristic by means of a straight line that crosses this characteristic at two specified points. (See Figure 6-6b.)

**switching quadrant:** A quadrant of the principal voltage-current characteristic in which a device is intended to switch between the off state and the on state.

**6.1 Thyristors (cont'd)**

**6.1.1 General terms and definitions (cont'd)**

**terminal 1 (T1) (of a bidirectional diode thyristor):** The terminal that is designated “1” by the manufacturer.

**terminal 2 (T2) (of a bidirectional diode thyristor):** The terminal that is designated “2” by the manufacturer.

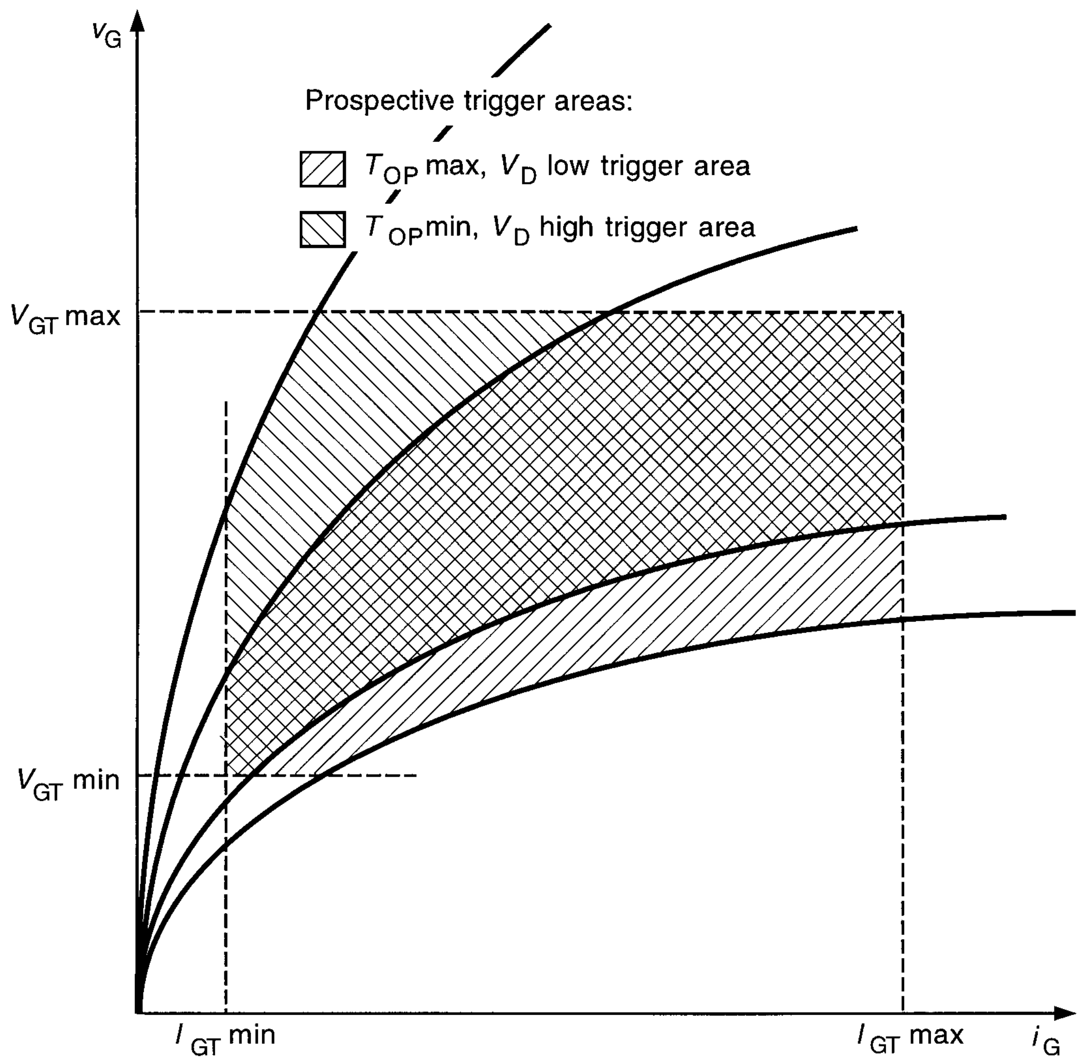
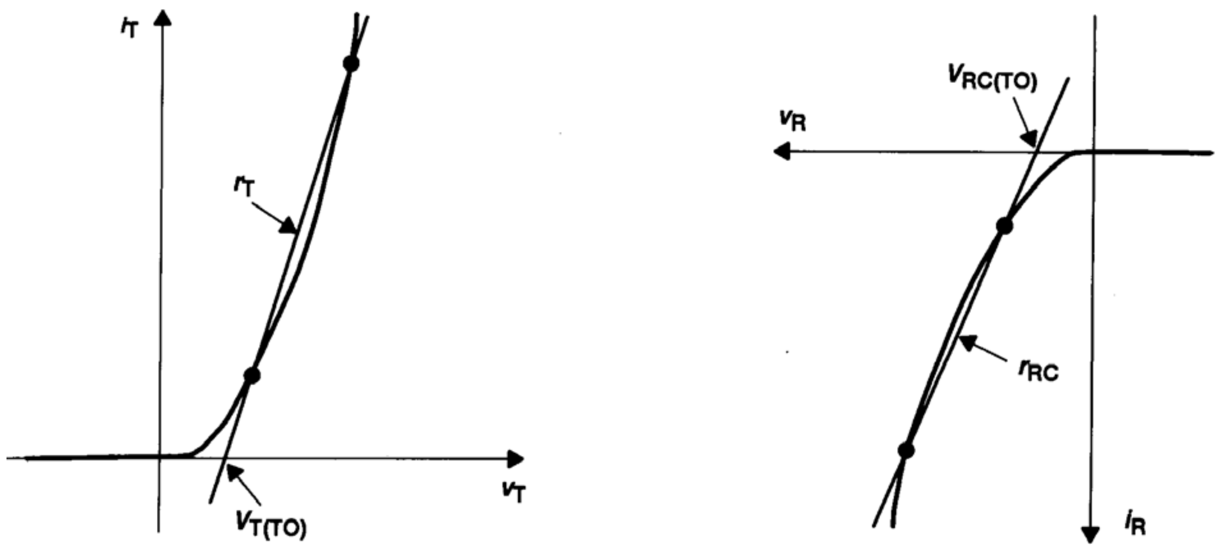



**Figure 6-5 — Gate characteristics and prospective trigger areas**

**6.1 Thyristors (cont'd)**

**6.1.1 General terms and definitions (cont'd)**




(

**a) On-state characteristics** **(b) Reverse-conducting characteristics**

**Figure 6-6 — Straight-line approximation of characteristics**

**thyristor** (general)**:** A semiconductor device that is capable, due to internal feedback, of assuming either of two stable states and maintaining the assumed state either with no sustained control current or voltage or at least with considerably less than that necessary to initially establish that state, and that is designed to operate as a switch for the principal or on-state current.

NOTE 1 A thyristor is a switch that can be switched on either for only one direction of the principal current (a unidirectional thyristor) or for both directions (a bidirectional thyristor).

NOTE 2 The usual configuration is a pnpn configuration to which can be added other elements needed for additional functions.

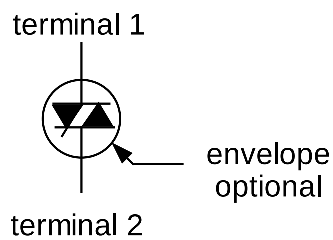
NOTE 3 The term “thyristor” may be used for any member of the pnpn family (including devices having more than four layers) when such use does not result in ambiguity or misunderstanding. In particular, the abbreviated term “thyristor” is widely used for the reverse-blocking triode thyristor, formerly called “SCR”, “semiconductor controlled rectifier”, or “silicon controlled rectifier”.

**6.1 Thyristors (cont'd)**

**6.1.1 General terms and definitions (cont'd)**

**thyristor, bidirectional diode:** A two-terminal thyristor having substantially the same switching behavior in the first and third quadrants of the thyristor voltage-current characteristic. (See Figure 6-1.)

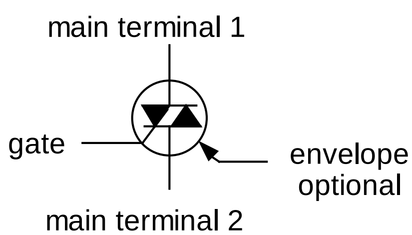
Graphic symbol (ref. IEEE Std 315):




**thyristor, bidirectional triode:** A three-terminal thyristor having substantially the same switching behavior in the first and third quadrants of the principal characteristic. (See Figure 6-2.)

NOTE Usually the configuration is pnpnp or npnpn.

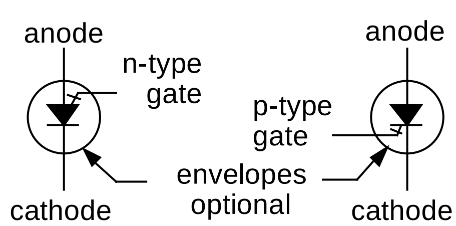
Graphic symbol (ref. IEEE Std 315):




**thyristor, gate-turn-off, (asymmetrical):** A gate-turn-off thyristor whose rated reverse voltage is significantly lower than its rated off-state voltage.

**thyristor, gate-turn-off, (reverse-blocking); GTO thyristor:** A reverse-blocking triode thyristor that can be switched from the on state to the off state as well as from the off state to the on state by applying control signals of appropriate polarity to the gate terminal.

Graphic symbols (ref. IEEE Std 315):



## 6.1 Thyristors (cont'd)

### 6.1.1 General terms and definitions (cont'd)

**thyristor, gate-turn-off, reverse-conducting:** A reverse-conducting triode thyristor that can be switched from the on state to the off state as well as from the off state to the on state by applying control signals of appropriate polarity to the gate terminal.

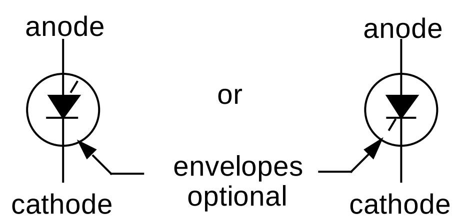
**thyristor, gate-turn-off, symmetrical:** A gate-turn-off thyristor whose rated reverse voltage and rated off-state voltage are essentially equal.

**thyristor, n-gate:** A unidirectional triode thyristor whose gate terminal is connected to the n-region nearest the anode and that is normally switched to the on-state by applying a negative signal to the gate terminal with respect to the anode terminal.

**thyristor, p-gate:** A unidirectional triode thyristor whose gate terminal is connected to the p-region nearest the cathode and that is normally switched to the on-state by applying a positive signal to the gate terminal with respect to the cathode terminal.

**thyristor, reverse-blocking diode:** A unidirectional diode thyristor that exhibits a blocking state in the reverse direction. (See Figure 6-3.)

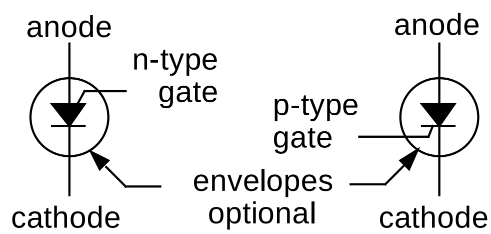
Graphic symbols (ref. IEEE Std 315):




**thyristor, reverse-blocking triode:** A unidirectional triode thyristor that exhibits a blocking state in the reverse direction. (See Figure 6-3.)

NOTE If no ambiguity is likely to occur, the term may be abbreviated to "thyristor".

Graphic symbols (ref. IEEE Std 315):



**6.1 Thyristors (cont'd)**

**6.1.1 General terms and definitions (cont'd)**

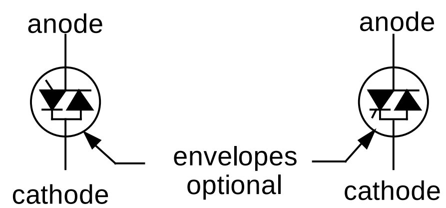
**thyristor, reverse-blocking triode, asymmetrical:** A reverse-blocking triode thyristor whose rated reverse voltage is significantly lower than its rated off-state voltage. (See Figure 6-3.)

**thyristor, reverse-blocking triode, (symmetrical):** A reverse-blocking triode thyristor whose rated reverse voltage and rated off-state voltage are essentially equal.

**thyristor, reverse-conducting diode:** A unidirectional diode thyristor that conducts large currents in the reverse direction at reverse voltages comparable in magnitude to the forward on-state voltage. (See Figure 6-4.)

NOTE Thyristors intended for use as surge protective devices (see 7.2) and meeting this definition are referred to as forward conducting rather than reverse conducting.

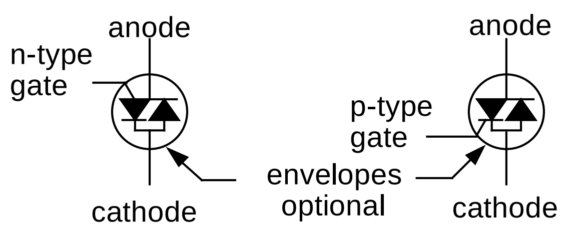
Graphic symbols:




**thyristor, reverse-conducting triode:** A unidirectional triode thyristor that conducts large currents in the reverse direction at reverse voltages comparable in magnitude to the forward on-state voltage. (See Figure 6-4.)

NOTE Thyristors intended for use as surge protective devices (see 7.2) and meeting this definition are referred to as forward conducting rather than reverse conducting.

Graphic symbols:




**thyristor, unidirectional diode:** A two-terminal thyristor that can switch only when the anode voltage is positive. (See Figures 6-3 and 6-4.)

**6.1 Thyristors (cont'd)**

**6.1.1 General terms and definitions (cont'd)**

**thyristor, unidirectional triode:** A three-terminal thyristor that can switch only when the anode voltage is positive. (See Figures 6-3 and 6-4.)

NOTE In this definition, a second cathode or anode terminal for connecting to the control circuit is not counted.

**thyristor voltage (of a bidirectional diode thyristor):** The voltage between the two terminals.

NOTE The polarity of the thyristor voltage (with regard to terminals 1 and 2) must be specified.

**triac:** An alternative term for "thyristor, bidirectional triode".

**6.1.2 Letter symbols, terms, and definitions (not applicable to thyristor surge suppressors; see section 7)**

$(\mathrm{d}i_T/\mathrm{d}t)\mathrm{cr}$ **critical rate of rise of on-state current:** The highest value of the rate of rise of on-state current that a thyristor can withstand without deleterious effect.

$(\mathrm{d}v_{D(com)}/\mathrm{d}t)\mathrm{cr}$ **critical rate of rise of commutating voltage (of a reverse-conducting triode thyristor):** The highest value of the rate of rise of off-state voltage, immediately following reverse current conduction, that will not cause switching from the off state to the on state.

NOTE 1 The measuring method for the rate of rise must be specified.

NOTE 2 If no ambiguity is likely to result, the shorter expression $\mathrm{d}v(\mathrm{com})/\mathrm{d}t$ may be used.

$(\mathrm{d}v_{D(com)}/\mathrm{d}t)\mathrm{cr}$ **critical rate of rise of commutating voltage; critical rate of rise of the reapplied off-state voltage (of a triac):** The highest value of the rate of rise of off-state voltage, immediately following on-state current conduction in the opposite direction, that will not cause switching from the off state to the on state.

NOTE 1 The measuring method for the rate of rise must be specified.

NOTE 2 If no ambiguity is likely to result, the shorter expression $\mathrm{d}v(\mathrm{com})/\mathrm{d}t$ may be used.

$(\mathrm{d}v_D/\mathrm{d}t)\mathrm{cr}$ **critical rate of rise of off-state voltage:** The highest value of the rate of rise of off-state voltage that will not cause switching from the off state to the on state.

NOTE 1 The measuring method for the rate of rise must be specified.

NOTE 2 If no ambiguity is likely to result, the shorter expression $\mathrm{d}v/\mathrm{d}t$ may be used.

## 6.1 Thyristors (cont'd)

### 6.1.2 Letter symbols, terms, and definitions (not applicable to thyristor surge suppressors; see section 7) (cont'd)

$E_{DQ}$ — **turn-off energy loss:** The energy loss during the turn-off interval.

$I^2t$ — **$I^2t$ value (of a surge on-state current):** A value used for the specification of a maximum-rated value of surge on-state current:

$$I^2t = \int_0^{t_i} i^2 \cdot dt,$$

where $t_i$ is a specified short integration duration.

$I^2t$ — **case nonrupture $I^2t$ value:** The value of $I^2t$ that should not be exceeded in order to avoid bursting of the case or the emission of a plasma beam, under specified conditions of on-state current, waveshape, and time, and given as follows:

$$I^2t = \int_0^{t_p} i^2 \cdot dt,$$

where $t_p$ is the current pulse duration.

NOTE This definition implies that a fine crack in the case would be tolerated, if found in a device subjected to the peak case nonrupture current, provided that no plasma beam was emitted, parts of the case did not break away, and the device did not melt externally or burst into flames.

$I_{(BO)}$, $i_{(BO)}$ — **breakover current*:** The anode, principal, or thyristor current at the breakover point. (See Figures 6-1 through 6-4.)

$I_{(BR)}$, $i_{(BR)}$ — **breakdown current*:** The anode, principal, or thyristor current at the breakdown voltage.

$I_D$, $I_{D(RMS)}$, $I_{D(AV)}$, $i_D$, $I_{DM}$ — **off-state current*:** The anode, principal, or thyristor current when the thyristor is in the off state. (See Figures 6-1 through 6-4.)

$I_{DQM}$ — **off-state recovery current:** The maximum (peak) value of the current that results from the application of off-state voltage during the transition from an opposite-polarity off state, a reverse-blocking state, or a reverse-conducting state.

$I_{DRM}$ — **repetitive peak off-state current:** The maximum (peak) instantaneous value of the off-state current that results from the application of repetitive peak off-state voltage. (Ref. EIA-397.)

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* See Table 6-1 for detailed meaning of symbols.

**6.1 Thyristors (cont'd)**

**6.1.2 Letter symbols, terms, and definitions (not applicable to thyristor surge suppressors; see section 7) (cont'd)**

| | |
|---|---|
| $I_{FG}$ | **forward gate current:** (1) For p-gate thyristors, the positive gate current.<br><br>(2) For n-gate thyristors, the negative gate current. |
| $I_{FGB}$ | **on-state gate bias current:** The forward gate current during the period following the period within which thyristor was turning on. |
| $I_{FGsus}$ | **sustaining gate current (of a GTO thyristor):** The minimum forward gate current required to ensure that, if the anode current drops below the value required to keep all the subdivided cathode areas in conduction, they all will return to conduction when the anode current is increased again. |
| $i_{FGT}$ | **turn-on gate current:** The forward gate current during the period within which the thyristor is turning on. |
| $I_{FGTM}$ | **peak turn-on gate drive current:** The peak value of the turn-on gate drive current pulse. (See Figure 6-11.) |
| $I_G$, $I_{G(AV)}$, $i_G$, $I_{GM}$ | **gate current*:** The (control) current into the gate terminal. |
| $I_{GD}$ | **gate nontrigger current:** The lowest value of gate current for which any increase will cause a substantial increase in the principal current. |
| $I_{GQ}$, $i_{GQ}$, $I_{GQM}$ | **gate turn-off current*:** The minimum gate current required to switch a gate-turn-off thyristor from the off state to the on state. (Ref. EIA-397.) |
| $I_{GT}$, $i_{GT}$, $I_{GTM}$ | **gate trigger current*:** The gate current at the trigger point. (See Figure 6-5.) |
| $I_H$, $i_H$ | **holding current*:** The minimum anode, principal, or thyristor current that will maintain the thyristor in the on state. |
| $I_L$, $i_L$ | **latching current*:** The minimum anode or principal current required to maintain the thyristor in the on-state immediately after the triggering condition has been removed following switching from the off state to the on state.<br><br>NOTE The value of the latching current is dependent on operating conditions. |

* See Table 6-1 for detailed meaning of symbols.

**6.1 Thyristors (cont'd)**

**6.1.2 Letter symbols, terms, and definitions (not applicable to thyristor surge suppressors; see section 7) (cont'd)**

$I_R$, $I_{R(RMS)}$, $I_{R(AV)}$, $i_R$, $I_{RM}$ — **reverse current (of a unidirectional thyristor)*:** The anode current for a negative anode voltage. (See Figure 6-3.)

$I_{RC}$, $I_{RC(RMS)}$, $I_{RC(AV)}$, $i_{RC}$, $I_{RCM}$ — **reverse-conducting current (of a reverse-conducting thyristor)*:** The reverse current of a reverse-conducting thyristor. (See Figure 6-4.)

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

NOTE 1 Devices may be subjected to overload currents as frequently as called for by the application, while being subjected to normal operating voltages.

NOTE 2 If not otherwise stated, specifications for the rated (limiting) value of an overload reverse-conducting current refer to a waveshape that is substantially the same as for the rated value of the reverse-conducting current.

$I_{RCSM}$ — **surge reverse-conducting current**: A reverse-conducting current pulse of short duration and specified waveshape, whose application causes or would cause the maximum-rated virtual 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).

$I_{RG}$ — **reverse gate current:** (1) For p-gate thyristors, the negative gate current.

(2) For n-gate thyristors, the positive gate current.

$I_{RGB}$ — **off-state gate bias current:** The reverse gate current during the period following the period within which the thyristor was turning off.

$I_{RGQ}$, $i_{RGQ}$, $I_{RGQM}$ — **turn-off gate current (of a GTO thyristor)*:** The reverse gate current during the period within which the thyristor is turning off.

$I_{RGQB}$ — **turn-off gate bias current (of a GTO thyristor):** The gate current associated with the turn-off gate bias voltage $V_{RGQB}$.

* See Table 6-1 for detailed meaning of symbols.

## 6.1 Thyristors (cont'd)

### 6.1.2 Letter symbols, terms, and definitions (not applicable to thyristor surge suppressors; see section 7) (cont'd)

$I_{RGQM}$ **peak turn-off gate current (of a GTO thyristor):** The peak value of the reverse gate current reached at the end of its rapid rise in the beginning of the turn-off process. (See Figure 6-12.)

NOTE Specifications refer to the minimum value of $I_{RGQM}$ that the gate turn-off pulse generator must be capable of supplying as a function of the peak on-state current to be switched off under specified conditions.

$i_{RR}$ IEC alternative symbol for $i_{R(REC)}$.

NOTE For the peak value of the reverse recovery current during the reverse recovery time, only the letter symbol $I_{RM}$ or $I_{RM(REC)}$ may be used because the letter symbol $I_{RRM}$ is already attributed to the repetitive peak reverse current.

$i_{R(REC)}$, $I_{RM(REC)}$ **reverse recovery current (of a unidirectional thyristor)*:** The reverse current that occurs during the reverse recovery time. (See Figure 6-14.)

$I_{RRM}$ **repetitive peak reverse current (of a reverse-blocking thyristor):** The maximum (peak) instantaneous value of the reverse current that results from the application of repetitive peak reverse voltage. (Ref. EIA-397.)

$I_{RSM}$ **nonrepetitive peak reverse current (of a reverse-blocking thyristor):** The maximum (peak) surge reverse current having a specified waveform and a short, specified time interval.

$I_T$, $I_{T(RMS)}$, $I_{T(AV)}$, $i_T$, $I_{TM}$ **on-state current*:** The anode, principal, or thyristor current when the thyristor is in the on state. (See Figures 6-1 through 6-4.)

$I_{TM}$ **peak case nonrupture current:** The peak value of on-state 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 on-state current, waveshape, and time.

NOTE This definition implies that a fine crack in the case would be tolerated, if found in a device subjected to the peak case nonrupture current, provided that no plasma beam was emitted, parts of the case did not break away, and the device did not melt externally or burst into flames.

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* See Table 6-1 for detailed meaning of symbols.

## 6.1 Thyristors (cont'd)

### 6.1.2 Letter symbols, terms, and definitions (not applicable to thyristor surge suppressors; see section 7) (cont'd)

$i_{T(OV)}$, $I_{TM(OV)}$ **overload on-state current*:** An on-state current whose continuous application would cause the maximum-rated virtual junction temperature to be exceeded, but that is limited in duration such that this temperature is not exceeded. (See Figure 6-7.)

NOTE 1 Devices may be subjected to overload currents as frequently as called for by the application while being subjected to normal operating voltages.

NOTE 2 If not otherwise stated, specifications for the rated (limiting) value of an overload on-state current refer to a waveshape that is substantially the same as for the rated value of the on-state current.

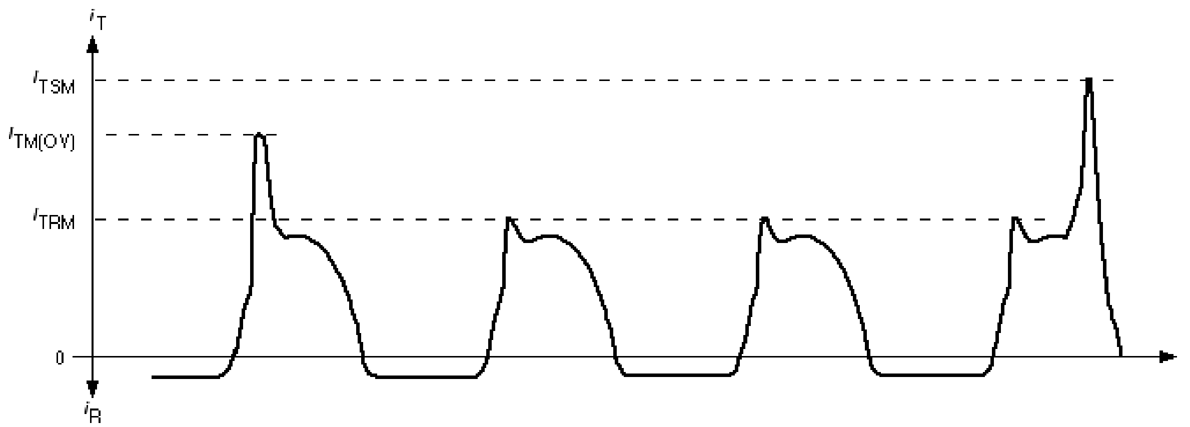


**Figure 6-7 — Peak values of on-state currents**

$I_{TQRM}$ **repetitive peak controllable on-state current (of a GTO thyristor):** The highest peak value of the on-state current that can be turned off periodically by means of gate control.

NOTE A repetitive current is usually a function of the circuit and increases the heating effect within the device. A nonrepetitive transient current is usually due to an external cause, and it is assumed that its effect will have completely disappeared before the next transient arrives.

$I_{TQSM}$ **nonrepetitive peak controllable on-state current (of a GTO thyristor):** The highest nonrepetitive peak value of the on-state current that can be turned off by means of gate control.

NOTE A repetitive current is usually a function of the circuit and increases the heating effect within the device. A nonrepetitive transient current is usually due to an external cause, and it is assumed that its effect will have completely disappeared before the next transient arrives.

* See Table 6-1 for detailed meaning of symbols.

**6.1 Thyristors (cont'd)**

**6.1.2 Letter symbols, terms, and definitions (not applicable to thyristor surge suppressors; see section 7) (cont'd)**

$I_{TRM}$ **repetitive peak on-state current:** he peak value of the on-state current, including all repetitive transient currents. (See Figure 6-7.)

$I_{TSM}$ **surge on-state current:** An on-state current pulse of short duration and specified waveshape, whose application causes or would cause the maximum-rated virtual 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). (See Figure 6-7.)

$i_Z$ **tail current (of a GTO thyristor):** The anode current that flows during the tail time. (See Figure 6-12.)

$I_{ZM}$ **peak tail current (of a GTO thyristor):** The peak value of tail current that occurs shortly after the beginning of the tail time. (See Figure 6-12.)

$P_{add(AV)}$ **mean additional power loss:** The sum of all average power losses, during a full cycle: $P_{add(AV)} = P_{TT(AV)} + P_{DQ(AV)} + P_{D(AV)} + P_{R(AV)}$.

$P_D$, $P_{D(AV)}$, $p_D$, $P_{DM}$ **off-state power*:** The power while the thyristor is in the off state.

NOTE If not otherwise specified, the term refers to the power (1) during the interval between the crossing of the origin ($I = 0$ or $V = 0$) and the beginning of the turn-on time, and (2) during the interval between the ending of the turn-off time and the crossing of the origin.

$P_{DQ(AV)}$, $p_{DQ}$, $P_{DQM}$ **turn-off power*:** The power during the interval in which the thyristor is turning off. (See Figure 6-8.)

NOTE If not otherwise specified, this interval corresponds with the turn-off time.

$P_G$, $P_{G(AV)}$, $p_G$, $P_{GM}$ **gate power*:** The product of the instantaneous values of gate current and gate voltage.

$P_R$, $P_{R(AV)}$, $p_R$, $P_{RM}$ **reverse power*:** The power when the thyristor is in the reverse-blocking state.

NOTE If not otherwise specified, the term refers to the power in the period between the ending of the turn-off time and the change from the reverse-blocking state to the off state (either $I = 0$ or $V = 0$).

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* See Table 6-2 for detailed meaning of symbols.

## 6.1 Thyristors (cont'd)

### 6.1.2 Letter symbols, terms, and definitions (not applicable to thyristor surge suppressors; see section 7) (cont'd)

**Table 6-1 — Current**

| Quantity | DC value with no alternating component | Total rms value | Mean value averaged over full cycle | Instantaneous total value | Peak total value |
|---|---|---|---|---|---|
| Breakover current | $I_{(BO)}$ | - | - | $i_{(BO)}$ | - |
| Breakdown current | $I_{(BR)}$ | - | - | $i_{(BR)}$ | - |
| Off-state current | $I_D$ | $I_{D(RMS)}$ | $I_{D(AV)}$ | $i_D$ | $I_{DM}$ |
| Off-state recovery current | - | - | - | - | $I_{DQM}$ |
| Repetitive peak off-state current | - | - | - | - | $I_{DRM}$ |
| Forward gate current | $I_{FG}$ | - | - | - | - |
| On-state gate bias current | $I_{FGB}$ | - | - | - | - |
| Turn-on gate current | - | - | - | $i_{FGT}$ | - |
| Peak turn-on gate drive current | - | - | - | - | $I_{FGTM}$ |
| Sustaining gate current | $I_{FGsus}$ | - | - | - | - |
| Gate current | $I_G$ | - | $I_{G(AV)}$ | $i_G$ | $I_{GM}$ |
| Gate nontrigger current | $I_{GD}$ | - | - | - | - |
| Gate turn-off current | $I_{GQ}$ | - | - | $i_{GQ}$ | $I_{GQM}$ |
| Gate trigger current | $I_{GT}$ | - | - | $i_{GT}$ | $I_{GTM}$ |
| Holding current | $I_H$ | - | - | $i_H$ | - |
| Latching current | $I_L$ | - | - | $i_L$ | - |
| Reverse (blocking) current | $I_R$ | $I_{R(RMS)}$ | $I_{R(AV)}$ | $i_R$ | $I_{RM}$ |
| Reverse-conducting current | $I_{RC}$ | $I_{R(RMS)}$ | $I_{RC(AV)}$ | $i_{RC}$ | $I_{RCM}$ |
| Overload reverse-conducting current | - | - | - | $i_{RC(OV)}$ | $I_{RCM(OV)}$ |
| Surge reverse-conducting current | - | - | - | - | $I_{RCSM}$ |
| Reverse gate current | $I_{RG}$ | - | - | - | - |
| Off-state gate bias current | $I_{RGB}$ | - | - | - | - |
| Turn-off gate current | $I_{RGQ}$ | - | - | $i_{RGQ}$ | $I_{RGQM}$ |
| Turn-off gate bias current | $I_{RGQB}$ | - | - | - | - |
| Reverse recovery current | - | - | - | $i_{R(REC)}$ | $I_{RM(REC)}$ |
| Repetitive peak reverse current | - | - | - | - | $I_{RRM}$ |
| Nonrepetitive peak reverse current | - | - | - | - | $I_{RSM}$ |
| On-state current | $I_T$ | $I_{T(RMS)}$ | $I_{T(AV)}$ | $i_T$ | $I_{TM}$ |
| Peak case nonrupture current | - | - | - | - | $I_{TM}$ |
| Overload on-state current | - | - | - | $i_{T(OV)}$ | $I_{TM(OV)}$ |
| Repetitive peak controllable on-state current | - | - | - | - | $I_{TQRM}$ |
| Nonrepetitive peak controllable on-state current | - | - | - | - | $I_{TQSM}$ |
| Repetitive peak on-state current | - | - | - | - | $I_{TRM}$ |
| Surge on-state current | - | - | - | - | $I_{TSM}$ |
| Tail current | - | - | - | $i_Z$ | $I_{ZM}$ |

**6.1 Thyristors (cont'd)**

**6.1.2 Letter symbols, terms, and definitions (not applicable to thyristor surge suppressors; see section 7) (cont'd)**

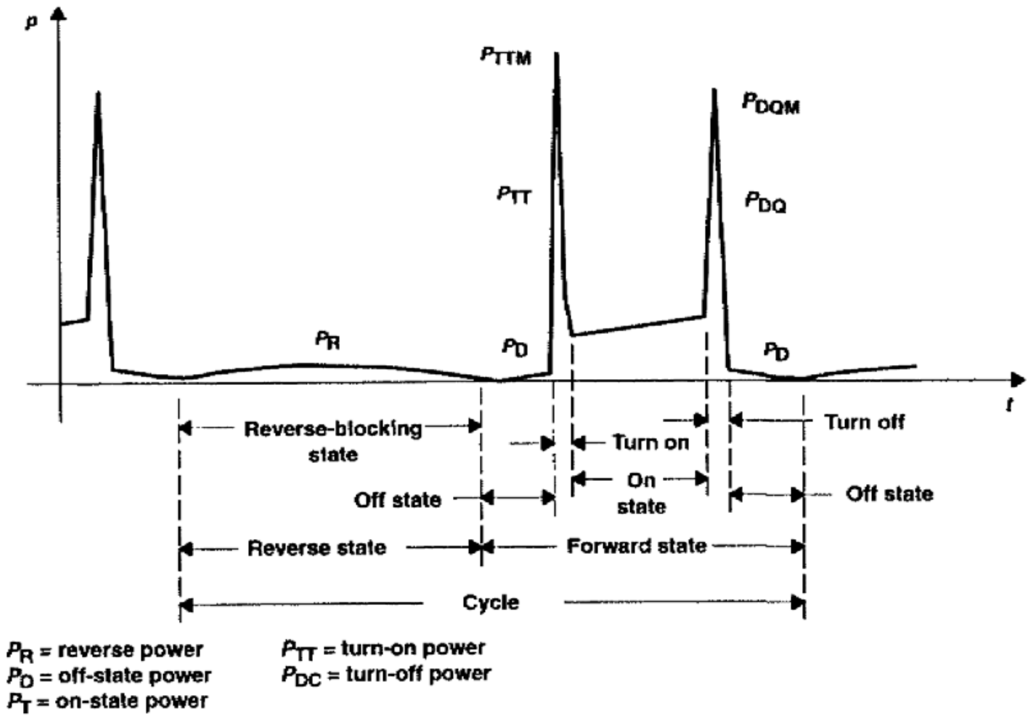


**Figure 6-8 — Partial power losses at relatively low frequencies**

$P_{RC}$, $P_{RC(AV)}$, $p_{RC}$, $P_{RCM}$ — **reverse-conducting power (of a reverse-conducting thyristor)*:** The power while the thyristor is in the reverse-conducting state.

NOTE If not otherwise specified, the term refers to the power in the period between the ending of the turn-off time and the change from the reverse-conducting state to the off state (either $I$ = 0 or $V$ = 0).

$P_T$, $P_{T(AV)}$, $p_T$, $P_{TM}$ — **on-state power*:** The power while the thyristor is in the on state.

NOTE If not otherwise specified, the term refers to the power during the period between the ending of the turn-on time and the beginning of the turn-off time.

$P_{tot(AV)}$ — **mean total power loss:** The sum of all mean partial power losses and the mean gate power loss, during a full cycle: $P_{tot(AV)} = P_{T(AV)} + P_{add(AV)} + P_{G(AV)}$.

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* See Table 6-2 for detailed meaning of symbols.

## 6.1 Thyristors (cont'd)

### 6.1.2 Letter symbols, terms, and definitions (not applicable to thyristor surge suppressors; see section 7) (cont'd)

$P_{TT(AV)}$, $p_{TT}$, $P_{TTM}$ **turn-on power*:** The power in the period during which the thyristor is turning on. (See Figure 6-8.)

NOTE If not otherwise specified, this period corresponds with the turn-on time.

**Table 6-2 — Power**

| Quantity | DC value with no alternating component | Total rms value | Mean value averaged over full cycle | Instantaneous total value | Peak total value |
|---|---|---|---|---|---|
| Off-state power | $P_D$ | - | $P_{D(AV)}$ | $P_D$ | $P_{DM}$ |
| Turn-off power | - | - | $P_{DQ(AV)}$ | $P_{DQ}$ | $P_{DQM}$ |
| Gate power | $P_G$ | - | $P_{G(AV)}$ | $P_G$ | $P_{GM}$ |
| Reverse power | $P_R$ | - | $P_{R(AV)}$ | $P_R$ | $P_{RM}$ |
| Reverse-conducting power | $P_{RC}$ | - | $P_{RC(AV)}$ | $P_{RC}$ | $P_{RCM}$ |
| On-state power | $P_T$ | - | $P_{T(AV)}$ | $P_T$ | $P_{TM}$ |
| Turn-on power | - | - | $P_{TT(AV)}$ | $P_{TT}$ | $P_{TTM}$ |
| Mean additional power loss | - | - | $P_{add(AV)}$ | - | - |
| Mean total power loss | - | - | $P_{tot(AV)}$ | - | - |

NOTE The term “power dissipation” has been used as an exact synonym for “power loss”. This is no longer recommended. The term “loss” should refer to the electrical loss (*IR* drop) at the place of its conversion to heat, and the term “dissipation” should refer to the heat that is dissipated from the surface of the device into the environment. Different terms must be provided for the two quantities because, due to the internal storage of heat, the two differ with time.

As an exception, “mean power dissipation” may still be used as a synonym for “mean power loss”, but only when appropriate, i.e., if the differences with time have no influence on the mean values of the two. This is the case for mean values that are averaged over a cycle. In the latter case, the subscript “(AV)” is usually omitted from the letter symbols.

$Q_{dr}$ **off-state recovered charge (of a reverse-conducting triode thyristor):** The total charge recovered from the thyristor during a specified integration time after switching from a specified reverse-current condition to a specified off-state condition.

NOTE The formula and figure (Figure 6-9) shown for $Q_R$ apply analogously.

$Q_{gq}$ **gate turn-off charge (of a GTO thyristor):** The total charge derived from the integration of the reverse gate current between the instant when the falling forward gate current crosses zero and the instant when the reverse gate current reaches its peak value $I_{RGQM}$. (See Figure 6-12.)

**6.1 Thyristors (cont'd)**

**6.1.2 Letter symbols, terms, and definitions (not applicable to thyristor surge suppressors; see section 7) (cont'd)**

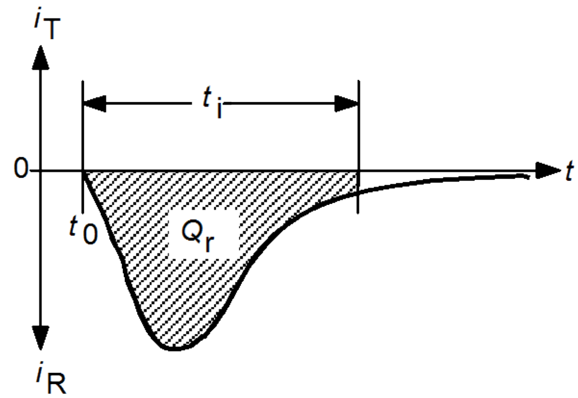



**Figure 6-9 — Recovered charge $Q_r$**

$Q_r$ **recovered charge (of a reverse-blocking triode thyristor):** The total charge recovered from the thyristor during a specified integration time after switching from a specified on-state current condition to a specified reverse condition:

$$Q_{\mathrm{r}} = \int_{t_0}^{t_0+t_i} i_R \cdot dt,$$

where

$t_0$ is the instant when the current passes through zero;

$t_i$ is the specified integration interval. (See Figure 6-9.)

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

$r_{RC}$ **reverse-conducting slope resistance:** The value of the resistance calculated from the slope of the straight-line approximation of the reverse-conducting characteristic. (See Figure 6-6b.)

$r_T$ **on-state slope resistance:** The value of the resistance calculated from the slope of the straight-line approximation of the on-state characteristic. (See Figure 6-6a.)

**6.1 Thyristors (cont'd)**

**6.1.2 Letter symbols, terms, and definitions (not applicable to thyristor surge suppressors; see section 7) (cont'd)**

$R_{\text{thJCA}}$ **anode-side (partial) junction-to-case thermal resistance (of a thyristor in a disc-type housing):** The thermal resistance between the virtual junction and the anode side of the case.

$R_{\text{thJCD}}$ **diode junction-to-case thermal resistance (of a reverse-conducting thyristor with an integrated reverse-conducting diode):** The temperature difference between the diode junction and the reference point, divided by the steady-state reverse-conducting power loss in the diode, under the condition that the whole power loss in the device is due to reverse-conducting current.

$R_{\text{thJCK}}$ **cathode-side (partial) junction-to-case thermal resistance (of a thyristor in a disc-type housing):** The thermal resistance between the virtual junction and the cathode side of the case.

$R_{\text{thJCT}}$ **thyristor junction-to-case thermal resistance (of a reverse-conducting thyristor with an integrated reverse-conducting diode):** The temperature difference between the thyristor junction and the reference point, divided by the steady-state on-state power loss in the thyristor, under the condition that the whole power loss in the device is due to on-state current.

$t_{\text{dr}}$ **off-state recovery time (of a reverse-conducting thyristor):** The time interval between (1) the instant when the current passes through zero while changing from the reverse-conducting state to the off state, and (2) the instant when either the off-state current is reduced from its peak value $I_{\text{DM}}$ to a specified low value (as shown in Figure 6-10a and which may be zero), or the extrapolated reverse current reaches zero (as shown in Figure 6-10b).

NOTE 1 The extrapolation is carried out with respect to specified points A and B, as shown in generalized form in Figure 6-10b.

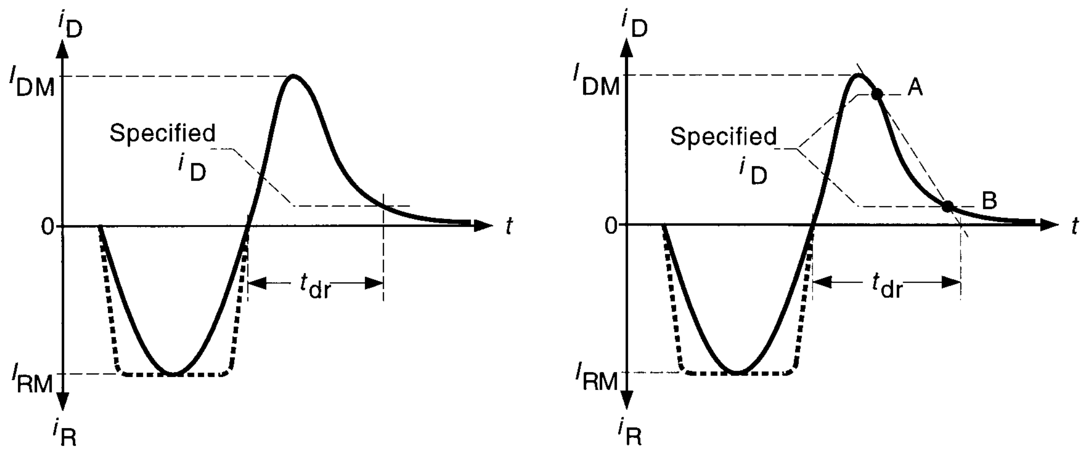
NOTE 2 Specified values of $t_{\text{dr}}$ refer to a specified waveform of the preceding reverse-current pulse, which may be either a half sine wave (solid line) or a trapezoidal wave (dashed line).

$t_{\text{gd}}$ **gate-controlled turn-on delay time:** The time interval between (1) the instant when the rising gate drive current pulse reaches a specified low value, and (2) the instant when the decreasing off-state voltage reaches an upper specified value near its initial value $V_{\text{D}}$. (See Figure 6-11.)

NOTE If no ambiguity is likely to occur, the term and symbol may be abbreviated to “turn-on delay time, $t_{\text{d}}$”.

**6.1 Thyristors (cont'd)**

**6.1.2 Letter symbols, terms, and definitions (not applicable to thyristor surge suppressors; see section 7) (cont'd)**




**(a)** **(b)**

**Figure 6-10 — Off-state recovery time**

$t_{gf}$ **gate-controlled fall time:** The time interval between (1) the instant when the anode current has decreased to the upper reference value that defines the end of the gate-controlled storage time $t_{gs}$, and (2) the instant when the anode current reaches, at the end of its steep decrease, the valley point current $I_{ZV}$. (See Figure 6-12.)

NOTE If no ambiguity is likely to occur, the term and symbol may be abbreviated to "turn-off fall time, $t_f$".

$t_{gq}$ **gate-controlled turn-off time:** The sum of gate-controlled storage time and fall time: $t_{gq} = t_{gs} + t_{gf}$. (See Figure 6-12.)

NOTE If no ambiguity is likely to occur, the term may be abbreviated to turn-off time, but the symbol should remain $t_{gq}$.

$t_{gr}$ **gate-controlled turn-on rise time:** The time interval between (1) the instant when the off-state voltage reaches the upper specified value that defines the end of the gate-controlled turn-on delay time $t_{gd}$, and (2) the instant when the decreasing off-state voltage reaches a lower specified value near its final steady-state value. (See Figure 6-12.)

NOTE If no ambiguity is likely to occur, the term and symbol may be abbreviated to "turn-on rise time, $t_r$".

**6.1 Thyristors (cont'd)**

**6.1.2 Letter symbols, terms, and definitions (not applicable to thyristor surge suppressors; see section 7) (cont'd)**

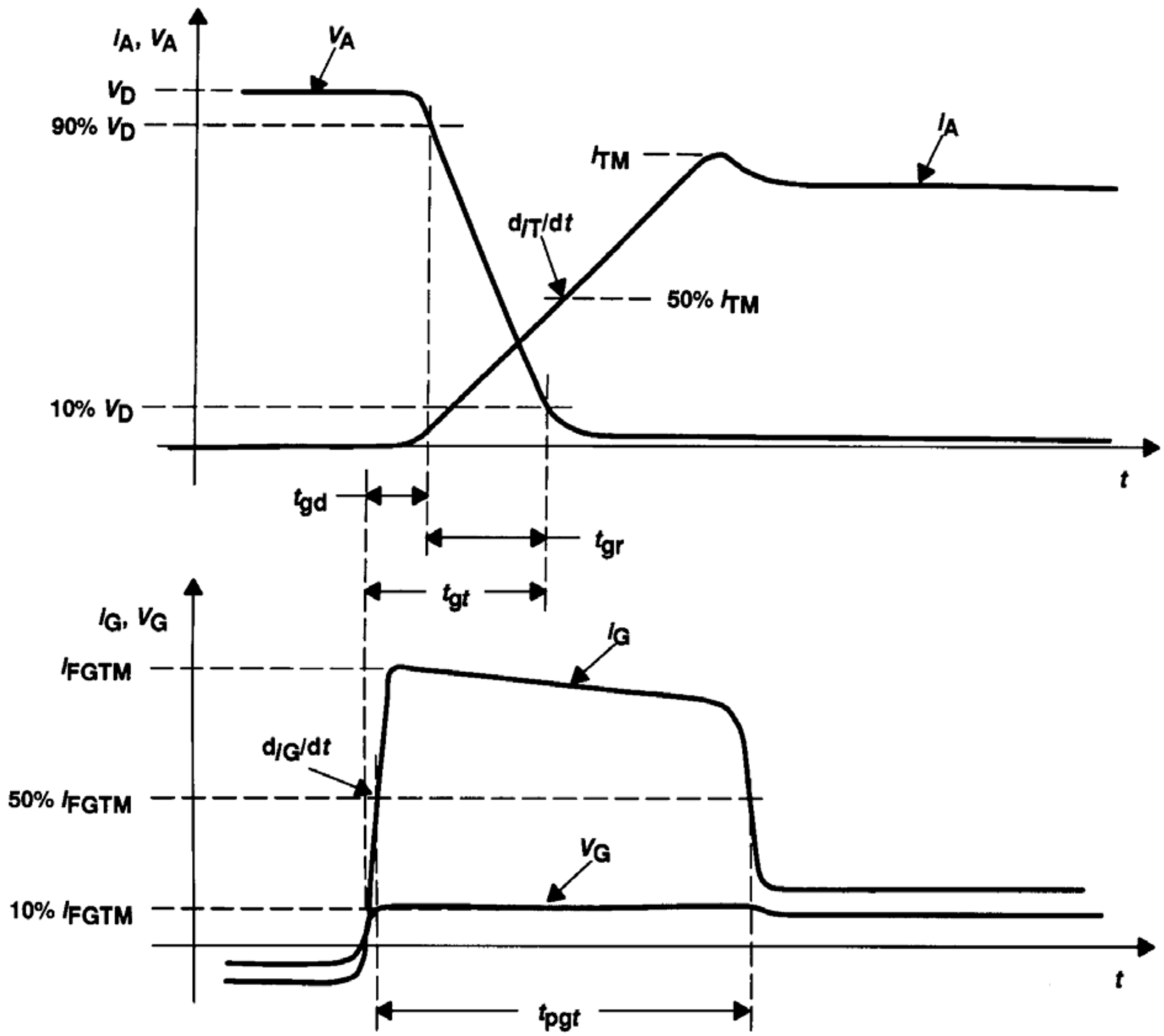
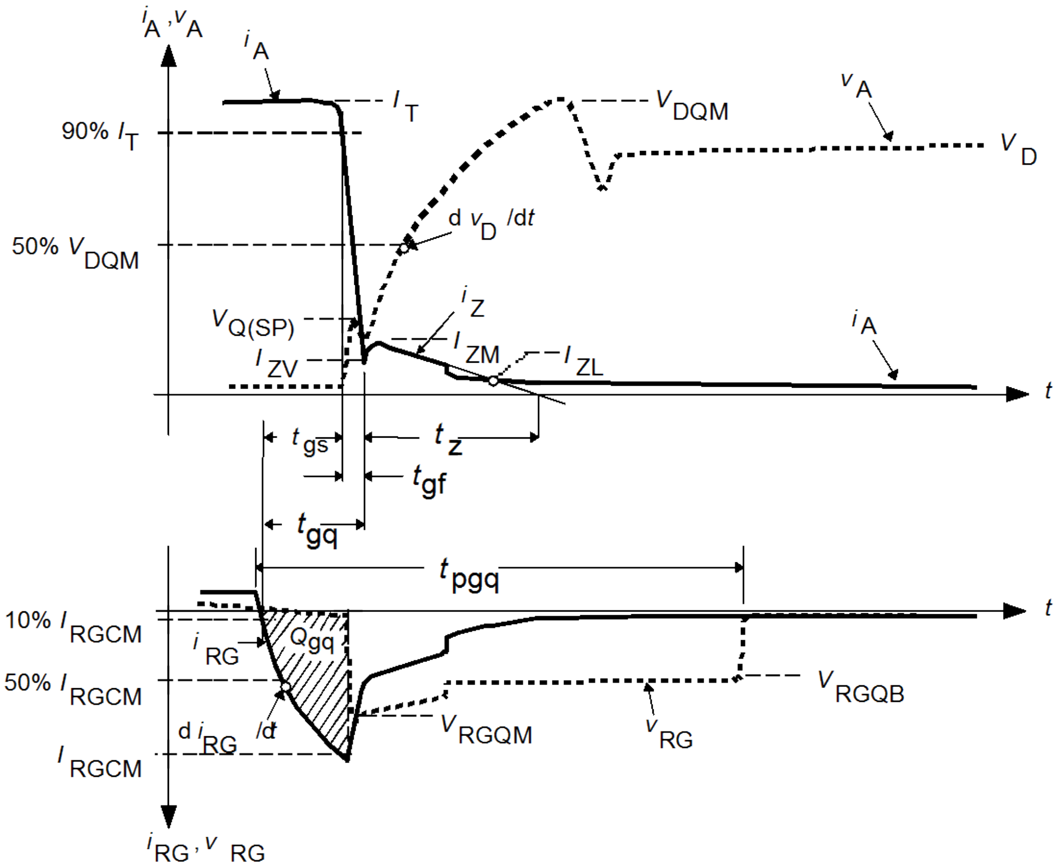



**Figure 6-11 — Gate-controlled turn-on times**

**6.1 Thyristors (cont'd)**

**6.1.2 Letter symbols, terms, and definitions (not applicable to thyristor surge suppressors; see section 7) (cont'd)**




NOTE 1 This figure illustrates the switching of a GTO thyristor from the on-state to the off-state by means of a reverse gate drive current pulse that is supported by an additional reverse gate drive voltage pulse and that is followed by a smaller reverse gate bias current.

NOTE 2 The reference values of current and voltage referred to in the definitions of the illustrated turn-off times are given below.

Gate current
- specified low value near zero…………………… 10% $I_{RGQM}$
- specified level for the measurement of $di_{RG}/dt$….. 50% $I_{RGQM}$

Anode current
- upper reference value…………………………… 90% $I_T$

Anode voltage
- specified level for the measurement of $dv_D/dt$….. 50% $V_{DQM}$

**Figure 6-12 — Gate-controlled turn-off times**

## 6.1 Thyristors (cont'd)

### 6.1.2 Letter symbols, terms, and definitions (not applicable to thyristor surge suppressors; see section 7) (cont'd)

$t_{gs}$ **gate-controlled storage time:** The time interval between (1) the instant when the rising reverse gate current reaches a low reference value near zero, and (2) the instant when the anode current has decreased to an upper reference value near its initial value $I_T$. (See Figure 6-12.)

NOTE If no ambiguity is likely to occur, the term and symbol may be abbreviated to “turn-off storage time, $t_s$”.

$t_{gt}$ **gate-controlled turn-on time:** The sum of gate-controlled turn-on delay time and rise time: $t_{gt} = t_{gd} + t_{gr}$. (See Figure 6-11.)

NOTE If no ambiguity is likely to occur, the term may be abbreviated to “turn-on time”.

$t_H$ **hold-off interval (in a converter):** The time interval between (1) the instant when the anode currents of the thyristors of a converter has decreased to zero, and (2) the instant when the same thyristors are subjected to off-state voltage.

NOTE The hold-off interval is not a characteristic of the thyristor but a service condition of the converter. It must exceed the longest expected individual circuit-commuted turn-off time, which also depends on the service conditions of the converter.

$t_{pgq}$ **gate turn-off drive-pulse duration:** The duration of the reverse gate-drive voltage pulse measured between two specified levels of reverse gate-drive voltage.

$t_{pgq(cr)}$ **critical gate turn-off drive-pulse duration:** The lowest value to which the gate turn-off drive-pulse duration can be reduced without causing the thyristor to fail to turn off.

$t_{pgt}$ **gate turn-on drive-pulse duration:** The duration of the forward gate-drive current pulse measured between two specified levels of forward gate current. (See Figure 6-11.)

$t_{pqt(cr)}$ **critical gate turn-on drive-pulse duration:** The lowest value to which the gate turn-on drive-pulse duration can be reduced without causing the thyristor to fail to turn on.

$t_q$ **circuit-commutated turn-off time:** The time interval between (1) the instant when the on-state current has decreased to zero after external switching of the main circuit, and (2) the earliest instant when a steeply rising off-state voltage that the thyristor is capable of supporting without breaking over either passes through zero (waveform “a” in Figure 6-13) or begins from a low positive value (waveform “b” in Figure 6-13).

NOTE Waveform “a” refers to a simple reverse-blocking triode thyristor. Waveform “b” may appear if the thyristor is bypassed by an external or internal flyback diode (reverse-conducting thyristor), due to the lead inductance of the diode.

**6.1 Thyristors (cont'd)**

**6.1.2 Letter symbols, terms, and definitions (not applicable to thyristor surge suppressors; see section 7) (cont'd)**

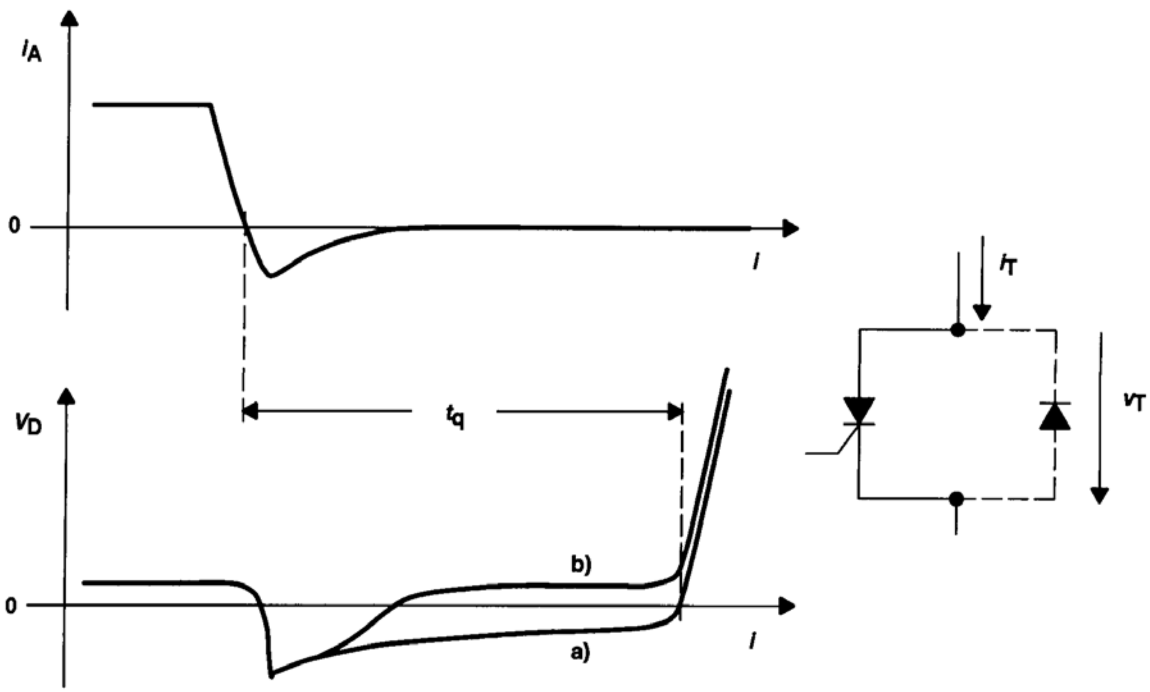



**Figure 6-13 — Circuit-commutated turn-off time**

$t_{rr}$ **reverse recovery time (of a reverse-blocking thyristor):** The time interval between (1) the instant when the current passes through zero while changing from the on state to the reverse-blocking state, and (2) the instant when either the reverse current is reduced from its peak value $I_{RM}$ or $I_{RM(REC)}$ to a specified low value (as shown in Figure 6-14a and which may be zero), or the extrapolated reverse current reaches zero (as shown in Figure 6-14b).

NOTE 1 The extrapolation is carried out with respect to specified points A and B, as shown in generalized form in Figure 6-14b.

NOTE 2 Specified values of $t_{rr}$ refer to a specified waveform of the preceding on-state-current pulse, which may be either a half sine wave (solid line) or a trapezoidal wave (dashed line).

**6.1 Thyristors (cont'd)**

**6.1.2 Letter symbols, terms, and definitions (not applicable to thyristor surge suppressors; see section 7) (cont'd)**

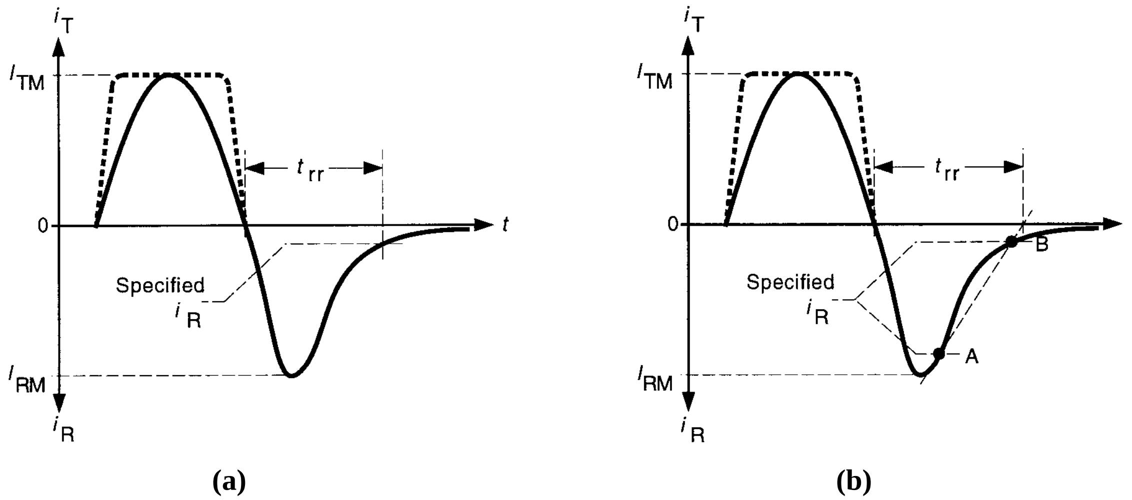



**Figure 6-14 — Reverse recovery time**

$t_z$ — **tail time:** The time interval between (1) the instant when the anode current has decreased to the valley point $I_{ZV}$ that defines the end of the gate-controlled fall time $t_{gf}$, and (2) the instant when the extrapolated tail current reaches zero. (See Figure 6-12.)

NOTE Unless otherwise specified, the extrapolation is carried out between the peak point of the tail current $I_{ZM}$ and $I_{ZL}$, where $I_{ZL}$= 25% $I_{ZM}$.

$V_{(BO)}$, $v_{(BO)}$ — **breakover voltage*:** The voltage at the breakover point.

$V_{(BR)}$, $v_{(BR)}$ — **reverse breakdown voltage (of a unidirectional thyristor)*:** A voltage in the reverse breakdown region.

$V_D$, $V_{D(RMS)}$, $V_{D(AV)}$, $v_D$, $V_{DM}$ — **off-state voltage*:** The anode, principal, or thyristor voltage when the thyristor is in the off state.

$V_{DQM}$ — **turn-off peak off-state voltage (of a GTO thyristor):** The peak value, higher than the final steady-state value, to which the reapplied off-state voltage rises towards the end of the turn-off process. (See Figure 6-12.)

NOTE The turn-off peak off-state voltage is not an inherent characteristic of the GTO thyristor as its value depends on the design of the external circuits. Its value has an influence on the turn-off energy loss.

* See Table 6-3 for detailed meaning of symbols.

**6.1 Thyristors (cont'd)**

**6.1.2 Letter symbols, terms, and definitions (not applicable to thyristor surge suppressors; see section 7) (cont'd)**

$V_{DRM}$ **repetitive peak off-state voltage:** The highest instantaneous value of the off-state voltage, including all repetitive transient voltages but excluding all nonrepetitive transient voltages. (See Figure 6-15.)

NOTE The repetitive voltage is usually a function of the circuit and increases the power loss of the device. A nonrepetitive transient voltage is usually due to an external cause, and it is assumed that its effect will have completely disappeared before the next transient arrives.

$V_{DSM}$ **nonrepetitive peak off-state voltage; peak transient off-state voltage:** The highest instantaneous value of any nonrepetitive transient off-state voltage. (See Figure 6-15.)

NOTE 1 The repetitive voltage is usually a function of the circuit and increases the power loss of the device. A nonrepetitive transient voltage is usually due to an external cause, and it is assumed that its effect will have completely disappeared before the next transient arrives.

NOTE 2 Preference should be given to the term “nonrepetitive peak off-state voltage”.

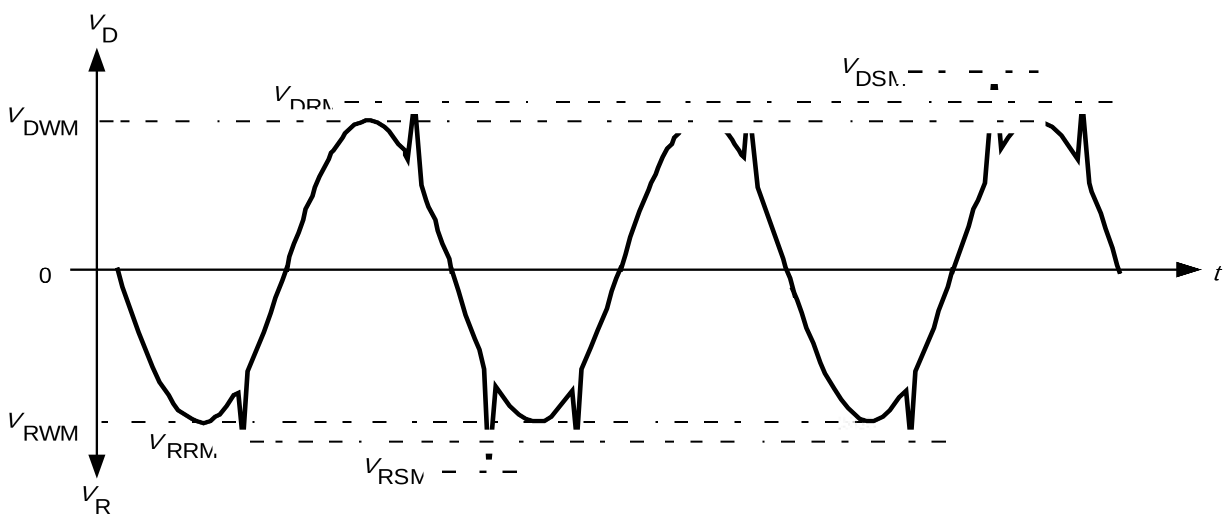



**Figure 6-15 — Peak reverse and peak off-state voltage of a thyristor**

$V_{DWM}$ **crest working off-state voltage; peak working off-state voltage:** The highest instantaneous value of the off-state voltage, excluding all repetitive and nonrepetitive transient voltages. (See Figure 6-15.)

NOTE The repetitive voltage is usually a function of the circuit and increases the power loss of the device. A nonrepetitive transient voltage is usually due to an external cause, and it is assumed that its effect will have completely disappeared before the next transient arrives.

**6.1 Thyristors (cont'd)**

**6.1.2 Letter symbols, terms, and definitions (not applicable to thyristor surge suppressors; see section 7) (cont'd)**

$V_{FG}$ — **forward gate voltage:** (1) For p-gate thyristors, the positive gate-cathode voltage.

(2) For n-gate thyristors, the negative gate-anode voltage.

$V_{FGB}$ — **on-state gate bias voltage:** The forward gate voltage during the period following the period within which the thyristor was turning on.

$V_{FGT}$, $V_{FGTM}$ — **turn-on gate voltage*:** The forward gate voltage during the period within which the thyristor is turning on.

$V_G$, $V_{G(AV)}$, $v_G$, $V_{GM}$ — **gate voltage*:** (1) For unidirectional triode thyristors, the voltage between the gate terminal and the cathode for p-gate thyristors or the anode for n-gate thyristors.

(2) For bidirectional triode thyristors, the voltage between the gate terminal and the specified main terminal.

$V_{GD}$ — **gate nontrigger voltage:** The lowest value of gate voltage for which any increase will cause a substantial increase in the principal current.

$V_{GQ}$, $v_{GQ}$, $V_{GQM}$ — **gate turn-off voltage*:** The gate voltage resulting from the gate turn-off current. (Ref. EIA-397.)

$V_{GT}$, $v_G$, $V_{GTM}$ — **gate trigger voltage*:** The gate voltage at the trigger point. (See Figure 6-5.)

$V_{Q(SP)}$ — **turn-off (off-state) voltage spike (of a GTO thyristor):** The peak value of a spike on the reapplied off-state voltage that occurs shortly after the off-state voltage begins to rise. (See Figure 6-12.)

NOTE The turn-off voltage spike is not an inherent characteristic of the thyristor, as its value depends on the parasitic inductance in the snubber network connected in parallel to the GTO thyristor. Its value has an influence on the turn-off energy loss.

$V_R$, $V_{R(RMS)}$, $V_{R(AV)}$, $v_R$, $V_{RM}$ — **reverse voltage (of a unidirectional thyristor)*:** A negative anode voltage.

$V_{RC(TO)}$ — **reverse-conducting threshold voltage:** The value of the reverse voltage obtained at the intersection of its straight-line approximation with the voltage axis. (See Figure 6-6b.)

$V_{RG}$ — **reverse gate voltage:** (1) For p-gate thyristors, the negative gate-cathode voltage.

(2) For n-gate thyristors, the positive gate-anode voltage.

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* See Table 6-3 for detailed meaning of symbols.

**6.1 Thyristors (cont'd)**

**6.1.2 Letter symbols, terms, and definitions (not applicable to thyristor surge suppressors; see section 7) (cont'd)**

$V_{RGB}$ **off-state gate bias voltage (of a GTO thyristor):** The reverse gate voltage during the period following the period within which the thyristor was turning off.

$V_{RGQ}$, $v_{RGQ}$, $V_{RGQM}$ **turn-off gate voltage (of a GTO thyristor)*:** The reverse gate voltage during the period within which the thyristor is turning off.

$V_{RGQB}$ **turn-off gate bias voltage (of a GTO thyristor):** The essentially constant value of the turn-off gate voltage that occurs towards the end of the turn-off process in the case where the gate-control circuit supports this process by maintaining the turn-off gate voltage at a value that is higher than the off-state gate bias voltage. (See Figure 6-12.)

$V_{RGQM}$ **peak turn-off gate voltage (of a GTO thyristor):** The peak value of the turn-off gate voltage at the end of its rapid rise after the peak value of turn-off gate current ($I_{RGQM}$) has been reached. (See Figure 6-12.)

$V_{RRM}$ **repetitive peak reverse voltage (of a unidirectional thyristor):** The highest instantaneous value of the reverse voltage, including all repetitive transient voltages but excluding all nonrepetitive transient voltages. (See Figure 6-15.)

NOTE The repetitive voltage is usually a function of the circuit and increases the power loss of the device. A nonrepetitive transient voltage is usually due to an external cause, and it is assumed that its effect will have completely disappeared before the next transient arrives.

$V_{RSM}$ **nonrepetitive peak reverse voltage; peak transient reverse voltage (of a unidirectional thyristor):** The highest instantaneous value of a nonrepetitive transient reverse voltage. (See Figure 6-15.)

NOTE 1 The repetitive voltage is usually a function of the circuit and increases the power loss of the device. A nonrepetitive transient voltage is usually due to an external cause, and it is assumed that its effect will have completely disappeared before the next transient arrives.

NOTE 2 The term “nonrepetitive peak reverse voltage” is preferred.

$V_{RWM}$ **crest working reverse voltage; peak working reverse voltage (of a unidirectional thyristor):** The highest instantaneous value of the reverse voltage, excluding all repetitive and nonrepetitive transient voltages. (See Figure 6-15.)

NOTE The repetitive voltage is usually a function of the circuit and increases the power loss of the device. A nonrepetitive transient voltage is usually due to an external cause, and it is assumed that its effect will have completely disappeared before the next transient arrives.

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* See Table 6-3 for detailed meaning of symbols.

## 6.1 Thyristors (cont'd)

### 6.1.2 Letter symbols, terms, and definitions (not applicable to thyristor surge suppressors; see section 7) (cont'd)

$V_T$, $V_{T(RMS)}$, $V_{T(AV)}$, $v_T$, $V_{TM}$ — **on-state voltage*:** The anode, principal, or thyristor voltage when the thyristor is in the on state.

$V_{(TO)}$ — IEC alternative symbol for $V_{T(TO)}$.

$V_{T(TO)}$, $v_{T(TO)}$ — **on-state threshold voltage*:** The value of the on-state voltage obtained at the intersection of its straight-line approximation with the voltage axis. (See Figure 6-6a.)

**Table 6-3 — Voltage**

| Quantity | DC value with no alternating component | Total rms value | Mean value averaged over full cycle | Instantaneous total value | Peak total value |
|---|---|---|---|---|---|
| Breakover voltage | $V_{(BO)}$ | - | - | $v_{(BO)}$ | - |
| Reverse breakdown voltage | $V_{(BR)}$ | - | - | $v_{(BR)}$ | - |
| Off-state voltage | $V_D$ | $V_{D(RMS)}$ | $V_{D(AV)}$ | $v_D$ | $V_{DM}$ |
| Turn-off peak off-state voltage | - | - | - | - | $V_{DQM}$ |
| Repetitive peak off-state voltage | - | - | - | - | $V_{DRM}$ |
| Nonrepetitive peak off-state voltage | - | - | - | - | $V_{DSM}$ |
| Peak working off-state voltage | - | - | - | - | $V_{DWM}$ |
| Forward gate voltage | $V_{FG}$ | - | - | - | - |
| On-state gate bias voltage | $V_{FGB}$ | - | - | - | - |
| Turn-on gate voltage | - | - | - | $v_{FGT}$ | $V_{FGTM}$ |
| Gate voltage | $V_G$ | - | $V_{G(AV)}$ | $v_G$ | $V_{GM}$ |
| Gate turn-off voltage | $V_{GQ}$ | - | - | $v_{GQ}$ | $V_{GQM}$ |
| Gate trigger voltage | $V_{GT}$ | - | - | $v_{GT}$ | $V_{GTM}$ |
| Turn-off voltage spike | - | - | - | - | $V_{Q(SP)}$ |
| Reverse voltage | $V_R$ | $V_{R(RMS)}$ | - | $v_R$ | $V_{RM}$ |
| Reverse-conducting threshold voltage | $V_{RC(TO)}$ | - | $V_{R(AV)}$ | - | - |
| Reverse gate voltage | $V_{RG}$ | - | - | - | - |
| Off-state gate bias voltage | $V_{RGB}$ | - | - | - | - |
| Turn-off gate voltage | $V_{RGQ}$ | - | - | $v_{RGQ}$ | $V_{RGQM}$ |
| Turn-off gate bias voltage | $V_{RGQB}$ | - | - | - | - |
| Repetitive peak reverse voltage | - | - | - | - | $V_{RRM}$ |
| Nonrepetitive peak reverse voltage | - | - | - | - | $V_{RSM}$ |
| Peak working reverse voltage | - | - | - | - | $V_{RWM}$ |
| On-state voltage | $V_T$ | $V_{T(RMS)}$ | - | $v_T$ | $V_{TM}$ |
| Minimum on-state voltage | $V_{T(MIN)}$ | - | $V_{T(AV)}$ | - | - |
| On-state threshold voltage | $V_{T(TO)}$ | - | - | $v_{T(TO)}$ | |

* See Table 6-3 for detailed meaning of symbols.

## 6.2 Programmable unijunction transistors

### 6.2.1 General terms and definitions

**anode terminal (A, a):** The general definition in 2.1 applies.

**cathode terminal (K, k):** The general definition in 2.1 applies.

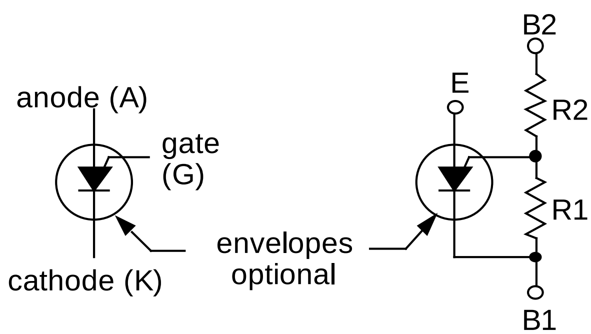
**gate terminal (G, g):** The terminal whose bias conditions determine the values of the unijunction characteristics.

**peak point:** The point on the current-voltage characteristic corresponding to the lowest current at which $\mathrm{d}v_{AK}/\mathrm{d}i_A = 0$ when the gate is biased from a resistive voltage divider.

**programmable unijunction transistor (PUT):** A three-terminal thyristor that, when biased with two external resistors and a voltage source, can provide a negative-resistance characteristic similar to the characteristic of a unijunction transistor.

NOTE The negative-resistance characteristics are controlled by the resistor and voltage values.

Graphic symbol:




PUT with bias resistors

NOTE B1, B2, and E are the equivalent unijunction terminals with interbase resistance $r_{BB} = R_1 + R_2$ and intrinsic standoff ratio $\eta = R_1/(R_1 + R_2)$.

**valley point:** The point on the current-voltage characteristic corresponding to the second lowest current at which $\mathrm{d}v_{AK}/\mathrm{d}i_A = 0$ when the gate is biased from a resistive voltage divider.

**6.2 Programmable unijunction transistors (cont'd)**

**6.2.2 Letter symbols, terms, and definitions**

**For illustration of static current-voltage characteristics, see Figure 6-16.**

$I_{GAO}$ **gate reverse current, cathode open:** The current through the gate terminal when it is positive with respect to the anode terminal and the cathode terminal is open circuited.

$I_{GAS}$ **gate reverse current, cathode short circuited to anode (of a p-gate PUT):** The current through the gate terminal when it is negative with respect to the anode terminal and the cathode terminal is short circuited to the anode terminal.

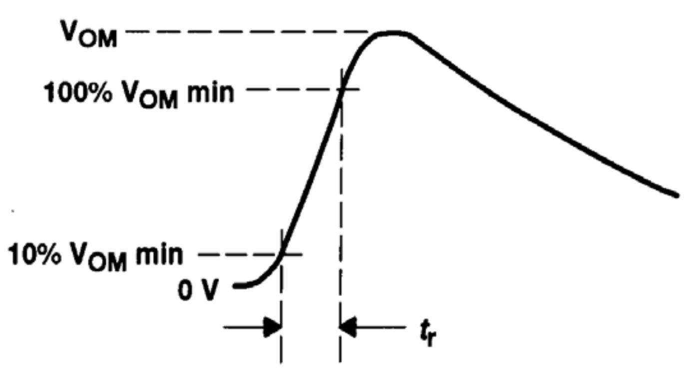
$I_{GKO}$ **gate reverse current, anode open:** The current through the gate terminal when it is negative with respect to the cathode terminal and the anode terminal is open circuited.

$I_{GKS}$ **gate reverse current, anode short circuited to cathode (of an n-gate PUT):** The current through the gate terminal when it is positive with respect to the cathode terminal and the anode terminal is short circuited to the cathode terminal.

$I_P$ **peak-point current:** The anode current at the peak point.

$I_V$ **valley-point current:** The anode current at the valley point.

$t_r$ **output pulse rise time:** The time interval during which the voltage changes from 10% to 100% of the specified minimum value of the peak pulse output voltage, $V_{OM}$.




$V_F$ **anode-cathode on-state voltage:** The anode-cathode voltage at a forward current greater than the valley-point current.

$V_{OM}$ **peak pulse output voltage:** The peak voltage measured across a resistor connected between cathode and ground when the device is operated as a relaxation oscillator in a specified circuit.

**6.2 Programmable unijunction transistors (cont'd)**

**6.2.2 Letter symbols, terms, and definitions (cont'd)**

$V_P$ **peak-point voltage:** The voltage between the anode and cathode at the peak point.

$V_P - V_S$ **offset voltage:** The voltage difference between the peak-point voltage and the test supply voltage.

$V_S$ **test supply voltage:** The supply voltage connected in series with resistor $R_G$ between gate and cathode terminals when testing characteristics such as $I_P$, $I_V$, $V_F$, and $V_P$ - $V_S$.

NOTE This voltage normally approximates the value of anode-cathode voltage where the static current-voltage characteristic passes through zero anode current. The degree of approximation is affected by gate current and $R_G$.

$V_V$ **valley-point voltage:** The voltage between the anode and cathode at the valley point.

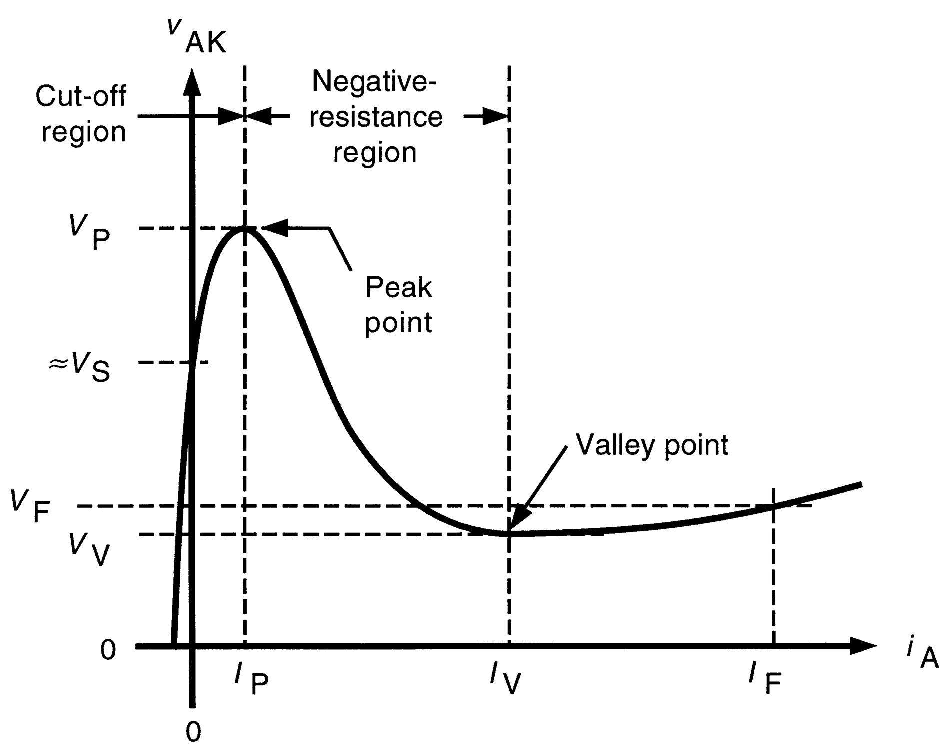



**Figure 6-16 — Static current-voltage characteristics when biased with appropriate resistive voltage divider**

# SECTION 7 TRANSIENT VOLTAGE SUPPRESSORS; SURGE PROTECTIVE DEVICES

For the definitions of “transient voltage suppressor” and “surge protective device”, see 2.1.

## 7.1 Avalanche breakdown diode (ABD) transient voltage suppressors

All terms, definitions, and symbols in this subclause 7.1 come from JESD210.

### 7.1.1 General terms and definitions

**ABD array:** A device having three or more terminals and containing multiple diodes within a single package, with at least one of the diodes being an ABD.

NOTE ABD arrays can be classified as 1) devices with multiple discrete semiconductor chips; and 2) devices with multiple diode junctions diffused into a single semiconductor chip.

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

NOTE For unidirectional blocking or low-capacitance ABDs, any rectifier diode(s) that may be included are ignored in the determination of the anode terminal.

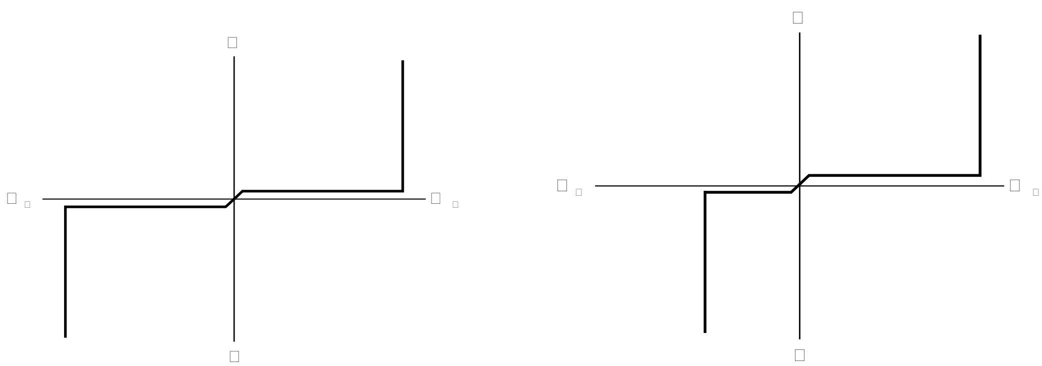
**avalanche breakdown diode (ABD):** A transient voltage suppressor that is a semiconductor diode with a single p-n junction (or with multiple p-n junctions none of which interact) whose operation depends in part on its breakdown characteristics.

## 7.1 Avalanche breakdown diode (ABD) transient voltage suppressors (cont'd)

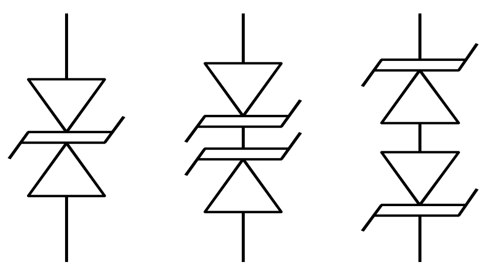
### 7.1.1 General terms and definitions(cont'd)

**bidirectional ABD:** A two-terminal ABD with a voltage-current avalanche breakdown characteristic in both directions, which can be either symmetrical (Figure 7-1a) or asymmetrical (Figure 7-1b). Figure 7-1c shows several alternative symbols for the bidirectional ABD.

NOTE Large transient currents will be clamped for voltage of either polarity across two similar p-n junctions in series connected in opposite directions. During a transient current event in this operating mode, one of the two p-n junctions is always in avalanche breakdown and the other is in the forward-conducting, low-voltage mode. The voltage across the bidirectional ABD is the sum of these two voltages. The avalanche breakdown voltage is substantially the same in both directions for a symmetrical bidirectional ABD; however, it may also be intentionally different or asymmetrical by design for special applications. Since multiple p-n junction capacitances in series reduce the overall total capacitance, the bidirectional ABD has lower capacitance than its unidirectional counterpart.



**(a) Symmetrical bidirectional ABD** **(b) Asymmetrical bidirectional ABD**



**(c) Bidirectional ABD symbol options**

**Figure 7-1 — Bidirectional ABD voltage-current characteristics and symbols**

### 7.1 Avalanche breakdown diode (ABD) transient voltage suppressors (cont'd)

#### 7.1.1 General terms and definitions(cont'd)

**bidirectional low-capacitance ABD:** A two-terminal device comprising two anti-parallel unidirectional-blocking low-capacitance ABD devices. (See Figure 7-2.)

NOTE The rectifier p-n junctions have low capacitance and must have a reverse blocking voltage greater than the avalanche breakdown voltage of the anti-parallel unidirectional ABD element.

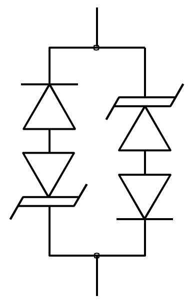


**Figure 7-2 — Bidirectional low-capacitance ABD**

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

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

NOTE For unidirectional blocking or low-capacitance ABDs, any rectifier diode(s) that may be included are ignored in the determination of the cathode terminal.

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

**insertion loss:** The ratio of power delivered to a load with no ABD in the circuit to that delivered after the ABD is inserted.

NOTE Insertion loss is generally expressed in decibels. It is frequency-dependent due to the inductance, capacitance, and resistance of the ABD.

**low-capacitance ABD:** A two-terminal device that has at least one unidirectional ABD with at least one rectifier p-n junction connected in series with each ABD in the opposite polarity in order to reduce capacitance.

NOTE The rectifier p-n junction(s) operate only in their forward-conducting mode during a transient event.

### 7.1 Avalanche breakdown diode (ABD) transient voltage suppressors (cont'd)

#### 7.1.1 General terms and definitions(cont'd)

**simultaneous surge:** An impulse current pulse applied simultaneously to multiple terminals of a single-chip ABD array.

NOTE A simultaneous surge test may be used to determine the worst-case impulse current through an array of p-n junction ABDs having a common chip connection where current crowding may cause a failure or degradation of the device.

**(standard) impulse waveshape:** A waveform that has a defined virtual front time and a defined virtual time to half peak value. (See Figure 7-3.)

NOTE 1 Impulse waveshapes may be given for either voltage or current. See Figure 7-3 for examples.

NOTE 2 Virtual front time is the time interval between the virtual origin and the instant when the extrapolated leading edge reaches its peak; the extrapolation is made through the 10% and 90% amplitude points for current and the 30% and 90% points for voltage.

NOTE 3 Virtual time to half-peak value is the time interval between the virtual origin and the instant when the amplitude of the trailing edge reaches 50%. This is expressed as a combined front time and time to half-peak value such as 8/20 µs or 10/1000 µs.

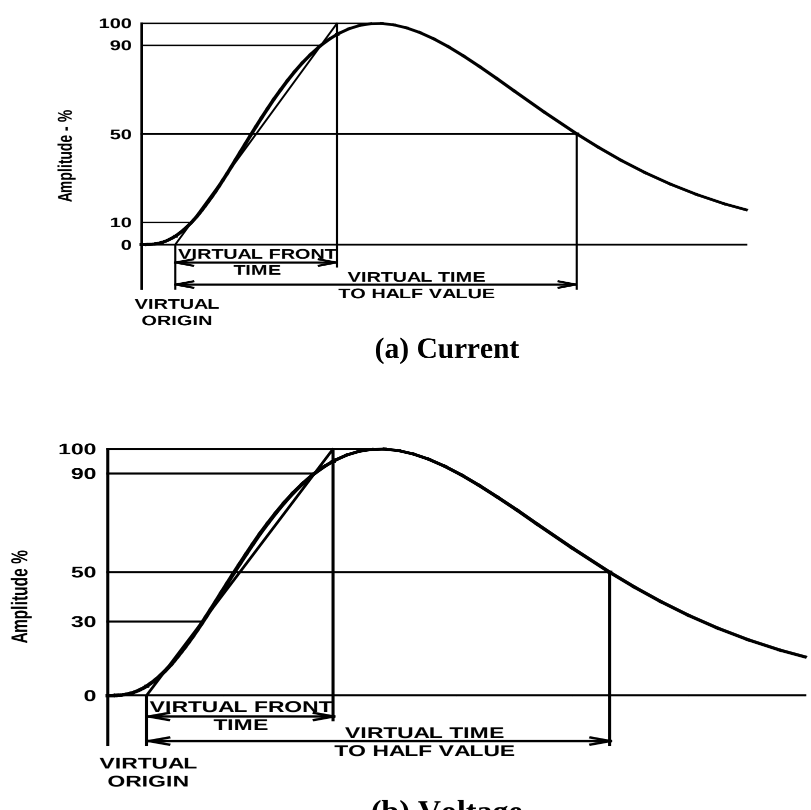



**Figure 7-3 — Standard impulse waveshapes**

### 7.1 Avalanche breakdown diode (ABD) transient voltage suppressors (cont'd)

#### 7.1.1 General terms and definitions(cont'd)

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

**temperature derating:** A specification showing how a rating stated at a particular temperature is reduced at higher temperatures.

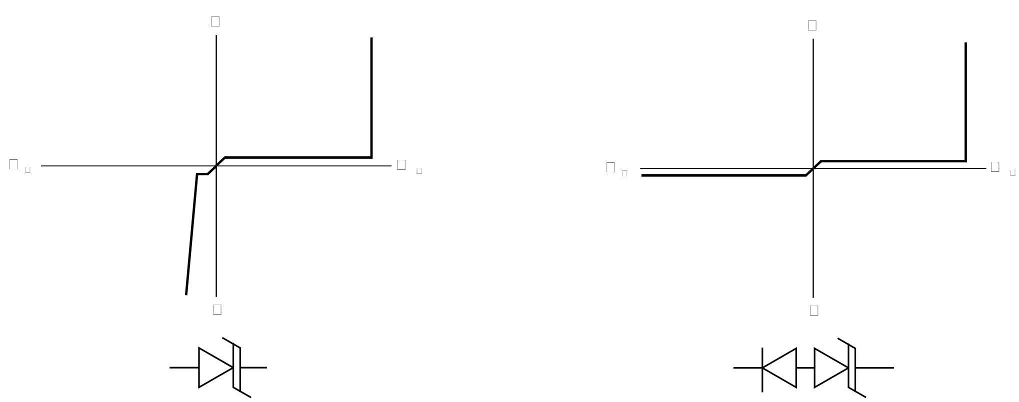
NOTE 1 Derating is usually expressed graphically or in terms of derating factors (e.g., mA/°C or mW/°C).

NOTE 2 For ABDs, derating applies to ratings for peak pulse current ($I_{PPSM}$), peak pulse power ($P_{PPSM}$), and average power dissipation ($P_{M(AV)}$).

NOTE 3 Average power ratings are derated to zero at the maximum-rated junction temperature. Peak pulse power ratings may exceed zero at the maximum-rated junction temperature.

**unidirectional ABD:** A two-terminal ABD with a voltage-current avalanche breakdown characteristic in one direction and either a forward or a blocking characteristic in the other. (See Figure 7-4.)

NOTE Large transient currents will be clamped for positive cathode-to-anode voltages when driven into the avalanche breakdown region with one or more p-n junctions placed in series or parallel with each junction connected in the same direction. Large transient currents may also be clamped for negative cathode-to-anode voltages at significantly lower voltages with the typical forward-conducting characteristics of a single p-n junction (or of multiple p-n junctions connected in the same direction). The most common type of unidirectional ABD has a forward-conducting characteristic.



**(a) Unidirectional-conducting ABD** **(b) Unidirectional-blocking ABD**

**Figure 7-4 — Unidirectional ABD voltage-current characteristic and symbols**

### 7.1 Avalanche breakdown diode (ABD) transient voltage suppressors (cont'd)

#### 7.1.1 General terms and definitions(cont'd)

**unidirectional-blocking low-capacitance ABD:** A two-terminal device that has at least one unidirectional ABD with at least one rectifier p-n junction connected in series in the opposite polarity in order to reduce capacitance. (See Figure 7-5.)

NOTE The unidirectional-blocking low-capacitance ABD is intended to suppress transients in only one direction. The rectifier p-n junction(s) have low capacitance and block in the reverse direction; they are not intended to be operated in their reverse avalanche breakdown regions. The p-n junction that serves as the unidirectional ABD determines which terminal is the anode and which is the cathode; for that determination, the rectifier p-n junction is ignored.

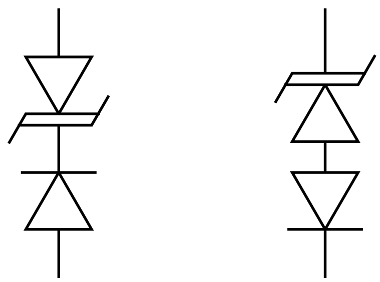


**Figure 7-5 — Unidirectional-blocking low-capacitance ABD**

**unidirectional-conducting low-capacitance ABD:** A two-terminal device comprising a unidirectional-blocking low-capacitance ABD and an anti-parallel diode. (See figure 7-6.)

NOTE To create a low-capacitance ABD with a forward-conducting, low-voltage characteristic, a low-capacitance diode (such as a rectifier) is placed in anti-parallel to the unidirectional-blocking low-capacitance ABD. This diode must have a reverse blocking voltage greater than the avalanche breakdown voltage of the unidirectional ABD.

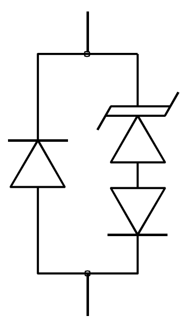


**Figure 7-6 — Unidirectional-conducting low – capacitance ABD**

## 7.1 Avalanche breakdown diode (ABD) transient voltage suppressors (cont'd)

### 7.1.2 Letter symbols, terms, and definitions

| | |
|---|---|
| $C$ or $C_J$ | **capacitance:** The capacitance between the two terminals of an ABD. |
| CF | **clamping factor:** The ratio of clamping voltage ($V_C$ or $V_{CF}$) to breakdown voltage ($V_{(BR)}$). |
| $I_{(BR)}$ | **breakdown current:** A specified current in the breakdown region. |
| $I_D$ | **standby current:** The current through an ABD at rated stand-off voltage. |
| $I_{FS}$ | **forward surge current:** A pulsed current through an ABD in the forward conducting region. |
| $I_{FSM}$ | **rated forward surge current:** The maximum-rated value of peak forward current that may be applied as a single 8.3-ms or 10-ms half-sine-wave pulse. |
| $I_{IB}$ | **blocking leakage current:** The current through a unidirectional-blocking low-capacitance ABD at rated inverse blocking voltage ($V_{WIB}$). |
| $I_{PP}$ | **peak impulse current:** The peak current that is applied to an ABD to determine the clamping voltage ($V_C$) for a specified impulse waveform. |
| $I_{PPSM}$ | **rated random recurring peak impulse current; rated nonrepetitive peak impulse current:** The maximum-rated value of random recurring [nonrepetitive] peak impulse current that may be applied to a device.<br>NOTE 1 A repetitive current is usually a function of the circuit and increases the heating effects within the device. A random recurring or nonrepetitive transient current is usually due to an external cause, and it is assumed that its effect will have completely disappeared before the next transient arrives.<br>NOTE 2 The symbol $I_{PP}$ or $I_{PPM}$ is often used by the industry; however $I_{PPSM}$ is preferred. |
| $P_{M(AV)}$ | **rated average power dissipation:** The maximum-rated value of power dissipation resulting from all sources, including transients and standby current, averaged over a short period of time.<br>NOTE This value should be comparable to the dc power rating of the device. |
| $P_{PPSM}$ | **rated random recurring peak impulse power dissipation; rated nonrepetitive peak impulse power dissipation:** The maximum-rated value of the product of rated random recurring [nonrepetitive] peak impulse current ($I_{PPSM}$) and specified maximum clamping voltage ($V_C$).<br>NOTE 1 A repetitive peak impulse power is usually a function of the circuit and increases the heating effects within the device. A random recurring or nonrepetitive transient peak impulse power is usually due to an external cause, and it is assumed that its effect will have completely disappeared before the next transient arrives.<br>NOTE 2 The symbol $P_{PP}$ or $P_{PPM}$ is often used by the industry; however $P_{PPSM}$ is preferred. |

## 7.1 Avalanche breakdown diode (ABD) transient voltage suppressors (cont'd)

### 7.1.2 Letter symbols, terms, and definitions (cont'd)

$R_S$ — **incremental surge resistance:** The difference between two instantaneous values of the clamping voltage, divided by the difference between the corresponding values of the peak impulse current.

$$R_S = \frac{V_{C2} - V_{C1}}{I_{PP2} - I_{PP1}}$$

NOTE This resistance is composed of thermal and nonlinear avalanche components.

$V_{(BR)}$ — **breakdown [avalanche] voltage:** The voltage across an ABD at a specified current $I_{(BR)}$ in the breakdown region.

$V_C$ or $V_{CF}$ — **clamping voltage:** The voltage across an ABD in a region of low differential resistance that serves to limit the voltage across the device terminals.

NOTE 1 For an asymmetrical device, $V_C$ refers to the clamping voltage in the reverse direction, and $V_{CF}$ refers to the clamping voltage in the forward direction.

NOTE 2 Clamping voltage is measured as the peak voltage across an ABD during the application of an impulse current ($I_{PP}$) for a specified waveform.

NOTE 3 Due to thermal, reactive, or other effects, peak voltage and peak pulse current may not necessarily be coincident.

$V_{CT}$ — **cross-talk voltage:** The incremental voltage across the terminals of one ABD resulting from an electrical pulse in an adjacent ABD within a single array package.

$V_{FS}$ — **peak forward surge voltage:** The peak voltage across an ABD for a specified forward surge current ($I_{FS}$) and time duration.

$V_{OS}$ — **peak overshoot voltage:** The excess voltage above the clamping voltage ($V_C$) of a device for a given test waveform that occurs when waveshapes having a virtual front time of less than 10 µs are applied.

NOTE This value may be expressed as a percentage of the clamping voltage. It is dependent on the lead inductance of the device and the fast front time of the test waveform.

$V_P$ — **peak ESD limiting voltage:** The peak voltage resulting from a fast-front-time waveform, such as electrostatic discharge (ESD).

$V_{WIB}$ — **rated inverse blocking voltage:** The maximum-rated value of dc or peak blocking voltage that may be applied to a unidirectional-blocking low-capacitance ABD in the inverse direction.

NOTE Above this rated voltage, the ABD is not to be surge or impulse tested for any reason.

### 7.1 Avalanche breakdown diode (ABD) transient voltage suppressors (cont'd)

#### 7.1.2 Letter symbols, terms, and definitions (cont'd)

$V_{WM}$ **rated working standoff voltage:** The maximum-rated value of dc or repetitive peak positive cathode-to-anode voltage that may be continuously applied to an ABD over the standard operating temperature range.

$\alpha_{V(BR)}$ **temperature coefficient of breakdown voltage:** The change in breakdown voltage divided by the change in temperature.

NOTE This quotient may be expressed as mV/°C, mV/K, %/°C, or %/K.

### 7.2 Thyristor surge protective devices

#### 7.2.1 General terms and definitions

For thyristor general terms and definitions not included here, see 6.1.

**bidirectional thyristor surge protective device:** A thyristor surge protective device having substantially the same switching characteristics in the first and third quadrants.

**breakdown region:** The portion of the characteristic that starts with the transition from the high dynamic resistance off state to a substantially lower dynamic resistance and extending to the switching point.

**breakover point:** In a quadrant in which switching can occur, the point for which the differential resistance is zero and the off-state voltage reaches a maximum value.

**forward-conducting diode thyristor surge protective device:** A two-terminal internally triggered thyristor surge protective device that switches only for negative terminal-2 (cathode) voltage and conducts large currents at positive terminal-2 (cathode) voltages comparable in magnitude to the on-state voltage.

NOTE 1 In conventional thyristor terminology, this device would be called a reverse-conducting diode thyristor.

NOTE 2 When terminal 2 (cathode) is positive, the device characteristics are similar to those of a forward-biased diode.

NOTE 3 When terminal 2 (cathode) is negative, the device characteristics are similar to those of a breakover-triggered SCR.

**forward-conducting triode thyristor surge protective device:** A three-terminal thyristor surge protective device that switches only for negative main terminal-2 (cathode) voltage and conducts large currents at positive main terminal-2 (cathode) voltages comparable in magnitude to the on-state voltage.

NOTE 1 In conventional thyristor terminology, this device would be called a reverse-conducting triode thyristor.

NOTE 2 Application of an appropriate fixed gate voltage allows switching to take place at voltages well below the intrinsic breakover value.

### 7.2 Thyristor surge protective devices (cont'd)

#### 7.2.1 General terms and definitions (cont'd)

**negative-breakdown-resistance thyristor surge protective device:** A thyristor surge suppressor whose static characteristic has a negative-resistance slope between the breakover point and a higher-current, lower-voltage point at which switching occurs.

**off state:** The state of a thyristor surge protective device, in a quadrant in which switching can occur, that corresponds to the high dynamic-resistance portion of the characteristic between the origin and the beginning of the breakdown region.

**positive-breakdown-resistance thyristor surge protective device:** A thyristor surge suppressor whose static characteristic for the breakdown region has a net positive-resistance slope prior to switching.

**reverse-blocking diode thyristor surge protective device:** A two-terminal thyristor surge protective device that exhibits a blocking state for positive cathode voltage.

**reverse-blocking triode thyristor surge protective device:** A three-terminal (gated) thyristor surge protective device that exhibits a blocking state for positive cathode voltage.

**thyristor surge protective device (TSPD):** A thyristor that is intended to operate as a transient voltage suppressor.

**thyristor surge suppressor (TSS):** Synonym for "thyristor surge protective device".

**unidirectional thyristor surge protective device:** A thyristor surge protective device that can switch in only one quadrant.

NOTE The two types are forward-conducting TSPDs and reverse-blocking TSPDs.

#### 7.2.2 Letter symbols, terms, and definitions

The terms and symbols that follow are based on long-term usage within a specialized segment of the industry and, in several cases, are not considered consistent with the general conventions of this standard.

$C_{\mathrm{O}}$ **off-state capacitance:** The capacitance in the off state.

$I_{\mathrm{(BO)}}$ **breakover current:** The anode, principal, or thyristor current at the breakover point.

$I_{\mathrm{(BR)}}$ **breakdown current:** The anode, principal, or thyristor current at the breakdown voltage.

$I_{\mathrm{D}}$ **off-state current:** The anode, principal, or thyristor current when the thyristor is in the off state.

$I_{\mathrm{DRM}}$ **repetitive peak off-state current:** The maximum (peak) instantaneous value of the off-state current that results from the application of repetitive peak off-state voltage.

**7.2 Thyristor surge protective devices (cont'd)**

**7.2.2 Letter symbols, terms, and definitions (cont'd)**

$I_F$ **forward current (of a forward-conducting TSPD):** The current through the device resulting in a positive cathode-to-anode thyristor voltage.

NOTE This is the voltage polarity that forward-biases the antiparallel diode.

$I_H$ **holding current:** The minimum anode, principal, or thyristor current that will maintain the thyristor in the on state.

$I_S$ **switching current:** The instantaneous anode, principal, or thyristor current at which the thyristor begins to switch from the breakdown region to the on state.

$I_T$ **on-state current:** The anode, principal, or thyristor current when the thyristor is in the on state.

$I_{TSM}$ **nonrepetitive peak on-state current:** The maximum (peak) value of on-state surge current of specified waveform, frequency, and duration or number of cycles.

$R_S$ **switching resistance:** The quotient of (1) the difference between the breakover voltage and the switching voltage and (2) the difference between the breakover current and the switching current.

$$R_S = \frac{V_{(BO)} - V_S}{I_{(BO)} - I_S}$$

$V_{(BO)}$ **breakover voltage:** The voltage at the breakover point.

$V_{(BR)}$ **breakdown voltage:** A voltage across the device in the breakdown region.

$V_D$ **off-state voltage:** The anode, principal, or thyristor voltage when the thyristor is in the off state.

$V_{DRM}$ **repetitive peak off-state voltage:** The highest instantaneous value of the off-state voltage, including all repetitive transient voltages but excluding all nonrepetitive transient voltages.

$V_F$ **forward voltage (of a forward-conducting TSPD):** A positive cathode-to-anode thyristor voltage.

NOTE This is the polarity that forward-biases the antiparallel diode.

$V_{GDM}$ **peak off-state gate voltage:** The maximum (peak) gate voltage that may be applied such that a specified off-state current, $I_D$, is not exceeded.

**7.2 Thyristor surge protective devices (cont'd)**

**7.2.2 Letter symbols, terms, and definitions (cont'd)**

$V_R$ **reverse voltage (of a reverse-blocking TSPD):** A positive cathode-to-anode voltage.

$V_{RRM}$ **repetitive peak reverse voltage (of a reverse-blocking TSPD):** The highest instantaneous value of the reverse voltage, including all repetitive transient voltage but excluding all nonrepetitive transient voltages.

$V_S$ **switching voltage (of a negative-breakdown TSPD):** The instantaneous anode, principal, or thyristor voltage at which the thyristor begins to switch from the breakdown region to the on state.

$V_T$ **on-state voltage:** The anode, principal, or thyristor voltage when the thyristor is in the on state.

**7.3 Varistors; varistor surge protective devices**

**7.3.1 General terms and definitions**

**metal-oxide varistor (MOV):** A varistor having a sintered metal-oxide element.

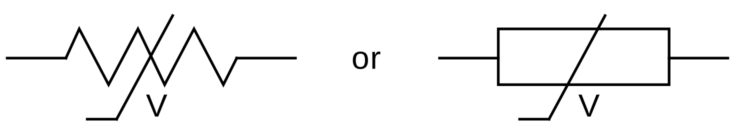
NOTE The device exhibits a symmetrical voltage-current characteristic.

**silicon carbide varistor:** A varistor having a silicon carbide element.

NOTE The device exhibits a symmetrical voltage-current characteristic.

**varistor:** A transient voltage suppressor that is a two-terminal semiconductor device having a nonlinear voltage-current characteristic.

Graphic symbols (ref. IEEE Std 315):



**7.3 Varistors; varistor surge protective devices (cont'd)**

**7.3.2 Letter symbols, terms, and definitions**

The terms and symbols that follow are based on long-term usage within a specialized segment of the industry and, in several cases, are not considered consistent with the general conventions of this standard.

$C$ **capacitance:** The capacitance between the two terminals of a varistor at specified frequency and bias. (Ref. IEEE C62.33.)

$I_D$ **standby current:** The dc current at rated dc voltage, $V_{m(dc)}$.

$I_{tm}$ **rated peak single-pulse transient current:** The maximum-rated value of peak current that may be applied for a single 8/20 µs impulse with rated line voltage also applied. (Ref. IEEE C62.33.)

$P_d$ **ac standby power:** The varistor ac power dissipation at rated rms voltage, $V_{m(ac)}$. (Ref. IEEE C62.33.)

$P_{t(AV)m}$ **rated transient average power dissipation:** The maximum-rated value of average power that may be dissipated due to a group of pulses occurring within a specified isolated time period.

$R_x$ **static resistance:** The dc resistance of the varistor at a specified operating current, $I_X$.

$$R_X = \frac{V_X}{I_X}$$

$t_{os}$ **overshoot duration:** The time interval between the point on the pulse waveform at which the amplitude exceeds the clamping voltage level and the point at which the voltage level overshoot has decayed to 50% of its peak.

$t_{res}$ **response time:** The time interval between the point on the pulse waveform at which the amplitude exceeds the clamping voltage level and the point at which the voltage overshoot has peaked.

$V_c$ **clamping voltage:** The voltage in a region of low differential resistance that serves to limit the voltage across the device terminals.

$V_c/V_{pm}$ **voltage clamping ratio:** The ratio of clamping voltage to rated recurrent peak voltage.

$V_{m(ac)}$ **rated rms voltage:** The maximum-rated value of continuous sinusoidal rms voltage that may be applied. (Ref. IEEE C62.33.)

$V_{m(dc)}$ **rated dc voltage:** The maximum-rated value of continuous dc (steady-state) voltage that may be applied. (Ref. IEEE C62.33.)

**7.3 Varistors; varistor surge protective devices (cont'd)**

**7.3.2 Letter symbols, terms, and definitions (cont'd)**

$V_{N(ac)}$ **peak nominal voltage:** The voltage across a varistor at a peak ac current, $I_{N(ac)}$, of specified magnitude and duration. (Ref. IEEE C62.33.)

$V_{N(dc)}$ **nominal voltage:** The voltage across a varistor at a pulsed dc current, $I_{N(dc)}$, of specified magnitude and duration. (Ref. IEEE C62.33.)

$V_{os}$ **voltage overshoot:** The excess voltage, above the clamping voltage, that occurs when a current pulse having short rise time is applied.

NOTE This is sometimes expressed as a percentage of the clamping voltage.

$V_{pm}$ **rated recurrent peak voltage:** The maximum-rated value of recurrent peak voltage that may be applied for a specific duty cycle and waveform. (Ref. IEEE C62.33.)

$V_x$ **varistor voltage:** The voltage across a varistor at a specified current, $I_X$. (Ref. IEEE C62.33.)

$W_{tm}$ **rated single-pulse transient energy:** The maximum-rated value of energy that may be dissipated for a single impulse of maximum rated current at a specified waveshape, with rated rms voltage or rated dc voltage also applied. (Ref. IEEE C62.33.)

$Z_x$ **dynamic impedance:** The small-signal impedance of the varistor at a specified operating current, $I_X$.

$$Z_X = \frac{dV_X}{dI_X}$$

$\alpha_{V(BR)}$ **temperature coefficient of breakdown voltage:** The change in breakdown voltage divided by the change in temperature.

NOTE This quotient may be expressed as either mV/°C or %/°C.

## Annex A (informative) Differences between JESD77D and JESD77-B

These tables briefly describe most of the changes made to entries that appear in this standard, compared to its predecessors, JESD77C.01 (December 2009), JESD77C (October 2009), JESD77B.01 (July 2006), and JESD77-B (February 2000). If the change to a concept involves the symbol or any words added or deleted, it is included. Some punctuation changes are not mentioned.

### A.1 Differences between JESD77D and JESD77C.01

| Subclause | Term and description of change |
| --- | --- |
| Globally | Changed the Θ symbol when used in the subscripts of thermal parameters; e.g., $R_{\Theta **}$, $Z_{\Theta **}$ (where * represents any subscript), from italic ($\mathit{\Theta}$) to non-italic (Θ). This actually affected only 2.2 and the Index. |
| 2.1 | Added the following terms and definitions: **component (general), device, solid-state (within the scope of JEDEC), solid-state component, solid-state device, solid-state industry, solid-state physics,** and **solid-state technology**. |
| 2.1 | **dice; dies:** Added the alternative term "dies". |
| 3.4.1 | **voltage-regulator diode:** Changed the definition to agree with JESD211. |
| 3.4.1 | **Zener diode:** Changed the definition to agree with JESD211. |
| 3.4.1 | **temperature-compensated-regulator diode:** Added the term and definition. |
| 7.1.2 | **CF** **clamping factor**: Restored term and definition as it appeared in JESD77B. |
| 7.1.2 | $I_{(BR)}$ **breakdown current:** Restored term from JESD77B but changed the definition.. |

### A.2 Differences between JESD77C.01 and JESD77C

| Subclause | Term and description of change |
| --- | --- |
| 4.3.2 | $y_{os}$ **common-source small-signal short-circuit output admittance:** The correction that was made in JESD77B.01 was inadvertently undone in JESD77C. Again changed the definition to read: "The ac rms drain current divided by the ac rms drain-source voltage with the gate-source voltage held constant.<br><br>"NOTE The fact that the gate-source voltage is held constant implies that the gate terminal is ac short-circuited to the source terminal." |
| 6.1.2 | **Table 6-1:** Corrected "$I_{RC(AC)}$" to "$I_{RC(AV)}$". |

**Annex A (informative) Differences between JESD77D and JESD77-B (cont'd)**

## A.3 Differences between JESD77C and JESD77B.01

| Subclause | Term and description of change |
| --- | --- |
| 1.2.13 | **Typefaces:** Added clarifying words with no change of the rules intended. |
| 2.1 | **anode terminal (A, a):** In definition, changed "with the same polarity" to "and have the same polarity".<br>Added note 4. |
| 2.1 | **cathode terminal (K, k):** In definition, changed "with the same polarity" to "and have the same polarity".<br>Added note 4. |
| 2.1 | **temperature derating:** Added concept for "temperature derating" from JESD210. |
| 3.1.1 | **bridge rectifier circuit:** Added concept for "bridge rectifier circuit". |
| 3.1.1 | **double-way rectifier circuit:** Added concept for "double-way rectifier circuit". |
| 3.4.2 | $\alpha_{VZ}$ **temperature coefficient of regulator voltage:** Corrected symbol. Deleted from definition "usually expressed as a percentage of the regulator voltage". Added to note "may be expressed as mV/°C, mV/K, %/°C, or %/K and". |
| 3.4.2 | $\Delta V_{Z(temp)}$ **reference-voltage variation with temperature:** Corrected symbol. |
| 3.5.2 | $\alpha_{IS}$ **temperature coefficient of regulator current:** Corrected symbol. |
| 3.5.2 | $\Delta I_S$ **regulator-current variation:** Corrected symbol. |
| 5.1.2 | **Table 5.1:** Changed "foot$^2$" to "square foot", "meter$^2$" to "square meter", and "candela/foot$^2$" to "candela per square foot". |
| 7.1.1 | Deleted all material in subclause 7.1.1 and replaced with new material from JESD210. |
| 7.1.2 | Deleted all material in subclause 7.1.2 and replaced with new material from JESD210. |

## A.4 Differences between JESD77B.01 and JESD77-B

| Subclause | Term and description of change |
| --- | --- |
| 2.1 | **semiconductor device (general term):** In the definition, inserted "in whole or in part"; this replaced note 1. Note 2 became the only remaining note. |
| 2.1 | **space-charge region (of a semiconductor device):** Modified qualifier, changed "not zero" to "significantly different from zero", and added note 2. |
| 2.1 | **static value:** Split into definitions (1) and (2). |
| 3.1.1 | **semiconductor rectifier diode:** Added "Graphic symbol (Ref. IEEE Std 315):" |
| 3.1.1 | **semiconductor signal diode:** In the definition, changed "detection" to "processing".<br>Added "Graphic symbol (Ref. IEEE Std 315):" |
| 3.1.2 | **RRSF** **reverse recovery softness factor:** Corrected symbols d$i_{RR}$/d$t$, d$i_{RF}$/d$t$, and $I_{RM}$.<br>Added "(Ref. JESD282B.)". |
| 3.1.2 | **forward-polarity (microwave) diode:** Inserted "(microwave)" in the term and "microwave" in the definition. |
| 3.2.1 | **IMPATT [impact avalanche and transit-time] diode; avalanche diode operating in the IMPATT mode:** Underlined "p" in "impact". |
| 3.2.1 | **matched pair (of microwave diodes):** Inserted "(of microwave diodes)" in the term and "microwave" in the definition. |

**Annex A (informative) Differences between JESD77D and JESD77-B (cont'd)**

**A.4 Differences between JESD77B.01 and JESD77-B (cont'd)**

**Subclause Term and description of change**

3.2.1 **reverse-polarity (microwave) diode:** Inserted "(microwave)" in the term and "microwave" in the definition.

4.1.2 $I_{CEO}$ **collector cutoff current, base open:**
*through*
$I_{CEX}$ **collector cutoff current, circuit between base and emitter:** In the list following "respectively", changed the four commas to periods and deleted "or".

4.1.2 $p_T$ **total instantaneous power input to all terminals:** Inserted "input" in the term.

4.1.2 $V_{(BR)CEO}$ **collector-emitter breakdown voltage, base open:**
*through*
$V_{(BR)CEX}$ **collector-emitter breakdown voltage, circuit between base and emitter:** In the list following "respectively", changed the four commas to periods and deleted "or".

4.1.2 $V_{CEO}$ **collector-emitter voltage, base open:**
*through*
$V_{CEX}$ **collector-emitter voltage, circuit between base and emitter:** .In the list following "respectively", changed the four commas to periods and deleted "or".

4.1.2 $V_{CEO(sus)}$ **collector-emitter sustaining voltage, base open:**
*through*
$V_{CEX(sus)}$ **collector-emitter sustaining voltage, circuit between base and emitter:** In the list following "respectively", changed the four commas to periods and deleted "or". Changed note as the subscript does not describe the external condition, but it does identify it.

4.1.2 $y_{ie(imag)}$ **imaginary part of the common-emitter small-signal short-circuit input admittance:** Repositioned "common-emitter" in the term.

4.1.2 $y_{ie(real)}$ **real part of the common-emitter small-signal short-circuit input admittance:** Repositioned "common-emitter" in the term.

4.1.2 $y_{oe(imag)}$ **imaginary part of the common-emitter small-signal short-circuit output admittance:** Repositioned "common-emitter" in the term.

4.1.2 $y_{oe(real)}$ **real part of the common-emitter small-signal short-circuit output admittance:** Repositioned "common-emitter" in the term.

4.2.2 $I_P$ **peak-point current:** Changed the symbol subscript from a lowercase p in 14 points to an uppercase P in 12 points, consistent with $I_V$ and $V_P$.

4.3.1 **metal-oxide-semiconductor field-effect transistor (MOSFET):** In the definition, changed "oxide material; the gate" to "oxide material and the gate".

4.3.2 $I_{GSS}$ **reverse gate current, drain short-circuited to source:** Added "reverse-" before "biased".

**Annex A (informative)  Differences between JESD77D and JESD77-B (cont'd)**

**A.4 Differences between JESD77B.01 and JESD77-B (cont’d)**

| **Subclause** | **Term and description of change** |
|---|---|
| 4.3.2 | $V_{(BR)DSR}$ **drain-source breakdown voltage, resistance between gate and source:** *through* $V_{(BR)DSX}$ **drain-source breakdown voltage, circuit between gate and source:** In the list following “respectively”, changed the three commas to periods and deleted “or”. |
| 4.3.2 | $y_{os}$ **common-source small-signal short-circuit output admittance:** In the definition and note, changed "gate" to "drain" two places and "drain" to gate" three places. |
| 4.4.1 | **insulated-gate bipolar transistor (IGBT):** In the definition, replaced “npnp” with “pnpn/npnp”. In note 1, changed “vertical MOS power MOSFET” to “vertical power MOSFET”. In note 4, replaced “pnpn” with “pnpn/npnp”. |
| 5.5.1 | **flux density, luminous** and **flux density, radiant:** Separated the combined concept into two separate concepts. |
| 5.5.2 | $A_D$ **detector area:** Reversed the words in the term. |
| 5.2.2 | $E$, $E_e$ **irradiance:** Reworded editorially to be consistent with definitions of radiant exitance and flux density. |
| 5.2.2 | $E$, $E_v$ **illuminance; illumination:** Separated the terms “illuminance” and “illumination” with a semicolon and deleted the parentheses. Reworded definition editorially to be consistent with definitions of luminous exitance and flux density. |
| 6.1.2 | $I_{TQRM}$ **repetitive peak controllable on-state current (of a GTO thyristor):** In the note, changed “power loss” to” “heating effect”. |
| 6.1.2 | $I_{TQSM}$ **nonrepetitive peak controllable on-state current (of a GTO thyristor):** In the note, changed “power loss” to” “heating effect”. |
| 6.2.2 | $V_P - V_S$ **offset voltage:** In the symbol, changed the dash to a minus sign. |

## Index

Parametric terms in this index are often abbreviated by elimination of adjectives such as ac, dc, static, small-signal, short-circuit, repetitive peak, common-emitter, etc. Symbols are shown in this index only to facilitate the location of concepts in the main body. Where multiple symbols could be given, usually only one representative symbol is shown here. For example, below you will find the entry "input capacitance ($C_{ibo}$), 4.1.2", but in 4.1.2 following the entry for $C_{ibo}$ you can find other input capacitances: $C_{ieo}$, $C_{ibs}$, and $C_{ies}$.

**A**



**B**



**C**

**D**

**E**



**F**

**G**



**H**



**I**

**J**



**K**



**L**



**M**

**Q**



**R**

**Standard Improvement Form** **JEDEC JESD77D**

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Clause number ________ Identify the specific item within the clause by selecting one or more of the following:

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- [ ] Term ____________________
- [ ] Definition (Corresponding to term and/or definition filled in)
- [ ] Other ____________________

(b) The referenced item has proven to be:

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- [ ] In error
- [ ] Other ____________________

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____________________

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