

Semiconductor devices —

Part 7: Bipolar transistors

ICS 31.080.01

National foreword

This British Standard reproduces verbatim IEC 60747-7:2000 and implements it as the UK national standard. It supersedes BS 6493-1.7:1989 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee EPL/47, Semiconductors, which has the responsibility to:

- aid enquirers to understand the text;
- present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;
- monitor related international and European developments and promulgate them in the UK.

A list of organizations represented on this committee can be obtained on request to its secretary.

From 1 January 1997, all IEC publications have the number 60000 added to the old number. For instance, IEC 27-1 has been renumbered as IEC 60027-1. For a period of time during the change over from one numbering system to the other, publications may contain identifiers from both systems.

Cross-references

The British Standards which implement international publications referred to in this document may be found in the BSI Standards Catalogue under the section entitled “International Standards Correspondence Index”, or by using the “Find” facility of the BSI Standards Electronic Catalogue.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

This British Standard, having been prepared under the direction of the Electrotechnical Sector Committee, was published under the authority of the Standards Committee and comes into effect on 15 June 2001

Summary of pages

This document comprises a front cover, an inside front cover, the IEC title page, pages 2 to 120, an inside back cover and a back cover.

The BSI copyright date displayed in this document indicates when the document was last issued.

Amendments issued since publication

Amd. No.	Date	Comments

© BSI 06-2001

ISBN 0 580 37454 8

**NORME
INTERNATIONALE
INTERNATIONAL
STANDARD**

**CEI
IEC**

60747-7

Deuxième édition
Second edition
2000-12

Dispositifs à semiconducteurs –

**Partie 7:
Transistors bipolaires**

Semiconductor devices –

**Part 7:
Bipolar transistors**



Commission Electrotechnique Internationale
International Electrotechnical Commission
Международная Электротехническая Комиссия

CONTENTS

	Page
FOREWORD	6
Clause	
1 Scope	8
2 Normative references.....	8
3 Terms and definitions	9
3.1 Types of bipolar transistors.....	9
3.2 General terms.....	9
3.2.1 Specific physical regions (of a junction transistor).....	9
3.2.2 Specific functional regions	10
3.3 Circuit configurations	11
3.4 Terms related to ratings and characteristics.....	11
3.5 s parameters	16
3.5.1 General introduction	16
3.5.2 Definitions	18
3.5.3 Application of the s parameters.....	19
4 Letter symbols	22
4.1 Letter symbols for currents, voltages and powers	22
4.1.1 General.....	22
4.1.2 Additional subscripts.....	22
4.2 Letter symbols for electric parameters	22
4.2.1 General.....	22
4.2.2 Additional subscripts.....	22
4.3 Letter symbols for other quantities	22
4.3.1 General.....	22
4.4 List of letter symbols.....	23
4.4.1 Voltages	23
4.4.2 Currents.....	24
4.4.3 Powers	24
4.4.4 Electrical parameters	24
4.4.5 Frequency parameters	28
4.4.6 Switching parameters	29
4.4.7 Sundry quantities.....	30
4.4.8 External circuit parameters	31
4.4.9 Matched-pair bipolar transistors	31
5 Essential ratings and characteristics	31
5.1 Low-power signal transistors (excluding switching applications).....	31
5.1.1 General.....	31
5.1.2 Ratings (limiting values).....	32
5.1.3 Characteristics.....	32
5.1.4 Application data	37

Clause	Page
5.2 Power transistors (excluding switching and high-frequency applications)	37
5.2.1 General.....	37
5.2.2 Ratings (limiting values).....	38
5.2.3 Characteristics.....	39
5.2.4 Application data	40
5.3 High-frequency power transistors for amplifier and oscillator applications	40
5.3.1 Type	40
5.3.2 Semiconductor material	40
5.3.3 Polarity	40
5.3.4 Outline	40
5.3.5 Limiting values (absolute maximum system) over the operating temperature range, unless otherwise stated	40
5.3.6 Characteristics.....	41
5.3.7 Supplementary information	43
5.3.8 Environmental and/or endurance test information.....	43
5.4 Switching transistors.....	43
5.4.1 General.....	43
5.4.2 Ratings (limiting values).....	43
5.4.3 Characteristics.....	45
5.4.4 Application data	48
6 General and reference measuring methods.....	48
6.1 General measuring methods	48
6.1.1 General.....	48
6.1.2 Collector-base and emitter-base cut-off currents.....	48
6.1.3 Collector-emitter cut-off currents (d.c. method) (I_{CEO} , I_{CER} , I_{CEX} , I_{CES})	48
6.1.4 Collector-emitter saturation voltage (V_{CEsat})	49
6.1.5 Base-emitter saturation voltage (V_{BEsat})	51
6.1.6 Base-emitter voltage (d.c. method) (V_{BE})	53
6.1.7 Collector-emitter sustaining voltage ($V_{CEO(sus)}$, $V_{CER(sus)}$).....	54
6.1.8 Capacitances	56
6.1.9 Hybrid parameters (small-signal and large-signal).....	58
6.1.10 Voltage ratings and measurable characteristics limiting the working voltages ($V_{(BR)CBO}$, $V_{(BR)EBO}$, $I_{S/B}$)	66
6.1.11 Thermal resistance	69
6.1.12 Switching times (t_d , t_r , t_{on} , t_s , t_f , t_{off}).....	80
6.1.13 High-frequency parameters (f_T , C_{22b} , $Re(h_{11e})$, $y.e.$, $s..$).....	82
6.1.14 Noise (F).....	97
6.1.15 Measuring methods for matched-pair bipolar transistors	105
6.2 Reference measuring methods	107
6.2.1 General.....	107
6.2.2 Collector-base cut-off current (reverse current) (I_{CBO})	108
6.2.3 Emitter-base cut-off current (reverse current) (I_{EBO})	109
6.2.4 Collector-emitter saturation voltage (V_{CEsat})	110
6.2.5 Base-emitter saturation voltage (V_{BEsat})	113
6.2.6 Base-emitter forward voltage (V_{BE}).....	113

Clause	Page
6.2.7 Static value of common-emitter forward current transfer ratio (h_{21E}) (d.c. method)	114
6.2.8 Small-signal common-emitter forward current transfer ratio at low frequencies (h_{21E})	116
6.2.9 Switching parameters	118
7 Acceptance and reliability – Electrical endurance tests	118
7.1 General requirements	118
7.2 Specific requirements	118
7.2.1 List of endurance tests	118
7.2.2 Conditions for endurance tests	118
7.2.3 Failure-defining characteristics and failure criteria for acceptance tests	118
7.2.4 Failure-defining characteristics and failure criteria for reliability tests	118
7.2.5 Procedure in case of a testing error	118
Figure 1 – Switching transistor pulse characteristic	14
Figure 2 – Early voltage	16
Figure 3 – Circuit with four-pole network	17
Figure 4 – Equivalent circuit	35
Figure 5 – Basic circuit for the measurement of collector-emitter cut-off currents	48
Figure 6 – Basic circuit for the measurement of the collector-emitter saturation voltage (d.c. method)	49
Figure 7 – Basic circuit for the measurement of the collector-emitter saturation voltage (pulse method)	50
Figure 8a – Basic circuit for the measurement of the base-emitter saturation voltage (d.c. method)	51
Figure 8b – Basic circuit for the measurement of the base-emitter saturation voltage (pulse methods)	52
Figure 9 – Base circuit for the measurement of base-emitter voltage (d.c. method)	53
Figure 10 – Basic circuit for the measurement of the collector-emitter sustaining voltage	54
Figure 11 – I_C versus V_{CE} characteristic	55
Figure 12a – Transistor with base terminal connected to case	56
Figure 12b – Transistor with collector terminal connected to case	56
Figure 12 – Basic circuit for the measurement of the common-base output capacitance using a two-terminal bridge	56
Figure 13 – Basic circuit for the measurement of C_{22b} using a three-terminal bridge	57
Figure 14 – Basic circuit for the measurement of C_{cb} using a three-terminal bridge	58
Figure 15 – Basic circuit for the measurement of h_{11e} and h_{21e}	59
Figure 16 – Basic circuit for the measurement of h_{12e}	61
Figure 17 – Basic circuit for the measurement of h_{22e}	62
Figure 18 – Basic circuit for the measurement of h_{22b}	63
Figure 19 – Basic circuit for the measurement of h_{21E}	65
Figure 20 – Circuit for the measurement of $V_{(BR)CBO}$	67
Figure 21 – Circuit for the measurement of $I_{S/B}$	68
Figure 22 – Basic test circuit for measuring the thermal resistance of NPN transistors	72
Figure 23 – Emitter current (I_E) versus emitter-base voltage (V_{EB}) for the junction temperatures $T_j^{(1)}$ and $T_j^{(2)}$	73

	Page
Figure 24 – I_E and V_{EB} change with time	73
Figure 25 – Temperature coefficient (αV_{EB}) versus typical emitter current density (J_E)	77
Figure 26a – Cross-section of a typical transistor in metallic case (cavity).....	77
Figure 26b – Thermal equivalent circuit.....	78
Figure 27 – Typical transient thermal resistance characteristic versus heating pulse duration	78
Figure 28 – Typical ΔV_{EB} versus collector-base (V_{CB}) characteristic	79
Figure 29 – Typical safe operating area	80
Figure 30 – Circuit diagram	81
Figure 31 – Switching times	81
Figure 32 – Circuit for the measurement of the transition frequency	83
Figure 33 – Block-diagram of the circuit for the measurement of the resistive and reactive components of h_{11e}	86
Figure 34 – Circuit of the adaptor shown in figure 33.....	86
Figure 35 – Circuit for the measurement of complex common-emitter y parameters	87
Figure 36 – Three-pole circuit for the measurement of y_{11e}	88
Figure 37 – Three-pole circuit for the measurement of y_{22e}	89
Figure 38 – Three-pole circuit for the measurement of y_{21e}	90
Figure 39 – Three-pole circuit for the measurement of y_{12e}	91
Figure 40 – Block diagram of the circuit for the measurement of s_{11} and s_{22} parameters.....	92
Figure 41 – Block diagram of the circuit for the measurement of s_{12} and s_{21} parameters.....	95
Figure 42 – Basic block diagram for the measurement of the noise figure	98
Figure 43 – Basic circuit for the measurement of the noise figure up to 3 MHz	100
Figure 44 – Basic circuit for the measurement of the noise figure from 3 MHz to 300 MHz .	101
Figure 45 – Basic circuit for the measurement of the noise figure below 1 kHz (signal generator method)	103
Figure 46 – Basic circuit for the measurement of h_{21E1}/h_{21E2}	105
Figure 47 – Circuit for the measurement of I_{CBO}	108
Figure 48 – Basic circuit for the measurement of the collector-emitter saturation voltage (d.c. method).....	110
Figure 49 – Basic circuit for the measurement of the collector-emitter saturation voltage (pulse method)	111
Figure 50 – V_{CE} changes with time	112
Figure 51 – Basic circuit for the measurement of the base-emitter forward voltage.....	113
Figure 52 – Basic circuit for the measured of h_{21E} (d.c. method)	114
Figure 53 – Basic circuit for the measurement of h_{21E} at low frequencies.....	116
Table 1 – Failure-defining characteristics for acceptance after endurance tests	119
Table 2 – Conditions for endurance tests	120

INTERNATIONAL ELECTROTECHNICAL COMMISSION

SEMICONDUCTOR DEVICES –

Part 7: Bipolar transistors

FOREWORD

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

International Standard IEC 60747-7 has been prepared by subcommittee 47E: Discrete semiconductor devices, of IEC technical committee 47: Semiconductor devices.

This second edition cancels and replaces the first edition published in 1988, its amendments 1 (1991) and 2 (1994). This second edition constitutes a technical revision.

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

The text of this standard is based on the first edition, amendment 1, amendment 2 and the following documents:

FDIS	Report on voting
47E/150/FDIS	47E/162/RVD

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

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

The committee has decided that the contents of this publication will remain unchanged until 2003.
At this date, the publication will be

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

SEMICONDUCTOR DEVICES –

Part 7: Bipolar transistors

Introductory note

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

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

1 Scope

The present standard gives the requirements applicable to the following sub-categories of bipolar transistors:

- low power signal transistors (excluding switching applications);
- power transistors (excluding switching and high-frequency applications);
- high-frequency power transistors for amplifier and oscillator applications;
- switching transistors.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of IEC 60747. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of IEC 60747 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of IEC and ISO maintain registers of currently valid International Standards.

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

3 Terms and definitions

3.1 Types of bipolar transistors

3.1.1

junction transistor

transistor having a base region and two or more junctions

NOTE The operation of a junction transistor depends upon the injection of minority carriers into the base region.

3.1.2

bi-directional transistor

transistor which has substantially the same electrical characteristics when the terminals normally designated as emitter and collector are interchanged

NOTE Bi-directional transistors are sometimes called symmetrical transistors. This term, however, is deprecated as it might give the incorrect impression of an ideally symmetrical transistor.

3.1.3

tetrode transistor

four-electrode transistor, usually a conventional junction transistor having two separate base electrodes and two base terminals

3.2 General terms

3.2.1 Specific physical regions (of a junction transistor)

3.2.1.1

collector region

physical region that is designed by the manufacturer to contain in the normal operating mode the collection region and which, in a simple discrete transistor, is externally accessible by the designated collector terminal

3.2.1.2

emitter region

physical region that is designed by the manufacturer to contain in the normal operating mode the supply region and which, in a simple discrete transistor, is externally accessible by the designated emitter terminal

3.2.1.3

base region

physical region located between the collector junction and the emitter junction and containing the control region and which, in a simple discrete transistor, is externally accessible by the designated base terminal

3.2.1.4

collector(-base) junction

transition region between the collector region and the base region

3.2.1.5

emitter(-base) junction

transition region between the emitter region and the base region

3.2.1.6

collector terminal

specified externally available point of connection to the collector electrode and collector region

3.2.1.7

emitter terminal

specified externally available point of connection to the emitter electrode and emitter region

3.2.1.8

base terminal

specified externally available point of connection to the base electrode and base region

3.2.2 Specific functional regions

3.2.2.1

functional collector region

collection region that acquires principal-current charge carriers from the functional base region through the (collecting) junction between it and the functional base region

NOTE In the normal operating mode, this functional region is located in the collector region and, in the inverse operating mode, in the emitter region.

3.2.2.2

functional emitter region

supply region that delivers principal-current charge carriers into the functional base region through the (emitting) junction between it and the functional base region

NOTE In the normal operating mode, this functional region is located in the emitter region and, in the inverse operating mode, in the collector region.

3.2.2.3

functional base region

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

3.2.2.4

collector(-base) space-charge region;

collector(-base) depletion layer

space-charge region between the functional collector region and the functional base region

3.2.2.5

emitter(-base) space-charge region;

emitter(-base) depletion layer

space-charge region between the functional emitter region and the functional base region

3.3 Circuit configurations

3.3.1

common base

circuit configuration in which the base terminal is common to the input circuit and to the output circuit and in which the input terminal is the emitter terminal and the output terminal is the collector terminal

3.3.2

inverse common base

circuit configuration in which the base terminal is common to the input circuit and to the output circuit and in which the input terminal is the collector terminal and the output terminal is the emitter terminal

3.3.3

common collector

circuit configuration in which the collector terminal is common to the input circuit and to the output circuit and in which the input terminal is the base terminal and the output terminal is the emitter terminal

3.3.4

inverse common collector

circuit configuration in which the collector terminal is common to the input circuit and to the output circuit and in which the input terminal is the emitter terminal and the output terminal is the base terminal

3.3.5

common emitter

circuit configuration in which the emitter terminal is common to the input circuit and to the output circuit and in which the input terminal is the base terminal and the output terminal is the collector terminal

3.3.6

inverse common emitter

circuit configuration in which the emitter terminal is common to the input circuit and to the output circuit and in which the input terminal is the collector terminal and the output terminal is the base terminal

3.4 Terms related to ratings and characteristics

3.4.1

punch-through voltage

value of the collector-base voltage above which the open-circuit emitter-base voltage increases almost linearly with increasing collector-base voltage

NOTE 1 At this voltage, the collector depletion layer extends through the base to the emitter depletion layer.

NOTE 2 "Reach-through voltage" is a term also in the USA.

3.4.2 **saturation voltages**

3.4.2.1 **collector-emitter saturation voltage**

voltage between the collector and emitter electrodes 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

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

3.4.2.2 **base-emitter saturation voltage**

voltage between the base and emitter electrodes 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

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

3.4.3 **cut-off current (reverse current)**

reverse current of the base-collector junction (or base-emitter junction) when the emitter (or the collector) is open-circuited, the reverse voltage being specified

3.4.4 **collector series resistance**

resistance between the collector terminal and the internal inaccessible collector point in an equivalent circuit

3.4.5 **emitter series resistance**

resistance between the emitter terminal and the internal inaccessible emitter point in an equivalent circuit

3.4.6 **saturation resistance**

resistance between collector and emitter terminals under specified conditions of base current and collector current when the collector current is limited by the external circuit

NOTE The saturation resistance may be determined either as the ratio of total voltage to total current or as the ratio of differential voltage to differential current; the method of determination has to be specified.

3.4.7 **extrinsic base resistance**

resistance between the base terminal and the internal inaccessible base point in an equivalent circuit

3.4.8 **emitter depletion layer capacitance**

part of the capacitance across an emitter-base junction that is associated with its depletion layer

NOTE The emitter depletion layer capacitance is a function of the total potential difference across the depletion layer.

3.4.9

collector depletion layer capacitance

part of the capacitance across a collector-base junction that is associated with its depletion layer

NOTE The depletion layer capacitance is a function of the total potential difference across the depletion layer.

3.4.10

delay-time (of a switching transistor)

time interval between the application at the input terminals of a pulse which is switching the transistor from a non-conducting to a conducting state and the appearance at the output terminals of the pulse induced by the charge carriers

NOTE The time is usually measured between points corresponding to 10 % of the amplitude of the applied pulse and of the output pulse respectively (see figure 1).

3.4.11

rise time (of a switching transistor)

time interval between the instants at which the magnitude of the pulse at the output terminals reaches specified lower and upper limits, respectively, when the transistor is being switched from its non-conducting to its conducting state

NOTE The lower and upper limits are usually 10 % and 90 % respectively of the amplitude of the output pulse (see figure 1).

3.4.12

carrier storage time (of a switching transistor)

time interval between the beginning of the fall of the pulse applied to the input terminals and the beginning of the fall of the pulse generated by charge carriers at the output terminals

NOTE The time is generally measured between the 90 % values of the two pulse amplitudes (see figure 1).

3.4.13

fall time (of a switching transistor)

time interval between the instants at which the magnitude of the pulse at the output terminals reaches specified upper and lower limits respectively, when the transistor is being switched from its conducting to its non-conducting state

NOTE The upper and lower limits are usually 90 % and 10 % respectively of the amplitude of the output pulse (see figure 1).

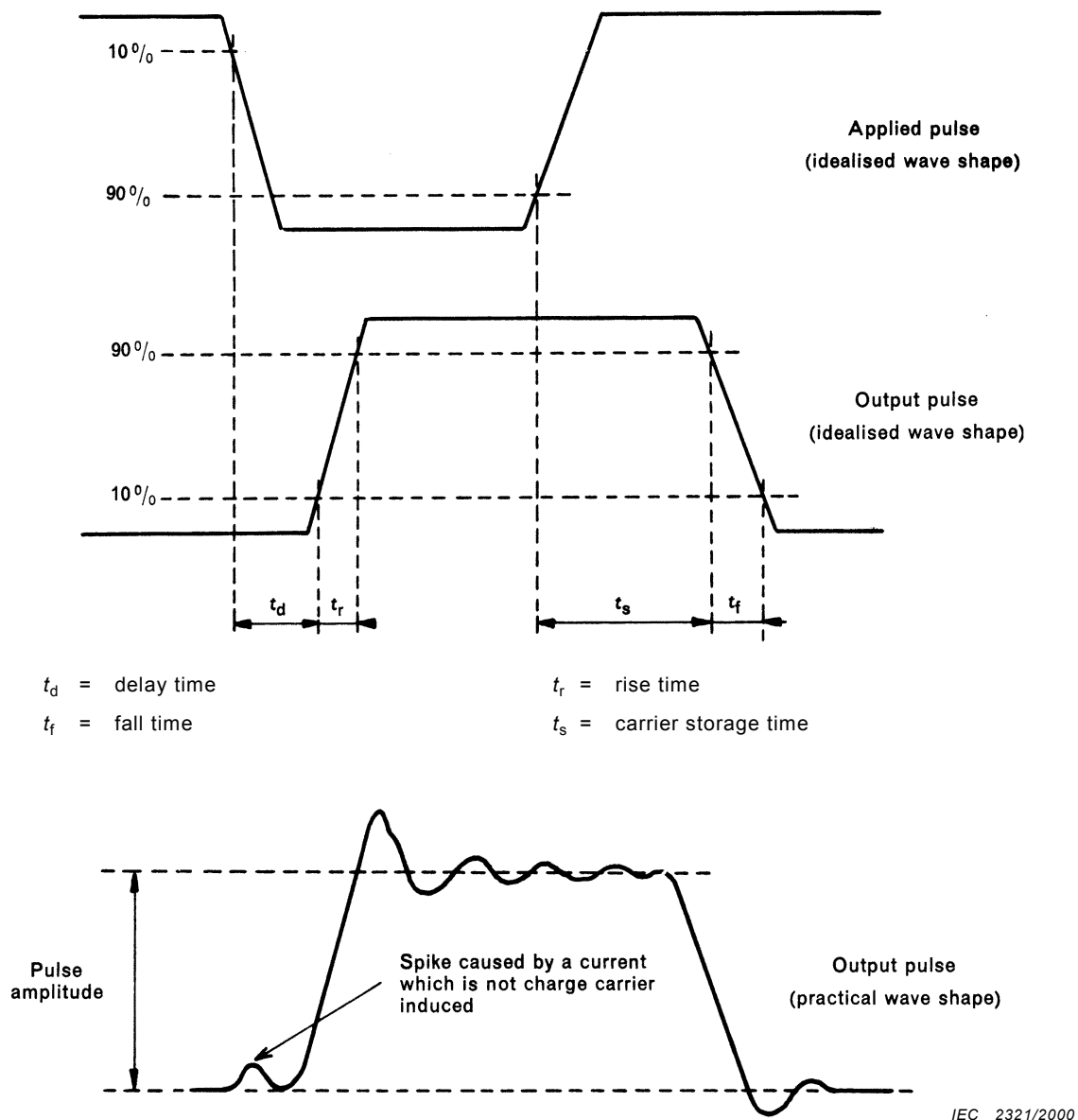


Figure 1 – Switching transistor pulse characteristic

3.4.14

maximum frequency of oscillation

maximum frequency at which a transistor can be made to oscillate under specified conditions

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

3.4.15

transition frequency (f_T)

product of the modulus of the common-emitter small-signal short-circuit forward current transfer ratio $|h_{21e}|$ and the frequency of measurement, this frequency being so chosen that $|h_{21e}|$ is decreasing at a slope of approximately 6 dB per octave

3.4.16

frequency of unity current transfer ratio (f_1)

frequency at which the modulus of the common-emitter small-signal short-circuit forward current transfer ratio $|h_{21e}|$ has decreased to unity

3.4.17

current transfer ratio; current amplification factor

3.4.17.1

small-signal short-circuit forward current transfer ratio

ratio between the alternating output current and the small sinusoidal input current producing it under small-signal conditions, the output being short-circuited to a.c.

3.4.17.2

static value of the forward current transfer ratio

ratio between the continuous (direct) output and the continuous (direct) input current, the output voltage being held constant

3.4.17.3

inherent (large-signal) forward current transfer ratio

difference between the continuous (direct) collector current and the collector-base cut-off current divided by the sum of the continuous (direct) base current and the collector-base cut-off current at a specified constant value of the collector-emitter voltage

3.4.18

small-signal open-circuit reverse voltage transfer ratio

ratio of the alternating voltage appearing at the input terminals, when they are a.c. open-circuited, to the alternating voltage applied to the output terminals, under small-signal conditions

3.4.19

transient current ratio in saturation (of a switching transistor)

quotient of the collector current suddenly demanded from a transistor and the minimum base current necessary to hold it in saturation

3.4.20

Early voltage V_{EY} (for computer-aided circuit design)

voltage corresponding to the point derived from the graph of collector current versus collector-to-emitter voltage, with the base current as a parameter, where the output characteristic extrapolates back to the voltage axis

NOTE The Early voltage is approximately independent of the actual value of the base current (see figure 2).

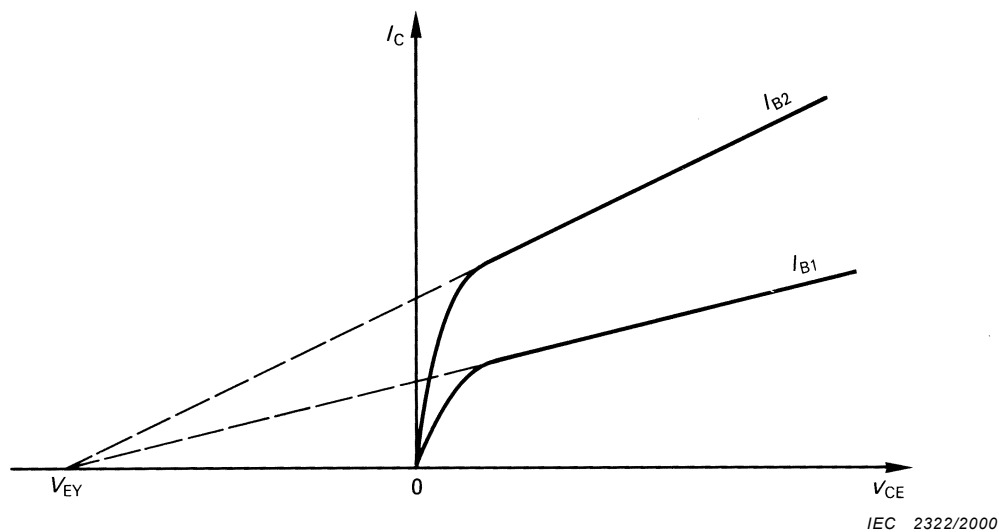


Figure 2 – Early voltage

3.5 s parameters

3.5.1 General introduction

The s parameters are defined by the following two equations:

$$\begin{aligned} b_1 &= s_{11} a_1 + s_{12} a_2 \\ b_2 &= s_{21} a_1 + s_{22} a_2 \end{aligned} \quad (1)$$

where a_1 and a_2 are the incident wave quantities, b_1 and b_2 the reflected wave quantities, all having the dimension $(\text{Watt})^{1/2}$.

The s parameters can be used for general two-port networks, including the special case of a four-pole network. In this latter case, a_i and b_i are defined as:

$$\begin{aligned} a_i &= \frac{V_i + Z_{0i} I_i}{2\sqrt{|R_{0i}|}} \\ b_i &= \frac{V_i - Z_{0i}^* I_i}{2\sqrt{|R_{0i}|}} \end{aligned} \quad (2)$$

where

$i = 1$ or 2 and $R_{0i} \neq 0$;

$Z_{0i} = R_{0i} + jX_{0i}$;

$Z_{0i}^* = R_{0i} - jX_{0i}$.

(See figure 3.)

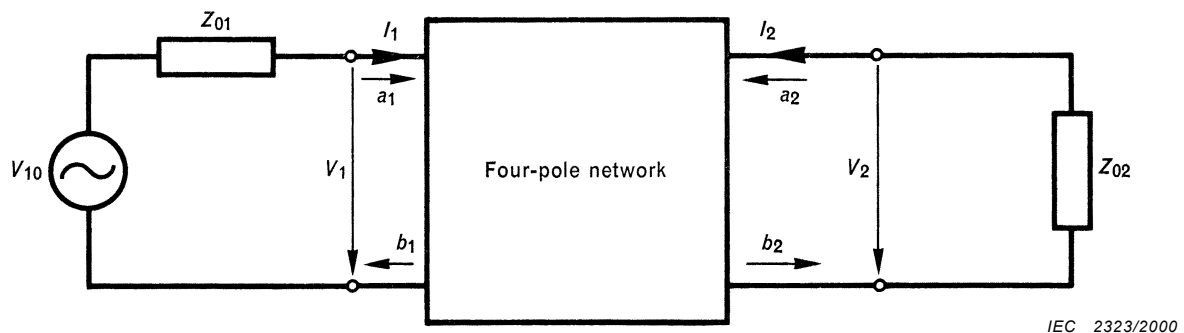


Figure 3 – Circuit with four-pole network

Z_{01} and Z_{02} are the reference impedances at the input and output, respectively.

In the general case, they are complex quantities.

For the use of s parameters for the specification of transistors mainly at VHF and UHF, $Z_{01} = Z_{02} = R_0$ (which, in most cases, will equal 50Ω).

The equations (1) can then be written in the following form:

$$\begin{aligned} V_1 - R_0 I_1 &= s_{11} (V_1 + R_0 I_1) + s_{12} (V_2 + R_0 I_2) \\ V_2 - R_0 I_2 &= s_{21} (V_1 + R_0 I_1) + s_{22} (V_2 + R_0 I_2) \end{aligned} \quad (3)$$

Both equations (1) and (3) can now be used to show the meaning of the s parameters:

$$s_{11} = \left(\frac{b_1}{a_1} \right) \text{ with } a_2 = 0 \quad \text{ratio of the complex value of the reflected wave at the input to that of the incident wave at the input, the output terminating resistance and the source resistance each having the value } R_0$$

$$= \left(\frac{V_1 - R_0 I_1}{V_1 + R_0 I_1} \right) \text{ with } (V_2 = -R_0 I_2) = \left(\frac{Z_1 - R_0}{Z_1 + R_0} \right) \text{ with } \left(-\frac{V_2}{I_2} = R_0 \right)$$

= reflection factor of the input impedance referred to R_0 , the output being terminated by R_0

Analogously:

s_{22} = ratio of the complex value of the reflected wave at the output to that of the incident wave at the output, the input terminating resistance and the source resistance each having the value R_0

= reflection factor of the output impedance referred to R_0 , the input being terminated by R_0

In addition:

$s_{21} = \left(\frac{b_2}{a_1} \right)$ with $a_2 = 0$ ratio of the complex value of the transmitted wave at the output to that of the incident wave at the input, the output terminating resistance and the source resistance each having the value R_0

$$= \left(\frac{V_2 - R_0 I_2}{V_1 + R_0 I_1} \right) \text{ with } (V_2 = -R_0 I_2) = \left(\frac{V_2}{\frac{1}{2} V_{10}} \right) \text{ with } \left(-\frac{V_2}{I_2} = R_0 \right)$$

= ratio of the output voltage V_2 to half the open-circuit source voltage V_{10} , with source and load resistances each having the value R_0

Analogously:

s_{12} = ratio of the complex value of the transmitted wave at the input to that of the incident wave at the output, the input terminating resistance and the source resistance each having the value R_0

= ratio of the input voltage V_1 to half the open-circuit source voltage V_{20} , with source and load resistances each having the value R_0

3.5.2 Definitions

The following definitions are given for the general case. For transistors, different values of these parameters may be obtained according to the configuration used, and for small- and large-signal conditions.

3.5.2.1

input reflection coefficient (s_{11})

ratio of the complex-value of the reflected wave at the input to that of the incident wave at the input, under small-signal conditions, the output terminating resistance and the source resistance each having the value R_0

NOTE This is equivalent to the reflection factor of the input impedance Z_1 of the transistor with respect to the source resistance R_0 , the output being terminated by R_0 .

3.5.2.2

output reflection coefficient (s_{22})

ratio of the complex value of the reflected wave at the output to that of the incident wave at the output, under small-signal conditions, the input terminating resistance and the source resistance each having the value R_0

NOTE This is equivalent to the reflection factor of the output impedance Z_2 of the transistor with respect to a resistance R_0 , the input being terminated by R_0 .

3.5.2.3

forward transmission coefficient (s_{21})

ratio of the complex value of the transmitted wave at the output to that of the incident wave at the input, under small-signal conditions, the output terminating resistance and the source resistance each having the value R_0

NOTE This is equivalent to the ratio of the complex value of the output voltage to that of half the open-circuit source voltage when the transistor is terminated at the output by a resistance R_0 and fed at the input from a source having a resistance R_0 .

3.5.2.4

reverse transmission coefficient (s_{12})

ratio of the complex value of the transmitted wave at the input to that of the incident wave at the output, under small-signal conditions, the input terminating resistance and the source resistance each having the value R_0

NOTE This is equivalent to the ratio of the complex value of the input voltage to that of half the open-circuit source voltage when the transistor is terminated at the input by a resistance R_0 and fed at the output from a source having a resistance R_0 .

General note

The resistance R_0 shall be the same for all four s parameters and usually will have the value 50Ω .

The above definitions, which infer ohmic source and terminating resistances, may not be practical for some classes of transistors (e.g. MOS field-effect transistors).

3.5.2.5

frequency of unity forward transmission coefficient (f_s, f_{1s})

frequency at which the modulus of the forward transmission coefficient s_{21} has decreased to unity

3.5.3 Application of the s parameters

The s parameters as defined in 3.5.2 can be used, for example, as follows.

3.5.3.1 Relation of s parameters with other parameters (y, z, h)

The following matrix equivalences hold:

$$(y) = \frac{1}{R_0 (1 + s_{11} + s_{22} + \det s)} \begin{bmatrix} (1 - s_{11} + s_{22} - \det s) & -2s_{12} \\ -2s_{21} & (1 + s_{11} - s_{22} - \det s) \end{bmatrix}$$

$$(z) = \frac{R_0}{1 - s_{11} - s_{22} + \det s} \begin{bmatrix} (1 + s_{11} - s_{22} - \det s) & 2s_{12} \\ 2s_{21} & (1 - s_{11} + s_{22} - \det s) \end{bmatrix}$$

$$(h) = \frac{1}{1 - s_{11} + s_{22} - \det s} \begin{bmatrix} (1 + s_{11} + s_{22} + \det s) & 2s_{12} \\ -2s_{21} & \frac{1}{R_0} (1 - s_{11} - s_{22} + \det s) \end{bmatrix}$$

$$\det y = \frac{1}{R_0^2} \frac{1 - s_{11} - s_{22} + \det s}{1 + s_{11} + s_{22} + \det s}$$

$$\det z = R_0^2 \frac{1 + s_{11} + s_{22} + \det s}{1 - s_{11} - s_{22} + \det s}$$

$$\det h = \frac{1 + s_{11} - s_{22} - \det s}{1 - s_{11} + s_{22} - \det s}$$

3.5.3.2 Conversion of s parameters to other parameters (y , z , h)

The following equivalences hold:

$$y_{11} = \left[\frac{s_{12}s_{21} + (1 - s_{11})(1 + s_{22})}{(1 + s_{11})(1 + s_{22}) - s_{12}s_{21}} \right] \frac{1}{R_0}$$

$$y_{12} = \left[\frac{-2s_{12}}{(1 - s_{11})(1 + s_{22}) - s_{12}s_{21}} \right] \frac{1}{R_0}$$

$$y_{21} = \left[\frac{-2s_{21}}{(1 + s_{11})(1 + s_{22}) - s_{12}s_{21}} \right] \frac{1}{R_0}$$

$$y_{22} = \left[\frac{s_{12}s_{21} + (1 + s_{11})(1 - s_{22})}{(1 + s_{11})(1 + s_{22}) - s_{12}s_{21}} \right] \frac{1}{R_0}$$

$$h_{11} = \left[\frac{(1 + s_{11})(1 + s_{22}) - s_{12}s_{21}}{s_{12}s_{21} + (1 - s_{11})(1 + s_{22})} \right] R_0$$

$$h_{12} = \left[\frac{2s_{12}}{s_{12}s_{21}(1 - s_{11})(1 + s_{22})} \right]$$

$$h_{21} = \left[\frac{-2s_{21}}{s_{12}s_{21}(1 - s_{11})(1 + s_{22})} \right]$$

$$h_{22} = \left[\frac{(1 - s_{11})(1 - s_{22}) - s_{12}s_{21}}{s_{12}s_{21} + (1 - s_{11})(1 + s_{22})} \right] \frac{1}{R_0}$$

$$z_{11} = \left[\frac{(1 + s_{11})(1 - s_{22}) + s_{12}s_{21}}{(1 - s_{11})(1 - s_{22}) - s_{12}s_{21}} \right] R_0$$

$$z_{12} = \left[\frac{2s_{12}}{(1 - s_{11})(1 - s_{22}) - s_{12}s_{21}} \right] R_0$$

$$z_{21} = \left[\frac{2s_{21}}{(1 - s_{11})(1 - s_{22}) - s_{12}s_{21}} \right] R_0$$

$$z_{22} = \left[\frac{(1 + s_{22})(1 - s_{11}) + s_{12}s_{21}}{(1 - s_{11})(1 - s_{22}) - s_{12}s_{21}} \right] R_0$$

3.5.3.3 Use of s parameters for the direct computation of transistor amplifier characteristics

r_1 = input reflection factor referred to R_0 , for a load impedance Z_L defined by the load reflection factor r_L

$$= s_{11} + \frac{r_L s_{12} s_{21}}{1 - r_L s_{22}}$$

$$r_1 = \frac{Z_1 - R_0}{Z_1 + R_0}$$

$$r_L = \frac{Z_L - R_0}{Z_L + R_0}$$

r_2 = output reflection factor referred to R_0 , for a source impedance Z_G defined by the source reflection factor r_G

$$= s_{22} + \frac{r_G s_{12} s_{21}}{1 - r_G s_{11}}$$

$$r_2 = \frac{Z_2 - R_0}{Z_2 + R_0}$$

$$r_G = \frac{Z_G - R_0}{Z_G + R_0}$$

$$A_1 = \text{current amplification} = \frac{-I_2}{I_1} = \frac{s_{21}(1 - r_L)}{(1 - s_{11}) - r_L(s_{22} - \det s)}$$

$$A_V = \text{voltage amplification} = \frac{V_2}{V_1} = \frac{s_{21}(1 - r_L)}{(1 + s_{11}) - r_L(s_{22} + \det s)}$$

$$G_P = \text{power gain} = \frac{P_2}{P_1} = |A_V|^2 \cdot \frac{1 - |r_L|^2}{1 - |r_1|^2} \cdot \frac{|s_{21}|^2}{|1 - r_L s_{22}|^2 - |s_{11} - r_L \det s|^2}$$

$$G_T = \text{transducer gain} = |s_{21}|^2 \cdot \frac{(1 - |r_G|^2)(1 - |r_L|^2)}{[(1 - r_G s_{11})(1 - r_L s_{22}) - r_G r_L s_{12} s_{21}]^2}$$

Conditions of unconditional stability:

$$\frac{1 - |s_{11}|^2 - |s_{22}|^2 + |\det s|^2}{2|s_{12} s_{21}|} > 1$$

$$1 - |s_{11}|^2 - |s_{12} s_{21}| > 0$$

$$1 - |s_{22}|^2 - |s_{12} s_{21}| > 0$$

4 Letter symbols

Mostly, existing letter symbols are added to the terms in titles. When several distinct forms exist, the most commonly used form is given.

4.1 Letter symbols for currents, voltages and powers

4.1.1 General

Clause 2 of IEC 60747-1, chapter V applies.

4.1.2 Additional subscripts

In addition to the list of recommended general subscripts given in 2.2.1 of IEC 60747-1, chapter V, the following special subscripts are recommended for the field of bipolar transistors:

B, b	= base terminal
C, c	= collector terminal
E, e	= emitter terminal
fl	= floating
pt	= punch-through (penetration, reach-through)
R (not as a first subscript)	= specified resistance
sat	= saturation
X	= specified circuit

4.2 Letter symbols for electric parameters

4.2.1 General

Clause 3 of IEC 60747-1, chapter V applies.

4.2.2 Additional subscripts

In addition to the list of recommended general subscripts given in 3.3.1 of IEC 60747-1, chapter V, the following special subscripts are recommended for the field of bipolar transistors:

B, b	= base; common-base configuration
C, c	= collector; common-collector configuration
E, e	= emitter; common-emitter configuration
L	= large signal
sat	= saturation
S, s	= storage
T	= transition

4.3 Letter symbols for other quantities

4.3.1 General

Clause 4 of IEC 60747-1, chapter V applies.

4.4 List of letter symbols

The symbols contained in the following list are recommended for use in the field of bipolar transistors; they have been compiled in accordance with the general rules.

4.4.1 Voltages

Name and designation	Letter symbol	Remarks
Collector-base (d.c.) voltage	V_{CB}	
Collector-emitter (d.c.) voltage	V_{CE}	
Emitter-base (d.c.) voltage	V_{EB}	
Base-emitter (d.c.) voltage	V_{BE}	
Collector-base (d.c.) voltage with $I_E = 0$ I_C specified	V_{CBO}	
Emitter-base (d.c.) voltage with $I_C = 0$ I_E specified	V_{EBO}	
Collector-emitter (d.c.) voltage with $I_B = 0$ I_C specified	V_{CEO}	
Collector-emitter (d.c.) voltage with $R_{BE} = R$ I_C specified	V_{CER}	
Collector-emitter (d.c.) voltage with $V_{BE} = 0$ I_C specified	V_{CES}	
Collector-emitter (d.c.) voltage with $V_{BE} = X$ specified (reverse biased emitter-base junction) I_C specified	V_{CEX}	
Breakdown voltages (open-circuit)	$V_{(BR)...O}$	The abbreviation BV is in common use for these quantities.
Breakdown voltage, collector-base with $I_E = 0$ I_C specified	$V_{(BR)CBO}$	
Breakdown voltage, emitter-base with $I_C = 0$ I_E specified	$V_{(BR)EBO}$	
Breakdown voltage, collector-emitter with $I_B = 0$ I_C specified	$V_{(BR)CEO}$	
Breakdown voltage (specified circuit)		The abbreviation BV is in common use for these quantities.
Breakdown voltage, collector-emitter with $R_{BE} = R$ I_C specified	$V_{(BR)CER}$	
Breakdown voltage, collector-emitter with $V_{BE} = X$ specified I_C specified	$V_{(BR)CEX}$	
Breakdown voltage (short-circuit)	$V_{(BR)...S}$	The abbreviation BV is in common use for these quantities.
Breakdown voltage, collector-emitter with $V_{BE} = 0$ I_C specified	$V_{(BR)CES}$	
Floating voltage, emitter-base with $I_E = 0$ V_{CB} specified	V_{EBfl}	
Punch-through (penetration) voltage	V_{pt}	
Saturation voltage, collector-emitter with I_B specified I_C specified	V_{CEsat}	
Saturation voltage, base-emitter with I_B specified I_C specified	V_{BEsat}	

4.4.2 Currents

Name and designation	Letter symbol	Remarks
Base (d.c.) current	I_B	
Collector (d.c.) current	I_C	
Emitter (d.c.) current	I_E	
Collector cut-off current with $I_E = 0$ V_{CB} specified	I_{CBO}	
Collector cut-off current with $I_B = 0$ V_{CE} specified	I_{CEO}	
Collector cut-off current with $I_C = 0$ V_{EB} specified	I_{EBO}	
Collector cut-off current with $R_{BE} = R$ V_{CE} specified	I_{CER}	
Collector cut-off current with $V_{BE} = 0$ V_{CE} specified	I_{CES}	
Collector cut-off current with $V_{BE} = X$ V_{CE} specified	I_{CEX}	
Base cut-off current with $V_{BE} = X$ V_{CE} specified	I_{BEX}	

4.4.3 Powers

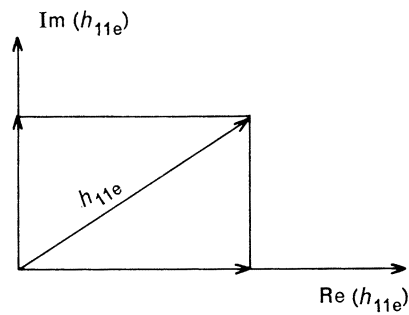
Name and designation	Letter symbol	Remarks
Collector power dissipation with T_{amb} or T_{case} specified	P_C	
Total input power (d.c. or average) to all electrodes with T_{amb} or T_{case} specified	P_{tot}	

4.4.4 Electrical parameters

4.4.4.1 Static parameters (specified for bias conditions)

Name and designation	Letter symbol	Remarks
Static value of the forward current transfer ratio (in common-emitter configuration)	h_{21E} or h_{FE}	$h_{21E} = \frac{I_C}{I_B} = \frac{I_E}{I_B} - 1$ with $V_{CE} = \text{constant}$
Static value of the input resistance (in common-emitter configuration)	h_{11E} or h_{iE}	$h_{11E} = \frac{V_{BE}}{I_B}$ with $V_{CE} = \text{constant}$
Inherent (large-signal) forward current transfer ratio	h_{21EL} or h_{FEL}	$h_{21EL} = \frac{I_C - I_{CBO}}{I_B + I_{CBO}}$ with $V_{CE} = \text{constant}$

4.4.4.2 Small-signal parameters (specified for bias and frequency conditions)

Name and designation	Letter symbol	Remarks
Small signal value of the short-circuit input impedance: – in common-emitter configuration – in common-base configuration	h_{11e} or h_{ie} h_{11b} or h_{ib}	$h_{11e} = \frac{V_{be}}{I_b}$ with $V_{ce} = \text{constant}$ $h_{11b} = \frac{V_{eb}}{I_e}$ with $V_{cb} = \text{constant}$
Small-signal value of the open-circuit reverse voltage transfer ratio: – in common-emitter configuration – in common-base configuration	h_{12e} or h_{re} h_{12b} or h_{rb}	$h_{12e} = \frac{V_{be}}{V_{ce}}$ with $I_b = \text{constant}$ $h_{12b} = \frac{V_{eb}}{V_{cb}}$ with $I_e = \text{constant}$
Small-signal value of the short-circuit forward current transfer ratio: – in common-emitter configuration – in common-base configuration	h_{21e} or h_{fe} h_{21b} or h_{fb}	$h_{21e} = \frac{I_c}{I_b}$ with $V_{ce} = \text{constant}$ $h_{21b} = \frac{I_c}{I_e}$ with $V_{cb} = \text{constant}$
Small-signal value of the open-circuit output admittance: – in common-emitter configuration – in common-base configuration	h_{22e} or h_{oe} h_{22b} or h_{ob}	$h_{22e} = \frac{I_c}{V_{ce}}$ with $I_b = \text{constant}$ $h_{22b} = \frac{I_c}{V_{cb}}$ with $I_e = \text{constant}$
Real part of the small-signal value of the short-circuit input impedance: – in common-emitter configuration – in common-base configuration	$\text{Re}(h_{11e})$ $\text{Re}(h_{11b})$	$h_{11e} = \text{Re}(h_{11e}) + \text{Im}(h_{11e})$ $h_{11b} = \text{Re}(h_{11b}) + \text{Im}(h_{11b})$
Imaginary part of the small-signal value of the short-circuit input impedance: – in common-emitter configuration – in common-base configuration	$\text{Im}(h_{11e})$ $\text{Im}(h_{11b})$	
Input capacitance, output short-circuited to a.c.: – in common-emitter configuration – in common-base configuration	C_{11es} or C_{ies} C_{11bs} or C_{ibs}	$h_{11e} \cong \text{Re}(h_{11e}) + \frac{1}{j\omega C_{11es}}$ $h_{11b} \cong \text{Re}(h_{11b}) + \frac{1}{j\omega C_{11bs}}$
Input capacitance, output open-circuited to a.c.: – in common-emitter configuration – in common-base configuration	C_{11eo} or C_{ieo} C_{11bo} or C_{ibo}	

4.4.4.2 (continued)

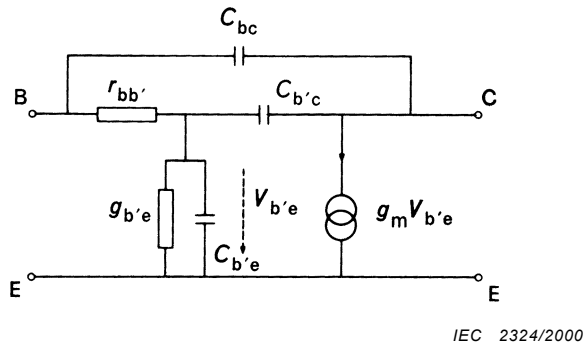
Name and designation	Letter symbol	Remarks
Output capacitance, input open-circuited to a.c.: – in common-emitter configuration – in common-base configuration	C_{22eo} or C_{oeo} C_{22bo} or C_{obo}	$h_{22e} = \text{Re}(h_{22e}) + j\omega C_{22eo}$ $h_{22b} = \text{Re}(h_{22b}) + j\omega C_{22bo}$
Output capacitance, input short-circuited to a.c.: – in common-emitter configuration – in common-base configuration	C_{22es} or C_{oes} C_{22bs} or C_{obs}	$y_{22e} = \text{Re}(y_{22e}) + j\omega C_{22es}$ $y_{22b} = \text{Re}(y_{22b}) + j\omega C_{22bs}$
Reverse transfer capacitance, input short-circuited to a.c.: – in common-emitter configuration – in common-base configuration	C_{12es} or C_{res} C_{12bs} or C_{rbs}	
Collector-base capacitance for transistors with isolated device terminals and a separate screen lead	C_{ocb}	
Small-signal value of the short-circuit input admittance: – in common-emitter configuration – in common-base configuration	y_{11e} or y_{ie} y_{11b} or y_{ib}	$y_{11e} = \frac{I_b}{V_{be}}$ with $V_{ce} = \text{constant}$ and $y_{11e} = \frac{1}{h_{11e}}$ $y_{11b} = \frac{I_e}{V_{eb}}$ with $V_{cb} = \text{constant}$ and $y_{11b} = \frac{1}{h_{11b}}$
Small-signal value of the short-circuit reverse transfer admittance: – in common-emitter configuration – in common-base configuration	y_{12e} or y_{re} y_{12b} or y_{rb}	$y_{12e} = \frac{I_b}{V_{ce}}$ with $V_{be} = \text{constant}$ $y_{12b} = \frac{I_e}{V_{cb}}$ with $V_{eb} = \text{constant}$
Small-signal value of the short-circuit forward transfer admittance: – in common-emitter configuration – in common-base configuration	y_{21e} or y_{fe} y_{21b} or y_{fb}	$y_{21e} = \frac{I_c}{V_{be}}$ with $V_{ce} = \text{constant}$ $y_{21b} = \frac{I_c}{V_{eb}}$ with $V_{cb} = \text{constant}$
Small-signal value of the short-circuit output admittance: – in common-emitter configuration – in common-base configuration	y_{22e} or y_{oe} y_{22b} or y_{ob}	$y_{22e} = \frac{I_c}{V_{ce}}$ with $V_{be} = \text{constant}$ $y_{22b} = \frac{I_c}{V_{cb}}$ with $V_{eb} = \text{constant}$

4.4.4.2 (continued)

Name and designation	Letter symbol	Remarks
Modulus of the short-circuit reverse transfer admittance: – in common-emitter configuration – in common-base configuration	$ y_{12e} $ or $ y_{re} $ $ y_{12b} $ or $ y_{rb} $	
Phase of the short-circuit reverse transfer admittance: – in common-emitter configuration – in common-base configuration	φ_{y12e} or φ_{yre} φ_{y12b} or φ_{yrb}	
Modulus of the short-circuit forward transfer admittance: – in common-emitter configuration – in common-base configuration	$ y_{21e} $ or $ y_{fe} $ $ y_{21b} $ or $ y_{fb} $	
Phase of the short-circuit forward transfer admittance: – in common-emitter configuration – in common-base configuration	φ_{y21e} or φ_{yfe} φ_{y21b} or φ_{yfb}	
Input reflection coefficient: – in common-emitter configuration – in common-base configuration – in common-collector configuration	S_{11e} or S_{ie} S_{11b} or S_{ib} S_{11c} or S_{ic}	
Output reflection coefficient: – in common-emitter configuration – in common-base configuration – in common-collector configuration	S_{22e} or S_{oe} S_{22b} or S_{ob} S_{22c} or S_{oc}	
Forward transmission coefficient: – in common-emitter configuration – in common-base configuration – in common-collector configuration	S_{21e} or S_{fe} S_{21b} or S_{fb} S_{21c} or S_{fc}	
Reverse transmission coefficient: – in common-emitter configuration – in common-base configuration – in common-collector configuration	S_{12e} or S_{re} S_{12b} or S_{rb} S_{12c} or S_{rc}	

4.4.4.3 Modified hybrid π equivalent circuit parameters

NOTE This equivalent circuit is only a first order approximation, valid for most transistors over a certain frequency range.



Name and designation	Letter symbol	Remarks
Base intrinsic resistance	$r_{bb'}$	
Intrinsic base-emitter conductance	$g_{b'e}$	
Intrinsic base-emitter capacitance	$C_{b'e}$	
Intrinsic base-collector capacitance	$C_{b'c}$	
Intrinsic transconductance	g_m	
Base-collector capacitance	C_{bc}	

4.4.5 Frequency parameters

Name and designation	Letter symbol	Remarks
Cut-off frequency:		
– in common-emitter configuration	f_{h21e} or f_{hfe}	
– in common-base configuration	f_{h21b} or f_{hfb}	
– in common-collector configuration	f_{h21c} or f_{hfc}	
Frequency of unity current transfer ratio	f_1	$f_1 = f$ for $ h_{21e} = 1$
Transition frequency	f_T	$f_T = f \times h_{21e} $ (h_{21e} is measured in a region where the roll-off is 6 dB/octave)
Maximum frequency of oscillation	f_{max}	
Frequency of unity forward transmission coefficient:		
– in common-emitter configuration	f_{se}, f_{1se}	$f_{se} = f$ for $ s_{21e} = 1$
– in common-base configuration	f_{sb}, f_{1sb}	$f_{sb} = f$ for $ s_{21b} = 1$
– in common-collector configuration	f_{sc}, f_{1sc}	$f_{sc} = f$ for $ s_{21c} = 1$

4.4.6 Switching parameters

Name and designation	Letter symbol	Remarks
Pulse average time	t_w	
Pulse time	t_p	
Duty cycle	D, δ	Duty cycle = $\frac{t}{T}$
Delay time	t_d	Input pulse Output pulse
Rise time	t_r	
Carrier storage time	t_s	
Fall time	t_f	

4.4.6 (continued)

Name and designation	Letter symbol	Remarks
Turn-on time	t_{on}	$t_d + t_r$
Turn-off time	t_{off}	$t_s + t_f$
Emitter depletion layer capacitance	C_{Te}	
Collector depletion layer capacitance	C_{Tc}	
Stored charge	Q_s	
Transient current ratio in saturation	h_{21Esat} or h_{FEsat}	
Collector-emitter saturation resistance: – small-signal value – large-signal value	r_{cesat} r_{CEsat}	

4.4.7 Sundry quantities

Name and designation	Letter symbol	Remarks
Noise	N, n	
Noise figure	F, F_n	
Noise current	I_n	
Noise voltage	V_n	
Noise power	P_n	
Effective noise bandwidth	B	
Amplification	A	
Current amplification	A_I, A_i	
Voltage amplification	A_V, A_v	
Gain	G	
Power gain	G_P, G_p	
Insertion power gain	G_I, G_i	
Transducer power gain	G_T, G_t	
Available power gain	G_A, G_a	
Efficiency	η	
Collector efficiency	η_c	

4.4.8 External circuit parameters

Name and designation	Letter symbol	Remarks
Emitter (d.c.) voltage supply	V_{EE}	
Base (d.c.) voltage supply	V_{BB}	
Collector (d.c.) voltage supply	V_{CC}	
External emitter resistance	R_E	
External base resistance	R_B	
External collector resistance	R_C	
External resistance connecting base to emitter	R_{BE}	
Generator resistance	R_G	
Load resistance	R_L	
Load capacitance	C_L	

4.4.9 Matched-pair bipolar transistors

Name and designation	Letter symbol	Remarks
Ratio of static values of common-emitter forward current transfer ratio	$\frac{h_{FE1}}{h_{FE2}}$ $\frac{h_{21E1}}{h_{21E2}}$	The smaller of the two values is taken as the numerator
Difference between base-emitter voltages	$V_{BE1} - V_{BE2}$	The smaller value is subtracted from the larger value
Change in difference of base-emitter voltages between two temperatures	$ \Delta(V_{BE1} - V_{BE2}) _{\Delta T}$	

5 Essential ratings and characteristics

5.1 Low-power signal transistors (excluding switching applications)

5.1.1 General

5.1.1.1 Range of application

The following subclauses give the requirements applicable to low-power signal transistors applicable for operation at either high or low frequencies.

5.1.1.2 Rating methods

Low-power signal transistors should be specified as ambient-rated or as case-rated devices.

5.1.1.3 Recommended temperatures

Many of the ratings and characteristics are required to be quoted at a temperature of 25 °C and at another specified temperature. Unless otherwise stated, the other temperature should be chosen by the manufacturer from the list in clause 5 of IEC 60747-1, chapter VI.

5.1.2 Ratings (limiting values)

The following ratings shall be stated.

5.1.2.1 Temperatures

5.1.2.1.1 Range of operating temperatures, ambient or case (T_{amb} or T_{case})

5.1.2.1.2 Range of storage temperatures (T_{stg})

5.1.2.2 Voltages and currents

The voltage and current ratings given must cover the operation of the device over the rated range of operating temperatures. Where such ratings (e.g. forward current, reverse voltage, etc.) are temperature dependent, this dependence shall be indicated.

The values of the following ratings apply for both continuous and peak conditions.

5.1.2.2.1 Maximum collector-base voltage with zero emitter current (V_{CBO})

5.1.2.2.2 Maximum collector-emitter voltage with zero base current (V_{CEO})

5.1.2.2.3 Maximum emitter-base reverse voltage with zero collector current (V_{EBO})

5.1.2.2.4 Maximum collector current (I_{C})

5.1.2.2.5 Maximum emitter current (where appropriate) (I_{E})

5.1.2.2.6 Maximum base current (where appropriate) (I_{B})

5.1.2.3 Power dissipation

Maximum total power dissipation as a function of temperature over the range of operating temperatures, or

maximum thermal resistance, junction to case or junction to ambient, maximum virtual (equivalent) junction temperature and maximum value of power dissipation

Any special requirements for ventilation and/or mounting shall be specified.

5.1.3 Characteristics

5.1.3.1 General

The following parameters shall be stated. The values shall be stated at one of the voltages and/or currents taken from the list in clause 6 of IEC 60747-1, chapter VI.

5.1.3.2 Collector-base cut-off current (reverse current) (I_{CBO})

5.1.3.2.1 Maximum value at 25 °C at the rated maximum collector-base voltage

5.1.3.2.2 Maximum value at a specified collector-base voltage, at a high operating temperature and at approximately zero power dissipation. The temperature shall be chosen from the list in clause 5 of IEC 60747-1, chapter VI.

5.1.3.3 Emitter-base cut-off current (reverse current) (I_{EBO})

Maximum value at 25 °C and at a specified emitter-base voltage

5.1.3.4 Collector-emitter saturation voltage (V_{CEsat})

Maximum value, or typical value as appropriate (see note), at 25 °C and at specified collector and base currents

NOTE For special cases (e.g. some high-frequency applications) where this characteristic is not essential, only a typical value for V_{CEsat} may be given.

5.1.3.5 Base-emitter voltage (V_{BE})

Typical value and, where appropriate, maximum value at 25 °C, at specified collector current and specified collector-emitter voltage

5.1.3.6 Static value of the common-emitter forward current transfer ratio (output voltage held constant) (h_{21E})

Minimum value and, where appropriate, maximum value (see note) at 25 °C, at specified collector-emitter voltage and specified collector current

NOTE For special cases (e.g. some high-frequency applications) where this characteristic is not essential, only a minimum value for h_{21E} is required.

5.1.3.7 Low-frequency small-signal parameters (common-emitter)

The following h parameters shall be stated at 25 °C, at a frequency at which there are no appreciable reactive components, and under specified d.c. bias conditions:

h_{11e} or h_{ie} = input resistance with output short-circuited to a.c. (where appropriate)
minimum and maximum values

h_{21e} or h_{fe} = forward current transfer ratio with output short-circuited to a.c.
(where appropriate)
minimum and maximum values

h_{22e} or h_{oe} = output conductance with input open-circuited to a.c. (where appropriate)
maximum value

5.1.3.8 Transition frequency f_T or value of $|h_{21e}|$ at a specified high frequency

Either:

typical and minimum values of f_T at specified values of collector current and collector-emitter voltage

or:

typical and minimum values of $|h_{21e}|$ at a specified frequency in the range in which $|h_{21e}|$ is decreasing at the rate of approximately 6 dB/octave, and at specified values of collector current and collector-emitter voltage

In specifying $|h_{21e}|$, the frequency shall be chosen preferably from the series 1, 2, 5×10^n Hz and should be such that $|h_{21e}|$ is in the range 2 to 10.

5.1.3.9 Output capacitance (C_{22b} or C_{ob})

NOTE For high-frequency transistors, the capacitance C_{22b} may be replaced by the sum of the collector junction capacitance C_c and the collector-base terminal capacitance C_{cb} .

The following information shall be given for a temperature of 25 °C only.

5.1.3.9.1 Three-terminal transistors

Maximum and, where appropriate, minimum values at zero d.c. emitter current, for specified voltage and frequency; the connection of the case shall be stated.

5.1.3.9.2 Four-terminal transistors

Maximum and, where appropriate, minimum values at zero d.c. emitter current, for specified voltage and frequency; the connection of the fourth terminal shall be stated.

5.1.3.10 Noise factor (where appropriate)

Maximum value under specified conditions of frequency range, bias and source impedance

5.1.3.11 High-frequency parameters (for high-frequency transistors)

In this subclause, the term "high frequency" is used in accordance with common practice with semiconductor devices to indicate the sort of parameters required and does not necessarily mean "high frequency" in the traditional sense used in radiocommunication, i.e. 3 MHz-30 MHz.

These parameters shall be stated for a temperature of 25 °C only.

5.1.3.11.1 General purpose applications

These parameters are intended to represent the performance of the transistor over a range of frequencies as indicated by the manufacturer and would be useful for general purpose small-signal amplifiers.

The parameters should be specified as follows:

- minimum value of the real part of the short-circuit common-emitter input impedance $\text{Re}(h_{11e})$, at specified values of I_C , V_{CE} and very high frequency;
- maximum value of the magnitude of the common-base open-circuit reverse voltage transfer ratio $|h_{12b}|$, at specified values of I_E , V_{CB} and appropriate frequency;
- minimum value of the magnitude of the short-circuit common-emitter forward current transfer ratio $|h_{21e}|$, at specified values of I_C and V_{CE} and appropriate frequency (see 5.1.3.8);
- maximum value of the output capacitance C_{22b} .

This parameter shall be specified in the same way as in 5.1.3.9.

Explanatory note concerning the relationship between the set of high-frequency parameters and the parameters of the modified hybrid π equivalent circuit.

The four characteristic values:

$\text{Re}(h_{11e})$ at a high frequency f_{h1} ,

$|h_{21b}|$ at a medium frequency f_m ,

$|h_{21e}|$ at a high frequency f_{h2} (where $|h_{21e}|$ is decreasing at a slope of approximately 6 dB/octave), and

C_{22b}

can be used for the design of an amplifier circuit by means of the following equivalent circuit:

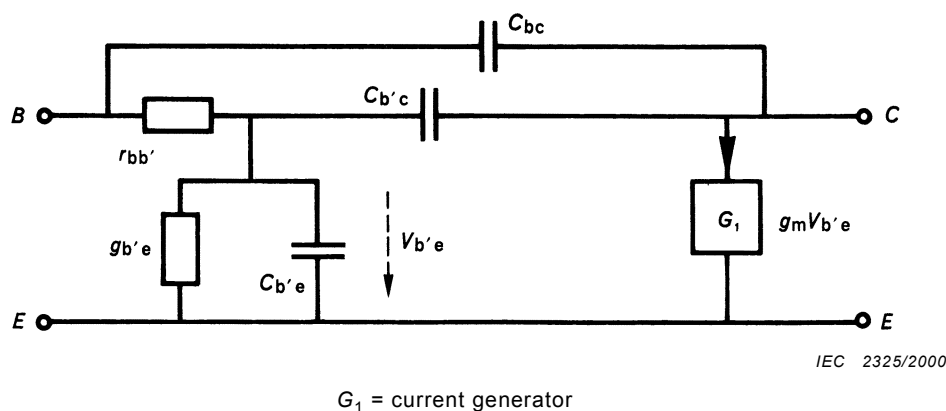


Figure 4 – Equivalent circuit

The values of the elements of this equivalent circuit can be calculated with a fairly good accuracy by means of the following formulae:

a) $r_{bb'} = \text{Re}(h_{11e})$ at high frequency f_{h1}

b) $g_{b'e} = \frac{qI_E}{kT} (1 - |h_{21bo}|)$

where h_{21bo} is the small-signal forward current transfer ratio, in the common-base configuration and at a low frequency

$$c) \quad C_{b'e} = \frac{q/E}{kT} \cdot \frac{1}{2\pi f_T}$$

f_T can be computed from the value of $|h_{21e}|$ at frequency f_{h2} , since:
 $f_T = |h_{21e}| \cdot f_{h2}$

$$d) \quad C_{b'e} = \frac{|h_{12b}|}{2\pi r_{bb'} f_m} = \frac{|h_{12b}|}{2\pi f_m \operatorname{Re}(h_{11e})}$$

$$e) \quad C_{b'e} + C_{be} = C_{22b}; \quad C_{be} = C_{22b} - C_{b'e}$$

$$f) \quad g_m = \frac{q/E}{kT}$$

It is pointed out that these formulae as well as the equivalent circuit itself are only a first order approximation, valid for most transistors over a certain frequency range. In particular, it should be borne in mind that g_m may involve an additional phase-shift which is not taken into account in the above formulae. (The values used in the above formulae are defined in 6.1.11.3.2).

5.1.3.11.2 Special purpose applications

a) *y* parameters

The following *y* parameters provide a set of four-pole parameters at a specified frequency, for instance at a standard intermediate frequency.

Typical values and, where appropriate, minimum and/or maximum values.

One complete set of the following parameters in the complex form is required at a specified frequency and for specified bias conditions,

either first set:

common-emitter short-circuit input admittance	Y_{11e}
common-emitter short-circuit reverse transfer admittance	Y_{12e}^*
common-emitter short-circuit forward transfer admittance	Y_{21e}
common-emitter short-circuit output admittance	Y_{22e}

or second set:

common-base short-circuit input admittance	Y_{11b}
common-base short-circuit reverse transfer admittance	Y_{12b}^*
common-base short-circuit forward transfer admittance	Y_{21b}
common-base short-circuit output admittance	Y_{22b}

* If y_{12} cannot be stated in one of the configurations because of the difficulty of measurement, y_{12} may be substituted in the other configuration.